Soil Physics and Rural Water Management –

Progress, Needs and Challenges

Proceedings of the International Symposium

SoPhyWa

September 28–29, 2006, Vienna / Austria

In honour of the retirement of Prof. Ferdinand Kastanek

Institute of Hydraulics and Rural Water Management
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A Compact Disc with the content of these proceedings including colour illustrations and the time schedule of the symposium is available at the Institute of Hydraulics and Rural Water Management, Department of Water, Atmosphere and Environment, University of Natural Resources and Applied Life Sciences, Vienna, Muthgasse 18, A-1190 Wien, Austria.

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Preface

Soil and water are natural resources vital for mankind's life. Processes ongoing at the soil-plant-atmosphere interface and in the unsaturated zone of the soil mainly determine the behaviour of the hydrological cycle. Sustainable management of these resources requires a comprehensive understanding of all physical, chemical and biological processes and their interactions occurring in the vadose zone. Soil erosion, drought, salinization, diffuse and point source contamination, floods, and climate change are major threats to the quantity as well as to the quality of these resources. It must be our mission to maintain its various functions in an optimal and sustainable manner, so as to safeguard its use for future generations.

In the past considerable knowledge has been gained in measuring and monitoring soil-water interactions. This was enabled by the development of new and powerful environmental sensors. Intensive research activities led to a better understanding of the various processes in the soil. New computer technologies facilitated to model these processes on different spatial and temporal scales. Additionally, great technical advances have been achieved in improving unfavourable soil hydrological conditions.

Soil physics and rural water management provide a sound basis to analyze the present state of soil and water and their interactions, to predict the response of the ecosystem to hydrological impacts and to manage these resources in a sustainable way.

The main topic of this symposium aims to reflect past, present and future of basic and applied research in rural water management. The knowledge of the dynamic processes in the unsaturated zone is a prerequisite.

Due to the broad range of the tasks, specific topics of this conference include field measurement and monitoring, laboratory and field experiments, modelling and simulation as well as case studies in the areas of:

- Irrigation and drainage
- Soil and water conservation
- Water and solute transport
- Regional water balance in rural areas
- Land use and climate change
- Diffuse and point sources of contamination
- Impact assessment and mitigation measures
- Development co-operation in rural water management.

This conference is organized in honour of the retirement of o.Univ.Prof. Dipl.-Ing. Dr. Ferdinand Kastanek. Prof. Kastanek dedicated his 40-year long scientific career to promote soil physics and rural water management in research and teaching. His scientific contributions substantially improved the auger hole method and the numerical modelling of the hysteresis effect in soils. In recent years he focussed on the concept and the application of the so-called "virtual lysimeter" for soil water balance studies.

Although the retirement of such profound scientists like Prof. Kastanek always leaves a gap in the Scientific Community, there exist many new challenges for young researchers who can build up on a sound scientific basis.

Andreas Klik
Head of the Institute of Hydraulics and Rural Water Management

Vienna, September 2006

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SECTION A

SOIL PARAMETERS

Soil Physics – and the Art of Interpretation

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ABSTRACT

This paper aims to reflect on recent projects in soil physics at the Institute of Hydraulics and Rural Water Management. The human factor is stressed to express the importance of interpretation within the causal chain of objective – hypotheses – investigation – interpretation and result.
Soil Physics is bound very strongly to rural water management, however the understanding of movement of matter is exceeding this boundaries far beyond. This is shown in an overview of the various applications and interdisciplinary studies. Agriculture related topics are still an important part of our activities, e.g. water balance studies for organic farming. Projects including water balance studies in waste disposal sites, infiltration capacity of flood plains, mass movement or studies of nutrient or metal uptake at a root scale require new partner.

1. INTRODUCTION

In Semiotics data are defined as potential Information. Data are information if they are related to a significant context. Hence, data become meaningful through interpretation and hence a vital part of activities in environmental research. Von Rauchhaupt (2005) defines in short: Information are interpreted data. Following the same author, information and knowledge are strongly bound to each other and therefore often used as a synonym. However, Information may be considered as encoded, condensed knowledge and knowledge on the other hand is arranged information, where the arrangement is only known to an insider.

Topics in relation to rural water management are still an integrative part of our research activities, but many projects are reaching far beyond this traditional boundary. This may lead to the risk of over interpretation of results. Environmental studies are object to many uncertainties. There are many modern means, like geostatistic tools available to estimate parameters or uncertainties, but a common observed limitation is the lack of enough data to perform these methods. Hence the personal judgment is again required. The interpretation is dependent on the concept of how an investigation, is set up, what simulations are performed and how are parameters obtained. In this context field site are a key feature and therefore treated prominently. The following case studies are examples what information in relation to environmental studies soil physicists are able to provide.

2. FIELD STUDIES

As mentioned before data are the start of the information flow. The obtained information is indispensable for process understanding and also for simulation. Taking this into account any investigation will have to evaluate the data availability and what is missing and needs to be collected. With modern equipment high sampling rates are not a limiting factor anymore, and hence time resolution may be considered as solved. However, mainly the two factors financial limitation and maintenance of natural conditions are responsible for an insufficient space resolution. To improve the space resolution a combination of field measuring sites and simulation is one possibility. Measurements serve to calibrate and verify the model.

2.1. Water balance – field plot scale

For agricultural research it is common to use a plot scale. When the effects of root parameters of cover crops on infiltration (Bodner et al. 2005) are investigated a sound water balance is indispensable. This is as well true for topics like nitrogen uptake and biomass yield of catch crops and effects on yield and quality of subsequent crops and nitrate contents in soil solution (Rinnofner et al. 2006). An immanent information is the estimate of the amount of Nitrate leached to groundwater under conditions of organic farming. Simulation in combination with a data acquisition serves to describe and understand the test conditions more deeply and hence helps to avoid misinterpretations. Simulation enables to close gaps when data are missing. With other words the question to be answered is: is the realization obtained by simulation (Fig.1) a realistic one and can we continue to work with this model for the given task, e.g. estimating the nitrate leaching rate to groundwater?

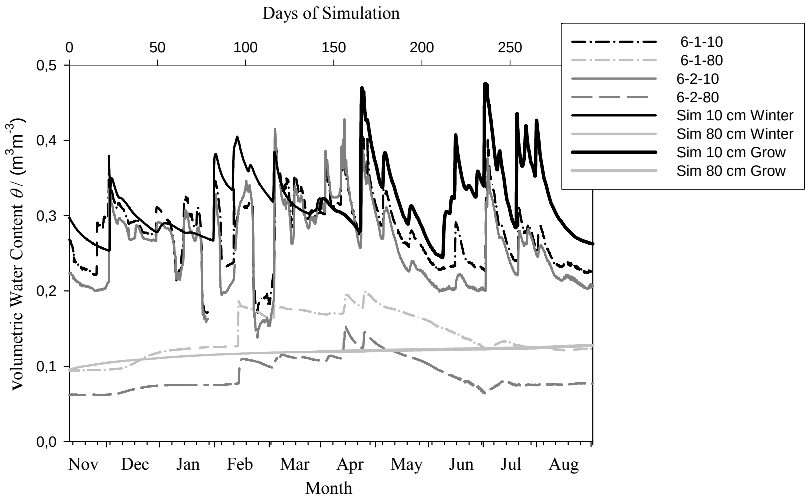

Figure 1. Measurement vs. simulation of volumetric water content change for winter rye 2003/2004, Plot 6, organic farming practise in the pannonian region.

By comparing two field measurements under same conditions with simulation it is obvious that also between measurement itself are differences. Information needed for interpretation are: a) During winter months soil water was frozen in top layers, the capacitive sensors react to the changed dielectric constant for ice by showing a low or zero water content, b) Simulation was performed in two steps, first for winter month, the end result was stored and then used as initial values for calculating the growing period, c) information on root growth were limited and have been estimated from literature d) The over estimation at the end of the growing period is due to an high input of precipitation in June, which was not reflected by measurements, the continuing dynamic however is again very similar. Besides the named uncertainties the simulation may be considered a good representation of the soil water dynamic.

2.2. Water balance and water movement in solid waste disposal sites

Questions related to solid waste disposal sites for example are the water balance in cover layers (Loiskandl, 1997) or flow patterns in a very structured and layered deposit. Top layers in general are more homogeneous whereas the in the deposits the non-uniform flow regime is caused by the heterogeneous character of the waste material itself as well as by the depositing and compaction procedure. Fellner (2004) proposed for municipal solid waste landfills a modelling concept comprising“ Cover layer – Matrix domain – Preferential flow path“. In particular the temporal and spatial leachate generation is considered. The calculation of the flow pattern calculation was achieved with a two-dimensional two-domain approach by use of HYDRUS-2D (Salinity Laboratory, Riverside, Ca). The different flow behaviour of matrix and preferential flow paths are controlled by appropriate selection of parameter. The preferential flow path (channel domain) is assigned a high permeability and a low or even no retention capacity, while the matrix domain is characterized by low permeability and high retention capacity. Based on the calibrated water flow model solute discharge simulations are performed. The result of this modeling effort is the fraction of waste mass participating in water flow. For the investigated landfills this fraction varies between 25 % and 50 %. Information about the uniformity of the water movement, obtained by the proposed model, improves existing assessment tools for predicting the future emission behavior of municipal solid waste deposits.

2.3. Infiltration

A small village in the Tyrolean Alps is threatened by frequent flooding To minimize conflicts between nature protection aspects (NATURA 2000 region) and the needed technical measures a sensitive flood protection management strategy was proposed (Hübl, 2005). To utilize this an inundation area was activated to decrease the flood wave. A major factor for the success of this concept is the infiltration capacity of the floodplains. To derive informazion for describing the infiltration capacity, field studies and laboratory experiments were carried out and a monitoring system was installed. Different scenarios of flooding and infiltration processes are simulated with numerical models. The outcome proofs very clearly that infiltration has the mayor effect whereas retentiion is hardly visible.

The triggering of a mass movement is closely linked to infiltration and water content increase. Gmeindl (2006) investigated this mechanism of a recent mass movement in the Bregenzer Wald region in Austria (Figure 2). The mass movement could be classified as debris flow process, with the sliding plane located in 6 m depth. By taking soil samples parameter are measured in the laboratory. Hydrological meteorological data together with obtained soil information are feeding a simulation model (Hydrus 2-D) to estimate how the degree of saturation can be linked with the occurrence of the slide. The result of the simulation showed that at the time of slope failure the upper 6 meters of the soil profile were nearly saturated. Thus, the depth of the sliding plane is nearly identical with the saturated soil profile.

Figure 2. Landslide Rindberg/Sibratsgfäll/Vorarlberg/Austria

2.4. Root water and solute uptake

A much smaller scale of investigation forms the rhizosphere, which is defined by the volume of soil around a root which is characterized by the concentration gradients of solute extending from the root surface into the bulk soil. These concentration gradients are induced by a number of processes. The root can deplete the soil through uptake of solutes. Exudation of soluble low molecular weight organic acids, microbial activity or mycorrhizal fungi may have an impact on solubility and uptake mechanism. Hyperaccumulating plants fro instance are capable of taking up and accumulating significant amounts of metals/metalloids in their shoots (Loiskandl et al., 2005). The plant potential for the use of phytoremediation purposes also depends upon their multifarious interactions with soil and contaminants. These relations are additionally affected by hydrological and climatic conditions.

3. CONCLUSION

The human factor is stressed to show that the result of an investigation in relation to environmental studies is directly linked to interpretation. Even it is believed that every scientist obeys this, the risk of a biased result is always present. Especially in interdisciplinary projects a clear understanding what is possible is necessary, then the interpretation will be based on realistic assumptions and expectations.

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Retention and Availability of Water of Different Soils Amended with Superabsorbent Hydrogels

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ABSTRACT

The use of superabsorbent hydrogels has arisen as a new tool to improve irrigation water management. A laboratory trial was performed with three soils (sandy, silt loam and clayey) with two commercial hydrogels applied at three doses. Water content at different matric tensions was determined for each treatment in the Richards pressure plate, using pressures that ranged from 10 to 1,500 kPa. Water holding at 10 kPa (field capacity) increased only with the application of product CH1. Soil water release to plant uptake depends on readily available water that was improved by CH1 hydrogel in the three soils for three levels of sensitivity to water stress (25, 45 and 75 kPa).

1. INTRODUCTION

Water is a key element in a high-density populated area as Madrid Region. Water balance within the system is the difference between resources and demand uses; when the latter exceed the resources water scarcity rise up and cause conflicts between demand sectors (Arroyo-Sanz *et al.*, 2006). Water resources in this region relay mainly on surface water, so the periodic occurrence of meteorological droughts implies scarcity of water supply. Demand uses are shared between environmental uses and economic uses as agriculture, industry and urban supply, which is increasing due to population growth and changes in society lifestyles. Traditional residential uses of water go with new uses as irrigation of private gardens and filling of swimming pools. Water use in streets washing down, fountains and ponds and irrigation of public parks come with irrigation of new sport facilities and amusement and theme parks. Irrigation of turf of public parks and private gardens uses an important amount of water in this semiarid climate zone, with 490-825 mm year^{-1} of irrigation water requirements and 6-8 months of irrigation period.

Efficient use of irrigation water has become and essential goal for technicians, taking into account also economic and agronomic characteristics of turf and plant cover and environmental, recreational and aesthetic values demanded by customers and citizens (Carrow, 2006). Water use efficiency may be increased implementing several measures as correct landscape design, efficient irrigation system design, improved irrigation scheduling, reuse of treated wastewater, etc. In recent years the use of superabsorbent hydrogels has arisen as a new tool to improve irrigation water management. These polymers can absorb and store up to 400 times their own weight of water (Fonteno and Bilderback, 1993). The hydrogels suitable for application in plant production must also release water to plants during the time period until the occurrence of the next rain or irrigation event (Morante, 2003).

The aim of this work is to study the effect of the application of two commercial hydrogels on water retention capacity and availability of soil moisture in three different textured soils.

2. MATERIAL AND METHODS

Three different and contrasting textured soils were selected. The coarser one is a sandy soil (Table 1) with very high proportion of sand. It is used as raw material for substrate preparation and it is extracted from quaternary alluvial deposits. The silt loam soil was collected from the first 30 cm of a commercial farm field located in Burgos province. It is a Calcic Xerofluvent developed from a tertiary limestone moor. The clayey soil is from a cultivated and drained field in a reclaimed river marsh in Sevilla province. I was developed by the accumulation of calcareous marls sediments carried by Guadalquivir river. The clay fraction is mainly illite type under a very advanced degree of alteration (Moreno *et al.*, 1995).

Table 1. Characteristics of soils used in the experiment.

Soil	Sand (%)	Silt (%)	Clay (%)	Organic carbon ($g\ kg^{-1}$)	Calcium carbonate (% $CaCO_3$)
Sand	97.4	1.8	0.8	0.3	1.0
Silt loam	23.4	53.8	22.8	7.6	36.1
Clay	5.7	27.6	66.7	8.1	20.0

Two commercial hydrogels were used: CH1 and CH2. Hydrogel CH1 is made up of biodegradable elements that can be divided into three linked groups: water-absorbing polymers, polymer binders and nutrients. CH2 is a crosslinked potassium/ammonium polyacrylate/polyacrylamide copolymer. Three doses were applied: recommended dose by the polymer manufacturer (i.e. CH1=1.2 g kg soil^{-1} and CH2= 0.33 g kg soil^{-1}), 150% of that dose and a control treatment without hydrogel.

Air dried soil samples were passed through the 2 mm sieve and the respective doses of hydrogels were added. Two replicates of 25 g samples of each treatment were water saturated for a 24 hour period. The moist samples were subjected to different pressures in the Richards pressure plate, using pressures that ranged from 10 to 1,500 kPa. Soil samples were oven-dried at 80 ºC for a week in order to avoid losses of any material other than water and gravimetric water content was calculated.

Total available water was calculated as the difference of soil moisture at 10 and 1,500 kPa. The relationship between soil water content and soil matric tension was studied using potential functions. Statistical analysis was done with STATGRAPHICS software and the Newman-Keuls test was used.

3. RESULTS AND DISCUSSION

Water holding at 10 kPa (field capacity) increased with the application of product CH1 in the three soils (Table 2), but only in sandy soils the effect was statistically significant. That increment was exponential with increasing doses of hydrogel in the sandy soil, as it was also described for a sandy substrate by Huttermann *et al.* (1999). Water retention by the two other soils increased linearly with CH1 gel application in agreement with the observation of Bres and Weston (1993) for a peat/perlite/vermiculite soilless medium. Soils amended with CH2 did not increased their water holding capacity at 10 kPa within the doses tested in this experiment, but Huttermann *et al.* (1999) found an increment for doses three times higher.

High and positive correlations were found between soil water content and matric tension using potential functions (Figure 1). These curves show that water holding capacity remained high at increasing matric tensions in soils amended wit hydrogels, so they retained the water even at low water potentials (Huttermann *et al.*, 1999). Total available water (the difference of soil moisture at 10 kPa and 1,500 kPa) increased with the application of CH1 hydrogel (Figure 2), whereas CH2 product had little or no effect.

Table 2. Retention of water at 10 kPa of different treatments in each type of soil.

Treatment	Sand	Silt loam	Clay
Control	4.2c	27.6	49.6
CH1 recommended dose	9.7b	30.3	54.7
CH1 150% recommended dose	18.2a	31.5	56.6
CH2 recommended dose	4.3c	28.8	49.7
CH2 150% recommended dose	4.3c	28.6	48.6
	P=0.0001	P=0.23	P=0.23

Readily available water is the difference between field capacity and soil moisture at a threshold value of matric tension that provokes plant water stress. This threshold value depends on plant species characteristics that contribute to water stress sensitivity and climatic evapotranspiration conditions. Plant characteristics include root density and canopy resistance (Beard and Kim, 1989). Thus, as root density increases crop transpiration is maintained at the maximum rate to increasingly higher soil water tensions. When the climatic evapotranspiration is high the plant can only maintain the maximum transpiration at low levels of matric tension and when this decreases the plant suffer water stress. Three tension values has been considered as threshold values: 25, 45 and 75 kPa for high, medium and low sensitive to water stress plant species, respectively (Figure 2). Thus, 25 kPa is the matric tension that provokes water stress in tomato crop or in some cool-season turf species (Gibeault *et al.*, 1989), whereas sugarbeet crop uses water with out yield depression until 45 kPa (Arroyo, 2002) and vineyard or some warm-season turf species can uptake water until 75 kPa.. Readily available water was improved by CH1 hydrogel in the three soils for the three levels of sensitivity to water stress (Figure 2), whereas CH2 product had little or no effect. So the water harvested by the gel should be readily released to plant uptake avoiding water stress, helping to maintain plant water potential and plant growth and survival (Bres and Weston, 1993; Huttermann *et al.*, 1999).

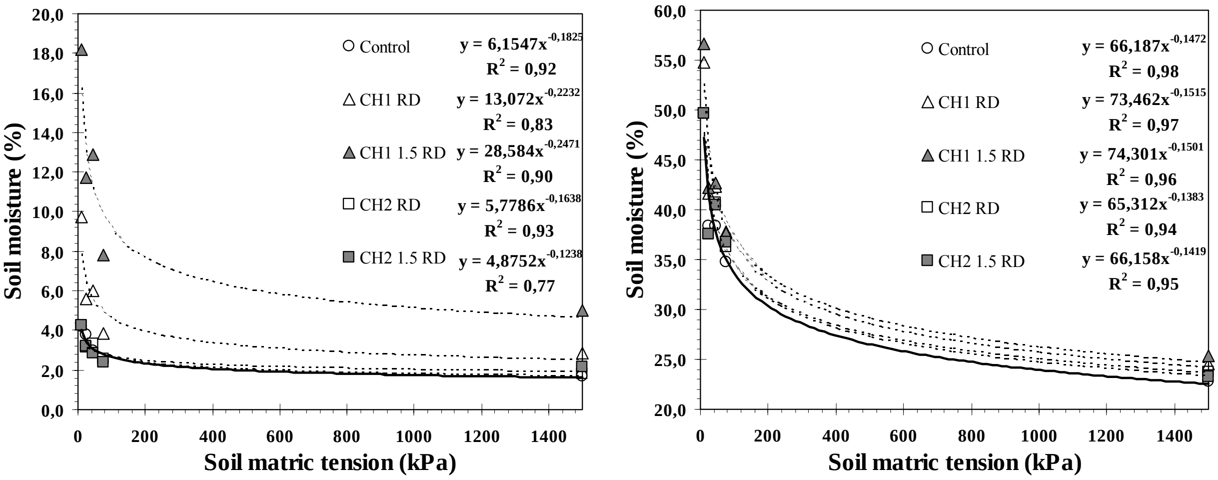

Figure 1. Relationship between soil water content and soil matric tension for the sandy (left) and clayey (right) soil (straight lines: control; dotted lines: hydrogels treatments).

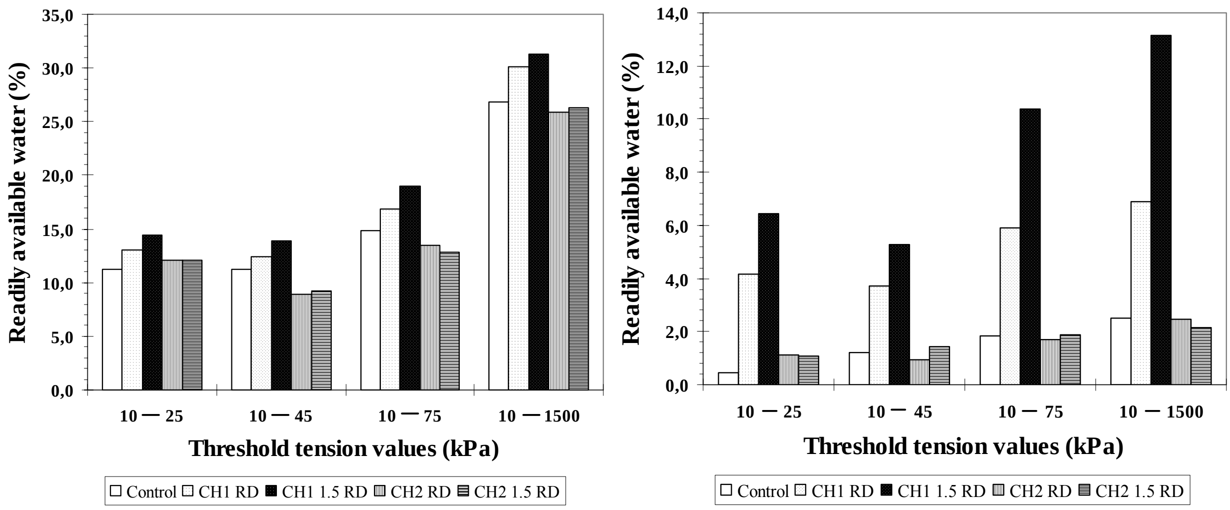

Figure 2. Readily available water for different tensions in the sandy (left) and clayey (right) soil.

4. CONCLUSIONS

These results suggest that the use of superabsorbent hydrogels should improve the water holding capacity of different types of soils and the release of this water to plants. Stored water in the gels that is actually available for different plant species should be evaluated in further research.

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Hydraulic Properties of Bulgarian Soils

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ABSTRACT

Functioning of soils as a component of ecosystems is largely determined by transport and storage processes of water and solutes, which are governed by the hydraulic properties of the soil. Modern approaches for systematizing the soil hydraulic characteristics envisage their parameterization. This paper presents the results from an attempt for systematization and parameterization of the hydraulic characteristics of Bulgarian soils.

A database on the physical properties of Bulgarian soils has been developed. Currently, the database holds information on particle-size distribution, bulk density, organic matter content, water retention and hydraulic conductivity, obtained from analyses of samples from 228 genetic horizons of 50 soil profiles. That data is used to parameterize the soil hydraulic characteristics by the models of Van Genuchten (1980) and van Genuchten and Nielsen (1985). Obtained mean parameters for soil texture classes can be used for estimating the hydraulic characteristics of Bulgarian soils depending on the soil texture class.

1. INTRODUCTION

Hydrological properties of soil give information about the physical state and mobility of soil water and determine to large degree suitability of soil as a medium for plant growth. Modern methods for assessments of soil functions as an environmental component are based on complex models for description of the state and the movement of soil water in the soil vadose zone. Wide use of such models is impossible without systematized data of soil hydraulic properties (Wösten et al. 1998).

Current approaches for summarizing the soil hydraulic properties (Van Genuchten et al., 1992) involve parameterization of relationships of volumetric water content (θ) and hydraulic conductivity (K) from the soil water matric potential head (h). This paper reports the results of an attempt for systematization and parameterization of the relationships $\theta(h)$ and $K(h)$ for Bulgarian soils using the widely used models of Van Genuchten (1980) and Van Genuchten and Nielsen (1985) and internationally recognized soil texture scheme.

2. MATERIALS AND METHODS

Information from laboratory analyses of water retention and hydraulic conductivity of samples from the genetic horizons of representative Bulgarian soils at a minimum of 8 points of soil water matric potential in the interval from 0 to 225 MPa is systematized in a database of the soil physical characteristics. The database is developed in MSO Access environment and holds also data of soil texture, bulk density and organic matter content of the soil samples. Soil water retention at matric potential from 0 to 6 kPa is measured using sand-box equipment, from 6 to 1600 kPa – using a membrane press apparatus, and from 1.6 to 225 MPa – following the hygroscopic method. Soil hydraulic conductivity is measured using horizontal soil columns (Globus, 1969) with undisturbed soil samples, soil texture – following the method of Katschinsky (1958) and soil bulk density – using metal rings with a volume of 200 cm^3 at soil moisture close to field capacity. Widely used models of the relationships of volumetric water content (θ) and soil hydraulic conductivity (K) from soil water matric potential (h) developed respectively by Van Genuchten and Nielsen (1985) and Van Genuchten (1980) were selected for the aims of this study:

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{(1+\alpha h^n)^m} \ , \tag{1}$$

$$K(h) = K_s \frac{((1+\alpha h^n)^m - \alpha h^{n-1})^2}{(1+\alpha h^n)^{m(l+2)}} \ . \tag{2}$$

The parameters in equations (1) and (2) have a physical meaning as follows:

- θ_r [cm^3 cm^{-3}] is the volumetric water content where $\frac{d\theta}{dh} \xrightarrow[h\to\infty]{} 0$;
- θ_s [cm^3 cm^{-3}] and K_s [cm day^{-1}] are respectively the volumetric water content and the hydraulic conductivity of saturated soil;
- α [cm^{-1}] is the reciprocal value of the soil water matric potential where $\frac{d\theta}{dh}$ turns to its minimum (i.e. points of inflexion of the relationships);
- n, m and l are dimensionless parameters, which determine the forms of the curves of the respective relationships.

The parameters of equations (1) and (2) are calculated for each soil sample using a quasi-Newton nonlinear approximation (StatSoft Inc., 2001) of all data pairs soil moisture content-matric potential to parameterize $\theta(h)$ and hydraulic conductivity-matric potential to parameterize $K(h)$. For systematization purposes obtained parameters as well as respective data of soil texture, bulk density and organic matter content were grouped into textural classes using the equilateral textural triangle used in the USDA system. To determine soil texture classes, soil particle-size distribution data were transformed from the classification scheme of Katchinsky to that of USDA following the procedure developed by Rousseva (1997).

3. RESULTS AND DISCUSSION

Currently, the database holds information about soil physical characteristics of samples from 228 genetic horizons of 50 soil profiles. Data of soil texture, bulk density and organic matter content, systematized in texture groups (Table 1) give general idea about the value ranges of the soil physical characteristics hold currently by the database. Variability of soil physical characteristics assessed by the values of standard deviations reveal respective variations within each soil texture class. Comparison of the distribution of studied soil samples among soil texture groups (0,4 % coarse, 18.4 % medium and 81,1 % fine) to information about soil texture distribution of Bulgarian soils presented by Boyadjiev (1994) (1.0% coarse, 17,8 % medium and 81,2 % fine) give grounds for conclusion that the data set included in the database is satisfactorily representative for Bulgarian soils.

The mean values of the parameters of the models of Van Genuchten (1980) and Van Genuchten and Nielsen (1985) for soil texture classes (Table 2) proof the adequacy of the selected models do describe the hydraulic characteristics of Bulgarian soil, which is verified by the logical changes depending on the soil texture class of θ_r, θ_s and K_s considering their physical meaning as well as the high values (from 0.95 to 0.99) of the coefficients of determination (r). Variability of the parameters revealed by the values of respective standard deviations reflects variations in soil texture, bulk density and organic matter content within each soil texture group (Table 1).

Table 1. Mean values and standard deviations of basic soil physical properties of Bulgarian soils depending on the soil texture class.

Texture Class	Number of Samples	Value	Bulk Density / $g.cm^{-3}$	Organic Matter / %	Clay / %	Silt / %	Sand / %
Sand	1	Mean	1,64	0,50	3,5	9,0	87,5
Loamy Sand	3	Mean	1,56	0,52	6,3	13,7	80,0
		Std. Dev.	0,19	0,42	1,4	2,1	3,4
Sandy Loam	20	Mean	1,54	0,89	13,7	20,5	65,8
		Std. Dev.	0,19	0,93	3,2	6,0	6,9
Loam	20	Mean	1,40	1,40	19,2	40,7	40,1
		Std. Dev.	0,17	0,69	5,1	4,3	6,6
Silty Loam	11	Mean	1,25	2,59	25,0	56,5	18,5
		Std. Dev.	0,13	1,72	3,1	4,5	5,3
Sandy Clay Loam	19	Mean	1,52	0,50	28,0	17,1	54,8
		Std. Dev.	0,19	0,59	3,8	5,3	7,8
Clay Loam	31	Mean	1,45	1,33	34,5	32,8	32,7
		Std. Dev.	0,14	0,87	3,7	7,5	6,8
Silty Clay Loam	28	Mean	1,38	1,66	34,1	53,9	12,0
		Std. Dev.	0,14	1,32	3,6	4,6	3,7
Silty Clay	22	Mean	1,39	1,53	42,9	46,6	10,6
		Std. Dev.	0,10	1,00	1,4	3,9	3,3
Clay	73	Mean	1,43	1,27	50,2	27,4	22,4
		Std. Dev.	0,11	1,11	7,5	6,6	9,4

Table 2. Mean values and standard deviations of the parameters of equations (1) and (2) for hydraulic characteristics of Bulgarian soils depending on the soil texture class.

Texture Class	Value	θ_r	θ_s	α	n	m	l	K_s	r
Sand	Mean	0,010	0,301	0,0167	1,3587	0,2640	3,22	65,0	0,987
Loamy Sand	Mean	0,015	0,385	0,0169	1,5213	0,3121	3,29	59,5	0,997
	Std. Dev.	0,009	0,028	0,0176	0,3744	0,1873			0,004
Sandy Loam	Mean	0,028	0,414	0,0391	1,5629	0,3407	3,50	49,1	0,983
	Std. Dev.	0,010	0,070	0,0720	0,3035	0,1070			0,011
Loam	Mean	0,045	0,396	0,0115	1,7270	0,3719	3,65	30,2	0,993
	Std. Dev.	0,013	0,048	0,0148	0,6163	0,1524			0,009
Silty Loam	Mean	0,047	0,441	0,0080	1,6632	0,3939	3,81	14,4	0,989
	Std. Dev.	0,007	0,079	0,0060	0,1515	0,0584			0,009
Sandy Clay Loam	Mean	0,050	0,434	0,0196	1,4705	0,2886	3,89	41,0	0,965
	Std. Dev.	0,008	0,064	0,0200	0,3831	0,1284			0,024
Clay Loam	Mean	0,050	0,450	0,0292	1,3657	0,2638	4,07	24,8	0,984
	Std. Dev.	0,013	0,056	0,0453	0,1082	0,0528			0,014
Silty Clay Loam	Mean	0,044	0,431	0,0123	1,3613	0,2614	4,06	9,6	0,989
	Std. Dev.	0,010	0,074	0,0119	0,1012	0,0563			0,010
Silty Clay	Mean	0,050	0,453	0,0111	1,3113	0,2324	4,30	8,6	0,980
	Std. Dev.	0,008	0,063	0,0093	0,1092	0,0636			0,016
Clay	Mean	0,060	0,460	0,0190	1,2800	0,2097	4,50	17,3	0,977
	Std. Dev.	0,017	0,048	0,0236	0,1445	0,0826			0,017

The values of θ_r, θ_s, α, n, m, l and K_s from Table 1 were substituted in equations (1) and (2) to illustrate (Figure 1) the relationships of volumetric water content (θ) and hydraulic conductivity (K) from soil water matric potential (h) depending on the soil texture class.

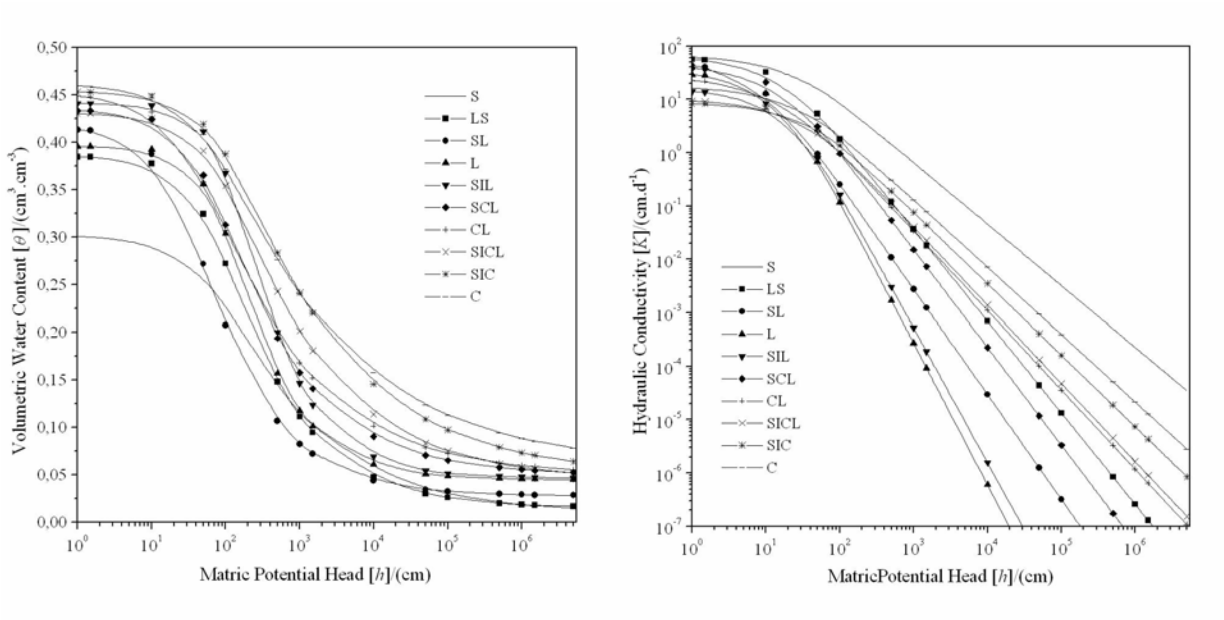

Figure 1. Relationships of volumetric water content (θ) and soil hydraulic conductivity (K) from soil water matric potential (h) depending on the soil texture class

4. CONCLUSIONS

Database on the physical characteristics of Bulgarian soils have been developed, holding representative information about soil texture, bulk density, organic matter content, water retention and hydraulic conductivity based on measurements for soil samples from 128 genetic horizons of 50 soil profiles. Collected information has been used for parameterization of the hydraulic characteristics using the models of Van Genuchten (1980) and Van Genuchten and Nielsen (1985) and obtained parameters have been grouped depending on the soil texture of the sample. Obtained parameters can be useful for assessments of hydraulic properties of Bulgarian soils depending on soil texture needed for different models for description of the state and the movement of soil water in the soil vadose zone, for soil erosion rates predictions, etc.

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Preferential Flow in Unsaturated Soils on Crystalline Bedrocks

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ABSTRACT

Preferential flow is a typical feature of the flow within soil profiles of coarse sandy loams formed on decayed crystalline bedrocks. Similar soils cover approximately 60% of the Czech basin. Preferential flow significantly influences the flow dynamics and the formation of the soil profile outflow hydrograph. To evaluate the effects of preferential flow in the vadose zone, dual permeability soil water flow and solute transport models are used.

1. INTRODUCTION

The primary reason of preferential flow detected in soil profiles formed on decayed crystalline bedrocks (soils covering approximately 60 % of the Czech basin), namely on coarse sandy loams with a high ratio of a gravel, is the soil structure with the wide range of soil particles. This results in heterogeneous pore space of a wide range of pore radii. Here the preferential flow is attributed to a relatively small part of a pore space of interconnected larger pores, forming natural preferential pathways. In response to a rainfall, these preferential pathways may become hydraulically interconnected and the gravity forces may become dominant and may initiate the preferential flow. Under dryer soil conditions this type of flow vanishes.

While filling the pore space, the soil air may be encapsulated forming the air residual saturation which is discontinues and practically immobile and blocks a part of preferential pathways. Its amount and the space distribution are variable depending strongly on the pore geometry as well as on the initial saturation and on the history of the filling and draining of the soil profile; the accompanying effect is the flow instability. The encapsulated air significantly influences the amount of preferential flow and the flow in the soil profile in general.

Beside the preferential flow also slower capillary flow in the soil matrix takes place at the same time. However the time scales between both types of flow differ substantially. In case of preferential flow the dominant processes occur in the order of minutes, meanwhile in case of practically never deceasing matrix flow often days or weeks play role. Matrix flow prevails during redistribution or during the infiltration of low intensity rainfalls. Preferential flow and the flow instability may generally occur in an arbitrary scale of observation. The flow instability in coarse sandy loams was at first detected during field ponded infiltration experiments (Císlerová et al., 1988), originally used to determine the saturated hydraulic conductivity estimate. Later it was studied on fully controlled infiltration outflow experiments on the large undisturbed soil samples in the laboratory; the method has appeared to be a convenient tool to detect the preferential flow (Votrubová et al., 2002; Císlerová et al., 2002).

A number of standard theories describing the flow in the unsaturated zone and a number of the experimental methods to determine state variables and soil hydraulic characteristics are disqualified by the existence of the preferential flow. From the point of view of the hydrological balance a much faster propagation of the rainfall and a limited retention capacity of the soil profile are the most important consequences. In the coarse sandy loams on the crystalline rocks, the preferential flow influences the overall response of watersheds, the rainfall infiltrates vertically to the bottom of more permeable soil layers and then it moves preferentially along the hillslopes towards the stream. The traditional hypothesis considering the role of the unsaturated zone as the retention reservoir which smoothes and delays the rainfall transformation, does not hold here and is quite far from the reality.

2. HYDRAULIC CHARACTERISTICS AND PREFERENTIAL FLOW

Measured retention curve supplies the information about the matrix moisture content in relation to the suction pressure heads. Evidently, it is an equilibrium hydraulic characteristic which does not consider at all the existence of large pores where the gravity driven preferential flow could take place. To obtain the soil hydraulic conductivity function, the saturated hydraulic conductivity (Ks) is commonly measured, in combination with the relative hydraulic conductivity prediction by means of a convenient capillary model method.

The measured value of Ks may be enormously biased by the preferential flow in a way that it does not represent the flow in the soil profile any more. The high variability of Ks is well known, large sets of Ks usually fit to the log-normal distribution. Often this fact is taken to support an opinion that the variability analysis of the saturated hydraulic conductivity is sufficient for the description of the preferential flow within the soil profile. Because the preferential flow initiates in a scale which is less than the volume of soils used to measure Ks, this conclusion is not true. The tracing of the actual flow paths within the undisturbed soil samples, during the measurement of the Ks in the lab, have proven it. In a standard description of the flow in the porous media, two types of the flow rates are defined:

- Darcy flux rate representing flux density over a given cross section area
- mean pore velocity, where only the cross section area related to pores (given by porosity) is considered.

Both flow rates are theoretically derived using the representative elementary area concept. In practice, the Ks values are pragmatically calculated as the flux density over a cross section area of a given soil volume used in an experiment (sampling cylinder, infiltration cylinder, etc.) in the condition of a full saturation. Using color tracing during the flow experiment, it is possible at the end to find out that the actual cross section area where the flow took place is often a very small portion of the sample cross section area. In the soil under study it was between 5-20%. It is evident that the actual flow rate is thus 20 – 5 times larger and the estimated Ks is thus significantly underestimated.

3. PREFERENTIAL FLOW DETECTION

Preferential flow is relatively well measurable in the lab scale. Beside a fully monitored infiltration outflow experiment (Císlerová et al., 2002) the noninvasive visualization by means of CT and MR imaging helps to evaluate the ratio of the fast flow during the infiltration.

Based on the results of experiments performed so far several important features were observed, partly they are summarized in following points:

1. Only a portion of the empty or less dense voxels of the sample which represented potential preferential pathways was filled with water during infiltration, in other words the CT information about the dry sample density distribution is not enough for the determination of the flow regions (Votrubová et al., 2003).

2. For the soil under study MR imaging supplies information only about the water obtained in large pores. In the crossection area of the sample in the direction perpendicular to the direction of flow the averaged ratio of voxels containing visible water is about 30%. The selection evaluating the signal intensity was done by means of T1 mapping (Votrubová et al., 2002).
3. It was detected that, for the heterogeneous soil samples under study, fast preferential flow forms at the pore scale due to gravity driven flow through large pores.
4. Not all water, driven by gravity, drains when the infiltration stops.
5. The so called "steady state" infiltration rate depends on the initial saturation of the sample. The higher initial saturation of the sample means less volume flowing through the sample preferentially.
6. In repetitive (subsequent) infiltration experiment, only a portion of previous flowing volume was moving through the sample. When distribution of water in particular voxels during the first and second infiltration run were compared it was found that in each case water was filling different voxels (Císlerová et al., 2002). This was found in all MR infiltration experiments. Also the volumes of water drained out of the samples after each infiltration run were different and remaining visible water was differently spatially distributed (Votrubová et al., 2002).
7. The total volume of fast flowing water during "steady state" conditions was decreasing in time while the total weight of the sample was increasing, documenting the changing driving forces field between gravity and capillarity driven volumes (Císlerová et al., 2002).
8. The main reason of the detected effects seems to be the discontinuous air phase distributed and partially closed within the sample in combination with uneven pore velocity field (changing over multiple time scales). The largest velocity values are in the range of seconds, the slowest ones are in the range of several days thus overlapping the time scale of the experiment and responsible for continuing redistribution even during the so called "steady state" flow. That means that very small volumes keep flowing very slowly inside of the sample, negligibly influencing the water balance but continuously changing the driving force distribution.

4. SIMULATION MODELS INCLUDING THE PREFERENTIAL FLOW

A promising approach to simulate preferential flow and transport derives from the principle of dual permeability concept (Gerke a van Genuchten, 1993). In a series of the simulation studies of Vogel et al. (1993, 2000), implementing this concept, the heterogeneous flow domain is split into two macrocontinua. One represents a fast flow domain capturing preferential flow; the second one corresponds to the flow in the soil matrix. In this model two governing equation are thus solved, independently for each subdomain. Mutual interaction of both domains is maintained by a first order transfer term.

To determine parameters of the soil hydraulic properties of both flow domains, the inverse modelling of infiltration/outflow experiments based on dual permeability principle was used (Dohnal et al., 2004). Application of the dual permeability approach improves the agreement of the simulated and measured outflow significantly, however the flow instability remains unaccounted for.

5. CONCLUSIONS

The purpose of this contribution is to inform the SOPHYWA audience about a complex work done at CTU in Prague towards better understanding to the dynamics of flow in heterogeneous natural soils to be used in construction of more appropriate simulation tools. The major part of the work has been published, as cited. The most interesting results will be shown during the presentation. To our opinion the including of preferential flow into simulation models is of fundamental significance for the realistic simulation of solute transport processes in the areas where the preferential flow contributes to the formation of outflow.

ACKNOWLEDGEMENT

The MRI was performed in cooperation with HSLMC Cambridge, for friendly cooperation we are grateful to Prof. Laurie Hall and Dr. Gao Amin. The work is supported by VAV/650/3/04 and GACR 103/04/0663.

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Root Water Extraction and Limiting Soil Hydraulic Conditions Estimated by Implicit Numerical Simulation with the Richards Equation

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ABSTRACT

Root density, soil hydraulic functions, and hydraulic head gradients play an important role in the reduction of transpiration below potential levels. An implicit numerical root water extraction model is presented to solve the Richards equation for the modeling of radial root water extraction. The dependence of a critical water content (at first occurrence of plant water stress) on potential transpiration and root density is evaluated. These critical values are shown to be a function of potential transpiration rate, soil hydraulic properties and root density. Matric flux potential is a convenient hydraulic property to determine the first occurrence of limiting hydraulic conditions, as it can be shown to be matric flux potential is independent of soil type. Numerical simulation shows that mean water content occurs at about 0.53 times the half-distance between roots from the axial center. Using an analytical solution, this allows calculating mean limiting soil water content and pressure head from the matric flux potential at this distance.

1. INTRODUCTION

In an engineering approach used in irrigation scheduling and hydrologic modeling, a threshold value for water content (θ) or pressure head (h) is often assumed below which transpiration rates decrease below maximum values. Models describing root water uptake based on the behavior of a single root (microscopic approach) or on the overall root system (macroscopic approach) may provide insight as to how the interaction between soil and roots determines root water uptake.

The overall objective of the present paper is to derive critical parameter values for macroscopic root water extraction models by implicit numerical microscopic (single root) modeling.

2. MATERIAL AND METHOD

2.1. Implicit numerical modeling

To solve the Richards equation for the case of radial root water extraction, a numerical procedure based on the scheme presented by Van Dam & Feddes (2000) was used with the following modifications: (1) the gravitational component is not considered; (2) fluxes are adapted to the 1-D axisymmetric nature of root extraction; (3) there is no sink; (4) flux density at the outermost compartment is zero; (5) flux density at the innermost compartment is equal to flux density entering the root.

Pressure head at the root surface is limited to a minimum, h_{lim}, here assumed to be equal to the commonly used pressure head at permanent wilting, -150 m. When the root potential reaches h_{lim} for the first time, the value of h_{mean} depends on the entire root extraction history. We will refer to the hydraulic conditions at this instant as limiting hydraulic conditions, which will be defined by the subscript *mean,lim*.

Segment size (d_r) was chosen smaller (10^{-8} m) near the root, increasing to 5.10^{-4} m at the outer border of the root influence sphere. Time steps, ranging from 1 second to 1 hour, were automatically adapted by the computer program in order to reach convergence in 3 to 5 iterations.

Assuming no sink or source and no gravitational or osmotic component, and in analogy to Van Dam & Feddes (2000), the problem can be discretized, yielding the following equation:

$$C_i^{j+1,p-1}\left(h_i^{j+1,p} - h_i^{j+1,p-1}\right) + \theta_i^{j+1,p-1} - \theta_i^j = \frac{t^{j+1} - t^j}{r_i \Delta r_i}\left[r_{i-0.5} K_{i-0.5}^j \frac{h_{i-1}^{j+1,p} - h_i^{j+1,p}}{r_i - r_{i-1}} - r_{i+0.5} K_{i+0.5}^j \frac{h_i^{j+1,p} - h_{i+1}^{j+1,p}}{r_{i+1} - r_i}\right] \quad (1)$$

where C is the differential water capacity ($d\theta/dh$, m^{-1}), r is the distance from the axial center (m), K is the hydraulic conductivity (m d^{-1}), and i, j and p are the segment number, timestep and iteration level, respectively. A solution to the problem can be found by applying Eq. (1) to each segment and solving the resulting equation system described by a tridiagonal matrix.

2.2. Simulation scenarios

Simulations were performed using hydraulic data for three top soils from the Dutch Staring series (Wösten et al., 2001): B3 – (loamy) Sand; B11 – (heavy) Clay and B13 – (sandy) Loam. The main simulation scenario parameters are listed in Table 1. Potential transpiration (T_p, mm d^{-1}) was supposed to vary daily according to a sine-wave function with its amplitude equal to its mean value $T_{p,mean}$.

Table 1. Boundary conditions for simulation scenarios.

Description	Symbol	Scenario	Value	Unit
Plant Surface Area	A_p		0.04	m^2
Rooting depth	z		0.5	m
Limiting root potential	h_{lim}		-150	m
Root radius	r_0		0.5	mm
Root length	L	Low R	2	m
		Medium R	20	m
		High R	200	m
Initial pressure head	h_{ini}		-1	m
Mean potential transpiration rate†	T_p	Low T_p	3	mm d^{-1}
		High T_p	6	mm d^{-1}
Daily amplitude in potential transpiration rate†	a_T	Low T_p	3	mm d^{-1}
		High T_p	6	mm d^{-1}

3. RESULTS AND DISCUSSION

3.1. Root pressure head, mean pressure head and transpiration as a function of time

Simulation results are shown in Fig. 0 for the two potential transpiration rates and two root densities (R) for the Clay soil. The daily fluctuation of h_{root} in order to match varying transpiration can be observed in this figure, especially at low R. In contrast, at high R, h_{root} remains almost equal to h_{mean} from beginning to end of the simulations.

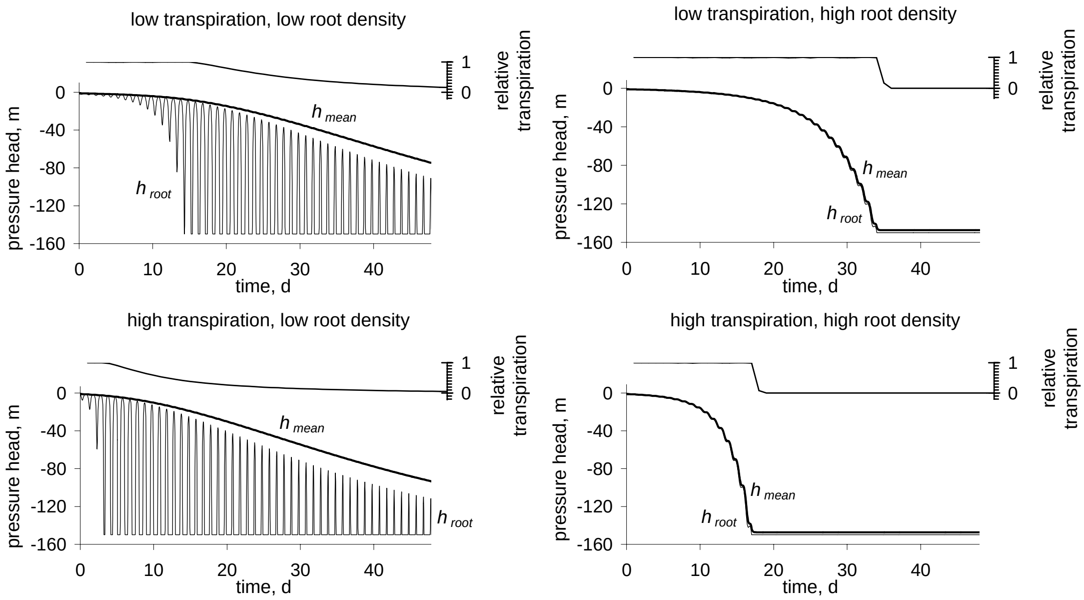

Figure 1. Simulated pressure head at root surface (h_{root}), mean pressure head (h_{mean}) and relative transpiration as a function of time in Clay soil.

3.2. Selection of a key soil physical variable controlling transpiration rate

Matric flux potential (M, m^2 d^{-1}), defined as the integral of hydraulic conductivity over pressure head starting at the pressure head at permanent wilting point, integrates hydraulic conductivity and pressure head, providing a good option for analysis. Evaluating the value of M corresponding to $h_{mean,lim}$, the result is a linear relation between M and T_p with intercept equal to zero, the slope of which is a function of root density, but independent of soil type. Limiting hydraulic conditions can therefore be characterized by a single M-value, independent of soil type. Using this result, a nomogram can be designed as shown in Figure 2.

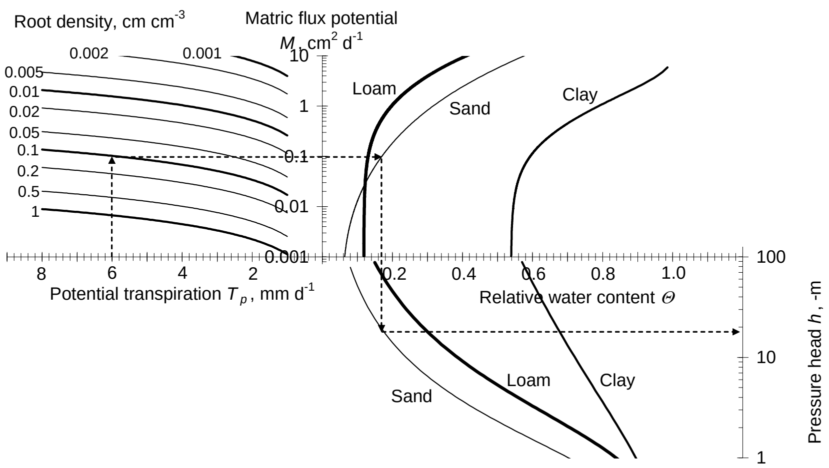

Figure 2. Nomogram for the determination of $h_{mean,lim}$ and $\Theta_{mean,lim}$ for three soils from transpiration and root density data.

This nomogram allows to determine $h_{mean,lim}$ and $\Theta_{mean,lim}$ if potential transpiration and root density are known. Dotted arrows illustrate nomogram use for a transpiration rate of 6 mm d^{-1} and a medium root density (0.1 cm cm^{-3}) for the Sand soil.

3.3. Comparison of simulation results to analytical solutions

The average water content can be determined from the r-weighted integral of the $\theta(r)$ profile over r and it can be shown analytically that, for $r_m \gg r_0$:

$$r_{mean} = r_m e^{-\frac{1}{2}} \approx 0.6065\, r_m \tag{2}$$

For each scenario of transpiration rate and rooting density, and while the transpiration rate is potential, the flux density at the root surface is independent of soil characteristics. Numerical simulation results show that this independency can be extended to the whole root sphere for the three evaluated soils. These results also show that the weighted mean water content corresponds to the water content in the root zone at a location between 0.53 r_m and 0.57 r_m for most cases, in rough agreement with Eq. [2].

An analytical expression for *M(r)* would allow the calculation of M at the distance $r_{mean.}$ Such a solution exists (for $T = T_p$, and $M = 0$ at the root surface) and is known as the steady rate solution (e.g. de Willigen et al, 2005):

$$M_{h_0} = \frac{T_p}{2z}\left[\frac{r^2 - r_0^2}{2} + \left(r_m^2 - r_0^2\right)\ln\frac{r}{r_0}\right] \tag{3}$$

Given $M(\theta)$ or $M(h)$ this provides an estimate of $\theta_{mean,lim}$ or $h_{mean,lim}$.

4. CONCLUSIONS

Numerical simulations showed the matric flux potential at first occurrence of limiting hydraulic conditions to be independent of soil type and to depend only on potential transpiration rate and root density. Analytically it was shown that this can be explained if water depletion $d\theta/dt$ has the same value within the entire root sphere.

Analytically, mean soil water content occurs at a distance from the axial center 0.6065 times the half-distance between roots (r_m). Numerical simulations showed that, in fact, this distance varies according to soil type, root density and transpiration rate, and has a value of ±0.53.

Combining the above two conclusions, we suggest that mean soil water content and pressure head at first occurrence of limiting hydraulic conditions can be calculated from the matric flux potential at 0.53 r_m, which is a function of transpiration rate and root density.

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Improving Evaluation of a Virtual Lysimeter by Inverse Calibration of Water Content Measurements

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ABSTRACT

Simultaneous readings of volumetric water content θ and matric potential h with adequate temporary and spatial resolution are supposed to hold similar information as a lysimeter – but without physical separation of the soil from its ambiance. Such a facility may therefore be termed virtual lysimeter.
For research purposes, several hydrological and soil hydraulic quantities have been measured on a field monitoring site at the experimental farm of the University of Natural Resources and Applied Life Sciences, Vienna, in April 2002. These quantities include h and θ in several depths in the soil and all necessary data above the ground for calculation of potential evapotranspiration, plus precipitation.
Inspection of the soil water balance showed a discrepancy between flow through the upper boundary, calculated from change in soil water content and deep drainage, and the amount of precipitation during rainfall events. The deviation was attributed to the measured water content, which was calculated with the standard calibration equation and default coefficients values. Because only two events occurred in the period of one month, whereas the standard equation has 3 parameters or degrees of freedom, some additional assumptions had to be made to make the numerical system over-determined. Then the calibration coefficients could be numerically optimized to yield exactly the measured precipitation height. The improved calibration equation is supposed to give not only better profile water contents during rainfall events, but also a more accurate determination of deep drainage or capillary rise at the lower border of the soil profile or groundwater recharge.

1. INTRODUCTION

Lysimeters are a traditional equipment for the determination of actual evapotranspiration and other purposes. However, they have some shortcomings, especially when the water balance is of main interest. Uniform soil tillage and plant cover in- and outside of the lysimeter is difficult to achieve and recovery of an undisturbed monolithic soil body is costly. Control of the lower boundary requires matric potential measurements outside of the lysimeter and special equipment in the lysimeter pit. Last not least they do not hold with necessary information for inverse determination of soil hydraulic properties.

On the other hand, a virtual lysimeter according to the definition of the Institute of Hydraulics and Rural Water Management comprises in-situ measurements of the soil hydrological state variables water content θ and matric potential h in the soil with adequate time and space resolution – especially at the lower border – and observation of precipitation. Such an equipment is supposed to provide us with knowledge of profile water content and the lower boundary condition over time and shall enable calculation of water balance quantities like actual evapotranspiration, deep drainage, groundwater recharge, capillary rise or water uptake by plant roots. The purpose of a virtual lysimeter is therefore quite similar as that of a real one. Whereas the most important quantity of the latter – the outflow – can be measured very easily with a tipping bucket, the evaluation of the virtual lysimeter requires modeling, a physical process equation and its inverse solution by finding out which hydraulic properties and which temporary lower (and upper) boundary conditions led to the observed values of the state variables θ and h.

It is obvious, that any model and any resulting process equation is only a simplification, introducing more or less pronounced deviations to the natural behavior. Moreover, measurements in the soil do have a priori much less accuracy than a tipping bucket. Therefore careful calibration of measurement devices is a requisite. What can be done when it has not been performed before and the monitoring station does not exist anymore, shall be presented in this paper.

2. MATERIALS AND METHODS

2.1. Monitoring Station

The University of Natural Resources and Applied Life Sciences, Vienna, operates an experimental farm in Groß-Enzersdorf, Lower Austria app. 20 km to the East of Vienna. For a long-term comparison between a virtual lysimeter and a real one, a field monitoring station was established there in 2001, near by the lysimeter station existing since several decades. An overview of the monitoring site arrangement is depicted in Fig. 1.

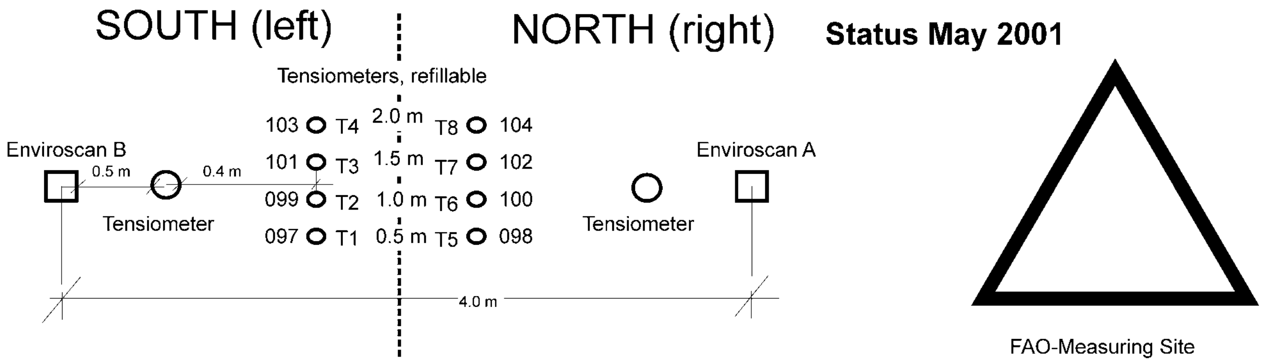

Figure 1. Arrangement of the virtual lysimeter monitoring station at Groß-Enzersdorf

Equipment in the soil was installed with two replications (Lysimeter North and Lysimeter South). The list of recorded data comprises following quantities:
Above ground:

- Air pressure
- Air humidity at 2.0 m and 5.0 m height
- Air temperature at 2.0 m and 5.0 m height
- Max. and min air temperature at 2.0 m height
- Global radiation from the ground
- Shortwave radiation, both directions
- Wind velocity at 2.0 m and 5.0 m height
- Precipitation

In the soil:

- Soil temperature at 5 cm, 20 cm and 50 cm depth
- Tensiometer potential at 50 cm, 100 cm, 150 cm and 200 cm depth
- Volumetric water content at 16 dephts from 10 cm to 200 cm depth

Matric potential was measured with tensiometers (UMS T6®), volumetric water content with capacitance probes in vertical access tubes (EnviroSCAN®, Sentek Pty. Ltd, Australia).

Extracted data of the monitoring station were intensively evaluated for the period of April 2002. Gained cognitions including water balance terms were published by Hauer et al. (2003).

2.2. Profile Water Content

Both EnviroSCAN probes were supplied with $i = 16$ individual sensors which were situated in the depth z_i, with z_i being the height over surface, oriented upwards ($z_{\text{Surface}} = 0$ cm, $z_1 = -10$ cm and $z_{16} = -200$ cm) and i the index of a single sensor. This high amount of measurement depths gives a good description of the profile water content distribution, even with a very simple interpolation procedure. One important disadvantage of water content measurement units in access tubes is that they do not measure close to surface. In this case the uppermost 10 cm of the soil profile (-10 cm $< z \leq 0$ cm) had not been measured. This required an extrapolation, which is critical due to the highest dynamics of θ in this horizon.
However, $\theta(-10\text{ cm} < z \leq 0\text{ cm}) = \theta(z_1)$ was assigned.

The standard calibration equation for EnviroSCAN sensors is according to the manufacturer

$$\frac{\theta(SF)}{\%} = \left(\frac{SF - c}{a}\right)^{1/b}, \tag{1}$$

where a, b and c are dimensionless calibration coefficients. The default values for the standard calibration are $a = 0.1957$, $b = 0.404$ and $c = 0.028520$.

It was assumed that water content distribution over depth at fixed beginning and end of rainfall can be approximated by a step function. Profile water content is then a sum of single water content values multiplied with a corresponding influence width:

$$W = \int_{z_{16}}^{0} \theta \, \mathrm{d}z \approx \sum_{i=1}^{16} \theta_i \cdot b_i, \tag{2}$$

where $b_1 = 0 - (z_1 + z_2)/2$, $b_i = (z_{i-1} - z_{i+1})/2$ for $i = 1\ldots15$ and $b_{16} = (z_{15} - z_{16})/2$.

3. OPTIMIZATION

The optimization was performed by means of one precipitation event which occurred on 14-04-2002. Beginning of the event was fixed to 09:22, end to 17:56. Total amount of precipitation for the event was 37.8 mm, and 28.8 mm of it fell between 09:22 and 17:56.

Hauer et al. (2003) concluded in their paper, that deep drainage resp. flux through the lower boundary must have been negligible. Total potential at the lower boundary was almost constant with time and increased slowly with depth, but water content was quite low ($\theta < 16$ %). The corresponding unsaturated hydraulic conductivity estimated with RETC was $k_u = 0.17$ cm/d. This gives an upward flux for the whole month of about 1 mm.

It was provided that all 16 individual sensors of the probe had been perfectly normalized and that identical coefficient values apply to all of them. Experience from laboratory calibration has shown, that the absolute error in θ strongly increases with SF (see Kammerer et al., 2005). This means on the other hand, that it is almost 0 in air-dry soil or for $SF = 0$. The coefficient c was not optimized therefore. Profile water content minus deep drainage – which was 0 – based on uncalibrated θ-readings is shown in Fig. 2 top. The increase in stored soil water obviously indicated by the figure was much bigger than the amount of precipitation. The improved water balance plots can be seen in Fig. 2 bottom.

The optimization itself resulted in following calibrated coefficient values:

$$a_{\text{cal}} = 0.0912,\ b_{\text{cal}} = 0.6413 \text{ and } c_{\text{cal}} = 0.028520.$$

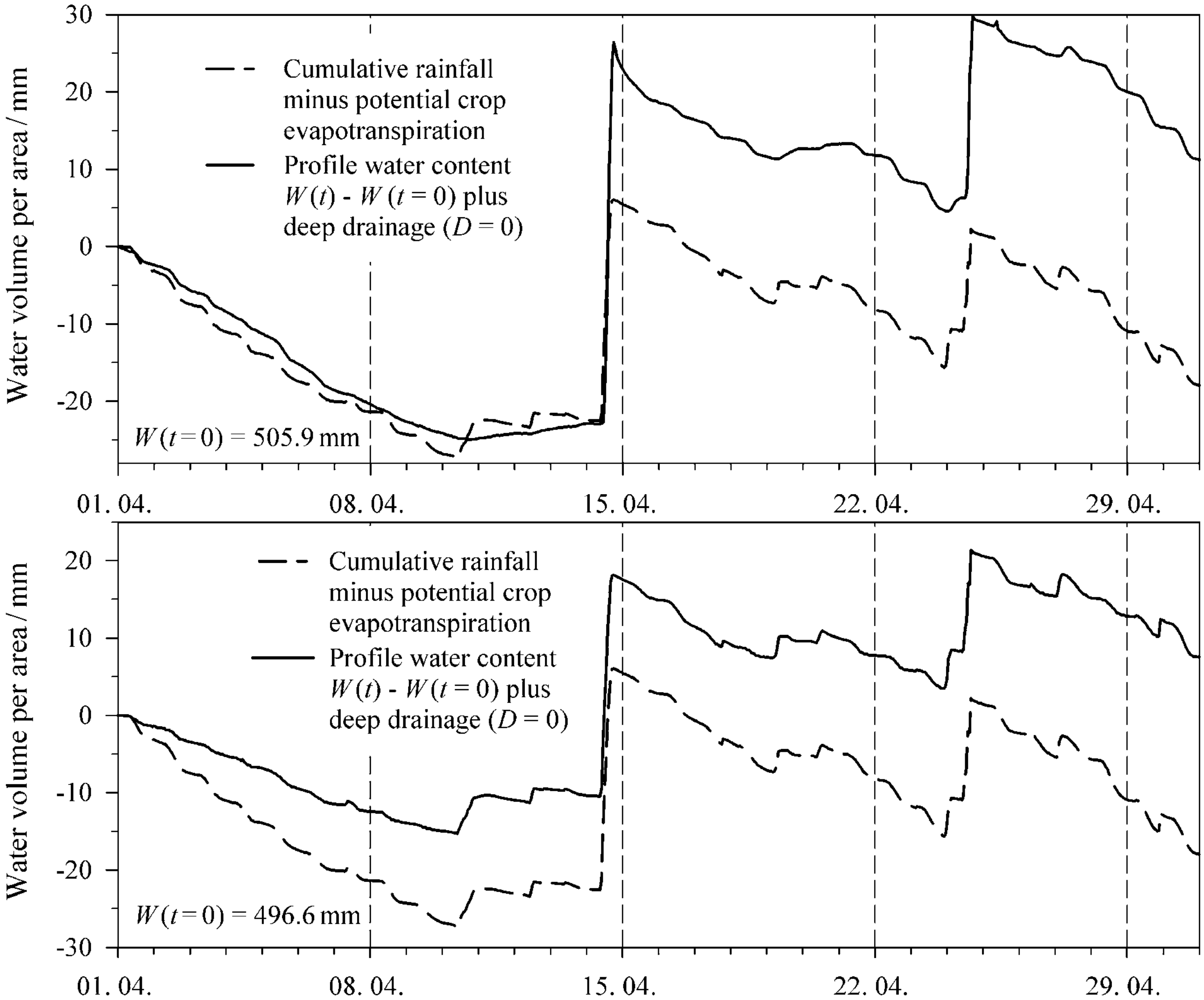

Figure 2. top: Water balance terms based on default calibration of capacitance sensors.
bottom: Terms based on inversely calibrated θ-readings.

4. CONCLUSIONS

Although the method itself might have been demonstrated in a very crude way, the idea behind does bear a powerful tool to make up for field calibration or to complete and to improve it. Especially when the observed data form a mathematically over-determined system, the sum of degrees of freedom should be extended and some of their information can be dedicated to a better determination of the calibration coefficients.

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Theory on Soil-Crop Water Status Management and Its Application

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ABSTRACT

The paper offers a theory of soil-and-crop water status estimation and management during the growing season. Using precise field experimental data obtained over 30 years, we found and introduced an integral index *L* of soil moisture energy levels for estimating this water status. We introduced an index of plant water susceptibility and defined extreme-critical, critical and important stages of plant growing season, which are related to soil water status and crop yield. We developed a decision support system as practical tool for managing the soil water status and plant production as amount and quality. Using this system, we can create specific energy levels of soil moisture for different crops in field during growing season. These levels are located above the equivalent natural energy level established without irrigation in the field. Experimental data regularities are shown.

1. INTRODUCTION

In our opinion, the cardinal problems with great importance for the precise agricultural practices are the following.

- Can we estimate the only ***essential influence*** of the soil water status (SWS) on plant production using one integral index and can we ***precisely control*** this influence under changing meteorological conditions during the growing season?
- Can we create a preliminary defined and chosen ***specific soil water status*** for the whole growing season for a given crop under the available financial, technical and resource (soil and water) conditions of a farm?
- Can we obtain a ***planned amount and quality of crop yield*** under the changing meteorological conditions and do we have an appropriate tool to do this?

These questions have intelligent theoretical and applied answers, which are not ease and not simple, but acceptable as tool for agricultural practices. Computer technology based on this theory is the offered tool.

Soil water status for the whole crop growing season is one of the most important factors with strong influence on the amount and the quality of plant production. For a long time, many researchers have tried, and some of them are still trying, to find a relationship between total water consumption of plant ecosystem and its bioproductivity. They used average data for periods covering many years. It was proved that the bioproductivity is not proportional to the total water consumption of ecosystems (Kozlovski, 1978). Moreover, there is no simple dependence between the increase of bioproductivity and the water added in irrigation activity.

The crop water consumption mainly depends on the evaporation demand of atmosphere. The assumption of existing relationship between total water consumption and crop productivity is not reasonable. It could be considered as a very rough approximation, which does not account the precipitation and plant-susceptibility distributions through the growing season.

The paper offers an ecological energetic concept on bioproductivity response to soil water factor impact, taking into account: (a) the plant stage susceptibility, (b) the precipitation distribution, and (c) the soil water supply formation after each rainfall.

2. THEORY

2.1. Susceptibility

The strongly changing action of soil water factor permanently exerts influence on the formation of productivity, including extreme cases of plant destruction.

Let us consider the simplified case that all other (except soil water) factors do not limit the plant growth and productivity formation.

We define the plant susceptibility as a specific plant property, which can be measured by the degree of irreversible biological change in a plant feature caused by the impact of the soil water status (SWS).

It is expedient to introduce both differential and total coefficients of the plant susceptibility to soil water status at a stage of plant growth.

The differential susceptibility coefficient S_d is defined as the relative plant yield reduction $\Delta Y_s/Y$ caused by the only lowering of ΔL_s = 1 $J^{0.5}$ $kg^{-0.5}$ from the soil-moisture energy level L for the stage s, or (Christov, 1994):

$$S_d = \Delta Y_s/(Y \Delta L_s) \quad (1)$$

where ΔY_s is the absolute amount of plant yield reduction and Y is the amount of yield obtained, when the energy level L has been established at all stages of the plant growth. The total susceptibility coefficient S_t at a stage s is defined as the relative plant yield reduction Δy_{ts} / Y caused by the only lowering of ΔL_{ts} = 40 $J^{0.5}$ $kg^{-0.5}$ of the level L at the same stage s, or:

$$S_t = \sum_{i=1}^{40} (S_d)_i \quad (2)$$

2.2. Fundamental postulates

The bioproductivity formation related to soil water factor depends on both the energetic limitations on plant providing with soil moisture and the degree of irreversible biological changes in the plant organism. This separation of the interaction between water impact and plant response into two components is ***the first fundamental postulate*** of the present scientific basis. It enables us to describe this phenomenon in a quantitative way (Christov, 1989 & 1998).

The mentioned energetic limitation is a physical impact component of the interaction. This is a permanently varying and acting component during the whole growing season. The degree of irreversible changes in plant features is different to one and the same impact when applied during various stages of plant ontogenesis. This is a biological response of plants, which remains as a specific imprint upon their growth and productivity. This response is a biological response component of the interaction under consideration (Christov, 1994).

The second fundamental postulate reads as follows. The growth depression caused by the physical component during a stage of plant ontogenesis and leading to a reduction of plant productivity reaches its maximum at the minimum soil water potential for the same stage. This postulate enables us to estimate the soil water status (SWS) for each of the stages, using a new integral index *L*.

The soil water status (SWS) can be estimated by this biophysical index *L* of specified energy levels of soil moisture *in situ*. This index is proportional to the lower limit ψmin of the soil water potential ψ, as absolute value raised to power of 1/2 (Christov, 1992 & 2004).

We introduced equivalent energy levels L_e for the quantitative estimation of plant-soil water status of the ecosystems by the equation (Christov, 1992):

$$L_e = f_1 L_{ec} + f_2 L_c + f_3 L_i, \qquad (3)$$

where L_{ec}, L_c and L_i are the soil-moisture energy levels established respectively during the *extreme-critical (ec), critical (c) and important (i) stages* of maize ontogenesis, and f_1, f_2 and f_3 are the weighting coefficients of the maize susceptibility.

The L_e index is a quantity of measuring the physical component of soil water impact on plant productivity, which is considered. The plant productivity response to this impact should be directly measured as crop yield (Idso, 1968).

The third fundamental postulate of the basis concerns the identification of the plant ontogenesis stages, each of which includes some plant growth phases with equal or almost the same plant susceptibility to soil water status (or to soil water deficiency in the ecosystem). The correct identification of the stage time intervals for every plant ecosystem is of great importance for a successful application of the scientific basis (Christov, 2004).

The fourth fundamental postulate requires the decision support computer system developed on complex scientific basis to be used currently during the growing season.

The fifth fundamental postulate concerns the estimates of other factors (except the soil water status) influencing the crop yield formation. Those factors should not be limiting the plant growth and its productivity.

3. APPLICATION

We applied this concept to the maize ecosystems and the maize susceptibility indices such as: • mass of grain yield (quantitative index), • nitrogen (N) content in grain (qualitative index), • phosphorus (P) content in grain (qualitative index) and • zinc (Zn) content in grain (qualitative index).

The environmental factor, named as soil water status (SWS), was estimated with the new index ***L*** as a whole for the growing season, and for different stages of plant ontogenesis. The same theory can be applied for natural plant ecosystems, too.

After the accomplishment of different research experiments and the application of the offered ecological concept, we established: • classification of the energy levels ***L*** of soil moisture, based on the soil-water potential minimum occurred at the three stages of plant growth, and serving as measuring scale for the soil water status (SWS) estimates (Christov, 1992); • well-expressed dependence of the maize productivity on the introduced ***L*** index of the soil water status (SWS) as environmental factor (Christov, 1992); • strong correlative relationship between the relative maize grain productivity reductions and the $\boldsymbol{L_s}$ index differences of energy level lowering during the extreme-critical stages of the plant growth (Christov, 1994); • average differential susceptibility coefficient $\boldsymbol{S_d(L)}$ for the extreme-critical stages of maize growth, which is equal to 3.1 % of grain yield per 1 $J^{0.5}$ $kg^{-0.5}$ (Christov, 1994); • total susceptibility coefficient S_t for the same stages, which is equal to 64.9 % of grain yield per 40 $J^{0.5}$ $kg^{-0.5}$ (Christov, 1994); • dependencies of nitrogen and phosphorus contents in grain of maize on the index ***L*** of soil water status (Christov, 1993); • well-expressed dependence of zinc content in grain of maize on the index ***L*** of soil water status (SWS). This dependence specifies the plant zinc susceptibility to soil water factor impact at different nutrient regimes (Christov, 1993).

4. CONCLUSION

The introduced ***L*** index of soil-moisture energy levels, its scale and classification can serve for estimating not only the soil water status (SWS) as a whole for the growing season and separately for its stages, but also the ecosystem water status (EWS). The last one takes into account both the soil water status (SWS) and the atmosphere water status (AWS). The SWS and AWS are interrelated. The share of AWS influence on plant photosynthesis can not reach 10 % of the SWS share.

The ***L*** method can be applied for estimating the water status of natural and anthropogenic plant ecosystems. The defined and quantified (by this ***L*** method) plant susceptibility to water deficit impact enables us precisely to carry out both research on ecosystem relationships / productivity and ecosystem management.

The developed quantitative concept is of great importance for managing the agroecosystems by appropriate crop irrigation scheduling.

Using the computer technology developed on complex biophysical basis, we can create appropriate ***L*** soil water status in different agroecosystems and obtain the yield planned in quantity and quality.

The concept of ecological susceptibility to soil water status is of theoretical and practical significance concerning: (1) modelling and monitoring; (2) efficient managing the productivity for optimum benefit; (3) minimizing the soil destruction by irrigation; and (4) minimizing or preventing the underground water pollution. It stimulates the development of complex technologies for ecological agriculture.

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Salinity Effects on a TDR Soil Moisture Sensor

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ABSTRACT

Time Domain Reflectometry (TDR) sensors apply an electric field to a surrounding medium in order to measure a response that is related to the medium's dielectric permittivity. The measurement of responses related to the dielectric permittivity of a soil can be used to estimate the moisture content. However, the relationship between the change in the response and the soil water content depends on the soil type and the frequency range of the apparatus because the dielectric permittivity is not related only to the water content. In agriculture, the bulk electrical conductivity due to salt content in soil can range between approximately 0.3 and 5.0 dS/m with a resultant effect on the dielectric permittivity. The salinity effect on a TDR soil moisture sensor was investigated. The experiment was conducted in a laboratory using a column filled with sand. An access tube was installed in the centre of the column. A Trime sensor was used to measure the responses and calculate the capacitance and dielectric permittivity of each treatment. Treatments consisted of flushing the soil columns with different concentrations of sodium chloride solution, starting with approximately 0.3 dS/m and increasing in steps up to 6 dS/m. The Trime device was not significantly affected by solution EC over the range and in the soil tested.

1. INTRODUCTION

For irrigation management, gravimetric or neutron scattering methods have been used throughout many years to determine the crop soil water uptake. New technologies based on TDR (time domain reflectometry) and FD (frequency domain) measurements allow continuous soil water monitoring, which could be beneficial for automatic irrigation (Baker and Allmaras, 1990; Herkelrath et al., 1991; Starr and Platineanu, 1998) if accurate. But these techniques may be influenced by salinity, as the salt content of irrigation water can affect the measured dielectric constant.

2. MATERIAL AND METHODS

This study was aimed at investigating the effect of salinity on the responses obtained from one type of TDR sensor in a laboratory trial. A Trime TDR sensor was employed, which is produced by IMKO Micromodultechnik, Germany. The sensor can be normally installed via access tube from the soil surface, using a combined drill-strike technique recommended by the manufacturers.

Time domain reflectometry is an indirect method to determine water content. It is based on the fact that water has a larger dielectric permittivity than soil particles. Because of this great difference, the speed of travel of a step pulse of electricity in a parallel transmission line buried in the soil is highly dependent on the soil water content. From the measured travel time, the water content can be estimated (Topp and Davis, 1985; Topp and Ferre, 1998). In this study the TDR-Trime-T3 probe was used (figure 1). It consists of an 18 cm long PVC cylinder with four aluminum plates serving as wave guides arranged in pairs on opposite sides of the cylinder. The probe measures from inside a polycarbonate plastic tube, which is installed in the soil with a drill and a percussion drill, which are used inside the plastic tube and are removed after installation. After the probe is lowered manually to a certain depth, measurements can be taken. According to the company's specification, accuracy is ± 2 % of volumetric water content with a 15 cm measuring radius.

The column container was made out of a 1 m tall by 0.4 m wide polyvinyl chloride (PVC) plastic tube by sealing the bottom with a PVC plate. At the bottom, a hole was drilled to let the water drain out from the container. Gravel with a 8 to 12 mm particle size diameter was placed in a 4 cm deep layer at the bottom and covered with a disk of nylon window screen to avoid mixing with the sand. The sand had a particle size diameter between 0.6 and 2 mm. Sand of all columns was packed in 5 cm increments above the gravel up to the top. Average density of the sand was 1.7 g/cm, and total porosity was 0.36 m^3 m^{-3} under consideration of a particle size density of 2.65 g/cm (figure 1). The access tube for measuring the response to water content and salinity was installed during column preparation. The access tube was positioned in the center of the column to minimize any interaction between the sensor and tube edge.

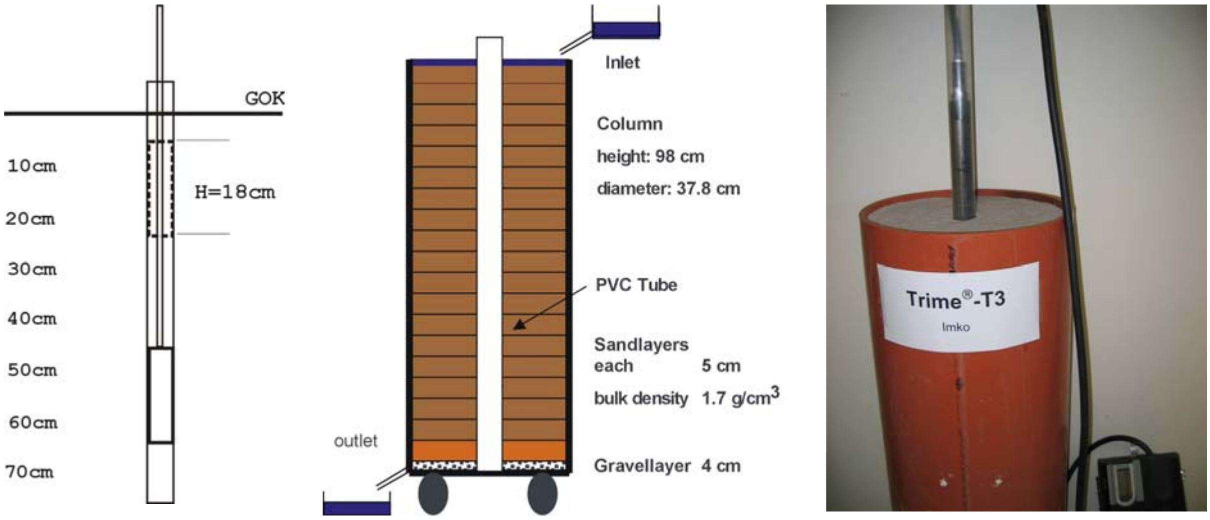

Figure 1. Cross sectional sketch of measurement depths, column preparation and picture of the soil column used and Trime T3 sensor

Treatments consisted of flushing the sand column with different concentrations of sodium chloride solution to simulate a range of irrigation water qualities (0.3, 0.4, 0.7, 1.2, 1.7, 2.0, 2.3, 2.6, 3.4, 3.9, 4.5, 5.2, 5.5, 6.2 dS/m). The first treatment was tap water with subsequent treatments sequentially increasing the salt content of the applied water. The solutions were applied to the tube until input water salinity and leachate salinity were same. After each treatment, the soil was allowed to drain for 24 hours prior to applying the next salinity treatment.

Measurements included apparent water content, and the amount and salinity of added and drained water. Apparent water content measurements taken with the Trime were made when the sand column was initially wetted and after draining to field capacity. Trime readings were taken according to the recommended factory procedures, which were 3 readings at each depth, turning the sensor 120° after each reading. The Trime readings were averaged for each depth. All measurements were done at constant temperature. The column was covered with plastic bags to avoid evaporation.

3. RESULTS

Due to the fact that water was applied at the surface, air was trapped in the sand and the theoretical saturated water content of 0.36 m^3 m^{-3} could not be reached. Taking into account the amount of added water and the volume of the column, water content reached its greatest value at approximately 0.25 m^3 m^{-3}. Even after initial wetting, apparent soil water content was not uniform from top to bottom of the columns (figure 2, right graph). Figure 2 also shows the apparent soil water content after wetting and after drainage for low and high water salinity.

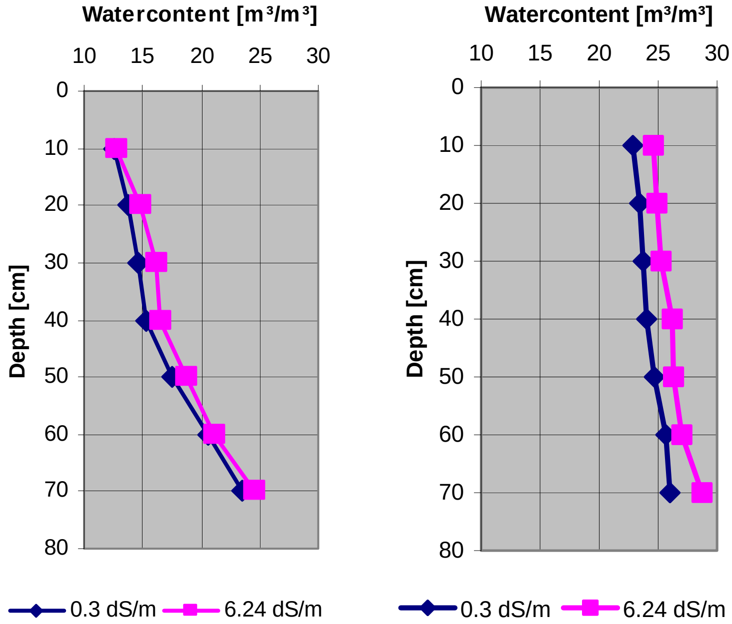

Figure 2. Apparent soil water content at saturation (left) and after drainage (right) for low and high soil water salinity

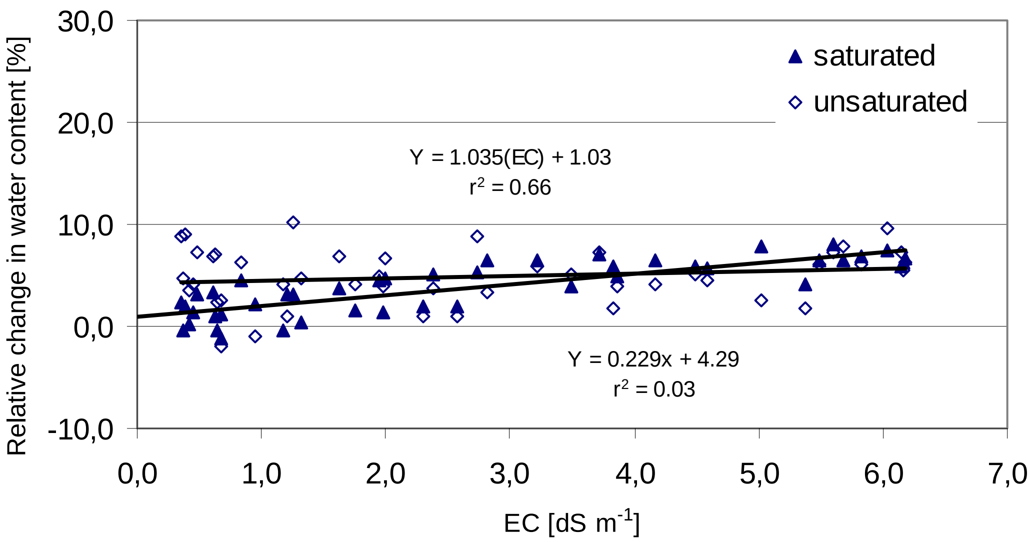

Figure 3. Relative change of apparent soil water content

Table 1. Regression equations of relative percent change in water content (Y) vs. solutions electrical conductivity (EC) in dS m^{-1}.

Device	Soil Condition	Regression Equation	r^2	Significance
Trime	Initial Wetting	Y = 1.035(EC) + 1.03	0.661	P<0.001
	Field capacity	Y = 0.229(EC) + 4.29	0.029	NS

Figure 3 shows the relation between the changes of the electrical conductivity of the irrigation water and the changes of the apparent water content values given by the Trime TDR device. Regression of the relative percent change in apparent water content vs. salinity was not significant for the Trime device when the soil was at field capacity, indicating that there was no discernible effect of electrical conductivity on the apparent water contents reported under these conditions (Table 1). After initial soil wetting, when the soil was at its greatest water content, there was a significant and positive relationship between the relative change in water content and the solution EC. However, this effect was relatively small, with the relative change increasing to 4% at the maximum EC of 6 dS m^{-1}.

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A Comparison of Prediction Methods for Mapping Soil Salinity

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ABSTRACT

The soil salinity is an important parameter affecting the design of subsurface drainage and land reclamation projects. In this study several prediction methods are compared for mapping electrical conductivity distribution. The used prediction methods are Inverse Distance Weighting (IDW), Ordinary Kriging (OK), Log-normal Ordinary Kriging (LOK), and Indicator Kriging (IK). The study area is located in Shib-Ab and Posht-Ab Payeen regions of Sistan Plain in southeast of Iran. 635 data sets of electrical conductivity measurements of the saturated paste extract (EC_e) determined at three depth intervals, 0-50, 50-100 and 100-150cm were used. The performance of each method is evaluated by Cross-validation technique with mean bias error (MBE) and mean absolute error (MAE) as validation criteria.

Keywords: spatial interpolation, geostatistics, kriging, Inverse Distance Weighting, and spatial electrical conductivity.

1. INTRODUCTION

One important parameter affecting the design of subsurface drainage and land reclamation projects is soil salinity. Mapping the spatial distribution of soil salinity requires either obtaining soil samples on a fine regular grid, which needs in turn too much laboratory analyses or spatially interpolated values of soil salinity of field measurements. To create an appropriate interpolated map of electrical conductivity of saturated paste extract (EC_e) of soil as an index of soil salinity spatial interpolations are needed. Unfortunately, in most cases spatial interpolators are performed without prior geostatistical analyses and without any validation of the results. This raises the need to investigate the quality of such interpolations and compare them with other alternatives. There are basically two different types of interpolators; those ignoring spatial autocorrelation of the data such as Inverse Distance Weighting and those accounting for spatial autocorrelation of the data such as Kriging. The relative performance of various prediction methods to map soil salinity has investigated for example by Gallichand et al. (1992), Bourgault et al. (1997), Mohammadi et al. (1997) and Walter et al. (2001).

The objectives of this study are to investigate spatial variability of EC_e and to compare the performance of Inverse Distance Weighting (IDW), Ordinary Kriging(OK), Lognormal Ordinary Kriging(LOK) and Indicator Kriging(IK) interpolators for estimating and mapping EC_e.

2. METHODOLOGY

2.1. Study Area and Summary Statistics

The study area called Shib-Ab and Posht-Ab Payeen is one part of sistan plain in southeast of Iran. It is located between 30° 40′ to 31° 20′ N latitude and 61° 15′ to 61° 50′ E longitude. The area is 47000 ha and soil samples were obtained from this area on a scattered grid (spacing of about 600m). The EC_e were determined for three depth intervals, 0- 50, 50-100 and 100-150cm. The Study area and the locations of sampling points are shown in Fig.1.

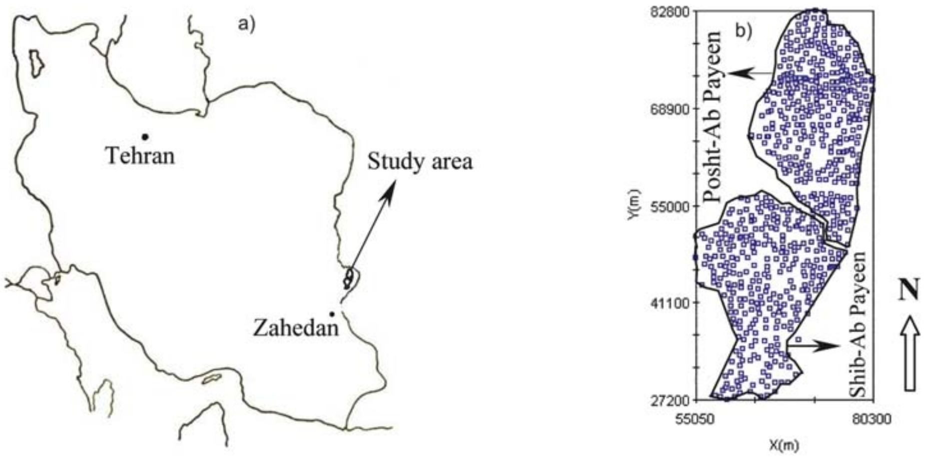

Figure 1. The study area (a) and location of measurement points (b)

2.2. Spatial Interpolation

In this study, Inverse distance Weighting (IDW) with distance power of 1, 2 and 3 and Kriging including OK, LOK and IK are used to create a regular grid of interpolated points amenable to contouring from an irregularly scattered EC_e data.

2.2.1. Inverse distance weighting (IDW)

IDW is a deterministic estimation method where unknown values are determined by a linear weighted moving averaging of values at known sampled points:

$$Z^*(x_u) = \sum_{i=1}^{n} \lambda_i \cdot Z(x_i) \tag{1}$$

Where $Z^*(x_u)$ is the estimated variable Z at location x_u, λ_i is the weighting factor assigned to the known variable Z at location x_i and n is the number of observations. The weighting factor λ_i is based on the inverse of the distance between locations of observed and estimated values.

$$\lambda_i = \frac{1/d_i^{\alpha}}{\sum_{i=1}^{n} 1/d_i^{\alpha}} \tag{2}$$

Where d_i is distance between the measurement points of i and the points being estimated and α is the power. In IDW it is supposed that samples closer to the unsampled location are more representative of the value to be estimated than samples further away. The choice of power parameter in IDW can significantly affect the interpolation results as a higher power places more weight on the nearer points while a lower power increases the influence of points that are further away. Another variable affecting the results of IDW is the number of measured neighborhoods.

2.2.2. Ordinary Kriging (OK)

OK is the most popular type of Kriging similar to IDW a linear combination of weights related to known points to estimate the value at an unknown point (Eq. (1)) is used. The main difference between IDW and OK is the way to calculate the weighting factor. In contrast to IDW, in kriging, the weights are based not only on the distance between the measured points and the prediction location, but also on the spatial arrangement of the samples. Kriging uses a semivariogram to calculate the weights. Semivariogram is the most popular tool to quantify spatial autocorrelation as it models how the variance (actually semi-variance) of a realization changes as a function of distance

$$\gamma^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \{Z(x_i) - Z(x_i + h)\}^2 , \tag{3}$$

where $\gamma^*(h)$ is the experimental semivariogram, $N(h)$ is the total number of pairs of observations separated by a distance h, $Z(x_i)$ is the observation at location x_i and $Z(x_i+h)$ is the observation at location x_i+h.

OK is called the best linear unbiased estimator (BLUE) as it chooses weights in such a way to provide the unbiased estimates and the minimum estimation variance. For detailed prescription of kriging readers could refer to Issak and Srivastava (1989). OK provides optimal estimation only when the probability distribution is normal. When this does not apply; a transformation of the data should be performed. One of the common transformations for extreme positive values is taking the lognormal of the data. OK is then used on the transformed data and therefore the final results have to be back transformed. In this study, the OK with lognormal transformation is called LOK.

2.2.3.Indicator Kriging (IK)

The utility of conventional variograms and OK for geostatistical analysis is limited by particular properties of the algorithms such as (i) normality and (ii) the independence of the OK standard error on data values. The indicator approach is one means of overcoming both of these limitations. The indicator approach involves the designation of several thresholds (for example, the deciles of the sample cumulative distribution (Goovaerts, 1997), which are used to transform the data to a set of binary variables. The indicator transform (as defined in Deutsch and Journel, 1998) $F(x_i; z_k)$ (at location x_i) for datum value $z(x_i)$ estimated for the K cut-offs z_k given as:

$$F(x_i; z_k) = \begin{cases} 1 & if \;\; z(x_i) \le z_k \\ 0 & otherwise \end{cases} \qquad k=1,\ldots,K \tag{4}$$

Indicator variograms are then computed for the k classes using the transformed data. With indicator kriging (IK), a least-squares estimate of the conditional cumulative distribution function (ccdf) is made for each cut-off (Deutsch et al. 1998). In fact, in IK indicator (binary) variables are kriged instead of continuous variables.

2.3. Validation Techniques

In this study, cross-validation (or "leaving-one-out" method) is used to compare different spatial interpolators. The method is based on removing one data point at a time, performing the interpolation for the location of the removed point using the remaining samples. This scenario is repeated until every sample has been, in turn, removed. The overall performance of the interpolators is then evaluated with two selected criteria, the mean absolute error (MAE) and the mean bias error (MBE):

$$MAE = \frac{1}{n} \sum_{\alpha=1}^{n} \left| z^*(x_i) - z(x_i) \right| \tag{5}$$

$$MBE = \frac{1}{n} \sum_{\alpha=1}^{n} \left\{ z^*(x_i) - z(x_i) \right\} \tag{6}$$

Where $z^*(x_i)$ and $z(x_i)$ are the estimated and actual values at location of x_i, respectively: $i=1...n$

Low MAE and close to zero MBE indicate an interpolator that is likely to give reliable estimates for unknown EC_e.

3. RESULTS AND DISCUSSION

3.1. Characterization of Soil Electrical Conductivity

Descriptive statistics of EC_e in three interval depths are reported (Table 1.). The results show that EC_e in the southeast of Iran has a high variance and the frequency distribution of data is also positively skewed. Top layer EC_e has the highest coefficient of variation and will be used for further discussion.

Table 1. Basic statistics of EC_e (ds/m) in Shib-Ab and Posht-Ab Payeen

Depth	Min.	Max.	Mean.	Median	Variance	CV	Skewness	Kurtosis
0-50	0.65	158.75	15.85	7.22	553.87	148.45	2.93	9.71
500-100	0.37	53.7	8.39	5.85	56.22	89.39	1.69	3.86
100-150	0.17	41.6	7.94	5.75	47.12	86.4	1.43	2.13

3.2. Spatial Autocorrelation of Soil Electrical Conductivity

3.2.1. Ordinary Kriging

Spatial continuity of EC_e was investigated by calculating experimental semivariogram of the data. A spherical model was the best-fitted model to the experimental semivariogram as described below:

$$\gamma(h) = \begin{cases} C_0 + C_1\left[\frac{3}{2}\frac{h}{a} - \frac{1}{2}\left(\frac{h}{a}\right)^3\right], & h \le a \\ C_0 + C_1 & h > a \end{cases} \tag{7}$$

Where $\gamma(h)$ is the spherical semivariogram, C_0 is the nugget effect, C_1 is the structural variance, h is lag distance and a, is the range of spatial continuity. The characteristic of this model for the EC_e data is given in Table 2.

Table 2. Characteristics of the best-fitted semivariogram model of the EC_e data.

Depth (cm)	Transformation	Model Type	C_0	Sill[a]	Range	C_0/Sill*100	R^2 [b]
0-50	Original	Sphe.	18	485	920	3.71	0.82
	Lognormal	Sphe.	0.63	1.33	800	47.37	0.76

a: sill is $C_0 + C_1$ in Eq. (7)

b: R^2 or Regression Coefficient is an indication of how well the model fits the variogram data

3.2.2 Indicator Kriging

Indicator variograms were computed using the GAMV routine provided in GSLIB (Deutsch and Journel, 1998). The cut-offs were based on the 5 deciles (0.1, 0.3, 0.4, 0.7 and 0.9) of the frequency distribution of the data.

3.3. Estimation

The results of Cross-Validation of estimating EC_e are presented in Table 3. The comparison of different prediction methods for estimating EC_e in the depth interval 0-50 cm shows that IDW with a power of one yields the smallest Error (MAE=14.68 ds/m). The EC_e for depth of 0-50 cm is mapped in Fig. 2. For this purpose, the mean EC_e is estimated for every unknown point of a 500 m by 500 m grid apart of the network covering the study area.

Table 3. EC_e with different prediction methods.

Method	IDW (α=1)	IDW (α=2)	IDW (α=3)	OK	LogK	IK
MAE (ds/m)	14.68	14.87	15.24	14.79	15.91	14.79
MBE (ds/m)	0.21	0.22	0.3	0.27	2.75	0.03

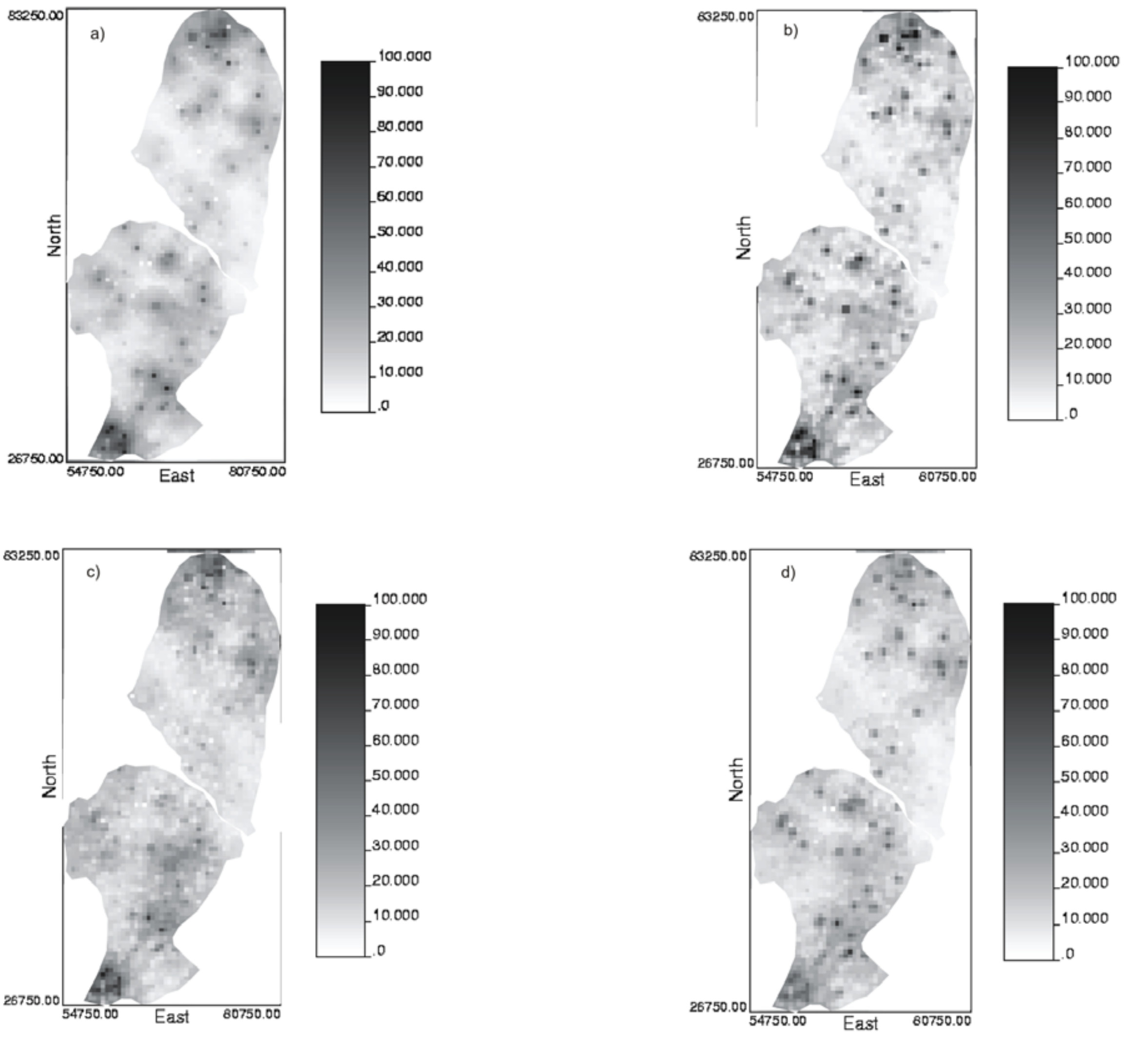

Figure 2. Mapping of mean EC_e estimates (ds/m) in depth of 0-50 cm by method of (a) IDW (α=1) (b) OK, (c) LOK and (d) IK.

4. CONCLUSION

Several approaches for spatial interpolation of top layer EC_e in southeast of Iran are described. The appropriate semivariogram model is spherical with a range of spatial correlation of 920m. Indicator semivariograms showed a better spatial connectivity of low and high EC_e while values of EC_e about 5 to 13 ds/m are spatially uncorrelated. Cross validation indicated IDW (α=1) has slightly better results than IK in predicting EC_e. The IDW method is simpler to program than kriging and does not require pre-modeling of semivariogram model. But it is sensitive to the size of neighborhoods and more important not able to detect any measure of uncertainty in local location. Eventually, the results of this study indicate if the priority is to discover local uncertainty of EC_e in addition to the estimation, IK is a good alternative.

The poor accuracy of the geostatistical predictions of EC_e in southeast of Iran may be caused by the uncertainty attached to the sampled values themselves, which arises from laboratory errors and lack of information of field condition.

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Root Parameters Distribution Required for Modeling of Soil Water Uptake by Plants

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ABSTRACT

This paper presents results of measurements on morphological parameters of root systems needed for macro scale modeling of root water uptake. Root mass-, root length- and root surface area density distributions were assessed for three different agricultural canopies, i.e. spring barley (*Hordeum vulgare L.*), winter rye *(Secale cereale L.*) and maize (*Zea mays, L.*). It was observed, that at early stages of plants ontogenesis relative vertical distributions of all root parameters were close to the exponential one with no major differences between their shapes. Statistically highly significant correlations between dry mass, length and surface area of the roots were established.

1. INTRODUCTION

Two controversial techniques to improve modeling of water and solute transport and their uptake by roots have been recently proposed: either via increasing complexity of the physically and physiologically based models or by keeping them as simple as possible (Feddes et al., 2001). In this study, the second approach is considered because the complicated models are difficult to fill with reliable and/or hardly determinable input data. Mathematical models describing water transport in Soil – Plant – Atmosphere Continuum (SPAC) are nearly all using one – dimensional Richards governing equation containing root extraction term. For assessment of this term, an estimation of the relative root distribution function through the soil profile is required.

The main objective of this study is to compare root parameter distributions of three crops (spring barley, winter rye and maize) grown under equivalent climate and soil conditions from a point of view of their application in the sink term estimation.

2. METHODS AND MATERIAL

2.1. Theory

Macroscopic root uptake models incorporate root water uptake term – sink term. The widely used approach to describe the root sink term is based on the originally Feddes' proposal applied in the simulation model SWATR (Feddes et al., 1978). For that, a transpiration rate is estimated independently and divided along a root depth according to a relative vertical distribution of some relevant root parameter.

In case of unstressed root water uptake non-limited by the soil water pressure head, we have:

$$S_p(z_i,t) = n_{rd}(z_i)E_{pt} \qquad (1)$$

where S_p is the potential root water uptake rate, E_{pt} is the potential transpiration rate, and $n_{rd}(z_i)$ is the relative root distribution function along the depth z_i.

The relative root distribution function can be expressed as

$$n_{rd}(\mathrm{z_i}) = \frac{R(z_i)}{R_t} \tag{2}$$

where $R(z_i)$ is the root parameter value at the depth z_i and R_t is the integral of the parameter R in vertical direction starting at the soil surface.

2.2. Site and soil

Measurement were conducted at the experimental field of Hydromelioration State Agency, Bratislava, near site Most pri Bratislave. The soil is Haplic Chernozem (FAO classification) and is classified as silt loam (USDA) with about 23 % clay, 63 % silt and 14 % sand. For the top 25 cm soil layer, a soil bulk density varies from 1.25 to 1.45 g cm^{-3} and a saturated hydraulic conductivity ranges from 7 to 35 cm d^{-1}.

Spring barley (*Hordeum vulgare L.*), winter rye (*Secale cereale L.*) and maize (*Zea mays, L.*) were cultivated according to the usual agricultural practice in this region. Root samples were taken intentionally at relatively early periods of plants development: at tillering and at the stage of stem elongation for spring barley, at heading for winter rye and at the 5^{th} leave stage for maize. Seven plants of each crop were taken for the analyses.

2.3. Sampling procedure and Analyses

Soil monoliths (covering a complete row width) were sampled until the 25 cm depth and split in 5 cm thick slices (depths). Roots were carefully washed out over a set of sieves up to 0.5 mm. Representative fractions of the root material were further studied using an image analyzer to assess their length, surface area, and diameter. First, the roots were stained, then spread in a thin water layer on a tray and scanned to get digital images following Himmelbauer et al. (2004). After the image analyzing, the roots were oven dried (60^{o}C) for evaluation of their dry mass in order to find out its proportions to the length and the surface area values. Obtained ratios were used to calculate the total length and the total surface area of the root samples. The rest of the root material was stored in a freezer and later on also oven dried at 60^{o}C to a constant weight.

3. RESULTS AND DISCUSSIONS

Using the results of the image analyses, root length density, root surface area density and root mass density per unit soil volume were estimated. Maximum values of these root parameters are shown in Table 1.

Table 1. Maximum root mass-, length- and surface area densities and average root diameter measured within 0o-o25ocm soil depth.

Plants	Maximum density of			Average root diameter
	Dry mass mg cm^{-3}	Length cm cm^{-3}	Surface area cm^2 cm^{-3}	mm
Spring barley	0.5	5.2	0.5	0.327
Winter rye	1.0	8.5	0.8	0.253
Maize	0.03	0.09	0.02	0.732

As demonstrated in Figure 1, for the time of sampling the relative distributions of all studied root parameters were close to the exponential one. An exception was observed for the distribution of maize roots, in which the maximum root densities were measured in the 5 to 10 cm soil layer.

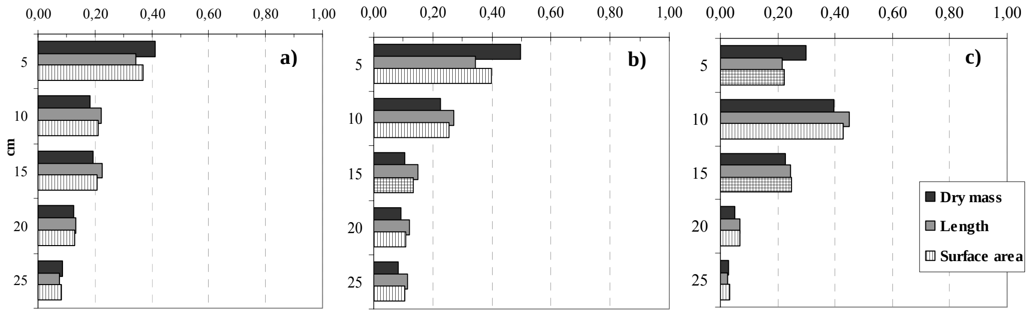

Figure 1. Relative density distributions of root dry mass, root length and root surface area through the soil profile for a) spring barley (first sampling), b) winter rye and c) maize.

Under equivalent environmental conditions, there were not considerable differences between shapes of the distribution curves for the three root parameters observed at early stages of plants development. Consequently, they can be expressed in uptake models by similar root distribution functions, approximated by the exponential one in our case.

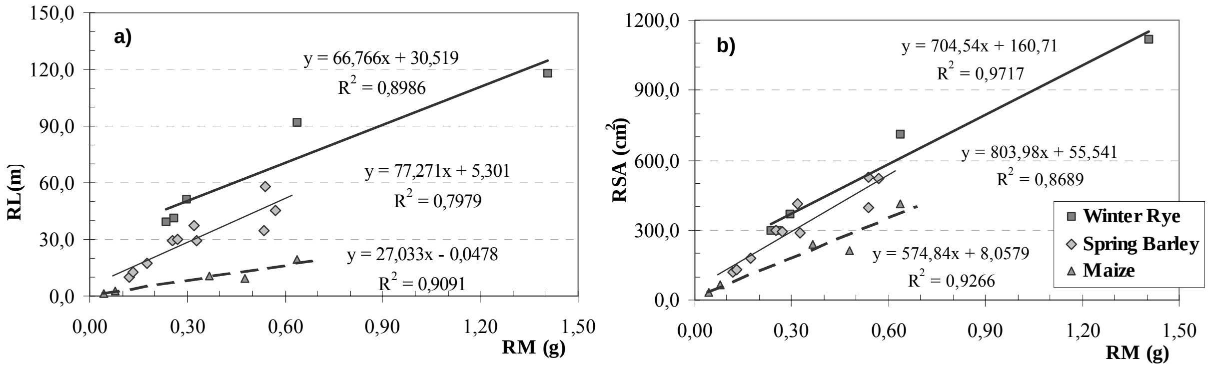

Figure 2. Relationships between root dry mass (RM) and: a) root length (RL) and b) root surface area (RSA) for winter rye, spring barley and maize.

As stated by Hopmans and Bristow (2002), one would use root length density distribution to represent the root distribution function as the root length is the most often evaluated root characteristic with regard to water and nutrient uptake (Noordwijk and de Willigen, 1991; Nye and Tinker, 1977). However many studies have shown that root surface area rather than root length controls plant water uptake (e.g. Varney and Canny, 1993). On the other hand, it is easier to measure root mass and therefore root mass density distribution has been frequently used to estimate the sink term in the Richards equation. The question is if the root mass density distribution, found to be exponential also for various kinds of plants all over the world (Jackson et al., 1996), is representative enough to be applied for the sink term estimation in our case. Therefore, one of the aims of our study was to establish conversion relationships between root dry mass (RM), root length (RL) and root surface area (RSA) for plants under study at the sampling occasions and soil depths. Obtained results are presented in Figures 2a and 2b. All estimated relationships were highly significant and can be approximated by linear equations. Hence, the proposition about the possibility to use the relative distribution function (Eq. 2) of any of these root parameters for the calculation of the sink term (Eq. 1) was confirmed in this study. This statement is rather restrained by the limited number of crops and dates of observation.

4. CONCLUSIONS

Established results showed that for sampling occasions and crops studied (spring barley, winter rye and maize) the relative vertical distributions of the root dry mass-, root length- and root surface area densities can be expressed by the exponential type of functions. There were no significant differences between the shapes of their curves established. Hence, these root parameters can be expressed in root uptake models by similar distribution functions.

Further important findings are estimated linear relationships between the root dry mass and the other root parameters measured via image analyzing, i.e. length and surface area of the three studied root systems. In this way, the root dry mass density, which is easier to obtain, can be used for the estimation of the relative root distribution function in the root sink term in case of lack of length and surface area measurements.

ACKNOWLEDGEMENT

The authors would like to thank ÖFG, MOEL-Plus-Förderungsprogramm for the three month fellowship of Dr. M.L. Himmelbauer at the Institute of Hydrology, Slovak Academy of Sciences, Bratislava. Presented study was done as a result of this partnership.

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Determination of Cover Crop Root Parameters and their Influence on Some Soil Physical Properties

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ABSTRACT

Cover crops are a widely used agro-environmental tool to reduce nitrate leaching and soil erosion. These ecological functions of cover crop plants are related to both, aboveground biomass and soil cover as well as their rooting pattern. Several root characteristics of four cover crop species from different plant families were measured using an image analysis system. Relations of the root parameters to hydraulic conductivity and aggregate stability were analyzed. Vetch differed significantly from the other species in most rooting parameters. Phacelia showed the most intense root system in the upper soil layers while having a low aboveground biomass. Fine roots tended to increase the near saturated hydraulic conductivity.

1. INTRODUCTION

Cover crops are a widely used agro-environmental measure in the frame of the Austrian Program for Sustainable Agriculture (ÖPUL). The use of cover crops has traditionally focused on the reduction of nitrate leaching and soil erosion. Some studies showed that cover cropping also could improve soil physical properties (e.g. Joyce et al., 2002). The rooting characteristics of plants are essential for their influences on soil physical and hydrological processes (Angers and Caron, 1998). Also modeling studies of water and nutrient uptake require an appropriate description of the root distribution with depth and in some cases with space. However, for cover crops there are only few studies providing detailed data on their root parameters. Therefore there is still a gap in our knowledge of the role that roots are playing for the environmental benefits of cover crops.

The objective of the present work is to compare several root parameters of cover crops from different plant families and to study their relation with some properties related to soil structure.

2. MATERIAL AND METHODS

The rooting pattern of phacelia, hairy vetch, rye and mustard, used as cover crops, was investigated in a field study located in the semi-arid region of eastern Austria (Hollabrunn). Plants have been sown the 20th of August 2005 in a randomized block design with three replications. Samples were taken the 15th of December 2005 at the end of the vegetation period when daily mean temperatures fell below 5° C.

Two samples were taken per plot, one in the row directly on the plant and one between the rows (row spacing: 15 cm) in order to observe the spatial distribution of the roots. Sampling depth was 40 cm where major root effects on soil physical properties are expected.

The samples were divided in three sub-samples (0-10, 10–20 and 20-40 cm). In the laboratory, roots were separated from soil by washing over a sieve with 0.5 mm mesh diameter. Dead organic matter was removed visually. After coloring with a Azur-Eosin-Methylenblue-Giemza solution, the roots were analyzed for root length, surface area and root diameter using the WinRhizo image analysis software. The whole procedure is described in detail by Himmelbauer et al. (2004).

Aboveground biomass samples were taken at the same sampling date as roots and oven dried until constant weight.

For analyzing relations between the root parameters and soil physical properties, aggregate stability and near saturated hydraulic conductivity were measured. Aggregate stability was determined as percent water stable aggregates (Ø 1 - 2 mm) by the method of Kemper and Koch (1966). Hydraulic conductivity was measured with a tension infiltrometer at the end of October during full cover crop growth and at the end of March before the cover crop residues were incorporated in the soil. A suction sequence of 0, 0.2, 0.8 and 1.5 kPa was applied for the measurement.

Analysis of variance, comparison of means and regression analysis were performed with the statistical software SAS. Differences in means using SNK test are indicated by different letters. If not indicated differently, the significance level was set to 0.05.

3. RESULTS

3.1. Root system characterization

The aboveground biomass of the cover crops is shown in Fig. 1. Biomass was significantly higher for vetch than for the other species. Rye had a significantly lower biomass compared to vetch and mustard.

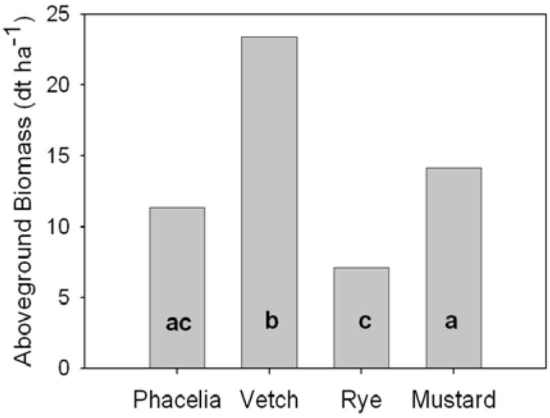

Figure 1. Aboveground biomass dry-matter

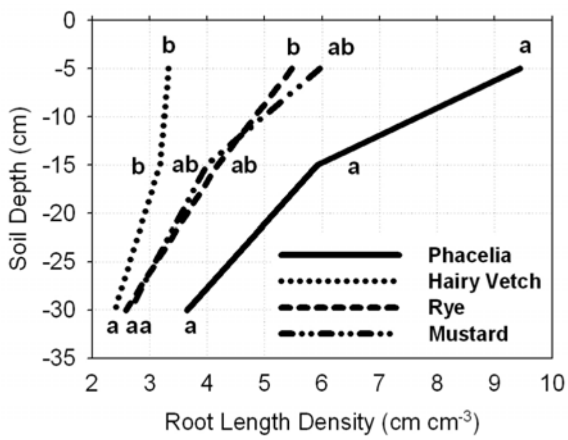

Figure 2. Root length density

Figs. 2-4 show the measured root parameters of the different cover crop species. The most intensive root growth in the main rooting zone was found for phacelia with a root length density being significantly higher compared to mustard and vetch in the upper and to vetch in the second soil layer. Concerning root surface area density, however there were no significant differences in the individual soil layers. When integrating over the whole measurement depth, the root surface area density of rye and mustard are significantly lower compared to phacelia, while vetch has an intermediate position. The average root diameter of vetch was generally higher than for the other varieties, differing significantly from all other species in the deeper soil layer (20-40 cm).

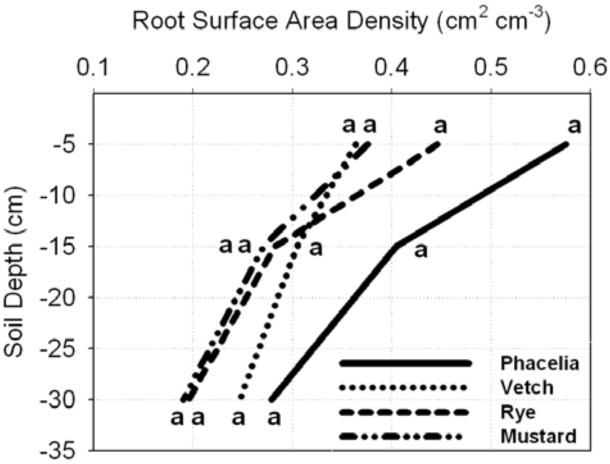

Figure 3. Root surface area

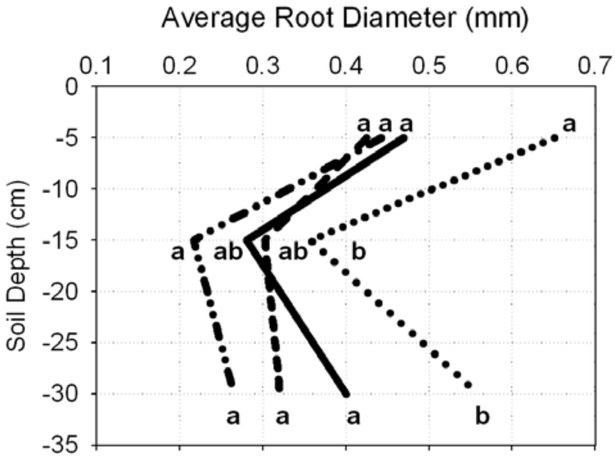

Figure 4. Average root diameter

The distribution of root length as a function of root diameter classes (Fig. 5) reveals that most root length of vetch (42 %) is found in a diameter range between 0.25-0.50 mm. For all other crops, more than 60 % of the whole root length are fine roots smaller than 0.25 mm in diameter.

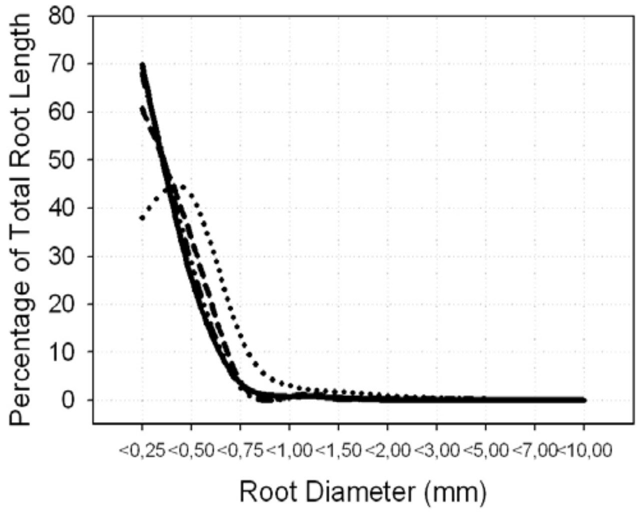

Figure 5. Root length density as function of root diameter classes

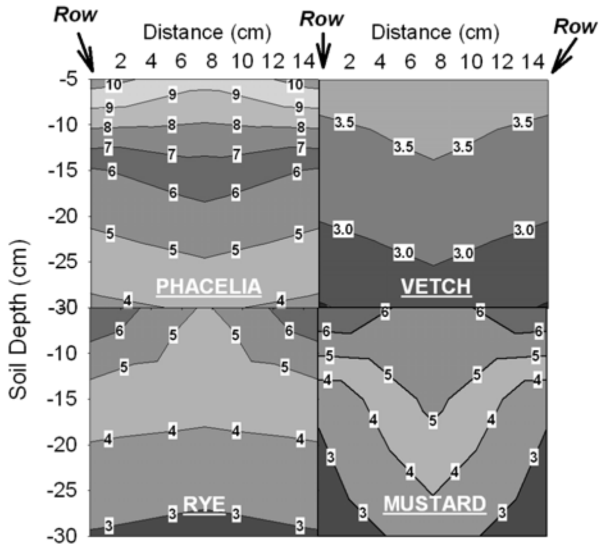

Figure 6. Spatial distribution of root length density (numbers in cm cm-3)

Fig. 6 shows the spatial distribution of root length density. For better illustration we assumed a plant with identical rooting pattern at 15 cm distance. Vetch and phacelia have a very homogeneous horizontal distribution in all layers, while for mustard and rye, the highest root length density in the upper layer was concentrated close to the plant base. Mustard showed a clear increase in root length density between the rows, while for rye the root length density in the row is always higher than between the rows.

3.2. Root-soil relationships

Several paths of root influence on soil physical properties are described in literature (e.g. Gregory, 2006). Fig. 7 shows the relations of root morphological parameters to the near saturated hydraulic conductivity. The length density of fine roots ≤ 0.25 mm in diameter increased the average hydraulic conductivity at field saturation and at 0.1 kPa of suction (Fig. 7a). The average root diameter showed a slightly negative relation to hydraulic conductivity for suctions between 1.15 to 1.5 kPa (Fig. 7b). However the relation is only significant at a level of $\alpha = 0.1$. These general trends were found for both measurement dates and for all suctions. However, only those cases being statistically significant are reported.

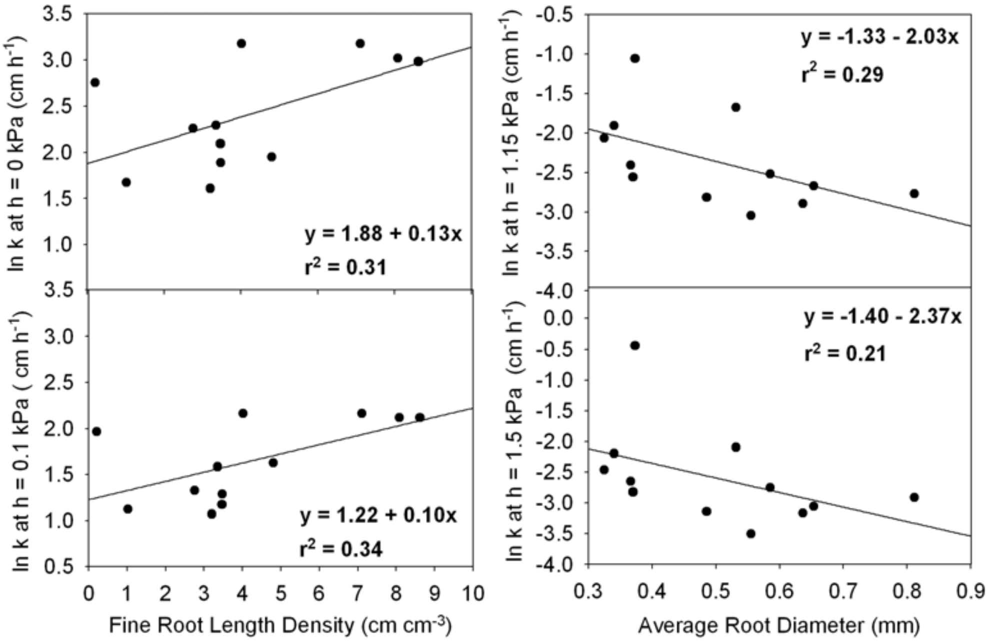

Figure 7. Relations between near saturated hydraulic conductivity and a.) root length density of fine roots and b.) average root diameter.

We did not find significant relations between root length density and water stable aggregates. The variability in aggregate stability was explained mainly by differences in clay content between the plots (r^2=0.63).

4. DISCUSSION AND CONCLUSIONS

Several root parameters of four cover crop species from different plant families were measured by image analysis. While vetch showed the highest aboveground biomass, root length density was lower compared to all other plants. The most intense root growth was found for phacelia with an aboveground biomass lower than vetch and mustard. Measured suction gradients in the soil profile (not shown here) suggest, that water uptake of phacelia occurred mainly in the upper 20 cm, while for vetch upward water fluxes down to 60 cm soil depth were recorded.

Concerning the spatial distribution, vetch and phacelia showed a homogeneous root distribution. Mustard had the highest root length density between the rows. For rye we found a clear reduction of rooting between the rows. We assume that for rye a limited development of the root system in accordance to the low aboveground biomass explains this spatial distribution pattern. An increase between the rows as found mainly for mustard indicates root overlapping which is particularly high for plants with an intense lateral root growth as described for brassica plant species by Kutschera (1960).

A tendency of the fine roots to increase the near saturated hydraulic conductivity could be shown. Roots can enhance hydraulic conductivity by biopore formation and wetting and drying cycles in the rhizosphere. For the root diameter, however, a slightly negative influence was found, particularly for the measurement date in October during full cover crop growth. This reduction could be caused by pore clogging of the growing roots. Soil structural parameters generally are a complex result of several environmental factors, where root growth is just one. Thus only relatively weak relations can be expected.

An evaluation of the impact of the rooting parameters analyzed in this study on the overall water balance should bring further insight in the complex interactions of plant roots with soil physical and hydrological properties.

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Modelling of Rhizosphere Processes with Emphasis on Reaction Kinetics

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ABSTRACT

Puschenreiter et al. (2005) investigated Ni bioavailability to the hyperaccumulator Thlaspi goesingense in a rhizobox experiment. Models based on the classical Barber and Cushman approach could not adequately reproduce measured concentration gradients of Ni in the rhizosphere (Schnepf et al., 2005). Based on additional experimental results, Puschenreiter et al. (2005) concluded, that exudate enhanced dissolution of Ni bearing silicates might be a relevant process. In this paper, we discuss a recently proposed model, accounting for the hypothesised, most decisive impacts of root exudates on rhizosphere processes (Klepsch et al. 2006). Firstly, we only model reaction kinetics, neglecting any transport processes, and secondly, we discuss the same model being coupled to the convection-dispersion equation (CDE).

1. INTROCUCTON

Hyperaccumulators are plants characterized by large heavy metal concentrations in their shoots. Due to their small biomass, they cannot be used for metal phytoextraction, but are considered to serve as model plants for studying rhizosphere processes involved in metal mobilisation and complexation.

A mathematical model for rhizosphere processes, accounting for the impact of root exudates on the fate of solutes, is proposed. In a first approach, we simulate pure reaction kinetics of root exudates, solutes, and the respective sorbed species using Matlab 7.0.1. The chemical reactions and corresponding differential equations are presented. Parameters in the model will be taken from literature or databases. The model considers interactions between heavy metals, exudates, as well as solute-exudate complexes, including equilibrium and kinetic sorption, ligand promoted dissolution, transformation- degradation- or decay processes.

In a second approach, we also model convection, dispersion, and different sources/sinks. Microbial transformation of the organic ligands is implemented by assuming Michaelis Menten kinetics. *T. goesingense* takes up free Ni^{2+} as opposed to Ni-complexes (Puschenreiter et al., 2005). This motivates that we assume a dissociation mechanism for the M^{m+}-exudate complex at the root surface. Heavy metal uptake by roots is modelled with Michaelis Menten kinetics. Furthermore, we assume that the root exudes chelating substances into the rhizosphere which effects heavy metal bioavailability. This proposed model will be non-dimensionalised to be able to highlight its decisive processes. Further simulations of the new rhizosphere model are planned.

2. MODELLING CONCEPT

2.1. Mathematical Model – Reaction Kinetics

Based on the processes described above, we propose the model illustrated in Fig.1. Although a simplification of the real system, it should capture the most relevant processes being responsible for the effects of root exudates on concentration distributions in the rhizosphere.

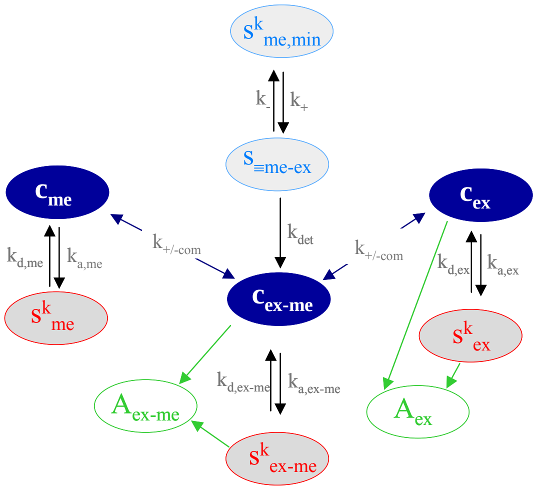

Figure 1. Scheme – reaction kinetics of exudates and metals (for denotations see Table 1 and 2).

The processes shown in Fig. 1 are described by equations 1-8 (included are water content and bulk density; decay of 1st order (A_{ex}, $A_{ex\text{-}me}$) is assumed solely for organic compounds; Equ. 1: inner sphere complex (ISC) formation, Equ. 2: ISC + detachment reaction, Equ. 3-8: complexation + sorption + decay reactions):

$$\partial_t s^k_{me,min} = \frac{1}{2} \cdot \left(-k_+ \cdot s^k_{me,min} \cdot \theta \cdot c_{ex} + k_- \cdot s_{\equiv me-ex} \right) \tag{1}$$

$$\partial_t s_{\equiv me-ex} = k_+ \cdot s^k_{me,min} \cdot \theta \cdot c_{ex} - k_- \cdot s_{\equiv me-ex} - k_{det} \cdot s_{\equiv me-ex} \tag{2}$$

$$\begin{aligned} \partial_t c_{ex-me} = {} & k_{+com} \cdot c_{me} \cdot c_{ex} - k_{-com} \cdot c_{ex-me} - k_{a,ex-me} \cdot c_{ex-me} + k_{d,ex-me} \cdot \frac{\rho}{\theta} \cdot s^k_{ex-me} + \\ & + k_{det} \cdot \frac{\rho}{\theta} \cdot s_{\equiv me-ex} - k_{decay,c_{ex-me}} \cdot c_{ex-me} \end{aligned} \tag{3}$$

$$\partial_t s^k_{ex-me} = k_{a,ex-me} \cdot \left(\frac{\rho}{\theta} \right)^{-1} \cdot c_{ex-me} - k_{d,ex-me} \cdot s^k_{ex-me} - k_{decay,s^k_{ex-me}} \cdot s^k_{ex-me} \tag{4}$$

$$\begin{aligned} \partial_t c_{ex} = {} & \frac{1}{2} \cdot \left(-k_{+com} \cdot c_{me} \cdot c_{ex} + k_{-com} \cdot c_{ex-me} - k_+ \cdot \rho \cdot s^k_{me,min} \cdot c_{ex} + k_- \cdot \frac{\rho}{\theta} \cdot s_{\equiv me-ex} \right) - \\ & - k_{a,ex} \cdot c_{ex} + k_{d,ex} \cdot \frac{\rho}{\theta} \cdot s^k_{ex} - k_{decay,c_{ex}} \cdot c_{ex} \end{aligned} \tag{5}$$

$$\partial_t s^k_{ex} = k_{a,ex} \cdot \left(\frac{\rho}{\theta} \right)^{-1} \cdot c_{ex} - k_{d,ex} \cdot s^k_{ex} - k_{decay,s^k_{ex}} \cdot s^k_{ex} \tag{6}$$

$$\partial_t c_{me} = \frac{1}{2} \cdot \left(-k_{+com} \cdot c_{me} \cdot c_{ex} + k_{-com} \cdot c_{ex-me} \right) - k_{a,me} \cdot c_{me} + k_{d,me} \cdot \frac{\rho}{\theta} \cdot s^k_{me} \tag{7}$$

$$\partial_t s^k_{me} = k_{a,me} \cdot \left(\frac{\rho}{\theta}\right)^{-1} \cdot c_{me} - k_{d,me} \cdot s^k_{me} \tag{8}$$

Table 1. List of symbols used for exudate/metal reactions kinetics.

Symbol	Denotation	Unit
t	Time	s
c_i	solute concentration *(i = me, ex, ex-me; me… e.g. Ni, ex… exudate, ex-me… exudate-metal complex)*	$\mu mol \cdot l^{-1}$
s^k_i	sorbed concentration (k... kinetic)	$\mu mol \cdot kg^{-1}$
$s^k_{me,min}$	me, bound on mineral (dissolution reaction)	$\mu mol \cdot kg^{-1}$
$s_{\equiv me\text{-}ex}$	inner sphere complex (detachment reaction)	$\mu mol \cdot kg^{-1}$
k_{+com}, k_{-com}	forward/backward complexation reaction rate coefficients	$(l \cdot \mu mol^{-1}) \cdot s^{-1}$, s^{-1}
k_+, k_-	forward/backward rate coefficients of inner sphere complex formation (*ligand promoted dissolution reaction*)	$(l \cdot \mu mol^{-1}) \cdot s^{-1}$, s^{-1}
k_{det}	detachment rate coefficient	s^{-1}
$k_{a,ex\text{-}me}$, $k_{d,\,ex\text{-}me}$	ad-/desorption reaction rate coefficients for exudate-metal complex	s^{-1}
$k_{a,ex}$, $k_{d,ex}$	ad-/desorption reaction rate coefficients for exudate	s^{-1}
$k_{a,me}$, $k_{d,me}$	ad-/desorption reaction rate coefficients for metal	s^{-1}
$k_{decay,ci}$, $k_{decay,si}$	decay rates for liquid and solid phases (i), respectively (zero order reaction)	s^{-1}

2.2. Non-dimensionalisation

The model is non-dimensionalised to find out whether some processes are dominant in this system and whether other processes may be regarded as negligible. For this we scaled the variables as follows (parameters in Table 2): [t] is the time scale and can be chosen depending on the time scale of interest, $[c_{me}] = K_m$, $[s_{me}] = \frac{k_{a,me}}{k_{d,me}}\frac{\theta}{\rho}K_m$, $[c_{ex}] = Ex$, $[s_{ex}] = \frac{k_{a,ex}}{k_{d,ex}}\frac{\theta}{\rho}Ex$, $[c_{ex,me}] = \frac{k_{+com}}{k_{-com}}K_m Ex$, $[s_{ex,me}] = \frac{k_{a,ex-me}}{k_{d,ex-me}}\frac{\theta}{\rho}\frac{k_{+com}}{k_{-com}}K_m Ex$, $[s_{me,min}] = MIN$, $[\equiv s_{me\text{-}ex}] = \frac{k_+}{k_-}Ex \cdot MIN$, where Ex and MIN are characteristic concentrations of exudates and strongly bound Ni, respectively. The non-dimensionalised equations are:

$$\frac{\partial s_{me,min}}{\partial t} = -\frac{1}{2}\alpha_1 s_{me,min} c_{ex} + \frac{1}{2}\alpha_1 s_{\equiv me-ex} \tag{9}$$

$$\varepsilon_2 \frac{\partial s_{\equiv me-ex}}{\partial t} = s_{me,min} c_{ex} - s_{\equiv me-ex} - \alpha_2 s_{\equiv me-ex} \tag{10}$$

$$\varepsilon_3 \frac{\partial c_{ex-me}}{\partial t} = c_{me} c_{ex} - c_{ex-me} - \alpha_3 c_{ex-me} + \alpha_3 s_{ex-me} + \beta_3 s_{\equiv me-ex} - \kappa_3 c_{ex-me} \tag{11}$$

$$\varepsilon_4 \frac{\partial s_{ex-me}}{\partial t} = c_{ex-me} - s_{ex-me} - \kappa_4 s_{ex-me} \tag{12}$$

$$\frac{\partial c_{ex}}{\partial t} = -\frac{1}{2}\alpha_5 c_{me} c_{ex} + \frac{1}{2}\alpha_5 c_{ex-me} - \frac{1}{2}\beta_5 s_{me,min} + \frac{1}{2}\beta_5 s_{\equiv me-ex} - \gamma_5 c_{ex} + \gamma_5 s_{ex} - \kappa_5 c_{ex} \tag{13}$$

$$\varepsilon_6 \frac{\partial s_{ex}}{\partial t} = c_{ex} - s_{ex} - \kappa_6 s_{ex} \tag{14}$$

$$\frac{\partial c_{me}}{\partial t} = -\frac{1}{2}\alpha_7 c_{me} c_{ex} + \frac{1}{2}\alpha_7 c_{ex-me} - \beta_7 c_{me} + \beta_7 s_{me} \tag{15}$$

$$\varepsilon_8 \frac{\partial s_{me}}{\partial t} = c_{me} - s_{me} \tag{16}$$

where the variables are: $\varepsilon_2 = \frac{1}{[t]\cdot k_-}$, $\varepsilon_3 = \frac{1}{[t]\cdot k_{-,com}}$, $\varepsilon_4 = \frac{1}{[t]\cdot k_{d,ex-me}}$, $\varepsilon_6 = \frac{1}{[t]\cdot k_{d,ex}}$, $\varepsilon_8 = \frac{1}{[t]\cdot k_{d,me}}$, $\alpha_1 = k_+[t]\theta\cdot Ex$, $\alpha_2 = \frac{k_{det}}{k_-}$, $\alpha_3 = \frac{k_{a,ex-me}}{k_{-,com}}$, $\beta_3 = \frac{k_{det}}{k_{+,com}}\frac{k_+}{k_-}\frac{\rho\cdot MIN}{\theta\cdot K_m}$, $\alpha_5 = k_{+,com}[t]\theta\cdot K_m$, $\beta_5 = k_+[t]\rho\cdot MIN$, $\gamma_5 = k_{a,ex}[t]$, $\alpha_7 = k_{+,com}[t]\theta\cdot Ex$, $\beta_7 = k_{a,me}[t]$, $\kappa_3 = \frac{k_{decay,c_{ex-me}}}{k_{-,com}}$, $\kappa_4 = \frac{k_{decay,s_{ex-me}}}{k_{d,ex-me}}$, $\kappa_5 = k_{decay,c_{ex}}[t]$, $\kappa_6 = \frac{k_{decay,s_{ex}}}{k_{d,ex}}$.

Based on the chosen time scale and the parameter values, we expect to find that some of the parameters ε_2-ε_8 will be small. Hence we will able to decide on a quantitative basis which of the kinetic reactions (1)-(8) can be regarded instantaneous on the time scale of interest.

2.3. General Model based on the CDE

The extended model accounts for convection and dispersion based on the Richards-equation for water movement through soils. Microbial transformation of the organic ligands is implemented by assuming Michaelis Menten kinetics. As boundary conditions at the root surface, a dissociation mechanism for the M^{m+}-exudate complex, and an expression function regarding exudates, are assumed. Heavy metal uptake by roots is modelled with Michaelis Menten kinetics (initial and boundary conditions are presented in Klepsch et al. (2006); parameters are explained in Table 2).

The generalised equation reads:

$$\theta\cdot\partial_t \sum_i c_i + \rho\cdot\partial_t \sum_i \left(s_i^e + s_i^k\right) = \nabla\left(\theta \mathbf{D}_i \nabla c_i\right) - \mathbf{q}\nabla\sum_i c_i - \sum_i A_i \tag{17}$$

3. OUTLOOK

We will also non-dimensionalise the extended model in order to analyse its crucial processes. Further planned steps are: upscaling/coupling with a root branching model, comparison with other models accounting for exudates, e.g. speciation models, design of experiments for measuring the model's parameters, and especially the investigation of time scales of the various processes, and of reactions that could be written as equilibrium reactions (e.g. complexation reactions). The presented model shall deepen our insight into the relevant processes initiated by exudates. Mathematical modelling may also serve to optimize design and success of phytoextraction experiments.

Table 2. List of additional symbols for non-dimensionalisation and extended model.

Symbol	Denotation	Unit
z	distance from soil surface, positive upwards	dm
ρ	soil bulk density	$kg \cdot dm^{-3}$
θ	water content	$dm^3 \cdot dm^{-3}$
s_i^e	sorbed concentration (e.. equilibrium, $s_i^e = K_{fi} c_i^{\nu_i}$)	$\mu mol \cdot kg^{-1}$
Q	water flux	$dm \cdot s^{-1}$
D_i	dispersion coefficient	$dm^2 \cdot s^{-1}$
K_{fi}, ν_i	Freundlich sorption isotherm parameter	$\mu mol^{1-\nu} \cdot l^{\nu} \cdot kg^{-1}$, –
α_i	1st order rate constant, if sorption modelled as $\partial_t s_i^k = \alpha_i \left(K_{fi} c_i^{\nu_i} - s_i^k \right)$	s^{-1}
A_i	decay terms (i = ex-me;): $A_i \equiv \mu_{l,i} \theta c_i + \mu_{s,i} \rho s_i + \gamma_{l,i} + \gamma_{s,i}$ for exudate *(i = ex; MM-kinet.):* $A_{ex} \equiv c_{max,ex} \theta \frac{c_{ex}}{K_M + c_{ex}}$	$\mu mol \cdot l^{-1} \cdot s^{-1}$
$\mu_{l,i}$, $\gamma_{l,i}$	first/zero order decay coefficients in liquid phase	s^{-1}, $\mu mol \cdot l^{-1} \cdot s^{-1}$
$\mu_{s,i}$, $\gamma_{s,I}$	first/zero order decay coefficients in solid phase	s^{-1}
K_M	Michaelis Menten constant	$\mu mol \cdot l^{-1}$

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Macroaggregate Associated Available Water and Carbon in Alfisol Fields

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ABSTRACT

Notill (NT) practice has been shown to increase aggregate stability and soil organic carbon (OC). Our objectives were to quantify effect of NT duration on macroaggregate-associated bulk density (ρ_b), available water content (AWC), hydrolysable (HOC) and nonhydrolyzable (NHOC) concentrations from Alfisol fields under corn (*Zea mays* L.) soybean (*Glycine max*) rotation. Macroaggregates were collected in triplicate at 0-10 and 10-20 cm depths of summit (SS) and toe (TS) slope positions in NT fields for the last 15 (NT15), 10 (NT10), 6 (NT6) years and annual chisel tillage (ACT). At 0-10 cm depth of SS, macroaggregate-associated ρ_b decreased, and AWC and HOC increased with increasing duration under NT. Linear regression showed a positive correlation between macroaggregate associated water stability (WSA) and HOC (r = 0.50 in SS; 0.76 in TS) and a negative correlation between WSA and NHOC (r = -0.78; -0.75). Increases in aggregate-associated HOC concentrations with increasing duration of NT indicated that permanent storage of C in aggregate is likely dependent on the continuation of NT.

1. INTRODUCTION

Soil aggregates are porous peds of different shapes and sizes and are formed as a result of flocculation of soil particles. Aggregates can be random combinations of soil organic and mineral components assembled into micro- (<250 μm mean diameter) and macroaggregates (>250 μm mean diameter). Water stability of aggregates (WSA) and the associated C dynamics are important to understanding the vadose zone hydrological properties and processes, and their C sequestration potential. The degree of protection of organic carbon (OC) within an aggregate is a function of soil mineralogy, charge characteristics, pH, specific surface area and texture. Besides, available water content (AWC) and porosity can also influence aggregate protection (Schjonning et al., 1999). Understanding of the process of aggregation and aggregate composition is important because of their effect on water infiltration, water retention, organic matter decomposition and aeration of the soil profile.

The formation, stability, and hydrological properties of macroaggregates can be influenced by the redistribution of light OC by water erosion and tillage. Among hydrological properties of individual aggregates, intraaggregate pore space has a major influence on water flow and is greatly influenced by wetting and drying cycles especially in soils containing predominantly 2:1 clay minerals. The mechanisms of aggregate formation and the stabilization factors are often site-specific and depend upon land use and management practices prevailing in the area. Few on-farm studies have reported the influence of OC on the stability and hydrological characteristics of macroaggregates at different slope positions of fields under NT choronosequence and annual tillage. Therefore, this study was undertaken to quantify the interactive effects of NT duration and slope positions on the macroaggregate associated physical and chemical properties.

2. MATERIALS AND METHODS

2.1. Site Description

Experimental sites are located in South Charleston, Clark County, Ohio. Average temperature for the study area ranged from –2.3°C in winter to 22°C in summer with average annual rainfall of 960 mm. Soil in the study area is a Miamian (fine, mixed, active, mesic Oxyaquic Hapludalfs). Three fields chosen were converted to NT, 15 years (NT15), 10 years (NT10) and 6 years (NT6) before 2003. A fourth field, a reference site, was under annual chisel till (ACT). All experimental fields were under annual corn (*Zea mays* L.) soybean (*Glycine max*) rotation. In the year of sampling, NT15, NT10, and ACT were planted to soybean and NT6 to corn.

2.2. Sampling and Analysis

The NT15 field was relatively flat; however, there were distinct summit (SS) and toe slope (TS) positions in NT10, NT6 and ACT. Push probe sampling showed that the depth of A-horizon varied from 18 to 24 cm in the SS and > 24 cm in the TS. Outwash material overlaying the A-horizon was clearly visible in the TS position. Soil samples were collected in triplicate at 0-10 and 10-20 cm depths of each slope position. Samples were air-dried, and 5-8 mm size fraction was separated. Bulk density (ρ_b) of macroaggregates from each sampling location was determined by clod method (Blake and Hartge, 1986), intraaggregate porosity (f_t) by using a particle density of 2.65 Mg m^{-3}, and available water content (AWC) ($\theta_{0.03\ MPa} - \theta_{1.5\ MPa}$) using pressure plate apparatus. Macroaggregate associated total carbon (TC) was determined by dry combustion method (Elementar, GmbH, Hanau, Germany) on finely ground and sieved (< 0.25 mm) samples. Since samples from 0-20 cm depth did not effervesce upon treatment with acid, TC was assumed equal to OC concentration associated with macroaggregates. Nonhydrolyzable OC (NHOC) was determined by acid hydrolysis (Paul et al., 2001), and hydrolysable OC (HOC) concentration was calculated as the difference between total and NHOC. Linear regression analysis was performed on measured macroaggregate properties and the amount of time under NT using Statistical Analysis System (SAS Institute, 1989).

3. RESULTS AND DISCUSSION

3.1. Macroaggregate Associated Physical Properties

Among NT fields, macroaggregate ρ_b was higher in NT6 (> 2 Mg m^{-3}) than NT15 and NT10 at 0-10 cm depth of SS position, consequently intraaggregate porosity was low (0.21). The low ground cover in NT6 exposed the mixed type of soil to wet and dry cycles and rainfall impact, and likely resulted in aggregate coalescence with significant reduction in intraaggregate volume consequently increasing ρ_b (Utomo and Dexter, 1981). Lowest macroaggregate associated AWC (0.21 cm^{3}cm^{-3}) for NT6 at 0-10 cm depth further supported the argument. A positive correlation (r = 0.79) between NT duration and AWC at 0-10 cm depth indicated that increasing NT duration increases intraaggregate porosity and AWC (Fig. 1).

Macroaggregate ρ_b (or f_t) did not vary across NT and ACT at 0-10 cm depth of TS but WSA did (Fig. 2). However at 10-20 cm depth, ρ_b was higher (f_t lower) for NT6 than ACT. Unlike SS, no relationship existed between NT duration and macroaggregate associated AWC at either depth. Among slope positions, no significant differences were obtained in macroaggregate associated physical properties, except for AWC, which was higher at 0-10 cm depth of SS than TS (data not shown). In contrast, macroaggregate associated AWC were similar among NT and ACT at 10–20 cm depth suggesting that unlike 0-10 cm, aggregate coalescence at 10-20 cm depth took place without significant intraaggregate volume reduction. Aggregates were collected from well developed and mixed Alfisol and an earlier study at the same sites reported that WSA was lower in ACT (50 % for SS and 40 % for TS) than NT (67 % for NT15, 71 % for NT10, 64 % for NT6 for SS; and 72 % for NT10, 58.9 % for NT6 for TS) at 0-10 cm depth (Shukla and Lal, 2005).

3.2. Macroaggregate Associated Chemical Properties

Among NT fields, macroaggregate associated HOC varied in the order NT15> NT10> NT6 at both depths of the SS and increasing NT duration increased HOC (r = 0.78 at 0-10 cm; 0.48 at 10-20 cm depth). HOC was also higher for NT15 than ACT and was in accord with higher WSA for NT15 than ACT. Thus, aggregate stability was influenced by the associated HOC. Macroaggregate associated NHOC was higher for NT15 than other NT fields at 0-10 cm depth of SS (Fig. 1). We also obtained a significant negative correlation (r = -0.78) between aggregate associated NHOC and WSA at 0-10 cm depth indicating that the physically protected recalcitrant OC was associated with microaggregates. Clay content of soil was positively correlated with aggregate associated NHOC at both depths (r = 0.17; 0.24) of the SS position. Correlations between clay content and HOC remained inconsistent with a positive correlation (r = 0.35) at the 0-10 cm depth and a negative correlation (r = -0.60) at the 10-20 cm depth.

At 0-10 cm depth of TS position, macroaggregate associated HOC was higher for NT10 than ACT; however, NHOC followed the opposite trend (Fig. 2). A positive correlation between macroaggregate associated HOC and WSA (r = 0.76) at 0-10 cm depth showed that aggregate stability increased with increasing HOC. Macroaggregate associated NHOC was positively related to ρ_b (r = 0.21 at the 0-10 and 0.43 at the 10-20 cm depth). Cation exchange capacity (CEC) of the whole soil was similar for all fields (10-20 C-mol$_c$ kg^{-1}) that indicated a large number of cation exchange sites on clay and OC. Soil of the study area was mixed with moderate to low shrink-swell potential; therefore, negative charge on clay particles was neither pH dependent nor related to increases in WSA. Instead, tillage and HOC were dominant discriminating factors for macroaggregate stability among NT15 and ACT at 0-10 cm depth. Among slope positions, HOC for NT6 and ACT were higher for TS than SS at both depths. This was possible as biologically active organic matter is light and a significant amount can be transported with relatively slight soil erosion (Gregorich et al., 1998). HOC is more susceptible to microbial degradation upon disruption of aggregates especially in the ACT. Thus, the permanent storage of C and N in the aggregate is more likely on the continuation of notill.

4. CONCLUSIONS

Macroaggregate associated ρ_b decreased and AWC and HOC concentration increased with increasing duration under NT at 0-10 cm depth of the summit slope position. Stability of macroaggregates increased with increasing aggregate associated HOC and NT duration. Aggregate associated HOC concentration was higher for NT15 than other fields at SS position, indicating that the sequestration potential is dependent upon NT duration.

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Acknowledgement: Authors thank Agriculture Experimental Station of NMSU, Lyn McKinley of NMSU, and Dr. Rattan Lal of the Ohio State University, Columbus.

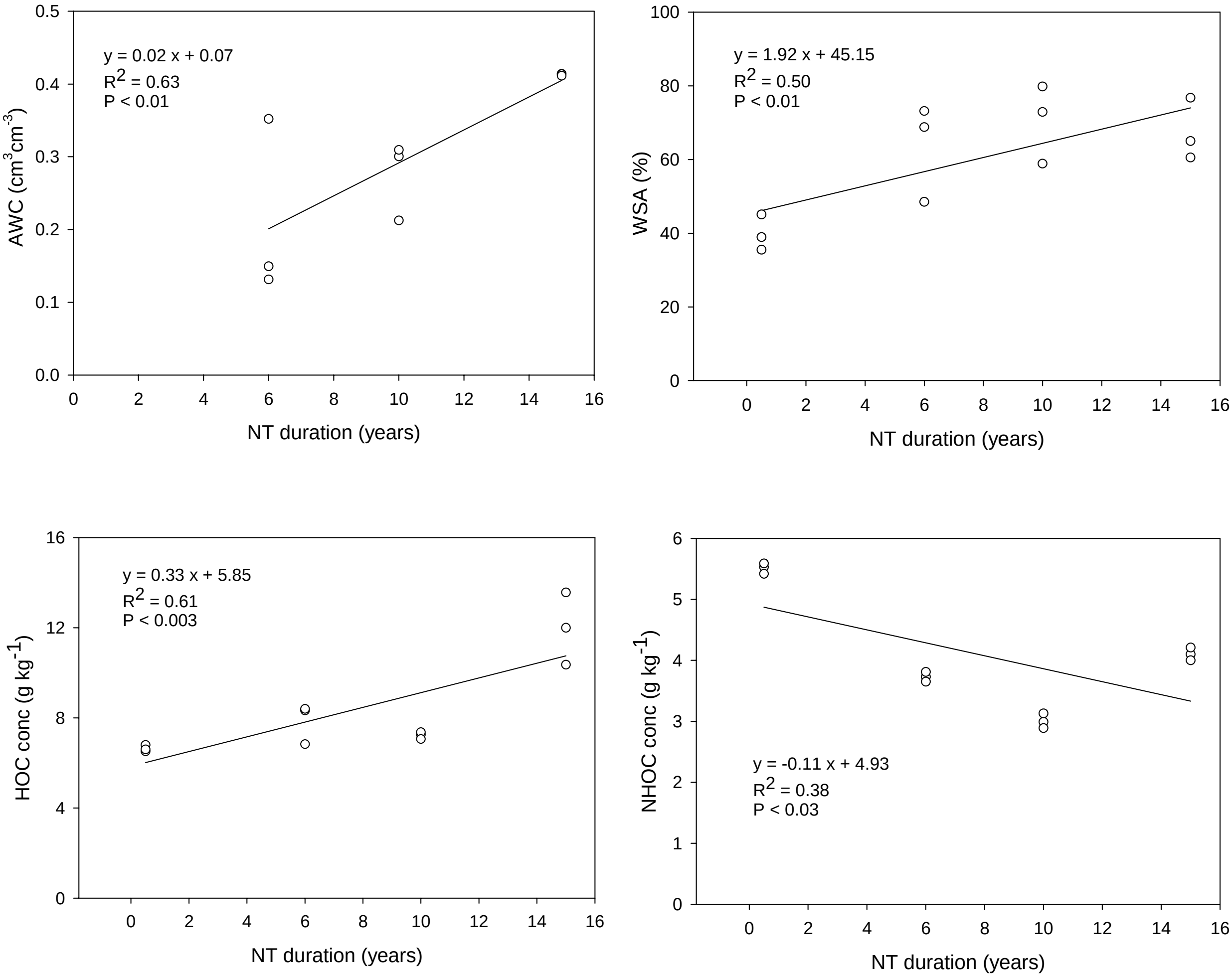

Figure 1. Interrelationships among macroaggregate properties and NT duration at SS position

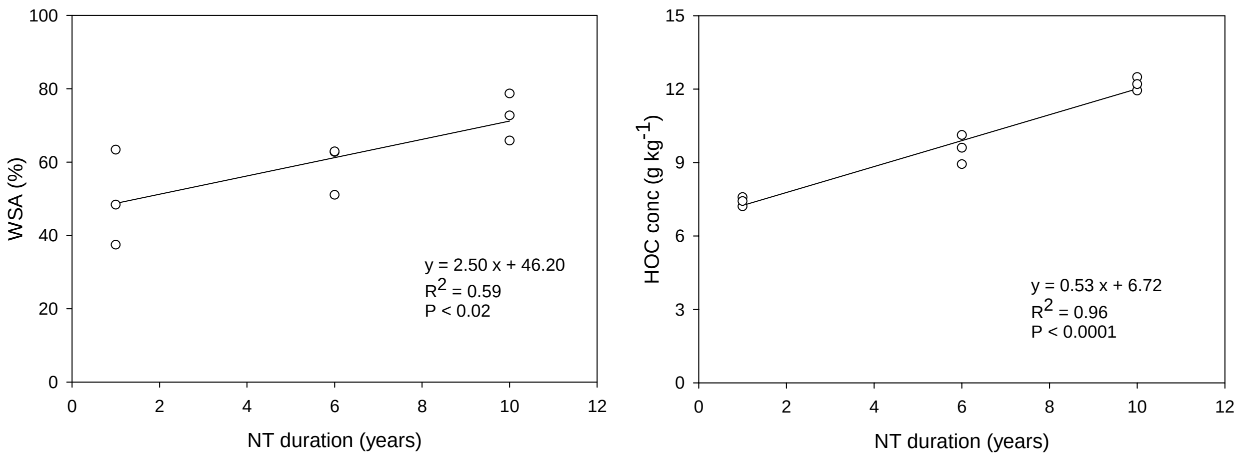

Figure 2. Interrelationships among macroaggregate properties and NT duration at TS position

Calibration of Electromagnetic Sensors for Water Content Monitoring in a Former Landslide

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ABSTRACT

Soil moisture measurements were performed for heavy clay soils and high moisture conditions, using frequency domain reflectometry sensors CS 615. A constant over estimation of the water content was observed for all sensors used. Besides effects of bulk density and temperature one further hypothesis was that chemical soil processes caused excessive electrical output signals. A specific sensor calibration was carried out using field data from measurements in a slide area (Salzkammergut, Upper Austria). The correlation between the gravimetrically obtained water content as independent variable and the measured signal output (frequency in msec) as dependent variable was tested via multiple regression analyses considering physical soil information. Best fits were obtained for spitted data sets, e.g. according to location or depth. By including soil temperature and porosity a correlation in an order of $r^2 > 0,96$ was achieved. The inverse regression equation was used for correction of the measured data.

1. INTROCUCTON

A number of ecological and environmental research projects have been carried out using time domain reflectometry (TDR) sensor systems for automated field monitoring (Jost et al., 2004, Granier et al., 2000). Veldkamp and O`Brien (2000) clearly highlight the economical advantages of frequency domain reflectometry (FDR) sensors (CS 615) for in situ measurements. The CS 615 Water Content Reflectometer (Campbell Scientific, 1999), or the improved version CS 616 (Campbell Scientific, 2002-2004), are based on a multivibrator which switches states triggered by the reflected pulse. The energy of the applied signal polarises the water molecules and affects the propagation time. The final output is a scaled multivibrator frequency or period (τ) of a square wave, which is converted to volumetric water content θ_V using calibration equations given in Campbell Scientific (1999, 2002-2004). For the calibration of TDR sensors the best known relationship between the soil water content and the dielectric constant ε was expressed by a third-order polynomial equ. (Topp et al. 1980), which seems to be sufficient for a wide range of TDR applications. Dielectric mixing models consider additional soil parameters assuming that ε of a multiphase mixture relates to ε and the volume fraction of its constituents. Veldkamp and O`Brien (2000) published a three-phase-mixing model for the FDR sensor CS 615. They used soil porosity to partition between the soil matrix and the pores and generated a geometry parameter that accounts for the soil structure.

The CS 615 sensor was used under very unfavourable field conditions in a soil with a high clay content and near saturation. The readings gave volumetric water content values which were obviously wrong (> 100%). To evaluate the reasons tests were performed in the field with other equipment and undisturbed soil samples were taken, providing water contents only in the wet part. On the other hand the permeability was too low to obtain a homogenous water content distribution by infiltration of water in a soil column in the laboratory. Using the information that the sensor had a relatively linear response, the obtained values were used to fix the CS 615-Polynomial in the wet range. But this step on its own proved to be insufficient. Roth et al. (1990) had detected a temperature influence of TDR sensors, also significantly observed for all used CS 615 sensors. A temperature correction was made, enabling improvements of results. However, for certain cases temperature compensation alone was insufficient. Examination of the soil data showed that these values were all correlated with a higher compaction in deeper soil layers. Based on these experiences, the relationship of the available field data was tested via multiple regression analyses, considering a variety of physical soil parameters.

2. METHOD

2.1. Background information and site description

The hydrological properties of an Alder stand on a former landslide in the upper catchment area of the creek Stambach (Salzkammergut, Upper Austria) were studied . The investigated site, situated in the Austrian Central Alps, is geologically characterised by a limestone fault which overlies layers of highly water-sensitive marl. In the 1980’s massive rock avalanches triggered a large scale mass movement affecting 35 ha of a former spruce-fir stand and moving flow material up to a depth of 45 m under the influence of melting water. Stabilisation measures included the improvement of the middle and lower water course to enable managed, risk-free sediment transport, the construction of an effective drainage network and the afforestation with White and Black Alder (*Alnus incana* L. and *Alnus glutinosa* L.).

The current soil type is slope pseudogley with hydromorphic mull as surface layer. Humus layers found buried at different soil depths indicate heavy disturbance of the soil. The particle size distribution is dominated by clay (up to 90 %). Clay mineralogy is characterized by swelling and expandable layer silicates (di- and tri-octahedral types). Actual field water contents typically range from 40 – 70 %. In 2001, a field monitoring program was started including the measurement of the following key variables: soil volumetric water content being logged throughout the year with Campbell CS 615 sensors (Figure 1) in two layers (0-30 cm, 30-60 cm), complementary readings of soil water potential by Campbell 223 Gypsum Blocks and meteorological factors controlling the water budget.

Figure 1. CS 615 sensor installation in heavy clay soil

2.2. Field Calibration

During a two years period undisturbed soil samples were collected. Six data sets (Table 1) according to different soil depths and measurement positions were available. For the determination of the gravimetric water content corresponding to the rod length the soil samples were taken in geometric horizons of 10 cm and were averaged for the top soil 0-30 cm and for the lower layer in 30-60 cm. The cylinder samples were taken in proximity as close as possible to the permanently buried sensors. The time corresponding sensor readings were used for the data pairs. Though a sufficient set of data could be used for the field calibration, the available moisture range was limited to the wetter part (50–70 % θ_V) due to extraordinary wheather conditions during the years 2001 and 2002. The sensor output (frequency in msec) was used as dependent variable for linear and multiple regression analyses. Porosity, soil temperature, pH and bulk density were tested as dependent variables. The inverse regression equation [1] was used for data correction (Figure 2).

$$\theta_v = \frac{m\sec - T*y - P*z - c}{x} \quad (1)$$

θ_v …water content, T…soil temperature, P…porosity, x,y,z …coefficients, c…constant

3. RESULTS AND DISCUSSION

The water content measured by CS 615 (θ_{CS615}) was compared to those of gravimetric samples ($\theta_{v,g}$) (Figure 2). The mean difference is 0.19m³m⁻³ with a standard deviation of 0.18m³m⁻³. There was an indication of location dependence, leading to the assumption that higher compaction in deeper soil layers (30-60cm) had a higher effect on the sensor output. The manufacturer points out that soils or media with high clay or organic contents might have attenuating effects on the probe signal (Campbell Scientific, 2002-2004), confirmed by Veldkamp et al. (2000). They report that the manufacturer's calibration function underestimated the soil water contents by up to 0.15m³m³, whereas the presented data, measured for similar soil conditions, showed exceptionally anomalous over-estimations up to 0.66m³m³. A closer look at the output data prooved that some of the measured frequencies (<2.11msec) were higher than the frequency in pure water (1.91msec, average of 7 measurements and σ 0,02msec). The physical mixing model as presented by Veldkamp et al. (2000) could not be applied under these circumstances.

Comparing linear and multiple regression analyses, best correlations were found for split data sets according to soil depths and measurement locations and including soil temperature and porosity as independent variables (Table 1). The mean difference and the standard deviation of the corrected data (Figure 2) could be improved to $0.0011 m^3m^{-3}$ with a standard deviation of $0.0266 m^3m^{-3}$. The collected data could be successfully adjusted by the applied regression equations, still, the reasons triggering the anomalous frequencies have not been found yet.

Table 1. Linear and multiple regression analyses; dependent variable: CS 615 output [msec], independent variables: θ_v (water content), T (soil temperature), P (porosity); R^2: (regression coefficient); SE (standard error of estimate)

Regression Type		R^2		SE		F		Significance		Coefficients of the regression equations (msec=θ*x+T*y+P*z+c)			
		Linear	Multiple Regr.	Linear	Multiple Regr.	Linear	Multiple Regr.	Linear	Multiple Regr.	x	y	z	c
All data		0.840	0.849	0.151	0.152	183.51	89.36	0,000	0,000	1.75	0.006	-0.55	0.94
Data Subsets	V1 0-30cm	0.966	0.998	0.078	0.033	84.72	162.72	0.003	0.058	2.14	0.010	-1.74	1.41
	V1 30-60cm	0.916	0.963	0.147	0.167	54.81	14.51	0.001	0.027	2.12	-0.004	-1.12	1.47
	V2 0-30cm	0.992	0.994	0.031	0.040	506.70	102.11	0,000	0.010	1.52	0.003	-0.31	0.89
	V2 30-60cm	0.969	0.987	0.669	0.061	125.11	50.92	0,000	0.019	1.58	-0.001	-1.19	1.39
	V3 0-30cm	0.972	0.991	0.065	0.053	141.32	72.33	0,000	0.014	1.10	-0.012	0.37	0.85
	V3 30-60cm	0.943	0.983	0.094	0.065	82.96	59.44	0,000	0.004	1.89	0.012	-0.85	0.91

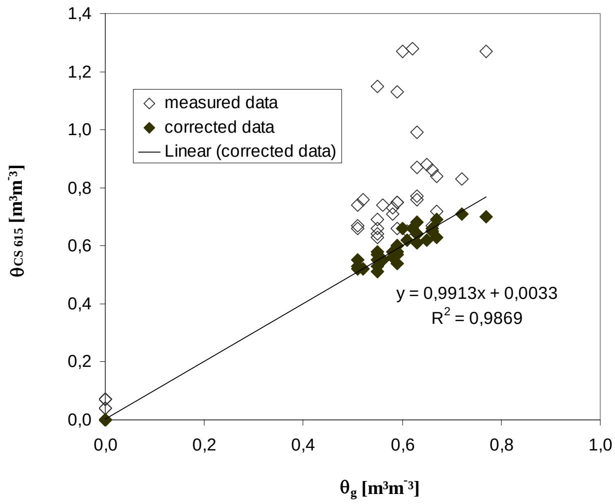

Figure 2. Gravimetric water content ($\theta_{v,g}$) versus CS 615 measured water content ($\theta_{CS\,615}$) – measured and corrected data

Chemical analyses of the monitored soils showed that the location with highest over-estimation (V1 30-60cm) appeared to have slight differences in following properties: lowest pH (4.5 in $CaCl_2$), lowest base saturation (70%), highest extractable Al and lowest extractable Ca. Acid conditions increase the presence of hydronium ions in the soil, while monovalent cations increase the thickness of the electric double layer around clay particles. Following the hypothesis, that, if the acidity leads to an increase in the clay particle spacing, it will change the bulk polarisation of the soil solids, and hence change the attenuation of electromagnetic waves in soil. An increase in the thickness of the clay particle electric double layer will increase the local dipole moment of the clay surfaces. A change of the relaxation behaviour can be expected, explaining the increase of the relaxation.

4. CONCLUSIONS

By elaborating and considering the most dominant effects, plausible water content values could be achieved. The need for soil specific tests is clearly demonstrated.

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Determination of Physical Soil Characteristics at Zabcice Schoolfarm

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ABSTRACT

The project is focused on soil moisture changes in selected area of the School Farm in Žabčice. The soil research proceeds during vegetation period 2006. The soil profiles sections are described in periodical intervals and the soil samples are taken from each soil section for following physical analyses. The results of soil analyses will be compared with the data obtained from selected area in previous time. Both data will be used as a part of the input data for the CERES model. This crop model will simulate the soil water balance regime. In the final stage will by proposed preventive proceedings for sustainability of agricultural land use.

1. INTRODUCTION

The aim of the project is to find out soil moisture three times in the vegetation period 2006. Other task is to compare the results with the data obtained from the selected area in previous time. The soil moisture regime will be simulated with the simulation model CERES.

2. MATERIALS AND METHODS

2.1. Description of the Selected Area

The model area of University Agriculture Enterprise in Žabčice (UAE) is situated 25 km south from Brno, in the region Brno-venkov. This farm was estabilished during the years 1922-25 and manages 1673 ha of farmland. Most of the area is taken in arable land (1449 ha), there are also vineyards 136 ha, gardens 41 ha, meadowland 38 ha and grassland 9 ha. The soil in this area is neutral to subacid with lack of the humus. The several soil classes occure here from majority of sandy soils to clay soils. In the UAE Žabčice the most offen occure genetical soil types of muck, alluvial soils and sod soils. The land plots are plane with average elevation above sea-level of 185 m. The 60 % of soils are situated in the water protective zone. The farm lies in arid and warm part of the South-Moravian region with typical continental climate (average annual precipitation 450-550 mm and average annual temperature 9,3^{o}C). Aridity of the climate is increased by the wind (in whole year average prevail the northwest direction), which evoke high vapour of soil moisture. The strong spring drying winds of south and south-east directions are also characteristic. These winds contribute to the wind erosion of the soil in large area of the farmland. The area of interest is also infuenced by the rain shadow. The rainfall in vegetation period is distributed very unevenly with average total amount 340-350 mm[1].

[1] http://old.mendelu.cz/~szp/historie.html

Figure 1. The selected area – part of the University Agriculture Enterprise in Žabčice

2.2. CERES Model DSSAT

The Decision Support System for Agrotechnology Transfer (DSSAT) has been in use for more than 15 years by researchers in over 100 countries worldwide. DSSAT is a microcomputer software program combining crop soil and weather data bases and programs to manage them, with crop models and application programs, to simulate multi-year outcomes of crop management strategies.

DSSAT was developed through collaboration between scientists at the University of Florida, the University of Georgia, University of Guelph, University of Hawaii, the International Center for Soil Fertility and Agricultural Development, Iowa State University and other scientists associated with ICASA.

DSSAT v 4 includes improved application programs for seasonal and sequence analyses that assess the economic risks and environmental impacts associated with irrigation, fertilizer and nutrient management, climate change, soil carbon sequestration, climate variability and precision management[2].

2.3. Methods

The soil profiles sections in selected UAE area are described in periodical intervals and the soil samples are taken from each soil section for following physical analyses for determination of soil moisture regime. The way of taking soil samples and working with them is based on methodics published by JANDÁK (2003) and REJŠEK (1999).

The volume and specific weight, porosity and soil moisture will be determined within physical characteristics. All physical characteristics will be determined by analysing soil sample which is taken by means of Kopecky cylinder (100cm^3) from 10, 20 and 30 cm depth (Jandák 2003). Soil moisture will be defined by gravimetric analysis. The results of soil analyses will be compared with the data obtained from selected area in previous time.

[2] http://www.icasa.net/dssat/index.html

The results of soil analyses will be also used as one of the input data for the CERES model. In my project this crop model will simulate the soil water balance regime, which was not its main aim, when it was developed, but can be used for doing it profitably as well. It is possible to simulate the soil moisture status for different conditions after data modification. To start simulation it is neccessary to add meteorological, pedological, agrotechnical and genetical input data. Genetical data are the preset parameters of DSSAT, but can be modified. Agrotechnical and pedological data will be obtained from the University Agriculture Enterprise in Žabčice and meteorological data will be obtained from the meteorological station placed in the UAE.

Figure 2. Taking of soil samples

Figure 3. Saturation of soil samples

3. RESULTS

The project is in stadium of taking soil samples and the physical analyses are proceeding in present time. The partial results of the project are going to be presented on the poster session of the symposium.

4. CONCLUSION

Particular results of the project will be following:

- modified syllabus of Landscape Engeneering study subject
- interconnection of new pieces of knowledge obtained by modeling of soil water balance for selected crops, including preventive proceeding concept against soil desiccations

The new knowledge will contribute on deepening of information about the soil water balance and on better realizing of using simulation models.

This contribution was written with the support of FRVŠ project number 366/2006 „Modelování vodní bilance v zemědělsky využívané krajině”.

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http://www.icasa.net/dssat/index.html

Field Calibration of Portable Capacitance Probes in a Sandy Loam Soil

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ABSTRACT

Careful calibration provided, capacitance probes have proved to be a reliable method for real-time water content measurements in a soil profile in the field, especially for irrigation management and for water balance studies. The objective of the study was the calibration of capacitance portable type probes against a sandy loam soil in the field, consisting of 3 layers. Three individual sensors of the same type were used in the experiment. In total 6 access tubes have been installed in 3 pairs. In one pair it was measured under prevailing dry conditions in mid of August 2005. On the surrounding surface of the second pair plenty of water was applied and measured one week later under wet conditions. The surface of the last couple was supplied with roughly 100 mm. The readings in these tubes were taken in mid of September in order to give time for redistribution of the water content and to achieve semi-wet conditions. 4 undisturbed soil samples were taken horizontally with Madera probes in 10 cm-steps up to a depth of 70 cm at each tube after reading, giving in total 4×7×6 = 168 samples of volumetric water content and dry bulk density.
For parameter optimization distinct water contents for each of the tubes would have been better than 2 replications with similar water content. Fitting results for layers give much less uncertainty than individual calibration curves for each measurement depth, mainly because of greater scattering of water content values. Deviations of the calibration curves between individual sensors are smaller than between default calibration curve and fitted ones for the soil under investigation. Achievable accuracy of the manually operated portable probe is possible with careful normalization and calibration of the measurements.

1. INTRODUCTION

Capacitance method has proven to be accurate and useful for real-time soil water monitoring studies (Paltineanu and Starr, 1997) as an alternative to more time consuming such as gravimetric and costly as well as regulative more demanding methods such as neutron scattering (Evett and Steiner, 1995). Its application proved to be reliable for real-time and quasi-continuous water content measurements in a soil profile in the field, especially for irrigation management and for water balance studies (Paltineanu and Starr, 1997, Starr and Paltineanu 1998, Baumhardt et al, 2000, Heng et al., 2004, Geesing et al., 2004). However, a careful calibration improves the quality of their information from relative levels to absolute values, which broadens their area of application considerably.

Capacitance sensors were developed as a multi-sensor stationary probe for automatic measurements and portable single-sensor for manual soil water status readings. Detailed description of multi-sensor capacitance probe system, along with comparisons to other measuring devices was given by Paltineanu and Starr (1997), as well as laboratory calibration (Baumhardt et al., 2000) and field calibration (Geesing et al., 2004).

Unlike for multi-sensor capacitance probes, published experience with portable single-sensor probes is scarce. Calibration was performed for a stony soil in Seibersdorf, Austria by Heng et al. (2002). Coefficient values were found similar to those given by the manufacturer, hence factory calibration was used. Recently published calibration equations for a portable capacitance probe showed that the portable sensor readings can be calibrated to provide accurate estimations of volumetric water content θ for homogenous soils under laboratory conditions (Groves and Rose, 2004). Laboratory calibration affords good control over the experiment conditions. Other research suggests that natural heterogeneity of field soils can reduce usefulness of lab results considerably (Starr and Paltineanu, 1998). Field calibration has the advantage to incorporate specific in-situ conditions based on soil heterogeneity that can't be reproduced in the lab, such as variation in texture, structure and bulk density. Field calibration also accounts for individual sensor variability, which may vary with site characteristics (Chandler et al, 2004).

At present there are insufficient data to know a priori how much the calibration might deviate from the standard calibration for a given method or water content sensor (Chandler et al, 2004). The calibration will vary with soil properties such as bulk density, salinity, with deviations tending to increase with clay content, and that it may vary with each individual sensor.

This paper attempts to enlighten the deviations between individual probes, possible improvements of the calibration experiment in the field and merging of single measurement depths into layers.

2. MATERIALS AND METHODS

2.1. Portable Single-Sensor Capacitance Probe

The portable probe is cheaper than the permanently installed multi-sensor probe, but requires manual readings. It acquires profile distribution of soil water content in 10 cm steps by down- and up movement of the sensor in the access tube. Design and development of portable capacitance probes started in the Sixties. Today still several problems exist, such as uncontrolled climate inside the PVC tube, the influence of orientation of the access tube top, large and variable air gaps between the free-floating probe and PVC tube, the extent of vertical axial sensitivity, non-uniformity of the PVC tube and thickness of its wall and poor field installation of the access tube resulting in air gaps or changes in soil bulk density along the tube (Paltineanu and Starr, 1997).

There is a correlation between the apparent dielectric constant K_a of the soil-air-water mixture and volumetric water content θ at different electromagnetic field frequencies. Capacitance method utilizes K_a of the soil surrounding the sensors in order to measure θ, which is an intrinsic characteristic of the water-air mixture (Paltineanu and Starr, 1997). Composite dielectric approach to measure soil water content is based on the fact that dielectric numbers of the air and solid phase are much less sensitive to temperature than that of water and that the influence of temperature on the dielectric number of wet soil decreases with water content (Roth et al., 1990).

The three tested sensors were of type Diviner 2000® (Sentek Pty. Ltd, Australia). This type consists of a robust probe and a hand-held data logging display unit allowing the user to make onsite management decisions. Instead of registering measured frequencies in soil F_S in the MHz-range directly, the data logger rather stores scaled frequencies SF, which are a linear transformation of F_S in order to yield 1 for measurement in water ($SF(F_W) = 1$) and 0 for measurement in air ($SF(F_A) = 0$):

$$SF(F_S) = \frac{F_A - F_S}{F_A - F_W}.$$

The constant normalization values F_A and F_W of the sensors were checked earlier (Kammerer et al., 2005). The relationship between scaled frequency SF and volumetric water content θ is established by following function for the standard calibration

$$\frac{\theta\,(SF)}{\%} = \quad {}^{1/b} \quad , \tag{1}$$

where a, b and c are dimensionless calibration coefficients. The default values for the standard calibration are $a = 0.2746$, $b = 0.314$ and $c = 0.0$.

2.2. Field Experiment

The field experiment was conducted at the experimental farm of the University of Natural Resources and Applied Life Sciences, Vienna in Groß-Enzersdorf, Lower Austria. Annual precipitation in the region is about 500 mm. The territory is totally flat and intensively used for agriculture. Harvested crop was barley, the field was cultivated just days before with a ripper. Although not very differing, the soil profile can be divided pedologically in three layers. The first layer from surface up to a depth of 15 cm and the second layer from 15 cm to 55 cm depth are only distinct in bulk density due to soil tillage. Its texture is sandy loam with 34 % Sand, 43 % Silt and 23 % Clay. The third layer is a loamy sand with 47 % Sand, 39 % Silt and 14 % Clay and reaches to a depth of 130 cm.

Three plots were arranged on the field and a couple of access tubes was centered on each plot as shown in Fig. 1 left. All six tubes were inserted according to the installation guide provided by the manufacturer of the probe on Thursday, August 11, 2005. After the readings with the 3 individual Diviner 2000 probes denoted BF, CP and KL, a trench was dug beside tubes # 36 and # 42 up to a depth of 1.2 m. 4 undisturbed soil samples were taken horizontally with Madera probes ($V = 60.0\,cm^3$) at all measuring depths of the capacitance sensor from 10 cm to 70 cm below soil surface (see Fig. 1 right). Two small dams were built in a circle with a radius of app. 1.5 m around the other two tube couples. On one plot plenty of water was ponded in order to achieve almost saturated conditions, whereas on the other plot app. 100 mm water was applied.

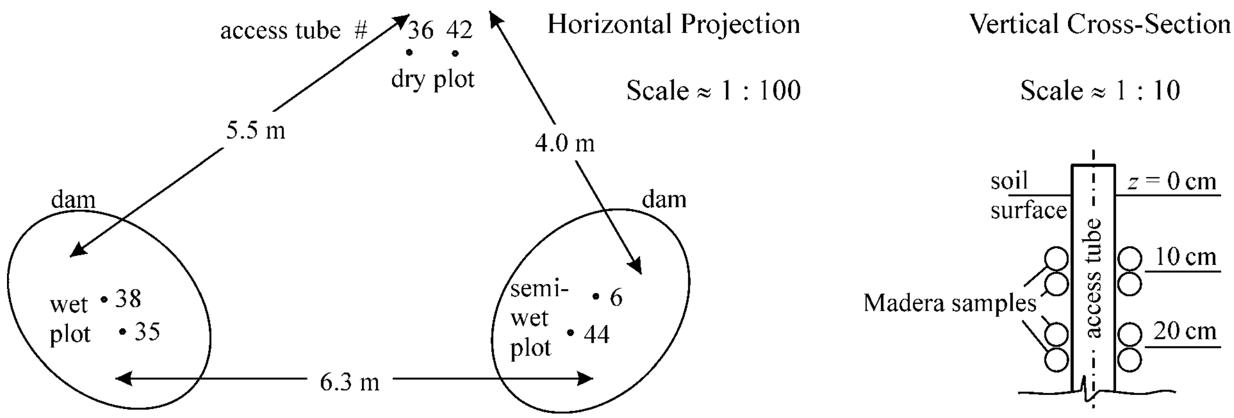

Figure 1. Horizontal projection of the experiment setup (left) and vertical cross section of sampling with Madera probes for one access tube (right)

Measurements with the 3 capacitance probes were taken in the 4 remaining tubes on Thursday, August 18, and the wet plot was investigated as the dry plot one week before. In order to give enough time for redistribution, the last two tubes were excavated on Monday, September 19. We gained in total $4 \times 7 \times 6 = 168$ undisturbed soil samples. 8 samples from the dry plot, 2 from the semi-wet and 6 from the wet plot had to be discarded later due to unplausible θ- or ρ_d-values.

2.3. Fitting of Calibration Curves

Readings with the Diviner probe were taken at least 10 times with each individual sensor and the means of scaled frequencies *SF* were calculated, giving 6×7 = 42 values for two sensors and 35 for the third (measurement with sensor BF had been forgotten in tube # 42). The mean values were coupled two to four times (depending on the number of discarded samples for each depth) with the corresponding θ-values from the individual Madera-samples (not with the averages!). *SF* was considered the independent and error-free *x*-variable, $\theta(SF)$ as variable *y* depending on the calibration parameters *a*, *b* and *c* (see Eq. 1) which had to be determined by minimizing the sum of quadratic deviations $\theta_{i\,\mathrm{Madera}} - \theta_i(SF_i)$. The Madera-values are considered error-free as well.

3. RESULTS

3.1. Volumetric Water Content from Undisturbed soil Samples

An overview of average volumetric water content (θ) and dry bulk density (ρ_d) distribution over depth is given in Fig. 2. Sampling for tubes # 36 and # 42 was on Aug. 11, for # 6 and # 44 on Sep. 19, and for # 35 and # 38 on Aug. 18. Please note that 16 samples had to be discarded. One average is based on only 2 values instead of 3 or 4 (θ and ρ_d in 30 cm depth for tube # 36). An impression of considerable scattering between individual samples may be obtained from the vertical deviations of the data points in Fig. 3.

It is immediately striking in Fig. 2 left that θ at shallow depth (0 cm to 40 cm) was not that low as hoped for on Aug. 18, and the topsoil had dried out again at the semi-wet plot, where sampling was performed on Sep. 19. θ for the wet plot (tubes # 35 and 38) may be close to field capacity, and far away from field saturation. The replications show good coincidence.

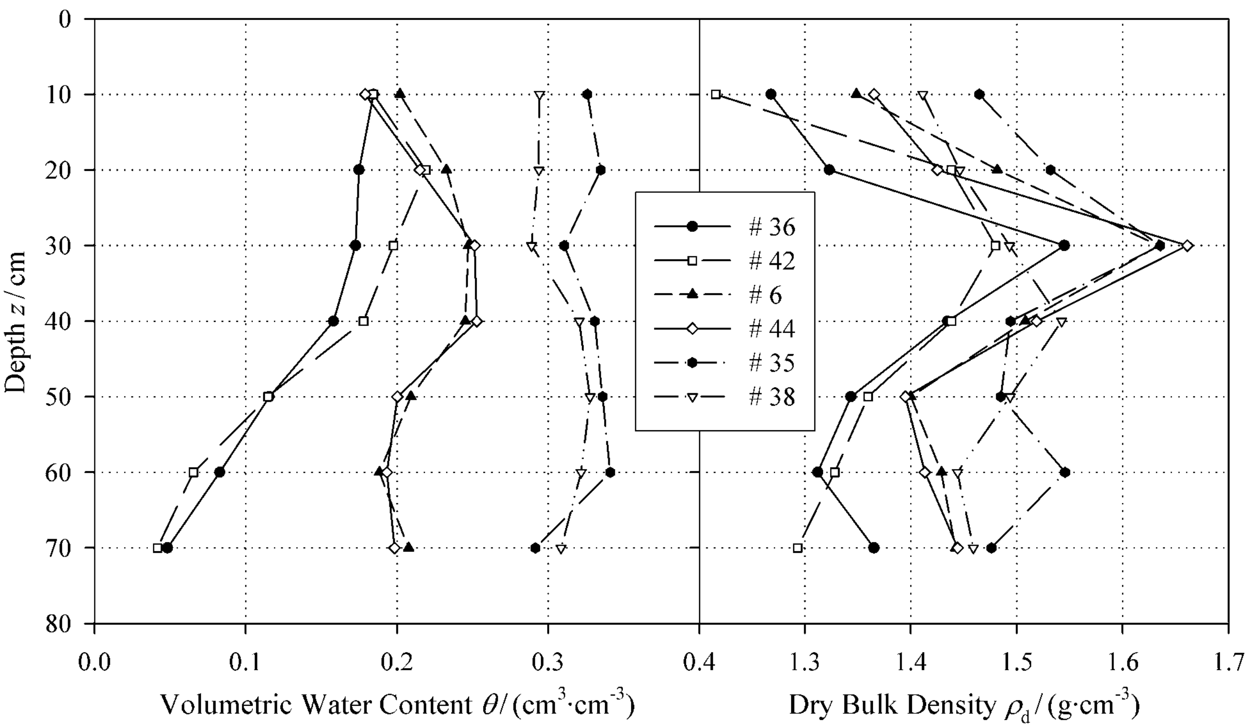

Figure 2. Average water content and bulk density distribution over depth for all 6 tubes.

On the other hand bulk densities vary considerably with depth and tube (Fig. 2 right). Whereas lower values in depths 10 and 20 cm are not surprising due to tillage and the highest value at 30 cm was also expected there, where soil compaction decreasing with depth still occurs, but is not remedied by plowing, deviations between tubes have no obvious explanations.

3.2. Parameter Optimization

Parameter optimization was performed for each sensor on three ways: for each depth separately, for each layer and for the whole profile. Measurement depth of 10 cm was allocated to layer 1, 20 cm, 30 cm, 40 cm and 50 cm to layer 2 and 60 cm and 70 cm to layer 3.

The graphs in Fig. 3 show the curve fitting results together with the data points for the whole profile. Input data for the optimization comprised 6×4 = 24 minus 4 (discarded) = 20 points for 10 cm depth, 22 for 20 cm, 21 for 30 cm, 21 for 40 cm, 23 for 50 cm, 21 for 60 cm and 24 for 70 cm; 152 points totally (130 points for the probe # BF; see missing values in the low range of left graph of Fig. 3). Standard calibration function is depicted in the graphs for comparison. Default coefficient values of the standard curve are $a = 0.2746$, $b = 0.3314$ and $c = 0.0$.

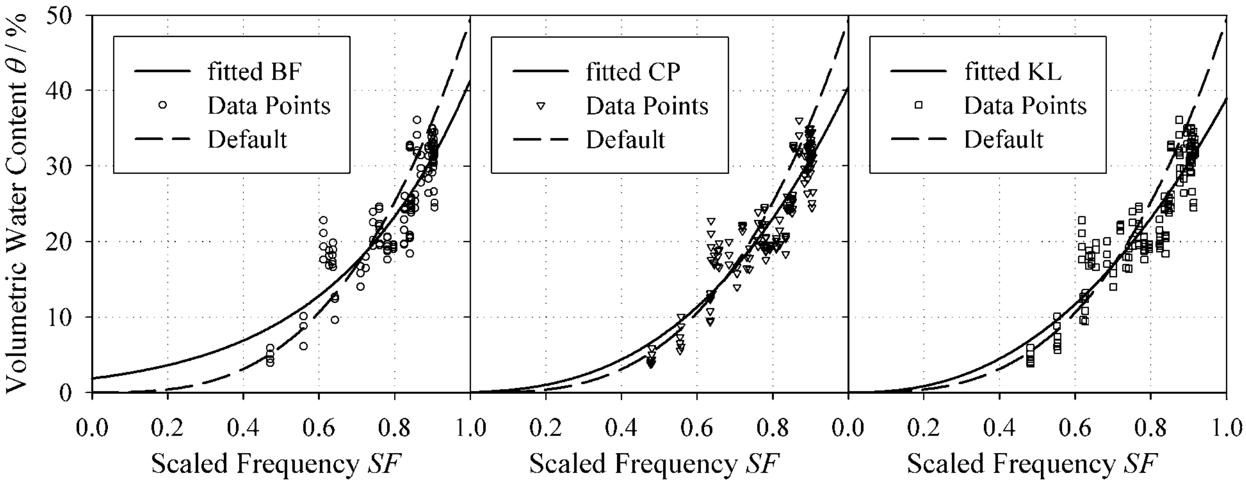

Figure 3. Calibration curves fitted on water content measurements in all depths and tubes for 3 individual Diviner2000 probes

Fitted calibration curves are all displayed in Fig. 4. The plots for “Profile” and “Default” are the same as “fitted” and “Default” in Figure 3.

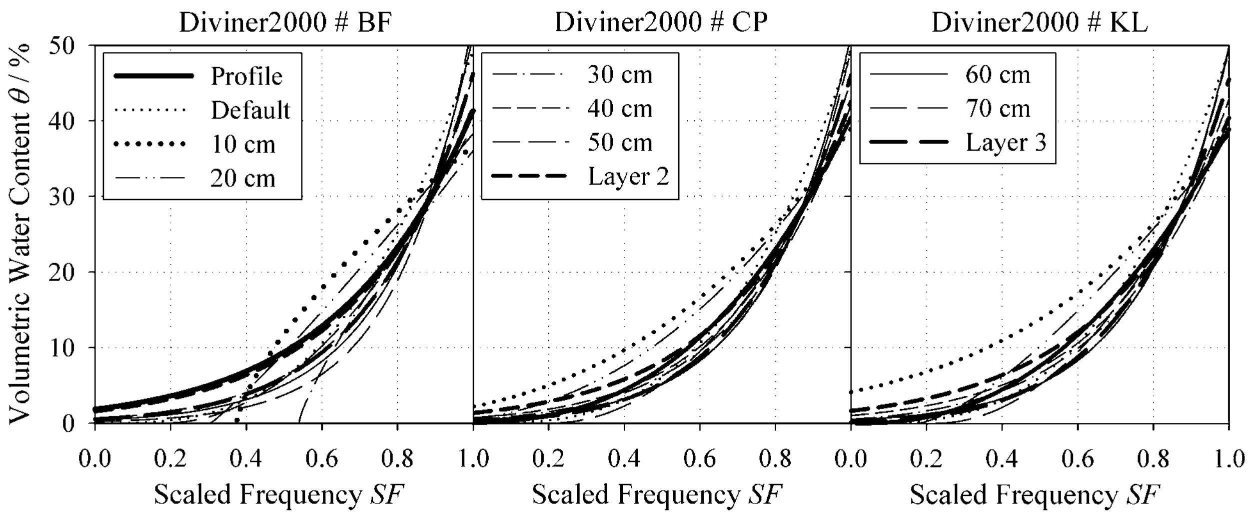

Figure 4. Calibration curves for 3 individual Diviner2000 probes (BF, CP and KL) for each depth separately, for the layers 2 and 3 and for the whole profile. Legends apply to all graphs.

Curves for a depth of 10 cm and 20 cm of the probe # BF are useless. This might be a consequence of the missing 6th tube (# 36) – at least for 20 cm depth. Tube # 36 provides the lowest value in the data range and enforces a positive curvature of all other calibration curves for 20 cm.

Although the curves in Fig. 4 look quite uniformly (besides the curves for 10 cm depth and the ones mentioned above), the coefficient values are very different. The parameters a and b are mathematically highly interdependent. Distinct determination is often more a matter of parameter settings of the numerical algorithm than of the arrangement of the data points. In these cases – many of the plots in Fig. 4 must be attributed to them – the standard errors of the coefficients are very high. Nevertheless the function values $\theta(SF)$ do not differ very much.

4. CONCLUSIONS

Instead of using three plots and 2 replications per plot, it would have been better to use 6 distinct plots with different water content and no replication. Even 4 plots and only 4 access tubes may lead to a similar determinability as our experiment. Then it has to be secured that the desired water content is present in the soil. Uncalibrated readings with a Diviner 2000 sensor are accurately enough for this purpose. Merging several depths to layers yields in more data points for parameter estimation and reduces standard errors of the coefficient values. Corresponding partitioning of the soil profile may based on pedological conditions or statistical tools.

Only small deviations between individual sensors occurred. The standard calibration curve is a good approximation for the investigated soil (whereas it gave high errors for the Silt Loam analyzed by Kammerer et al. (2005)). Because of the high interdependency of the coefficients a and b, neither their values nor their standard errors should be used as plausibility criterion of a calibration.

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SECTION B

SOIL WATER MOVEMENT

Integrated Modeling of Regional-Scale Flow and Reactive Salt Transport in the Western San Joaquin Valley

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ABSTRACT

The sustainability of irrigated agriculture in many arid and semi-arid areas of the world is at risk because of a combination of several interrelated factors, including lack of fresh water, lack of drainage, the presence of high water tables, and salinization of soil and groundwater resources. Nowhere in the United States are these issues more apparent than in the San Joaquin Valley of California. A solid understanding of salinization processes at regional spatial and decadal time scales is required to evaluate the sustainability of irrigated agriculture. A hydro-salinity model was developed to integrate subsurface hydrology with reactive salt transport for a 1,400 km^2 study area in the San Joaquin Valley of California. The model was used to reconstruct historical changes in salt storage by irrigated agriculture over the past 60 years. We show that patterns in soil and groundwater salinity were caused by spatial variations in soil hydrology, the change from local groundwater to snowmelt water as the main irrigation water supply, and by occasional droughts. Gypsum dissolution was a critical component of the regional salt balance. Although results show that the total salt input and output were about equal for the past 20 years, the model also predicts salinization of the deeper aquifers, thereby questioning the sustainability of irrigated agriculture.

1. INTRODUCTION

Salinization affects about 20-30 million ha of the world's current 260 million ha of irrigated land (Ghassemi et al., 1995), and limits world food production (Tilman et al., 2002). Salinity reduces water availability to plants (Maas and Grattan, 1999) by the accumulation of dissolved mineral salts in waters and soils due to evaporation, transpiration, and mineral dissolution. Subsequent salt leaching leads to salt buildup in both shallow groundwater below the plant root-zone and deeper groundwater bodies (aquifers). The San Joaquin Valley, which makes up the southern portion of California's Central Valley, is among the most productive farming areas in the United States. However, salt buildup in the soils and groundwater is threatening its productivity and sustainability.

Currently, there is a good understanding of the fundamental soil hydrological and chemical processes (Tanji, 1990) that control soil and groundwater salinity. Much of this understanding was achieved by using modeling approaches that consider the hydrology and soil chemistry separately, that assume simplified steady-state flow for spatial scales not larger than the field and that only consider the root-zone. However, recent research (Belitz and Philips, 1995; Deverel and Fio, 1991; Corwin et al., 1999; Alley et al, 1985) has shown that soils must be fully coupled with the vadose zone and groundwater systems for regional-scale studies, especially in areas where groundwater tables are shallow or groundwater pumping is used. Innovative predictive tools are needed that can be applied at the regional scale and at the long term, so that the sustainability of alternative management strategies can be evaluated. For this purpose, an integrated regional-scale hydro-salinity model was developed to fully couple the hydrology and salt chemistry of the vadose zone with the groundwater system. This enables us to reconstruct historical changes in soil and groundwater salinization in general, and for the western San Joaquin Valley, in particular (Schoups, 2004; Schoups et al., 2005).

2. RESULTS AND DISCUSSION

The adapted modeling approach is based on the coupling of a soil chemistry module (Suarez and Simunek, 1997) with a regional-scale hydrology model (Panday and Huyakorn, 2004), to yield an integrated approach for simulating three-dimensional variably-saturated subsurface flow and reactive salt transport (Schoups et al., 2005). The horizontal boundaries of the model domain coincided with the hydrologic boundaries of an earlier regional groundwater flow model (Belitz and Philips, 1995), defined by the trough of the San Joaquin Valley on the east, the Coast Range foothills in the west, and no-flow boundaries in the north and south of the regional flow domain. Hydrologic flows and salt transport were simulated for a 57-year period, from 1940 to 1997, using annual average boundary conditions and grid cell specific soil parameters. The salinity module included reactions such as cation exchange and precipitation and dissolution of gypsum and calcite (Schoups et al., 2006; Oster and Tanji, 1985). Using historical crop acreage and water delivery records for each water district, crops and irrigation amounts were randomly distributed, leading to the annual assignment of a single crop to each grid cell. Other required boundary conditions were needed to quantify vertical (across Corcoran clay and into deep groundwater) and lateral (towards San Joaquin River) water flow and salt fluxes and exchange between the simulated domain and its surroundings (Schoups et al., 2005), so that an annual salt balance could be estimated. Simulation model results included spatial maps of the groundwater table, drainage flows and groundwater pumping, as well as regional water fluxes across the domain boundaries, starting in 1940. The hydrologic component simulated the dynamics of the regional variation in water table depths well, reconstructing the gradual increase in shallow water table area from the fifties to the nineties due to increased recharge from irrigated agriculture compared to pre-development conditions, and the shift in irrigation water supply from locally pumped groundwater to imported surface water in the early seventies.

The corresponding soil salinity dynamics over the 57-year period (Fig. 1A) are represented by a time-series of the number of model grid cells with a root-zone average salt concentration (EC_e) greater than 4 dS/m, which identifies the salt-affected soils. The few measured data points in Fig. 1A were derived from aggregating measured soil salinity data reported in 1969 and 1992 soil surveys. Initially, soil salinity was high in 1940, but decreased until about 1975 due to salt leaching when water tables were relatively deep. This general pattern of soil salinity decrease reversed during the seventies, as continued irrigation raised the water table to levels that caused capillary rise of relatively high salinity groundwater into the rooting zones.

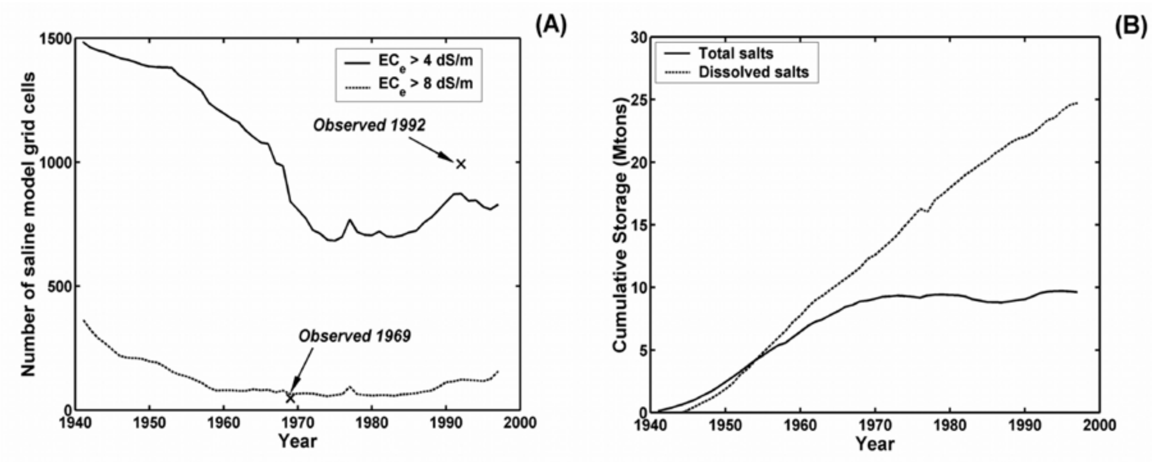

Figure 1. Time-series of number of model grid cells with a simulated average root-zone EC_e greater than 4 dS/m (solid line) and greater than 8 dS/m (left) and changes in total salt storage and dissolved salts (in million tons, Mtons) since 1940 (right).

When considering the salt balance equation over an extended period without major hydrologic changes, a pseudo-equilibrium will be approached, during which total salt inputs and outputs of the study area will be approximately equal. Salt inflows occur by infiltration of irrigation water and rainfall, whereas salts may leave the system by the drainage system, groundwater pumping above the Corcoran clay, deep groundwater percolation through the Corcoran clay and lateral groundwater flows towards the San Joaquin Valley trough. Moreover, much salt is produced by the net dissolution of gypsum. When analyzing the simulated annual total salt flows of the study area, the combined net influx was about 0.3-0.4 million tons (Mtons)/year during the fifties and sixties, resulting in an increase in salt storage over time. However, although annual salt accumulations fluctuated later, depending on irrigation water quantity and quality and drought, the average net salt accumulation of the simulated domain appears to be near zero after 1970. The simulated cumulative change in salt storage over the 57-year simulation period (Fig. 1B) shows that a pseudo-equilibrium developed after 1970, with a total net salt increase between 8 and 10 Mton since 1940. Although the salt balance results indicate that crop productivity can be maintained, sustainability is threatened in two ways. First, the storage of dissolved salts has increased continuously since 1945 at an average rate of about 0.5 MTons/yr (Fig. 1B) due to gypsum dissolution. Second, the simulations also showed that the deeper aquifers below the Corcoran clay accumulate salt, thereby degrading deep groundwater quality.

3. SUMMARY

The process of salinization of the deeper groundwater bodies may take many decades or longer, thus making the deeper groundwater less suitable for drinking or irrigation water purposes, and putting the sustainability of current irrigation practices into question. We conclude that the salinization issues are critical to the sustainability of irrigated agriculture in the San Joaquin Valley, and similarly probably to many other areas of the world with relatively closed groundwater systems.

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Lysimeter Station Requirements and Techniques for Water Balance, Solute Flux and Bioremediation Investigations

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ABSTRACT

Soils have a key role for many environmental research studies because of their multiple functions, especially for soil water balance, water quality and bioremediation. Lysimeter stations enable research on undisturbed soil monoliths between the laboratory scale and field scale with defined surface and volume under real climatic conditions and vegetation. Due to the high precision weighing system with a resolution of 0.01 mm of water and other technical improvements, lysimeters are now usable for precise water balance measurements. The bottom section of the monolithic pillar is now formed as a silicon suction cup rake and acts as matrix potential area, to which the field water tension is transmitted into the Lysimeter achieving field comparable fluxes.

1. INTRODUCTION

We want to introduce the general requirements for lysimeter stations and their operation, the technical conception, operation and quality control. Beside the specific needs of design and setup of lysimeter stations, there is need to define general requirements to enable comparable results based on standardized basic design and to reduce individual errors. Lysimeters as shown in Figure 1 only cover one scale of scientific or applied research working level, which is suited between laboratory scale and field scale. They combine the advantages of true field conditions and laboratory possibilities of varying parameters, handling and maintenance. The advantage of a defined surface and volume includes the disadvantage of having only a certain surface and certain volume, which may not cover field heterogeneity.

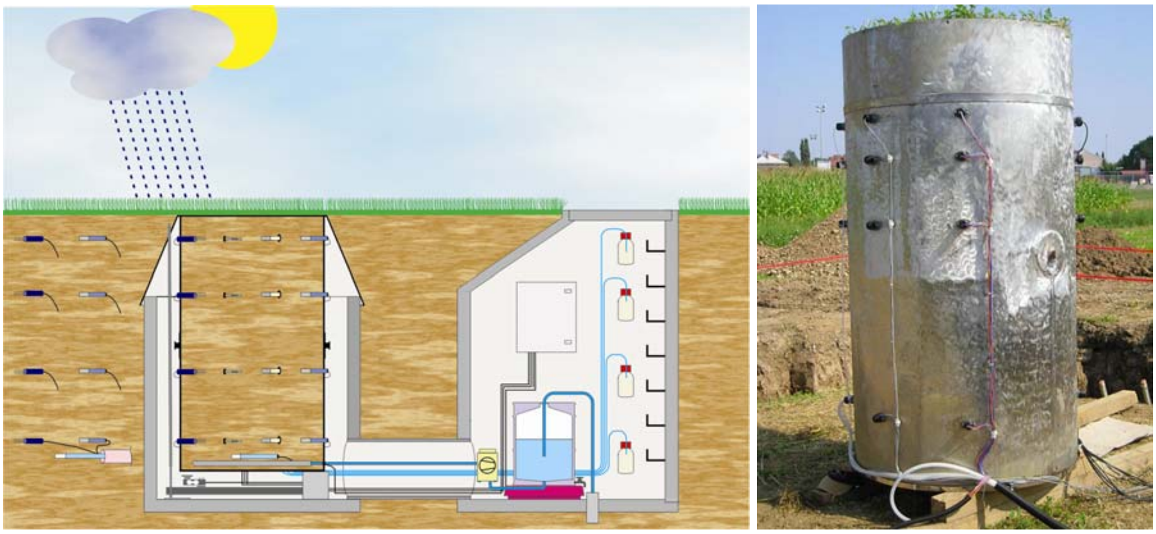


Figure 1. Schematic view and photo of a soil science lysimeter

2. REQUIREMENTS

Basic principles on the construction of and working with lysimeters are given by DVWK (1980). In 2000 a workshop has been organized to sum up the experiences on lysimeter investigations and to define technical concepts (Leis et al., 2001). At the groundwater test area Wagna (Austria) precise weighable monolithic scientific field lysimeters has been installed in the field allowing precise weighing and mechanical cultivation of the lysimeter itself (Fank & Unold, 2005). The experiences on lysimeter installation lead to some principle statements on lysimeter techniques.

2.1. Excavation

Soil structure and texture have to be representative for the area. Therefore soil profiles of the area are taken first to find the representative profile and site of excavation. Lysimeters soil excavation has to be monolithic – with the exception of rubble. The excavation principle must allow permanent control of the cutting edge conditions (Figure 2) to prevent gaps caused by stones or roots or other parts. The excavation method must save the soils pore structure, density, macro pores, surface, chemical behavior and any water flux dependant parameters. No synthetic macro pores or preferential paths caused by the excavation method are allowed. There is need to protocol applied forces and deformations and compactions. Also, soil samples should been taken over the complete length, at least for the typical soil horizons. Soil surface ends 30 mm below the upper cylinder border for take up of surface water at heavy rains.

Figure 2. Control of cutting edge, shearing and excavated monolith

After excavation and before installation into the building or cellar, the lysimeters must be conserved under natural conditions without heat by sunlight.

2.2. Lysimeter Construction

The Lysimeter cylinder is made of a corrosion free, chemical inert material with similar thermal expansion to soils and has minimal ductile deformation, resist geostatic load and has long term abilities. The cylinders axial deformation tolerance is lower than +/- 1 mm, the radial deformation tolerance +/- 8 mm. The wall thickness is small enough to minimize heat flow, but remains excavation forces. The lower cutting edge is chamfered formed to prevent compaction and deviation of the soil. For heavy rain and soils with low hydraulic conductivity a circular eaves gutter takes up water in a separate tank. A surface of 1 square meter is standardized, but other dimensions are possible depending on soil and plants heterogeneity. The monolith height depends on soil and application. As the field matrix potential is transmitted into the Lysimeter above bottom plate the soil water shade is no height issue for water balance studies. The construction has a rotating device (Figure 3) preventing deformation at the rotation process. The cylinder form is preferred because of uniform friction, load and deformation. Rectangular lysimeter have reinforced walls to take up geostatic load, but the danger of preferential flow at the walls or corners remain.

Figure 3. Rotating the 6 tons cylinder

2.3. Weight Measurement

To reach highest accuracy and resolution, the weight measurement devices are mounted on concrete base, free of shear force and vibration damped. A 0.01 mm resolution at 5.5 tons means to split the range into 12 million parts (0.45 grams) to reach a usable resolution of 5 Grams or 0.005 mm of drainage, evaporation or precipitation. This is not possible with standard weight measurement and need high end indicators, working on adopted analogue filtering, microcontroller based statistic and modelling. There is no interest in absolute weight accuracy, but in resolution inside the load varying range, thermal accuracy and long term stability.

2.4. Cellar

Dimension and material of the cellar depend on individual needs. An example is shown in Figure 4. The cellar must contain the lysimeter fundament of concrete, drainage water sampling devices, enough room for sensor maintenance, data logger, workshop, tools, and water samples handling desk, washbasin, water tanks, and water pumps to remove drainage water. Depending on ground water level, the construction must be heavy enough to prevent up-swimming, made of watertight concrete. Electricity and air conditioning as well as safety requirements depend on local regulations. For most applications, concrete is the cheapest material, available as components or for individual construction and fulfils the requirement of long term stability over 50 years. The gap between the lysimeter and the surrounding soil is big enough to ensure no force influence at any time, but as small as possible to prevent any microclimatic influence, as well as rain and dirt getting into the cellar. A 10 mm gap is possible when mounting the lysimeter on an adjustable X-Y-Z frame.

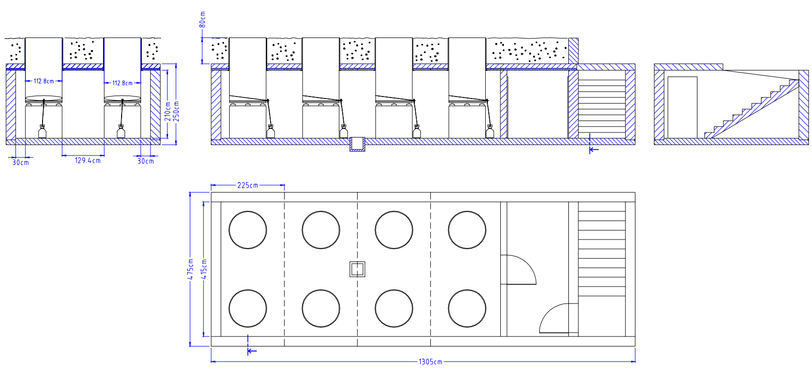
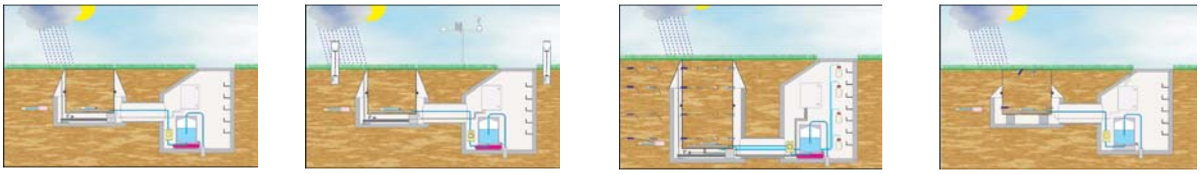


Figure 4. Example of an 8-Lysimeter cellar construction

3. TECHNIQUES FOR WATER BALANCE-, SOLUTE FLUX- AND BIOREMEDIATION INVESTIGATIONS

Monolithic precise weighable lysimeters are a tool for water balance studies and solute transport determination. It is useful to standardize four types of lysimeters with application-oriented design, as different tasks require different construction and measurement equipment, different handling and data tools. Thus, each type is aligned to hydrologic, climatologic, soil scientific or agronomic needs (Figure 5).



Hydro-Lysimeter® Meteo-Lysimeter® Soilscience-Lysimeter® Agro-Lysimeter®

Figure 5. Schematic view on four types of UMS® field-lysimeter-setups

Due to the high precision weighing system and other technical features, lysimeters are now usable for precise water balance measurements. The measure interval can be several seconds for European ET and ET_0 determination. The bottom section of the monolithic pillar is formed as a matric potential area to achieve field comparable fluxes by transmitting the externally measured soil water tension into the Lysimeter.

3.1. Instrumentation and Data Management

Due to the specific needs of each application the instrumentation varies. If water balance determination is the main goal, the Hydro-lysimeter measures precipitation and evapotranspiration as well as drainage. Additional field sensors may be useful to verify results over areas and regions. For infiltration determination, matrix potential sensors and water content probes are installed in several depths. For solute transport studies suction cups, for bio remediation research gas lances and gas sparging devices are installed. The new lysimeter setups follow up the fact that micro organisms interact in the rhizosphere with high dependencies on water, fluxes, temperature and chemical environment. Therefore precision weighing monolithic lysimeters offer specific microorganism approach. Applying the matrix rake device an artificial ground water level can be applied. Any instruments are maintained and calibrated in a yearly period. Every manipulation is documented in a data based log book protocol. Any data have to be visualized and verified weekly in accordance with the stations log book. This is important to react in time and to control the measuring process. Therefore, data base software and visualization tools are used for manipulation and verification for further usage and modeling.

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Monolithic Field Lysimeters for Precise Weighing – a Basis for Balancing Water Flow

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ABSTRACT

Based on the data set of the year 2005, the evaluation of water balance for a lysimeter at the Wagna test field is discussed and presented in this paper. The water balance equation can be solved in short time steps using precisely weighing monolithic lysimeters to measure precipitation, evapotranspiration, seepage water flow and the change in water content in the lysimeter monolith. After summing up the short time evaluation results, daily, monthly and yearly values of the different water balance parameters can be obtained. Precise measurement of water and solute balance in a well defined environment is the basis for validating soil water and solute transport models.

1. INTRODUCTION

The evaluation of lysimeter data allows a much more reliable calculation of the solute load carried towards the groundwater than any other method (Klocke et al., 1993). If the lysimeters are weighable, actual evapotranspiration can be deduced from their weight change (Young et al., 1996). Due to these characteristics, lysimeters are an excellent tool to derive or calibrate water and solute transport models (Wriedt, 2004). Exact information about the soil water balance is needed to quantify solute transfer within the unsaturated zone (Fank, 2006). A large weighable lysimeter is the best method for obtaining reliable data about seepage water quantity and quality. In Europe, the use of direct lysimetry methods for measuring water and solute flows in soils increased in recent years. The combination of lysimeter studies with field experiments at different scales opens new possibilities for modeling and management of watersheds (Meissner & Seyfarth, 2004).

Based on the definition of the requirements on measuring sites for validation and calibration of soil water and solute transport models in the unsaturated zone of agricultural environments (Fank et al., 2004), two lysimeters have been implemented in the Wagna agricultural test field in southern Austria (Fank & Unold, 2005). The main goal for ongoing investigations at the Wagna test field is to compare the impact of conventional and organic farming on the groundwater system. In two of the 32 test fields with an extent of 1000 m² each, measuring sites in the unsaturated zone have been built in to get detailed information on water flow and solute transport.

The main goal of this paper is (i) to present new lysimeter techniques for measuring the parameters of the water balance equation, (ii) necessities on data management and (iii) results on water balance and solute leaching determination for the year 2005.

2. MEASURING METHODS AND DATA MANAGEMENT

Each measuring site in the unsaturated zone consists of:

- A precise weighing monolithic field lysimeter:

Due to the high precision weighing system with a resolution of 0.01 mm of water, lysimeters are now usable for precise water balance measurements for individual time steps. The weight of the lysimeter is recorded in an interval of 10 seconds; mean values for one minute are stored on a data logger.
The bottom section of the monolithic pillar is formed as a matric potential head area to achieve field comparable fluxes by transmitting the measured soil water tension outside the vessels into the lysimeter. Undisturbed soil water tension is measured at the same horizon as the depth of the lysimeter bottom.
The upper ring of the lysimeter with a height of 35 cm is removed to cultivate the field mechanically. Crop yield at the lysimeter is measured at harvest time; the content of the main nutrients in the crops is analyzed.

- The amount of seepage water at the outflow of the lysimeters is recorded in an interval of ten minutes using a tipping bucket with a resolution of 0.1 mm; samples are taken once a week and analyzed for the main hydro-chemical parameters.
- Two soil hydrology measuring sites, one in the monolith and one in the undisturbed field beside. Probes for measuring soil water content (using TDR probes), matric potential head (using tensiometers and SIS sensors), and soil temperature are installed in 35, 60, 90 and 180 cm below surface. Values are recorded at ten-minute intervals.

Weather parameters like precipitation, air temperature, relative humidity, wind speed and net radiation are measured nearby in a time step of 1 minute at the official weather station of Leibnitz operated by ZAMG (Zentralanstalt für Meteorologie und Geodynamik). The parameters are used to calculate grass reference evapotranspiration for different time steps using the ASCE standardized reference evapotranspiration equation (Walter et al., 2005).

The accuracy of weighing data has been proofed in a calibration experiment on September, 27th 2005. The result of the calibration procedure for one of the two lysimeters is shown in Figure 1.

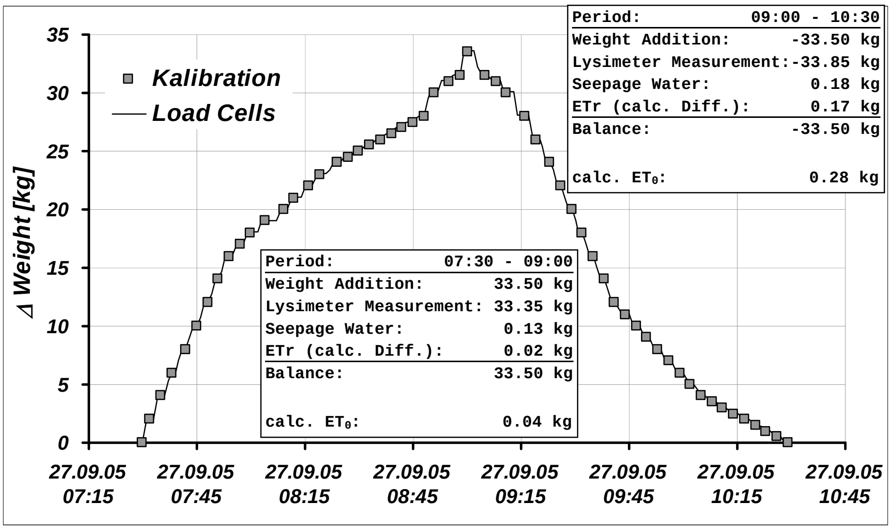


Figure 1. Calibration of the lysimeter weighing system

Barbells with exact weights of 0.5, 1.0 and 1.5 kg respectively have been put on the lysimeter every three minutes. As shown in Figure 1, during the period 07:30 to 09:00 33.5 kg of calibration weights has been added and removed from 09:00 to 10:30. Taking into account the amount of seepage water during calibration, the accordance is very good.

The calculated difference of 0.02 kg and 0.17 kg respectively is interpreted as the real evapotranspiration from the lysimeter.

In April 2005, a tracing experiment using bromide and deuterium has been carried out to investigate water flow velocity and solute residence time in the monolith and the appearance of bypass flux due to the excavation method of the monoliths. Up to now (June 2006) the bromide recovery rate is 30 to 35 %, the tracer breakthrough curve is well comparable between the two lysimeters. The first appearance of the tracer at the lysimeter with thinner soil cover (70 cm) was 6 weeks after tracer application, at the second lysimeter with a soil cover of 110 cm, the first appearance has been visible 4.5 months after application. No bypass flux due to the monolith excavation has been detected.

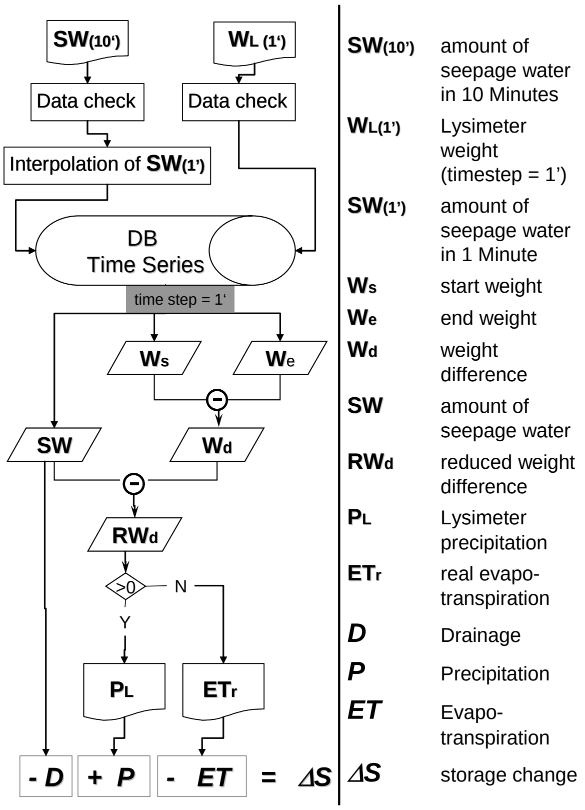


Figure 2. Flow chart of water balance parameter determination

The recording of the lysimeter weight in an interval of 1 minute and the amount of seepage water as a sum over ten minutes allows the direct determination of all water balance parameters for a plain site with only vertical movement of water and solutes. The flow chart for data management and the determination of water balance parameters is shown in Figure 2.

Because precipitation and evapotranspiration act in very short time intervals, it is necessary to store the lysimeter weight every minute. The amount of seepage water is detected using a tipping bucket; therefore there is no continuous recording available. The amount of seepage water has to be interpolated to the time interval of 1 minute. For the time step of 1 minute, lysimeter precipitation is determined from the positive change of the weight, real evapotranspiration from the negative change of the weight; both are corrected using the measured amount of seepage water. Following the procedure in Figure 2 all the parameters of the water balance equation may be determined from precise weighing lysimeter data.

3. RESULTS AND CONCLUSIONS

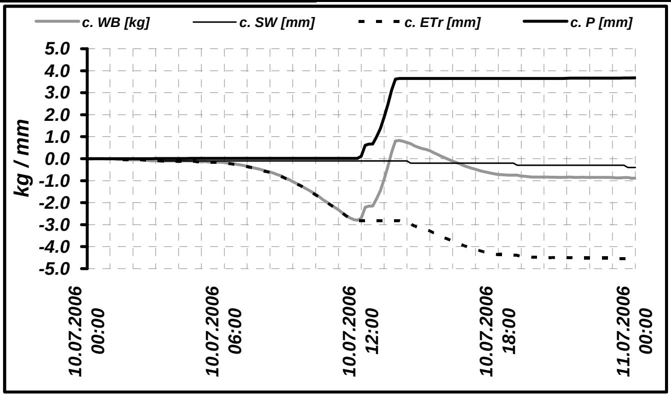
After applying the procedure shown in Figure 2, water balance parameters can be determined on selected intervals. Calculation results can be used to determine crop coefficients for further modeling. Figure 3 shows the water balance parameters of one lysimeter in the course of July, 10th 2006 and calculated crop coefficients. The values for the year 2005 are shown in Table 1.

Table 1. Water balance parameters for a lysimeter at the Wagna test field for the year 2005

Precipitation [mm]	$ET_{0\,(ASCE)}$ [mm]	ETr [mm]	Drainage [mm]	Storage change [mm]
959	682	586	374	-1

Precise measurement of water balance parameters in a well defined environment is the basis for the calculation of solute balances and the validation of soil water and solute transport models.

Water balance		P - ET - D - ΔS = 0 3.68 - 4.16 - 0.40 + 0.88 = 0	
Precipitation P [mm]	3.68	ETr [mm]	4.16
Seepage Water SW [mm]	0.40	Weight Balance WB [kg]	-0.88



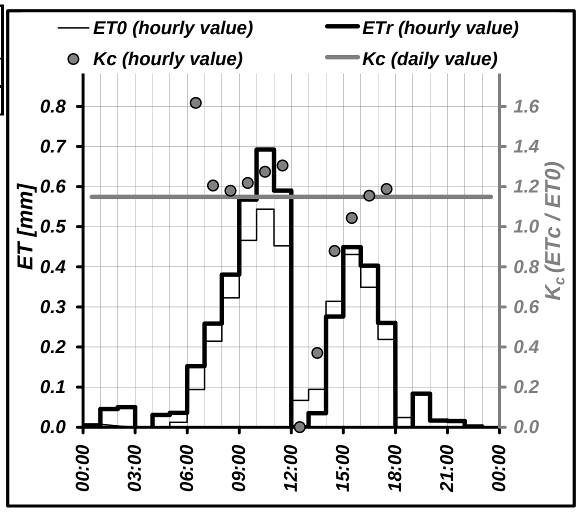


Figure 3. Water balance calculation for July, 10th 2006

left: daily water balance and water balance parameters in the course of the day

right: calculated crop coefficients (Kc) using hourly values of calculated ET0 and measured ETr compared to the daily Kc-value.

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Movement of Water Through the Chalk Unsaturated Zone: Development of a Depth-Dependent Model Parameterisation

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ABSTRACT

Recently, an equivalent continuum modeling approach has been suggested for the Chalk unsaturated zone (Mathias, 2006; Brouyère, 2006). In both cases, the matrix was parameterised based on literature data and the fracture parameters based on arbitrary assumptions. In this study, we parameterise the model using field data, with the fracture parameters scaled as a function of depth to account for changing near surface hydraulic properties. A parametric model is proposed for the hydraulic properties, based on the model of Kosugi (1996). The model is successfully fit to observed drying curves. A demonstrative simulation is performed, using a Richards' equation model, which shows that the model reproduces the observed, progressive attenuation of the flux, pressure and water content with depth.

1. INTRODUCTION

Due to the particular hydrogeological properties of the Chalk, quantification of the movement of water through the Chalk unsaturated zone has proved difficult, despite a history of some 30 years of study. At the same time, the importance of the (largely) unconfined Chalk aquifers as a major UK water supply provides an incentive to understand better the recharge processes and the migration of potential pollutants from the ground surface to the water table. Chalk is made up of a fine grained porous matrix, intersected by a fracture network. Whereas the matrix has a high porosity (20-40%), a low hydraulic conductivity (10^{-2}-10^{-4} m/day) and a low air-entry pressure (approx. -30 m H_2O), the fractures have a low porosity (<2%), high hydraulic conductivity (>10^{-1} m/day) and a high air-entry pressure (approx. -0.5 m H_2O) (Price et al., 1993). Due to the highly conductive nature of the fractures, the saturated zone tends to have large transmissivities, and (hence) shallow gradient water tables, leading to deep unsaturated zones (up to 100 m deep at the interfluves). In most of the unsaturated zone, for most of the time, the matric potential remains between -30 m and -0.5 m, meaning that the matrix is saturated by capillary action, and the fractures are de-watered. Therefore, the debate has often focussed on the importance of the fractures, as compared with the matrix, for the movement of water.

As part of a national research initiative into groundwater dominated catchments, an extensive field monitoring programme has been implemented in the Pang and Lambourn catchments (Berkshire, UK). This includes comprehensive soil moisture measurements (water content, θ, and matric potential, ψ), an extensive network of piezometers and observation wells measuring water table response, and the direct measurement of actual evaporation as well as standard meteorological variables, including rainfall. In this paper, data from West Ilsley were used (grid reference SU484836, elevation 173 mAOD, mean annual rainfall 752 mm, land use is grass crop and average depth to water table is 72 m). Photographs of the Chalk profile at this site are shown in Figure 1. The data collected in this study were used to attempt to fit parametric relationships describing the hydraulic properties of the fractures and the matrix over the entire profile of the Chalk, and to assess the performance of contemporary modelling techniques which have been proposed for the Chalk.

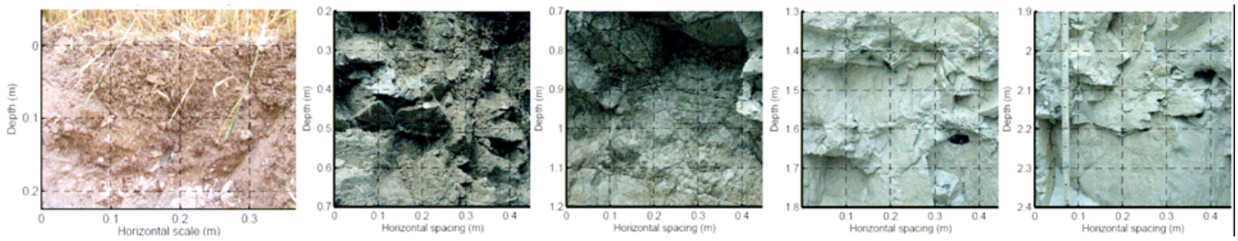

Figure 1. Chalk profile at West Ilsley

2. THE MODEL

A number of models have been developed to represent flow in fractured porous media (a group of materials which includes Chalk as a special case). Recently, Mathias et al. (2006) and Brouyère (2006) have (independently) proposed using an Equivalent Continuum Model, ECM, for the Chalk. This assumes that the fractures can be treated as a porous medium (i.e. flow described by Darcy's law) and that the discrete fracture and matrix domains can be treated as a single domain – an equivalent continuum. This requires that the fractures and matrix are in pressure equilibrium, and whilst the theoretical basis for this assumption is reasonable, it has not been demonstrated empirically. The model governing equation is Richards' equation, given by (Tocci, 1997):

$$\frac{\partial}{\partial z}\left(K(\psi)\left(\frac{\partial \psi}{\partial z}-1\right)\right)+S=\left(C(\psi)+S_s S_e(\psi)\right)\frac{\partial \psi}{\partial t}$$

A 1-dimensional Richards' equation model was coded in MATLAB, using finite differences for the spatial derivatives and integrating these in time with the ODE solve ODE15S. The upper boundary condition on the model was a flux, generated from the observed rainfall. Actual evaporation (based on observed data) was removed from the root zone with a standard root distribution function. Observations of water table level were also available, but for simplicity, a constant atmospheric head lower boundary condition was applied, located at the maximum water table depth (75 m below ground level).

3. PARAMETERISATION

Richards' equation models require that the relationships between matric potential, ψ, and water content, $\theta(\psi)$, specific capacity, $C(\psi)$, and hydraulic conductivity $K(\psi)$, be defined. Various parametric models have been proposed for these highly non-linear relationships, e.g van Genuchten (1982). In this study, the two parameter lognormal distribution model proposed by Kosugi (1996), is used, defined by the following three equations:

$$S_e=\frac{\theta-\theta_r}{\theta_s-\theta_r}; \qquad S_e=Q\left[\ln(\psi/\psi_0)/\sigma-\sigma\right]; \qquad Q(x)=\int_0^\infty \frac{1}{(2\pi)^{1/2}}\exp\left(-\frac{x^2}{2}\right)\mathrm{d}x$$

Correspondingly, $C(\psi)$ and $K(\psi)$ are given as a function of $\psi_m = \psi_{o.}\exp(\sigma^2)$:

$$K(\psi)=K_s S_e^{1/2}\left(Q\left[\ln(\psi/\psi_m)/\sigma+\sigma\right]\right)^2; \qquad C(\psi)=\frac{\theta_s-\theta_r}{-(2\pi)^{1/2}\sigma\psi}\exp\left(-\frac{[\ln(\psi/\psi_m)]^2}{2\sigma^2}\right)$$

The model parameters (the mode, ψ_0, and standard deviation, σ, of the lognormal distribution function) can be calculated from any two points on the $\theta(\psi)$ curve (i.e. $\theta_1(\psi_1)$ and $\theta_2(\psi_2)$). This allows us to define the model as a function of the 5 and 95 percentile pressures, ψ_1 and ψ_2, i.e. $\theta = f(\psi, \psi_1, \psi_2, \theta_r, \theta_s)$.

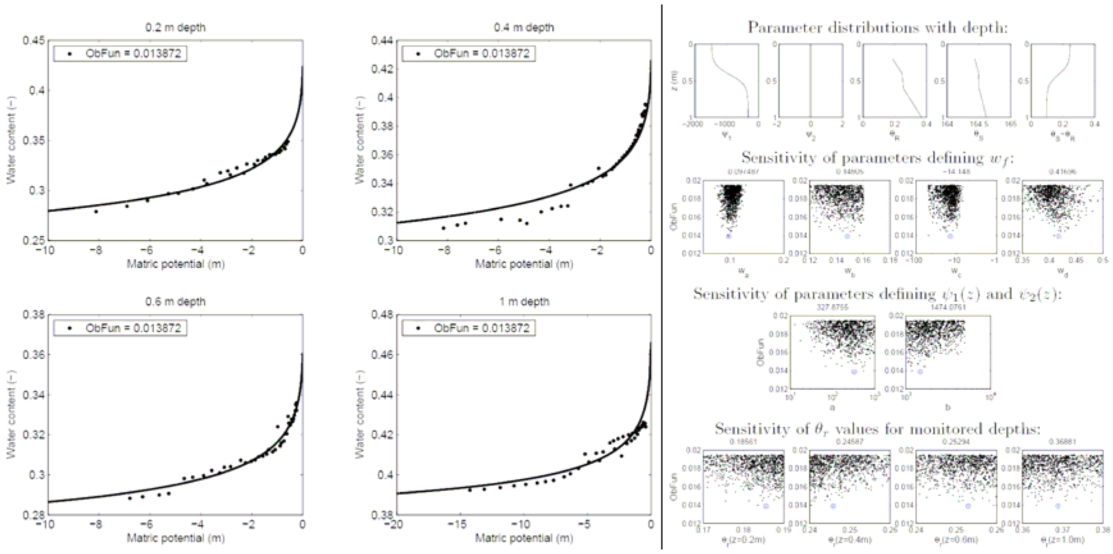

Figure 2. Soil moisture characteristic curves for the Fractures, showing imposed parameter distributions with depth and parameter sensitivity plots

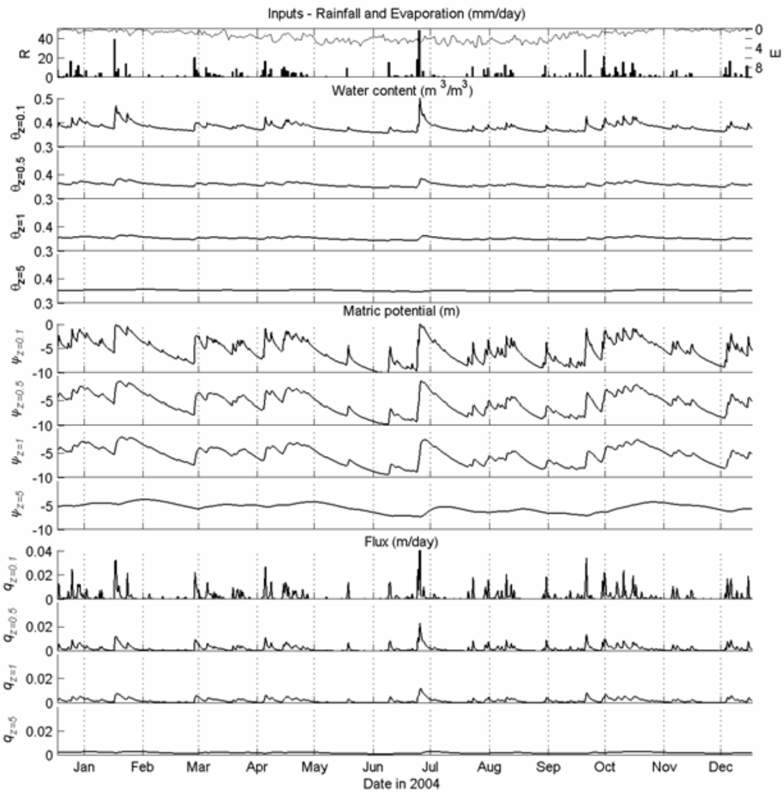

Figure 3. Model output for depths z = 0.1, 0.5, 1.0 and 5.0 m

An efficient representation of the vertical distribution of properties is desirable. It was assumed that the matrix properties would be constant, and the changes in bulk properties could be attributable to changes in the fractures. Matrix properties were obtained from the literature

(Mathias, 2006). For the fractures, it was hypothesised that by fixing ψ_1 and scaling ψ_2 as a function of z, we would be able account for the variation in hydraulic properties which occurs in the near surface ($z \leq 1$ m), as a result of increasing weathering of the Chalk and the soil layer (apparent in Figure 1.). As was pointed out by Cooper et al. (1990), and demonstrated numerically by Mathias et al. (2006), the attenuation of rainfall inputs in the near surface by a soil layer is a crucial control on the hydrological processes occurring in the Chalk profile.

For the fractures an S-shaped curve was used to scale both ψ_2 and w_f with depth (where $w_f = \theta_s - \theta_r$). This consisted of two shape parameters (the same for ψ_2 and w_f) and two limit parameters (different for each), i.e. a total of 6 parameters. ψ_1 was found to be relatively insensitive, so was fixed at a value of – 0.01 m. A Monte Carlo analysis using 1,000,000 realisations was performed to optimise the 10 parameter model (6 S-shaped curve parameters and 4 θ_r parameters – one for each depth), and the result is shown in Figure 2. The observed data are drying curves, a subset of the observed θ and ψ data at 0.2, 0.4, 0.6 and 1.0 m depth. The model is shown to fit these data well, and the dotty plots show that the parameters are all reasonably well identified. Additional parameters (saturated hydraulic conductivity and specific storage for the matrix and fractures $K_{s,m}$, $K_{s,f}$, S_{sm} and S_{sf}) were explored by a sensitivity study (not presented here). Reasonable results were obtained by setting K_{sm} = 0.001 m/day, K_{sf} = 0.4 m/day, S_{sm} = 1x10^{-6} m^{-1} and S_{sf} = 1x10^{-7} m^{-1}, all of which are consistent with values in the literature (Mathias, 2006).

4. RESULTS AND CONCLUSIONS

A simulation was run using the depth scaled parameterisation described above, for data from 2004. The initial condition was interpolated from observed pressures. Figure 3 shows time series plots of simulated θ, ψ and fluxes, q, at various depths in the near surface. This simulation demonstrates that the model is able to attenuate the larger input fluxes. Detailed comparison with observed data is ongoing. At this stage, the model does not reproduce observed time series of ψ and θ particularly well, and work is ongoing to improve the model parameterisation, to determine whether a good fit can be achieved, or there is in fact an inherent limitation with the ECM methodology when applied to the unsaturated Chalk.

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Results of the 15 Years Work of the "Lysimeter Research Group" Applications – Limitations – Conclusions of Lysimetry

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ABSTRACT

The Lysimeter Research Group is a platform for interdisciplinary exchange of information between researchers and users in the field of lysimetry on an international level. The focus of the research activities is on different kinds of land-use and their effects on aquatic systems. "Land-use" does not only implement agricultural activities, but lysimeters are also used to help to find solutions for environmental problems as remediation of excavation-sites and contaminated land, land set-asides or landfill cover systems. The research activities mentioned above point out that the fields of applications for lysimeters are wide, but it is important to keep in mind, that every lysimeter must be designed for its specific application, individually considering question and location. This individual design and the variety of lysimeter-types make it difficult to define common quality standards for lysimeters and their use. A regular validation and calibration of data gained from lysimeters is always necessary.

1. INTRODUCTION

The Lysimeter Research Group is a platform for interdisciplinary exchange of information between researchers and users in the field of lysimetry on an international level.

The group initiates, coordinates and contributes details to specific fields of this research topic. In addition to these research activities every two years lysimeter conferences are organized.

The results of the research activities of this group have been collected for the last 15 years and are now compiled and compared, available for everybody interested in lysimetry and its practical application.

The focus of the research activities is on different kinds of land-use and their effects on aquatic systems. There "land-use" does not only implement agricultural activities, but lysimeters are also used to help to find solutions for environmental problems as remediation of excavation-sites and contaminated land, land set-asides or landfill cover systems.

In this paper, some of the results focussed on lysimeter applications and limitations, together with recommendations shall be presented.

2. APPLICATIONS OF LYSIMETRY

As already mentioned, the fields of applications of lysimetry are wide. Refer to Figure 1, which shows the research topics covered by the research activities of the member of the "Lysimeter Research Group".

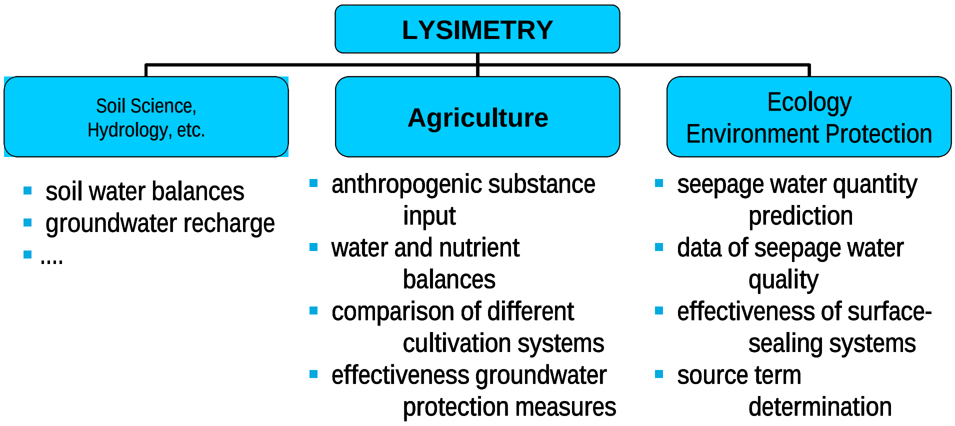

Figure 1. Applications of Lysimetry

In the following research activities and findings within two of these topics, shall be described more detailed.

2.1. Comparison of Different Cultivation Systems – Catch Crops

It has been fact for a long time, that the cultivation of catch crops can decrease the nitrogen discharge into the seepage water. Nigrogen, which was not used by the main crops before harvest is absorbed and conservated by the catch crops.

In his abstract Dressel (1992) even stated, that a catch crop without fertilizer can minimize the nitrogene discharge down to 50 %.

By comparison with other lysimeter experiments, this statement was tried to be validated.

For example Böhm/Dersch/Hösch (1999) presented the results of a study, where rape, winter rye and vetch was used as catch crops. Finally it was shown, that independent on applied fertilizer amount, culivation with rape as catch crop lead to the smalles amount of nitrogen leaching. Also the quantitative results of Dressel were confirmed.

2.2. Source Term Determination

The main focus of site investigations of brownfield areas is set on assessing the possible influence of the contamination on the groundwater, and so on assessing the risk potential of the investigated site.

In order to assess this risk potential a number of laboratoy methods are used, especially eluation methods. All these laboratory methods are supposed to be insufficient caused by the missing “orientation by nature” (Bode/Becker 2005).

With the help of different lysimeter projects, the source term of incineration ash of municipal waste was assessed – and these results were compared to the results of different laboratory methods.

Recapulating it can be said, that the laboratory results did not show any connection to the seepage water concentration. Especially the concentration in the beginning of the eluation process were underestimated by the laboratory methods.

3. LIMITATIONS

In most cases lysimeters are used for balancing the water-household and related to this, for mass transport.

At an “undisturbed, natural site” the water-household depends on groundwater level, precipitation, lateral inflow and evaporation potential.

If a lysimeter shall deliver results, it has to be constructed as representative part of the site to be examined; nevertheless the following parameters/effects are a common source for lysimeter failures (Klaghofer 1991):

- Size of Lysimeter Surface
- Border-Effects
- Oasis-Effects
- Surface-Phenomenons at the Lysimeter Base

At the lysimeter base the natural soil profile is interrupted, the so caused disturbances of the natural water movement and pressure situation can lead to differences between lysismeter data and natural conditions.

3.1. Examples for Limitation of Lysimeter Failures

Several Studies have been conducted to minimize these failures, two examples shall be presented:

In Großobrigen (Germany), a lysimeter station was designed considering lysimeter failures and their possible limitation (ref. to Tab. 1).

Table 1. Considerations about Lysimeter Design (Roth 1994)

Parameter	Requirement	Realization
Micro Climate	• no oasis effect	• lysimeters in large fields (distance to field border approx. 200m) • no bare soil between lysimeter and field
Lysimeter Size Depth	• typical „planting structure“ • representative number of plants • no limitation of rooting space	• 2 m² lysimeter surface • 2,5 m depth
Soil Water Balance	• No change of soil profile • Close compound between soil and lysimeter • No build-up of water	• Undisturbed soil (Monolith) • Suction Plate

In Wagna (Styria) as part of the Research Station a monolithic weighable field lysimeter, which can be machined together with the surrounding field, was constructed (Fank 2005) to limitate oasis effects.

Figure 2. Integration of a Lysimeter into surrounding Vegetation in Wagna (Photo: Lanthaler).

4. RECOMMENDATIONS AND CONCLUSIONS

Some recommendations for lysimeter application can already be found in the publications of the „Lysimeter Research Group“ (Leis 2001). Nevertheless, it is important to keep in mind, that every lysimeter must be designed for its specific application, individually considering question and location. This individual design and the (therefore necessary) variety of lysimeter-types make it difficult to define common quality standards for lysimeters and their use.

Further efforts for a standardisation of lysimeters will be presented in the Lysimeter Conference in April 2007 in Gumpenstein, Austria with the topic “Lysimeters in the scope of national and international regulations". More information about the “Lysimeter Research Group” and its activities can be found on www.lysimeter.at.

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Comparison of Different Soil Water Measuring Systems and their Application for Soil Water Balance Studies in Rutzendorf, Lower Austria

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ABSTRACT

At the bio-farm “Rutzendorf” in Marchfeld two distinct FDR systems (Easy AG® and Diviner 2000®) were used to measure soil water content from April to July 2006. Measurement results of both systems are compared. In April the soil water content was approximately 10 % higher than in July. In order to verify these values, undisturbed soil samples were taken at these times as reference. From the surface down to a depth of 30 cm the FDR-records showed a good coincidence, compared to the reference values, whereas they were generally higher in depths > 40 cm in April (under wet conditions). In July Easy AG readings were comparable to the reference values, but differed considerably in a depths of 50 cm. The amount of water in the soil profile determined from the Easy AG device is 25 % higher than from the Diviner 2000 readings. Dataset of soil water tension and soil water content was imported into the computer program RETC. The optimization yielded a hydraulic conductivity of k_o = 44,0 cm·d^{-1}. In the measuring period of three months no seepage water occurred.

1. INTRODUCTION

A long-term field monitoring project investigating the effects of organic farming on soil quality parameters is running at the bio-farm “Rutzendorf“. The changes from conventional to organic farming were documented by ten institutes of the University of Natural Resources and Applied Life Sciences, Vienna, since 2003 (Klik et al., 2005). Within this interdisciplinary project the aim of this study was to compare distinct systems used for measuring the volumetric water content and to assess the soil water movement/groundwater recharge on the experimental field in Rutzendorf.

2. MATERIALS AND METHODS

2.1. Site Description

Marchfeld is the main agricultural production region of Austria (latitude 48°12′N, longitude 16°34′E and altitude 150 m above sea level). Soils in the region are chernozems, sandy chernozems and fluvisols of 1.5 m to 2.0 m depth of the A-horizon. The limiting factor for agricultural production is the precipitation which reaches only 500 to 600 mm per year. The geohydrological situation in the Marchfeld is characterized by a steadily decreasing ground water level due to withdrawal of water for irrigation, local need for drinking water and for industrial purposes (Stauffer et al., 2001).

2.2. Experimental Setup

On the experimental field, the effects of three different variants of organic fertilizers (cover crops, compost and manure) on soil water content were investigated on each plot with two measurement sets. Two distinct Frequency Domain Reflectrometry (FDR) systems (Easy AGs in access tubes and Diviner 2000) were installed, to measure soil water content. Easy AGs measure automatically in depths of 10, 20, 30 and 50 cm quasi-continuously in 10-min interval. The diviner measurements were taken in 10 cm increments down to a depth of 100 cm once a week. This enables the comparison between point and continuous measurements. Undisturbed soil samples were taken in several horizons up to a depth of 100 cm.

3. METHODS

In order to establish the relationship between water content and water potential, experiments with pressure plate apparatus and Haines apparatus (Büchner funnel) were performed in the lab. Resulting data pairs were used for fitting the parameter values of the van-Genuchten equation:

$$\left|h(\theta)\right| = \frac{1}{\alpha}\cdot\left(\left(\frac{\theta-\theta_r}{\theta_s-\theta_r}\right)^{\frac{-1}{m}}-1\right)^{\frac{1}{n}}. \quad (1)$$

θ_r, θ_s ($\dim\theta = L^3L^{-3}$) are residual and saturated water contents, α ($\dim\alpha = L^{-1}$) and n ($\dim n = 1$) are curve shape parameters. m was set to $m = 1-1/n$.

The dataset of soil water tension and soil water content was imported into the computer program RETC (H. George E. Brown, Salinity Lab in Riverside, California). This is a special fitting software for parameters of retention and hydraulic conductivity functions of unsaturated soils. These relationships describe the hydraulic properties of soils, the basis of any model for water flow into and through the unsaturated zone (van Genuchten, Leij, Yates, 1991). Obtained results from the fitting process are shown in Table 1.

To study any soil water balance, it is necessary to measure the volumetric water content in the field. Water flux calculation is calculated on the basis of the classical extended Darcy's law:

$$q = -k_u\,(h)\cdot I. \quad (2)$$

q is the flux ($\dim q = LT^{-1}$) as a function of matric potential head h ($\dim h = L$), k_u is the unsaturated hydraulic conductivity ($\dim k_u = LT^{-1}$) and I is the slope of the total potential head of soil water ($\dim I = LL^{-1}$).

Deep drainage was analysed solely with uncalibrated data from the Easy AGs. The van-Genuchten equation was applied to calculate the matric potential from measured soil water content. Easy AG measurements were verified by comparison with the Diviner 2000 data and undisturbed soil samples which were taken next to the measurement devices.

Calculation of deep drainage requires knowledge of upper boundary condition and water content distribution in the soil profile. To close gaps in recorded Easy AG data, an interpolation and extrapolation over time was made. Determination of evapotranspiration was avoided by the assumption of zero flux at the soil surface during night periods without precipitation. Water content measured in the field at the lower boundary and at one horizon above combined with the function $h(\theta)$ gives the water tension $|h|$ in two depths. Implying the assumption above deep drainage flux at the lower boundary D ($\dim D = LT^{-1}$) can be calculated by

$$D = \Delta W/\Delta t\,. \quad (3)$$

ΔW is the change in profile water content during a time step (Δt). Applying Darcy's law (eq. 2), k_u is given by

$$k_u = -D/I. \quad (4)$$

In our case the retention function $h\,(\theta)$ was determined from the already existing lab data. Dataset of water tension and unsaturated conductivity was imported into RETC. The results of θ_r, θ_s, α

and n from the fitting process to the lab experiments were inserted as fixed parameters. To overcome numerical difficulties, the pore space conductivity parameter λ was set to 0.5. The only remaining parameter which was fitted by RETC in the model of Mualem (1976) (eq. 5) was k_o:

$$k_u(Se) = k_o \cdot Se^{\lambda} \left[1 - \left(1 - Se^{\frac{n}{n-1}} \right)^{1-1/n} \right]^2 \qquad (5)$$

4. RESULTS

4.1. Soil Water

Investigated period was from April to July 2006.The amount of precipitation was 212.2 mm for this time. Water content distribution in the soil profile at the beginning (April) and the end (July) as recorded by the FDR-system is shown in Fig. 1. Generally the soil water content was approximately 10 % higher in April than in July.

In order to verify these values, undisturbed soil samples were taken at these times as reference. From the surface down to a depth of 30 cm the FDR-records showed a good coincidence, compared to the reference values, whereas they were generally higher in depths > 40 cm in April (under wet conditions).

In July Easy AG readings were comparable to the reference values, but differed considerable in a depths of 50 cm (see Fig.1).

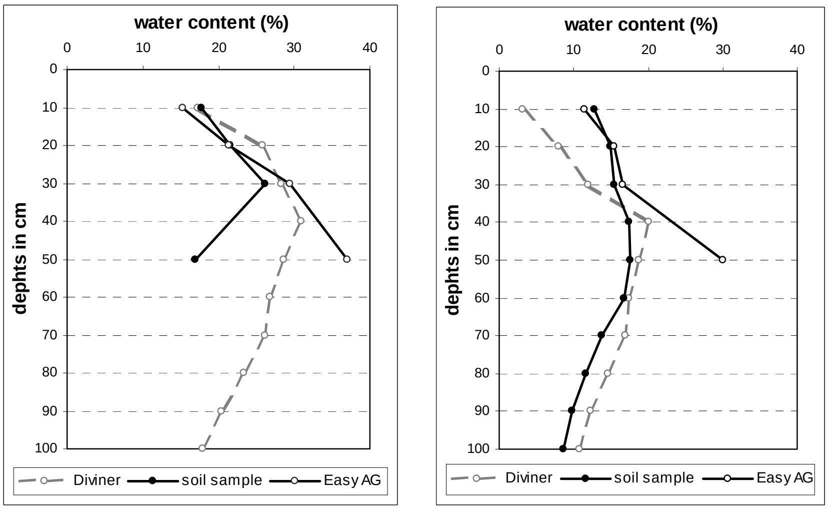

Figure 1. Comparison of volumetric water content measured with Diviner 2000 and Easy AG and reference values from soil samples – April (left) and July (right)

The amount of water in the soil profile determined from the Easy AG device 25 % higher than from the Diviner 2000 readings (see Fig. 2). From April to June, where a high precipitation is recorded, the matric potential is low, in July, where a dry period was documented, the matric potential was higher. In the upper soil layers (10 cm to 30 cm) the dynamics of soil water is more pronounced than in 50 cm.

4.2. Soil Water Movement

Lab measurements of the saturated hydraulic conductivity of monthly taken soil samples in two depths (10 cm to 15 cm and 30 cm to 35 cm) during growing season 2005 resulted in values between 0.85 $m \cdot d^{-1}$ and 21.41 $m \cdot d^{-1}$ (0 cm to-15 cm) and 0.77 $m \cdot d^{-1}$ and 18.10 $m \cdot d^{-1}$ (30 cm to 35 cm) with average K_{sat} values of 7.73 $m \cdot d^{-1}$ and 4.95 $m \cdot d^{-1}$ respectively (Lenz, 2005). These data show an acceptable agreement with RETC fitted k_o (see Table 1).

The matric potentials in 30 cm to 50 cm were used to calculate the hydraulic gradient I in 50 cm. I together with k_u yield the flux q. As expected there could not be proved any groundwater recharge in the three month research period in Rutzendorf.

Table 1. Fitted soil parameter values

determined lab data				field data	
θ_r	θ_s	α	n	λ	k_o
5.1 %	44.7 %	0.260 cm^{-1}	1.109	0.5	44.0 $cm \cdot d^{-1}$

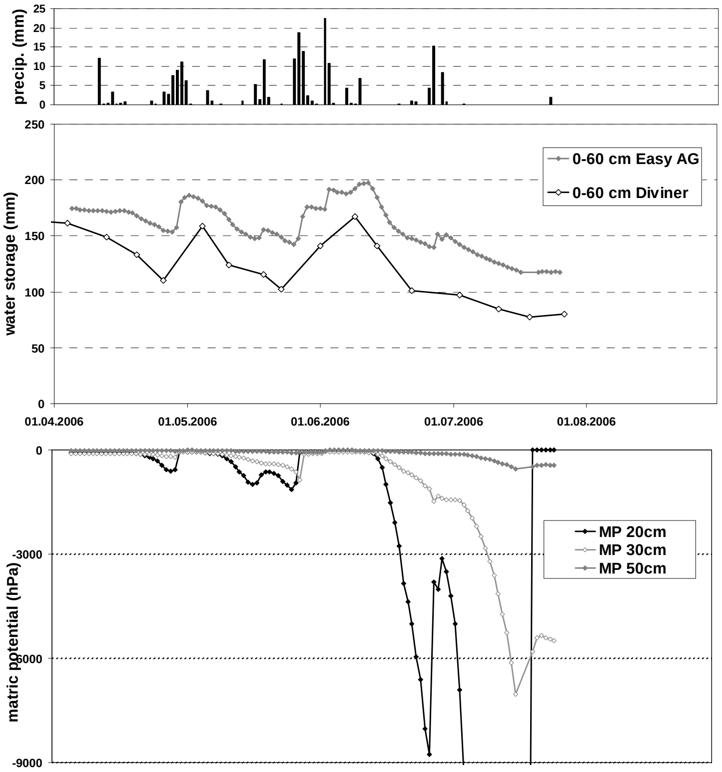

Figure 2. Comparison of stored soil water measured with FDR sensors (0-60 cm) and related matric potential

ACKNOWLEDGEMENT: This study was funded by the Austrian Ministry of Agriculture, Forestry, Environment and Water Management within the interdisciplinary project MUBIL.

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SECTION C

RURAL WATER MANAGEMENT

Local Actions within Rural Water Management – Building Blocks in a Framework for Integrated River Basin Management

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ABSTRACT

Local actions are activities focused on solving problems related to the management of water resources, the benefits of which are tangible at the local level. This includes structural or non-structural actions that have an impact on the local administration of water. The main aim of a local action is to seek options for the sustainable development of a region, without compromising the preservation of the local ecosystem (Def. acc. to 4th World Water Forum, Mexico 2006).

The task at river basin scale is as well to assess the impacts of the sum of measures on the water resources (bottom up) as to determine the optimum programmes of measures for local actions to mitigate the effect of global challenges (top down). Selected examples of own works are presented.

1. INTRODUCTION

Since centuries, rural water management was focussed almost exclusively towards site improvements for agricultural purposes – amelioration – for arable farming and grassland farming. Wetlands, mainly fen sites, were drained and flood plains were poldered. Water levels of lakes were lowered to gain new grasslands and hillside meadows were irrigated. All the water assumed excessive was drained out off the landscape as fast as possible. Other objectives of rural water management concerned fish farming, damming up of creeks and rivers for the operation of water mills, and finally, river training and canalisation for rafting and navigation.

For long time, economical success confirmed such actions and gave reason for further intensifying. The natural bearing capacity of the agrarian landscapes seemed to compensate the interventions. Such principles, orientated towards increase of yields and production, let little space only for nature protection, wetlands, or ecology of waters. Swamps and wetlands had a negative image. Only the extremely evident defects of depleted landscapes, vanishing biodiversity, eroded slopes, degraded fens, and eutrophicated waters, together with agricultural excess production and increased public awareness for the environment, led within the recent decades to the acceptance of necessary corrections of landscape water management.

Which ways towards a sustainable co-existence of agriculture, nature protection, and water management are thinkable? Which ways are practicable? Which targets and principles shall serve for our orientation?

Answers to these questions cannot be given by sectoral measures any longer. The environmental objectives of the EU Water Framework Directive, the challenges of climate change, the increasing economic withdrawal of water and soil resources require concepts for integrated management at river basin scale. Local actions are to be fitted into the network of regional interdependencies and programmes of measures to mitigate negative impacts of economically utilised cultural landscapes.

2. BASIC PRINCIPLES

Integrated river basin management aims towards a sustainable favourable balance of withdrawal and availability of water as well as towards a good ecological quality of waters in the context of a whole river basin. Water management – according to the definition of the German Standard DIN 4049 – is the target orientated order of all influences on surface and ground water.

Corresponding to the motto of the 4th World Water Forum Mexico 2006 "Local Actions for a Global Challenge" the main challenges for rural areas are characterised as follows:

1 Water Scarcity / Dryness / Drought
  - crop yield losses
  - damages of natural vegetation and biodiversity
  - drying up of waters and wetlands
  - lack of drinking water
  - degradation of sites

2 Water Excess / Storm / Flood
  - soil erosion, degradation of sites
  - flooding of utilised areas
  - logging of potential arable and grassland sites

3 Pollution of Waters by Non Point Source Emissions from Agricultural Sites:
  - damaging of aquatic biotopes and ecosystems
  - endangering drinking water resources

From these challenges, we deduce relevant research questions of local, regional and river basin relation:

Research questions with regard to land use:

- How does global change (climate, land use) affect water availability and waters quality?
- How can land use systems be adapted to a regionally differentiated water availability and to the matter emission related sensitivity of sites?
- How far will the existence of wetlands and waters be endangered and what is the water requirement for their conservation or revitalisation?
- What would be potential consequences of drying up / degradation of wetland and waters for regional site qualities?

Research questions with regard to water management at local and regional scale:

- How can seasonal variations of water availability during periods of water scarcity (summer) be compensated by storage of excessive water (winter)?
- How can conflicts among competing users (drinking water supply, industry, agriculture, ecology) be solved within the societal context?
- How can treated waste water be utilised for the stabilisation of water availability in the surrounding of metropolitan areas?
- At what extend can landscape water retention mitigate matter emissions and / or formation of floods?
- Which land use strategies allow for a sustainable flood risk management in inundation zones and poldered flood plains?

Research questions with regard to processes:

- How do biochemical processes beneath the root zone and in the aquifer affect matter retention and mitigation of emissions?
- What is the behaviour of matter related interactions at the edges of waters and what are the resulting conclusions for the design of buffer strips along waters?
- How do self purification mechanisms function in small water bodies of the agricultural

landscape and how can they be influenced target-orientated?
- What are the characteristic features of ecosystematic interactions between aquatic biotopes and adjacent terrestrial edge zones?
- Which bioindicators enable an appraisal of the quality of water bodies?
- Which models represent a region-specific hydrological behaviour at sufficient accuracy for considered issues?

Hierarchically graded, these research questions are further detailed to concentrate primarily on those research subjects which are important impact factors for the system behaviour and / or which are relevant to the implementation of mitigation or control measures.

At such aspects e. g. issues of basic ecological research are relativised. For an assessment of water availability and water consumption, knowledge of processes and models for regional evapotranspiration at the condition of climate change will, without doubt, play an eminent role. One may ask if the concentration of scientific potential towards phenomena of soil physics and soil hydrology will be of similar priority. In view of developing models for system behaviour as a basis for decision-finding, consideration should be given again and again to the question "Model of what?" and "Model for what?".

A strategy concept for the development of measures and measure programmes within the context of management plans for river basins is to be focussed on following questions:

- What are the problems and conflicts that destabilised the former evidently intact interrelations of landscape hydrology, agrarian land use, biological manifoldness and nature preservation value? Had these interrelations been out of order eventually for a longer period of time already, but without having caused crucial distortions?
- How was landscape water balance functioning formerly and how is it today? And finally, how can maldevelopments – especially those which are recognisable only from today's values – be mitigated and, at the end, be sustainably turned around by holistic land use concepts and water management measures?

This will result in the necessity to identify options for local actions. Local actions (acc. to 4th World Water Forum, Mexico 2006) are activities focused on solving problems related to the management of water resources. This includes structural or non-structural actions that have an impact on the local administration of water. The main aim of a local action is to seek options for the sustainable development of a region, without compromising the preservation of the local ecosystem. The scale of a local action depends on the scale of the problem at hand. It is important that the action involves the active participation of different sectors of society with various stakeholders at different social, cultural and political levels.

3. SELECTED EXAMPLES OF LOCAL ACTIONS

3.1. Mitigation of Diffuse Entries

Land use change at sensible areas: Matter immissions into waters are a mixture of emissions from different sites at different times of the past with transit duration ranging from hours and days up to years and decades. The modelling of true emission processes cannot be achieved. Reasonable and practicable is the determination of site specific emission pathways and transit durations and the allocation of matter degradation rates determined from process analyses, leading to the identification of sites where land use changes are most effective to mitigate loads to waters. We preferably apply this procedure and recommend it for Pleistocene landscapes (Quast et al., 2006).

Matter retention from agricultural drainage waters by constructed wetlands: Subsurface pipe drainage is indispensable for many potentially fertile backwater sites (e. g. in Germany more than 2 million hectares). Nutrient loads of drainage water can be reduced significantly by ponds with aquatic vegetation.

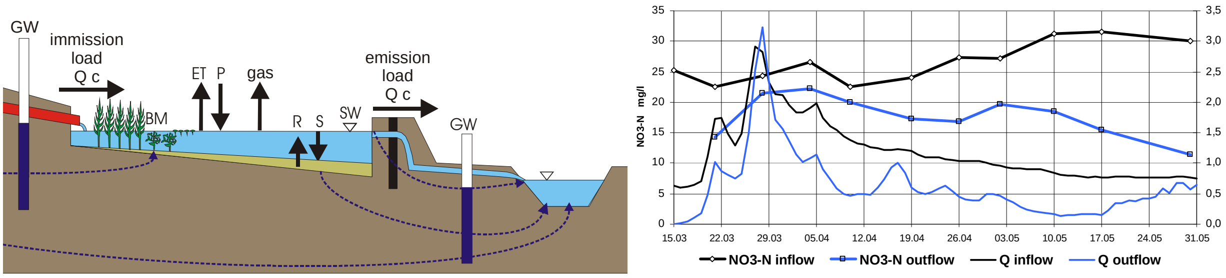

Figure 1. Scheme of typical processes in purification pond for drainage waters (left) and in- and outflowing NO_3-Nitrate concentration and water discharge Q during spring period (right) (Steidl et al., 2006)

Matter retention by buffer strips along waters: Erosion models enable an assessment of soil and matter emissions from agricultural sites, but neither of immission into waters nor of the retention potential of buffer strips. Their design is, thus, based on pilot studies and process investigations performed at typical sites.

3.2. Improvement of Landscape Water Balance by Retention Measures

The improvement of landscape water balance is mainly done by reactivating old backwater systems and ponds (at the assurance of ecological connectivity of waters by fish ladders) as well as by revitalising sink and biotope functions of rewetted fen areas. Precondition is the proof of water availability by catchment models and the preparation of region specific strategies on water storage for periods of water scarcity. In the surrounding of metropolitan areas, the use of treated wastewater will become relevant for irrigation especially with regard to energy crop production.

3.3. Integrated Polder Management

There were and still are many controversial discussions on eligibility and benefit of polders along rivers in the context of critical situations at levees and damages from levee breaks during flood events of the last decade: Hydraulically safe levee constructions (as implemented during reconstruction of levees in Germany at rivers Oder and Elbe after the floods of 1997 and 2002) are very expensive (1-2 million € per km) and a residual risk remains for the case of overtopping by extreme floods. Economic income from agricultural utilisation of polders covers today only a small portion of the expenses for flood protection and polder drainage. Thus, the levee systems require always state financing. Polders have reduced drastically the ecologic potential of the former natural flood plains, and there is a growing public interest in the change from existing polders towards renaturised former flood plain biotopes. On the other hand, the fertile polder areas might become important sites for a future energy crop production. In settled polders socio cultural values might be crucial for the conservation of polders.

Based on a weighting of all of the different interests, local polder management strategies are to be fitted into concepts for sustainable flood risk management at river basin scale. For the 900 km² wide Oderbruch-Polder with its socio-cultural tradition of 250 years at the lower Oder, the strategy concept “Konzept Oderbruch 2010” was developed and is being implemented since some years: Reduction of drainage at sites near levee and in depressions (cost savings and still optimum ground water levels for 80 to 85 % of the arable lands), mitigation of non-point-source emissions of pollutants by confined ground water level below the alluvial top layer, reduction of ecological deficits by revitalisation of wetlands and old river branches (establishing river continuum for fish migration), measures for the preservation of cultural heritage, measures and activities to promote tourism (and, thus, supporting livelihoods for the people), harmonised utilisation of upstream and downstream polders (suitable for temporary inundation during extreme floods as flood risk mitigation measure).

4. CONCLUSIONS

Worldwide, rural water management is gaining again more and more importance. Sustainable water management is to be based on actions at local level for the benefit of the concerned stakeholders. The local actions, well harmonised among each other, are the building blocks which contribute to the manifold tasks and targets of rural water management at global challenge. Rural water management, as one part of an integrated river basin management, has to look at local actions in two directions: While the bottom up view is necessary to assess the impacts of the sum of measures on the water resources, the top down approach enables the determination and design of optimum programmes of measures for local actions to mitigate the effects of global challenges. This bi-directional view clearly shows the importance of a thorough selection of local actions and their role in rural water management as well as in a river basin wide focus on a regional Integrated Land and Water Resources Management. The wide spectrum of different types of local actions is most strikingly represented by the term “Landeskulturelle Wasserwirtschaft” as it is used by the Universität für Bodenkultur Wien.

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Impacts of Alternative Management Measures in Vegetable Production Systems on Nitrate Leaching in the Eferdinger Becken, Austria

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ABSTRACT

The Eferdinger Becken is a major vegetable production region in Austria, where steadily increasing nitrate concentrations in groundwater have been observed over the last decades. A sanitation program has been launched with management measures that meet integrated crop production guidelines, reduce N-fertilization rates by 30 %, and integrate cover crops. We analyse the impacts of these management measures on nitrate leaching, percolation, and crop yields and apply a computer model to simulate soil processes of these sites. Monthly data from lysimeters in Wörth and Seebach between 1998 and 2001 are used to statistically test the performance of the bio-physical process model EPIC (Environmental Policy Integrated Climate). EPIC is calibrated to base-run data from Wörth and then the calibrated model is applied to the site in Seebach. The performance testing indicates that EPIC can be used to analyse short and long-run environmental impacts of management measures in agricultural land uses.

1. INTRODUCTION

Intensive production systems with major shares of vegetables in the crop rotations often lead to high nitrate emissions. In the Southern Eferdinger basin the vegetable growing sector is of economic importance and produces a variety of field vegetables for the fresh market as well as for the processing industry. Because nitrate concentrations in the groundwater are exceeding the threshold of 45 mg NO_3 per litre at different monitoring sites, management measures to reduce nitrate leaching need to be implemented (Liebhard et al., 2003). A widely applied method to evaluate different management measures is to collect seepage water in field lysimeters and analyse nitrate concentrations. However, especially for evaluation of long-term effects computer models are increasingly used to predict environmental impacts of alternative agricultural systems on soil and water resources. Model calibration to specific sites is necessary to test its performance and reliability of simulation outputs. In this study lysimeter measurements are compared with simulation results from the bio-physical process model EPIC (Environmental Policy Integrated Climate) as a basis for long-term simulations.

2. MATERIAL AND METHODS

2.1. Sampling Sites

Two representative farms in the villages Seebach and Wörth were chosen for the installation of seven field lysimeters (three in Seebach and four in Wörth). Data from April 1998 to December 2001 are used for calibrating EPIC and for testing its performance. The sites are characterised by long-time annual precipitation of 795 mm, soil texture of loamy sand till sandy loam (Seebach), and loamy sand (Wörth) and high soil water storage capacity. Figure 1 shows precipitation and temperature from the observed time period. Data were obtained from the meteorological station in Aschach/D, which is close to the sampling sites. In Seebach, one field was cultivated with green salad, whereas on two other fields crop rotations included green rye, phacelia and high mallow as cover crops. Fertilization was carried out following the N_{min} target values system (KNS). Nitrogen fertilization rates were reduced by 30% from the KNS-targets in two alternative fields in Wörth (variation 2 and 4) (Liebhard et al., 2003). Information on crop rotations and fertilization of the sites in Wörth are summarized in table 1.

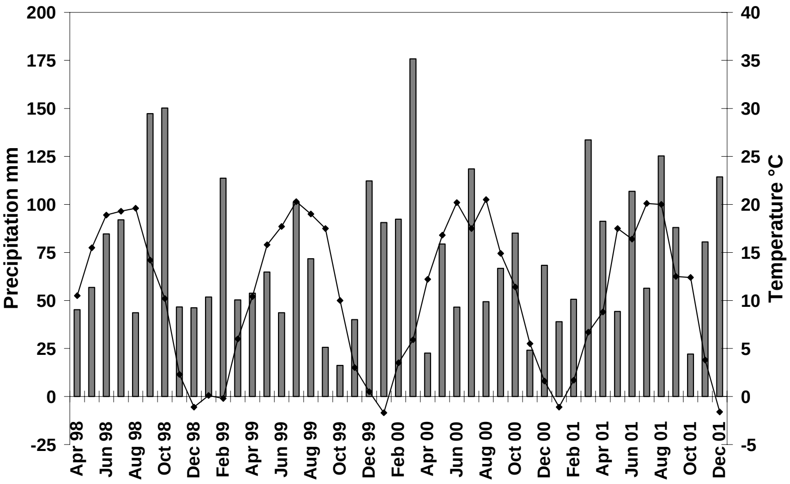


Figure 1. Precipitation (bars) and temperature (line) over the period of measurements.

Table 1. Crop rotations and nitrogen fertilization rates (N in kg ha-1 in brackets) for the four alternatives at the site in Wörth (with changes from Liebhard et al., 2003).

Year		Variation 1	Variation 2	Variation 3	Variation 4
1998	1st crop	Potatoes (140)	Potatoes (100)	Potatoes (100)	Potatoes (140)
	2nd crop	Chinese cabbage (91)	Chinese cabbage (82)	Chinese cabbage (82)	Chinese cabbage (91)
	Cover crop	-	-	Green rye / Winter vetch	Green rye / Winter vetch
1999	1st crop	Celery (154)	Celery (38)	Celery (57)	Celery (112)
	Cover crop	-	-	Green rye	Green rye
2000	1st crop	Cauliflower (255)	Cauliflower (148)	Cauliflower (194)	Cauliflower (241)
	Cover crop	Phacelia	Phacelia	Green rye / Phacelia	Green rye / Phacelia
2001	1st crop	Green salad (91)	Green salad (84)	Green salad (90)	Green salad (96)
	2nd crop	Green salad (97)	Green salad (60)	Green salad (49)	Green salad (98)
	3rd crop	Green salad (98)	Green salad (51)	Green salad (49)	Green salad (87)
	Cover crop	Winter wheat	Winter wheat	Winter wheat	Winter wheat

2.2. The Model

The bio-physical process model EPIC (Environmental Policy Integrated Climate) allows simulation of many processes important in agricultural land management. It was developed by a USDA modelling team in the early 80s to asses the status of U.S. soil and water resources (Williams et al., 1984). Since then it has been continuously expanded and refined (Williams 1995; Izaurralde et al., 2006). The major components in EPIC include weather simulation, hydrology, erosion-sedimentation, nutrient and carbon cycling, pesticide fate, plant growth and competition, soil temperature and moisture, tillage and plant environment control. EPIC operates on a daily time step and is capable of simulating hundreds of years if necessary. The model offers options for simulating several processes with different algorithm - five potential evapotranspiration equations, six erosion/sediment yield equations, two peak runoff rate equations, etc., which allow reasonable model applications in very distinct natural areas. In this study, EPIC is calibrated to base-run data from variation 1 in Wörth and then the calibrated model is applied to the different management alternatives and to the sites in Seebach.

3. RESULTS AND DISCUSSION

The management measures, which aiming at reducing nitrate leaching into groundwater, could decrease nitrogen emissions between 10 kg ha^{-1} y^{-1} and 80 kg ha^{-1} y^{-1}. The fertilization rates based on the KNS-system did not reduce quantity and quality of vegetables yields. However, the reduction in fertilization rates by 30 % (variation 2 and 4, Wörth) has resulted in yield losses for some vegetables. Intercropping shows positive effects on soil conditions. (Dietrich et al., 2002).

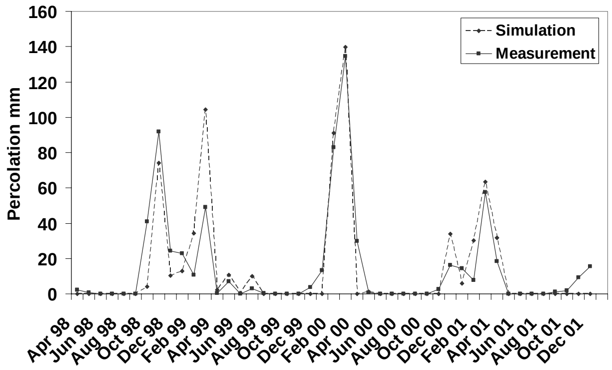
EPIC simulations and measurements of crop yields in Wörth are listed in table 2. In general, good agreements between simulation and measured data were reached in all variations. The biggest differences occurred for potatoes and Chinese cabbage yields of which both vegetables yields were underestimated by the model. However, potatoes yields were extraordinary high in the observed year (35 t ha^{-1}). Chinese cabbage can also achieve high yields depending on the variety. Therefore, adaptations of the crop parameters in the model may be needed to better capture different vegetable varieties.

Table 2. Simulated and measured fresh weight crop yields for the four variations in Wörth in kg·ha^{-1}·y^{-1}.

	Variation 1		Variation 2		Variation 3		Variation 4	
	Simulation	Measurem.	Simulation	Measurem.	Simulation	Measurem.	Simulation	Measurem.
Potatoes	14.8	35.4	14.3	32.3	14.3	32.3	14.8	35.4
Cabbage	36.5	124.6	36.5	83.7	36.5	69.4	36.5	96.7
Celery	40.2	43.3	40.2	42.6	40.2	43.5	40.2	43.4
Cauliflower	30.3	31.8	30.7	28.8	30.0	30.2	32.4	34.4
Green salad	19.1	21.4	19.1	18.6	19.1	14.7	19.1	18.8
Green salad	44.7	42.2	44.7	44.3	44.7	51.5	44.7	50.0
Green salad	23.8	26.3	23.8	24.1	24.9	25.9	23.8	24.1

The simulations demonstrate that mean values and variability of percolation water and nitrogen leaching can be reasonably reproduced by the model (figure 2). Peaks in nitrogen leaching in December 1998 could not be reproduced by the model, whereas higher values were obtained by the model in the following spring (peak in April 1999). In general, percolation water shows better correlation between simulated and measured values than nitrogen leaching, which is evident by the coefficient of determination (R^2) and index of agreement (d)[3] calculated following Liu et al. (2006) and presented in Table 3. The index of agreement ranges between 0 and 1, and a value of 1 implies perfect agreement. The best agreement shows variation 1 at the site in Wörth, which was used for model calibration. Model results from Wörth perform better agreements than results from Seebach. Especially nitrogen leaching from Seebach shows poor performance due to underestimation of the model (data not shown), which will be further investigated.

[3] $d = 1 - \frac{\sum_{i=1}^{n}(S_i - O_i)^2}{\sum_{i=1}^{n}\left[|S_i - \overline{O}| + |O_i - \overline{O}|\right]^2}$ S: simulated values,O: observed values



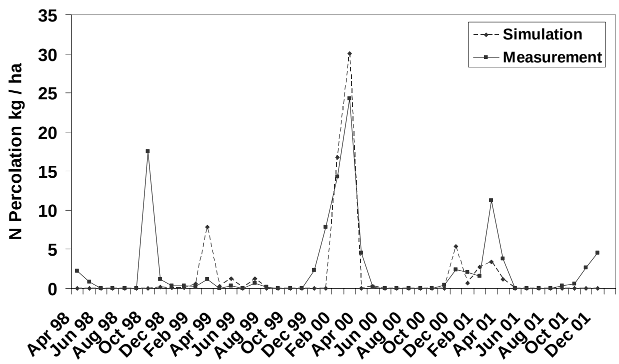


Figure 2. Simulation and measurements of water percolation (in mm) and N leaching (in kg ha-1) in Wörth (variation 1) at 1.2 m soil depth.

Table 3. Coefficient of determination (R2) and index of agreement (d) between simulated and measured percolation water and nitrogen leaching.

	Wörth								Seebach					
	Variation 1		Variation 2		Variation 3		Variation 4		Variation 1		Variation 2		Variation 3	
	R2	d	R2	d	R2	d	R2	d	R2	d	R2	d	R2	d
percolation	0.81	0.95	0.25	0.70	0.40	0.79	0.18	0.66	0.20	0.51	0.29	0.25	0.63	0.60
N leaching	0.57	0.86	0.05	0.49	0.05	0.48	0.05	0.45	0.24	0.50	0.03	0.33	0.47	0.72

This study shows that EPIC can be used to analyze environmental impacts of management practices. In future, long-term effects of these management measures will be analyzed. However, for a detailed analysis of the sites in Seebach further model calibration is necessary and more information on crop varieties may improve the model performance.

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Tendencies in Field Irrigation as Shown in the Example of the Region Marchfeld in Austria

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ABSTRACT

The Marchfeld is an important region in Austria for agriculture. Due to the dryness of the region irrigation has been established in the last decades. The irrigation and sufficient water supply is the basis for plant production and the income for the farmers.. The practice of the farmers has developed various techniques of irrigation. Today farmers are interested to optimize the application of water to lower their operation costs. To secure water supply in the Marchfeld, the Marchfeldkanal project was realized in the last two decades to bring additional water from the river Danube to the region.

1. RELEVANCE OF IRRIGATION IN AUSTRIA

In general Austria is very rich in water, the annual average for precipitation amounts to 1200 mm. But there are considerable regional differences. Especially in the Eastern provinces the rainfall goes down to 500 – 600 mm and below.

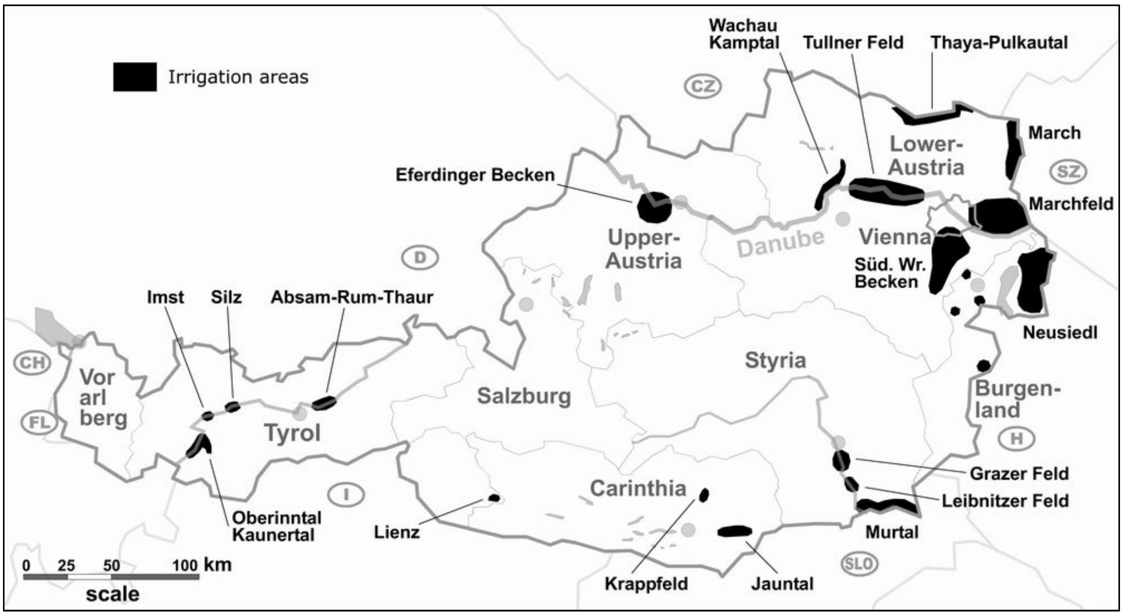

Figure 1. Irrigation areas in Austria.

It is in these areas where the existence of sufficient water supplies plays a decisive role for plant growth. The total amount of irrigated land in Austria is 150.000 ha. In Austria different methods of irrigation have been developed: more than 90 % of the irrigation land, basically arable land but also as frost-protection irrigation in fruit growing areas, is provided by sprinkler use. Drop irrigation is applied in viniculture in lower Austria and the Burgenland. Traditional gravity irrigation is used only on a small scale in Lower Austria and the Tyrol.

The aims of irrigation are the **safeguarding of yield stability** , **high-quality production**, and - in recent years very important – the **fulfillment of production contracts**.

2. MARCHFELD - THE MOST IMPORTANT IRRIGATION PROVINCE

The Marchfeld in the east of Austria is one of the most important agricultural provinces of the country. It is favoured by topography, soil fertility, ideal temperatures and agricultural structure and has developed into Austria´s main corn- and field vegetable growing area of about 60.000 ha farming land. The farms in the Marchfeld are of a large size in relation to the Austrian structure but small and medium-sized compared with the EU-situation.

On average the precipitation in the Marchfeld amounts to 520 mm annually and to 320 mm in the period of vegetation (from April to September).

The Marchfeld has an aquifer with an estimated amount of groundwater of 1,4 billion cubic meter. Due to the shortage of rainfall the farmers began to intensify plant production by irrigation with groundwater after the Second World War.

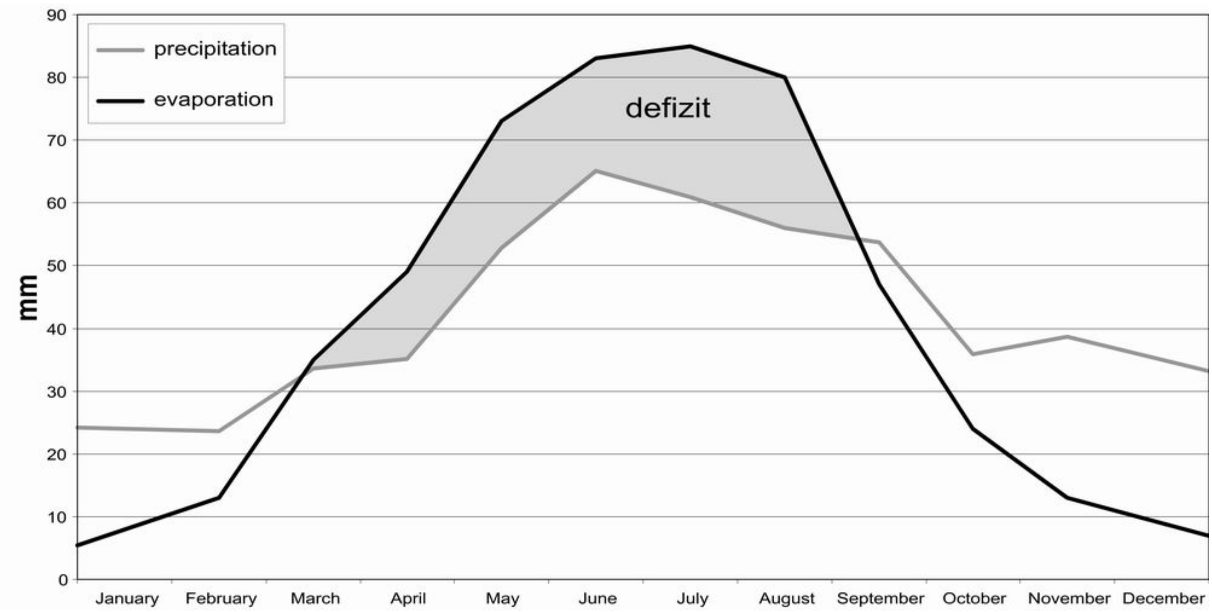

Figure 2. Climatic water balance – Precipitation and evaporation in the Marchfeld.

Today most of the farming land in the Marchfeld is equipped for irrigation.

3. PLANT PRODUCTION AND MARKETING

Plant production in the Marchfeld is mainly based on grain growing. But there is a significant trend towards vegetable growing.

High-quality vegetables are in particular the basis for durable goods and frozen food. Field vegetable farming has a high productive capacity and has been intensified in the last decade The most important field vegetables in the Marchfeld are onions, carrots, green peas, spinach and asparagus. Most of these have a low water tolerance and need - as well as the potato-growing area and the beet-growing area - sufficient water supply.

Table 1. Structure of plant growing and irrigated crops.

Crop	1986 Total arable area %	1986 Share of irrigated area[1)] %	2004 Total arable area %	2004 Share of irrigated area [2)] %	2004 Production Value Mio. €
Grain	69	20	50	1	14
Sugar beets	8	100	10	100	18
Corn	8	80	5	60	3
Field Vegetable	6	100	11	100	21
Potatoes	4	100	7	100	12
Others	5	-	17	-	-
Total	100	-	100	-	-

1) estimated for the period of some years

In the last two decades remarkable trends in farming and irrigation have taken place: grain irrigation has significantly decreased, on the other side irrigation of field vegetable has increased. Today especially field vegetables are very important for the income of the farmers.

4. IRRIGATION SYSTEMS AND MANAGEMENT

In the Marchfeld 20-35 % of the land is irrigated annually due to crop rotation. The **sprinkler system** is best suited to the soil and the crops. The most used system is the hand-moved sprinkler system or the permanent sprinkler system with small drops, which prevent delicate crops from damage. The use of the **traveling gun systems** has increased in the last decade. This system has higher initial costs but a low labor requirement. It should only be used on crops which tolerate large drops and a higher application rate.

The irrigation in the Marchfeld is mainly established on small-scale irrigation plants where nearly every plot has its own well and pump to take out groundwater. But companies for irrigation have also been established: there are companies for the electrification of pumps or companies to build large-size irrigation systems with one central pump station and the water pipelines. The operating costs of these systems can be reduced dramatically compared to small-scale singular irrigation plants.

The additional water applicated on fields by irrigation amounts from 50 to 150 mm depending on agricultural crops and weather situation. There are costs for operation from 0,1 to 0,2 € per m3 irrigation water. In recent time farmers are very interested to lower their costs by exact application of irrigation water. So they measure the soil moisture to control the water requirements. Optimizing irrigation water means less drought stress for plant growing and at the same time minimizing groundwater pollution by nitrates.

5. WATER BALANCE AND WATER MANAGEMENT

The withdrawals of groundwater especially for the demand of irrigation in the Marchfeld has led to a declining of the groundwater level of more than 3 meters since the 1960s. As a result the availability of groundwater for irrigation, households and industrial purposes could no longer be secured in some parts of the Marchfeld.

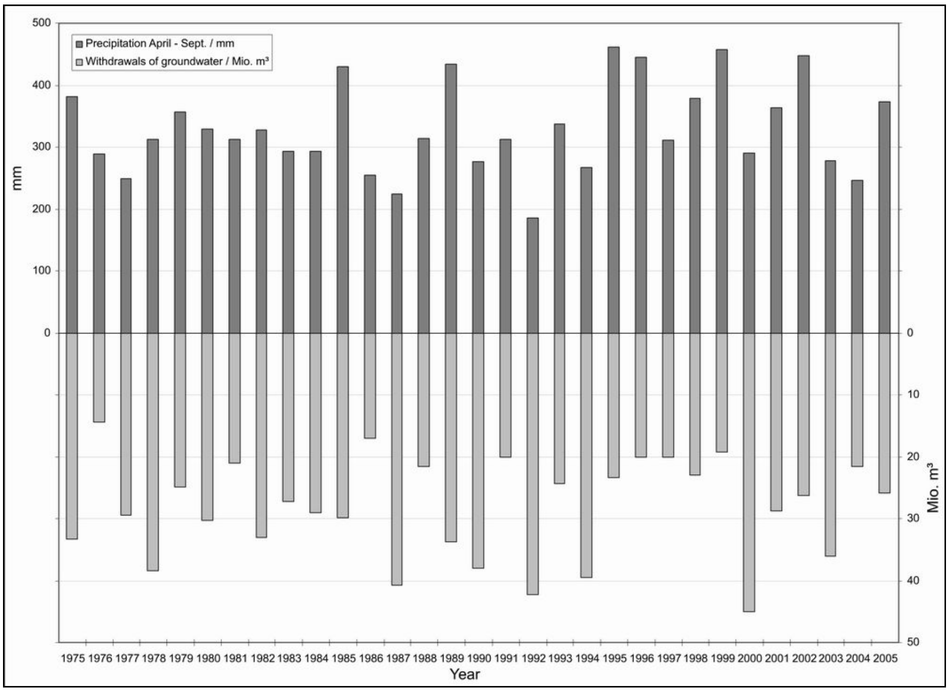

Figure 3. Groundwater use for irrigation and precipitation

In 1984 the Austrian government decided to start a project with the aim to supply the Marchfeld with external water from the river Danube. The **Marchfeldkanal-project** was realised in the year 2003 and is designed as multi-purpose project. Nowadays water supply in the Marchfeld is secured by artificial recharge of groundwater and partially by using surface water instead of groundwater.

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Impact of Variable Clover/Grass Fraction in Managed Pastures on Productivity and Soil Organic Carbon Under Climate Change

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ABSTRACT

We report on a physiologically based model of grass/clover coexistence to assess the potential for carbon (C) sequestration in managed temperate grasslands under climate change. The model was calibrated with biomass data for grass and clover grown in monoculture and mixtures obtained from the Swiss Free Air CO_2 enrichment (FACE) experiment. The climate change simulations included an equilibrium run for 2070 and a transient experiment for 2000-2100. We assumed a IPCC-A2 evolution of greenhouse gas concentrations, and shifts in regional climatic conditions as indicated by a recent survey of regional climate simulations. Our model experiments with varying climatic conditions suggest only little change in the organic C storage of grass monocultures. On the other hand, C-sequestration substantially increases in mixed swards. We conclude that maintaining a minimum fraction of clover through management in temperate grasslands is crucial for stimulating C-sequestration.

1. INTRODUCTION

Global climate scenarios predict increasing atmospheric CO_2-concentrations (CO_2), temperature (T) and frequency of summer droughts during the coming decades. This has major consequences for the productivity and carbon (C) storage (C-sequestration) of agricultural grasslands and may hamper the mitigation of anthropogenic greenhouse gas emissions through C-sequestration. Accumulation of soil organic C (SOC) is the result of a transfer of organic C from the plant litter into light and further into more stable SOC fractions. An increase in grassland productivity has a positive impact on SOC because of the enhanced litter production. However, below a certain threshold, increasing T accelerates SOC turnover, negatively affecting the SOC store. In general model experiments suggest that elevated CO_2 enriches the organic matter in plants increasing SOC (Thornley et al., 2000).

In managed grasslands, grasses are often associated with legumes, if coexistence is possible. Coexistence of grass and legumes in mixtures is strongly controlled by soil mineral nitrogen (N): At low levels of soil mineral N, and provided that sufficient light is available, the relative growth rate of clover is higher as the mineral N uptake is supplemented with symbiotically fixed N. This symbiotically fixed N is transferred to the companion grass, maintaing grassland productivity during periods of N-limitation in mixed swards (Boller and Nösberger, 1987). At high levels of soil mineral N, however, the relative growth rate of grass is higher. As grass becomes taller it intercepts more light, limiting the growth of clover. In summary, differences in the N-environment determine if and how species coexist (see Schwinning et al., 1996).

Field experiments demonstrated that the symbiotic N_2-fixation is often necessary to meet higher N-requirements of the sward at elevated CO_2 (Zanetti et al., 1996). By enhancing litter production, legumes may substantially contribute to C-sequestration in grasslands (Fisher et al., 1994). Hence, the appropriate management of the sward composition appears to be a major option for maintaining or even increasing C-sequestration in pastures under climate change (CC).

Grassland models are often applied to quantify the potential for C-sequestration in managed grasslands. However, most of them, including the Pasture Simulation Model PASIM (Riedo et al., 1998), treat the fraction of legumes (namely clover) in the sward as a fixed parameter. To test the effects of grass/clover coexistence on sward dynamics and C-sequestration und changing climatic conditions, we adapted the model of Schwinning et al. (1996) by including a simplified version of grass (Lolium perenne L.) dynamics as used in PASIM and a more realistic description of clover (Lolium perenne L.) growth. Interaction of species is enabled via N-uptake and light competition.

2. METHODS

As stated above, the overall structure of our model follows the one proposed by Thornley et al. (1995) and Schwinning et al. (1996). As in Schwinning et al (1996), species-specific N-uptake functions are used. For clover, uptake of mineral N from the soil is supplemented with the flux of N from biologic fixation. The N lost due to decomposition of dead biomass from both species feeds into the organic N soil pool. Losses from the organic N soil pool as mineralization are directed into the soil mineral N pool. The latter is also fed by mineral fertilizer, atmospheric deposition and depleted by N-uptake from both species.

To consider the effects of climate change on grass/clover coexistence and C-sequestration, we extended the model in the following points: (i) grass and clover growth are determined by the assimilation of C via photosynthesis, with the latter specified as in the Hurley Pasture Model (Thornley, 1998), respiration and turnover; (ii) C assimilation is modulated by temperature and CO_2; (iii) the growth of clover is limited through light shadowing by the companion grass depending on the leaf area index (LAI) profile of grass; (iv) all processes can be affected by water stress, when the actual soil water content falls below a given threshold. Soil water content is computed dynamically by solving the water budget equation of a single soil layer.

The model is run with an hourly time step. It was calibrated with biomass and LAI data spanning a 5-years period from the Swiss Free Air CO_2 enrichment (FACE) (see Hebeisen et al. (1997)). Specifically we refer to data for grass and clover grown in monocultures and mixtures under low N treatment, different cutting frequencies and two levels of CO_2 concentrations (370 and 600 ppm). A second experimental dataset was obtained from the experiment carried out at Oensingen (450 m a.s.l, Northern Switzerland) from 2000-2005 and was used to validate the model.

Climate change experiments were carried out with respect to the Oensingen site. We considered the following three settings: (i) “Climate 2000”, a scenario given by the observed 2001-2005 climatology; (ii) “Climate 2070”, a climatology valid for the year 2070 obtained by modifying the 2001-2005 data with seasonally varying T-shifts of +2.6°C, +2.5°C, +3.8°C and +3.0°C for winter, spring, summer and autumn and seasonally varying multiplicative factors for precipitation (1.11, 0.99, 0.77 and 0.91 for winter, spring, summer and autumn, respectively) (Frei, 2004). CO_2 was set to 610 ppm as in the IPCC-A2 scenario; (iii) “Transient 2100”, a climate record spanning the period 2001-2100, starting as in the "Climate 2000" scenario and linearly varying conditions until 2100, with changes consistent with the "Climate 2070" scenario. The CO_2 path of this latter experiment was specified as in the IPCC-A2 scenario. Scenarios (i) and (ii) were used to generate equilibrium conditions for the corresponding time slices. Initial conditions for the transient experiment (iii) were specified as the equilibrium conditions in the "Climate 2000" experiment.

3. RESULTS AND DISCUSSION

The calibration runs (results not shown) indicate that important aspects of clover and grass grown in monoculture and mixtures can be reasonably reproduced with our model. Model runs with the different climate scenarios indicate that:

1) C-sequestration benefits from the presence of clover in the sward as SOC increases in grass/clover mixtures relative to grass grown in monoculture for all scenarios (Fig. 1). This is due to additional N uptake by the clover via biologic fixation that is subsequently supplied to the grass via litter cycling in the soil. In the grass/clover mixture, the mineral N uptake by the grass is larger by 50% than in the monoculture.

2) C-sequestration and grass yield in mixtures increase in average for the scenario "Climate 2070" (Fig. 1 and 2). In the scenario, grass growth and thus N- and C-cycling (mineralization, symbiotic N fixation, N litter production) are stimulated by enhanced rates of C-assimilation (elevated CO_2 and higher temperatures). N- and C-cycling also profit from the lengthening of the vegetation period, in particular with favourable conditions during spring (Fig. 2). The increased yield in spring might even compensate for the yield loss in the drier and hotter summer months.

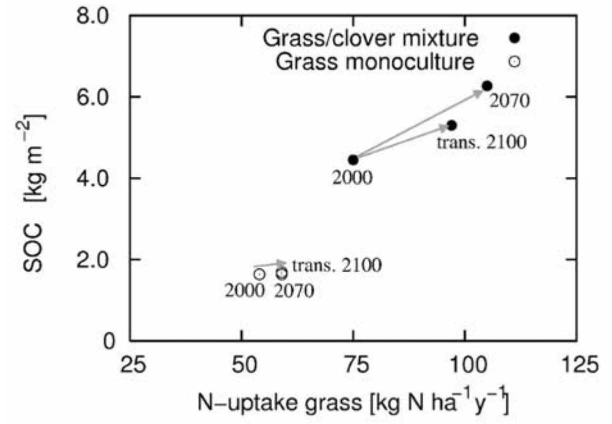

Figure 1. Dependence of the soil organic carbon to variable mean annual N-uptake rates for grass grown in monoculture (open circles) and in mixture (dots) and three types of climate scenarios.

3) Under transient climate, C-sequestration in 2100 is smaller than the corresponding equilibrium solution obtained in the "Climate 2070" experiment because the time needed to reach a new equilibrium exceeds the 100 years of integration. Nevertheless, elevated CO_2 levels (910ppm by 2100) ensures enhanced C-assimilation despite increasing soil water deficits during the summer months. This, however, is only possible if the sustained N-demand is supported by the N-supply. This is partly the case for mixtures as clover is also stimulated by higher CO_2 levels resulting in a higher N fixation. As seen in Fig. 1, the C-cycling is clearly N-limited in grass monocultures.

Our experiments suggest that the co-existence of grass and clover and the maintainance of a minimum fraction of legumes are essential for fostering C-sequestration in temperate grasslands.

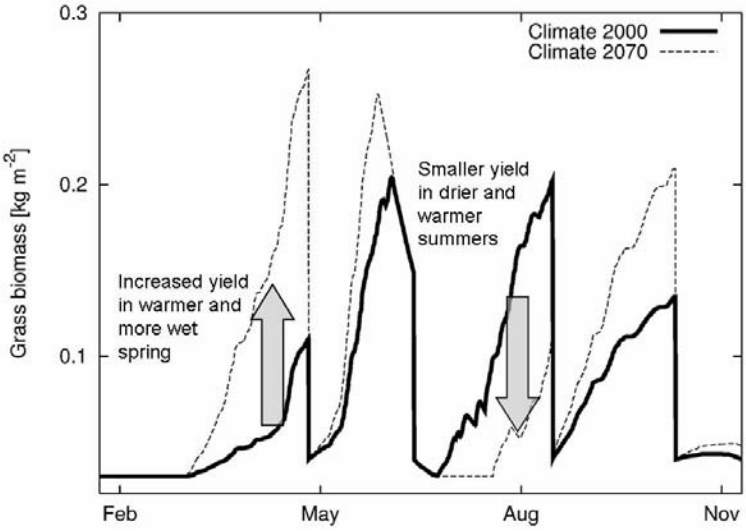

Figure 2. Example of simulated grass dynamics in an extensively managed grass/clover sward for the current climatic conditions (bold line) and the 2070 scenario (dashed line). Results for the experimental site of Oensingen.

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Irrigation- and Fertilization-Management of Wine in the Seewinkel

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ABSTRACT

Increased demand of quality, economic development and change of climatic conditions advance the application of irrigation management in the Seewinkel. Primarily in wine-production the main objective is to guarantee sustainable quality over many years. The interests in irrigation technologies established in other countries (e.g. Australia, Spain) are increasing. A project on subsurface drip irrigation and fertigation combined with monitoring-systems was started in 2003 in the Seewinkel. The aim was to get practical experience on how these irrigation technologies work under climatic and soil conditions in the Seewinkel. Following two development years the system works well and delivers continuous data for managing irrigation and fertilization. The data output requires precise interpretation and recommendations.

1. INTRODUCTION

In former days winegrowers in the Seewinkel did not irrigate their vineyards due to economical reasons. However, economic development and increased demand of quality, including the change of climatic conditions led to the implementation of irrigation systems. In the last decades the usual sprinkler irrigation systems were gradually replaced by drip irrigation technology. Due to the various advantages of drip irrigation for the individual winegrower and for the environment (e.g. reduction of evaporative loss, lower risk of disease pressure, uniform water supply, drier soil surface for easier cultivation, yield assurance and improved quality), the installation of drip irrigation was supported by the government of Burgenland. The association “BERTA” was entrusted with the implementation of various projects on drip irrigation.

With drip irrigation technology, however, it is very difficult to ensure a continuous water supply by very small amounts of water, because the water needs time to infiltrate into the ground and reach the lower soil layers where it can be taken up by the roots. Therefore, a further development of drip irrigation was established in some countries: subsurface drip irrigation - where the laterals are buried in the ground. This method results in higher water use efficiency, as the water is discharged directly in the root-zone. To increase a higher availability of nutrients during the growth period, subsurface drip irrigation is combined with fertilization (=”fertigation”).

In 2003 a few winegrower in Seewinkel in cooperation with “BERTA” initiated a project, in order to examine the practical use of subsurface drip irrigation. T-Systems Europe S. A. S. and the University of Natural Resources and Applied Life Sciences also support this project.

2. OBJECTIVES

The objectives of the project are minimization of the losses of water by implementing subsurface drip irrigation, continuous multi-depth moisture monitoring system, unique nutrition monitoring techniques, sustainable conservation of natural resources (water, energy, etc.) at the same time and increase of quality and development of wines through new environmental production technology.

3. MATERIALS AND METHODS

The Seewinkel lies in the easternmost part of Austria. The flat landscape near Lake Neusiedl represents the lowest part of Austria (115-125 m above sea level). The average amount of rainfall per year is less than 600 mm with an average temperature of about 9.5°C. In 2004 the precipitation was 515 mm and the temperature 10.3°C. 2005 was a wet year with 671 mm rainfall and an average temperature of 11.4°C. Due to these climatic conditions, irrigation is essential to guarantee crop yield and quality.

The use of subsurface drip irrigation is a widespread technology in wine production. The lateral placement of the tubes and the irrigation installation dates represent a challenge for the plant planning due to the different soil and climate conditions.

Figure 1. Subsurface Drip Irrigation: Flexible tubes are buried in the ground.

The company T-Systems International developed unique nutrient crop monitoring tools. The methods "Petiole SAP" and "QuickSoil" analyses are in use since the early 80's by the company Crop Tech Research in Australia (CropTech Australia, Pty, Ltd).

Petiole SAP analysis - observes the dynamic nutrient change by periodic sampling related to defined plant growth stages with consideration of the soil nutrient solution and soil moisture. Sampling begins when canes are 30 cm long. Strategic sampling times should be early flowering, early fruit set, fruit fill, pre-harvest, and post-harvest. The first fully expanded leaf - usually the fourth or fifth leaf back from the growing point of the runner – should be taken. The part to be tested is the petiole, or leaf stalk, so the whole leaf is needed. This system is a real time monitoring system whose standards and databases are in possession of the company T- System international. The analysis contains all essential macro and micro elements.

QuickSoil analysis - this simulates the available elements in the soil solution. EC, pH, nitrate and the important cations are measured within defined plant growth stages and analyzed together with Petiole SAP. Samples are taken in a depth of approx. 30 cm within a representative range of the active root zone.

Figure 2. Sampling for QuickSoil and SAP analyses

For managing irrigation a new sensor technology is used. The Capacitance-sensors placed in different depths (10, 20, 30, 50 and 90 cm) proved to be the best and most efficient method for soil moisture measurements. This technology makes it possible to study the effective depth of the root activity, respectively the water uptake in the root-zone. The soil water content data are recorded continuously and transmitted to a logger, where they are stored and available for on-line access. Sophisticated software packages (CropSense by T-Systems International, Inc.) help to use this information for irrigation management.

Figure 3. Soil Moisture Measurement: Sensors and logger station.

4. RESULTS

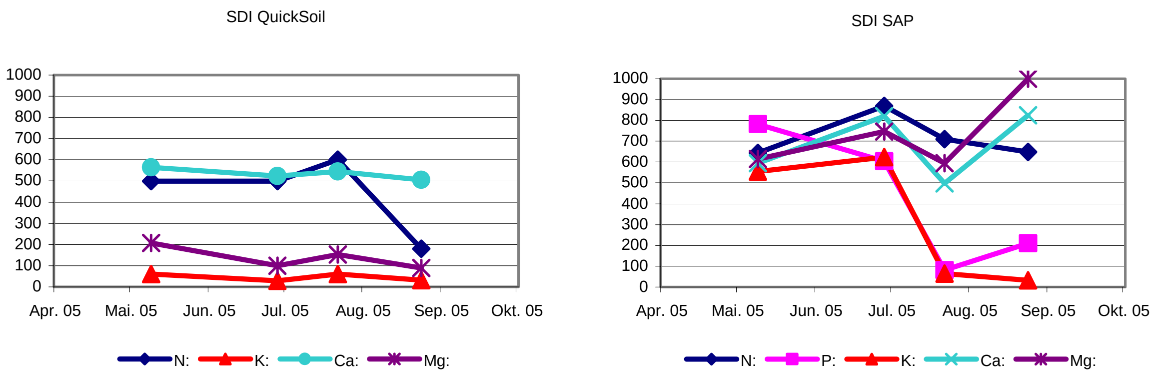

Figure 4. QuickSoil and SAP Results (Optimum between 500 and 700).

Figure 4 contains examples of some essential macro elements. Four samples, depending on the stages of the crops, were taken during the vegetation period in 2005. The left graph shows the indexed results of the QuickSoil analysis; the right figure represents the SAP analysis. In the soil (left) Potassium and Magnesium are lacking during the whole vegetation period. This deficit has an effect on the nutrient supply of the plant: In the leaves (SAP) the index-value of Potassium is far beneath the optimum (right). The future aim is to guarantee an optimal nutrient supply until harvest.

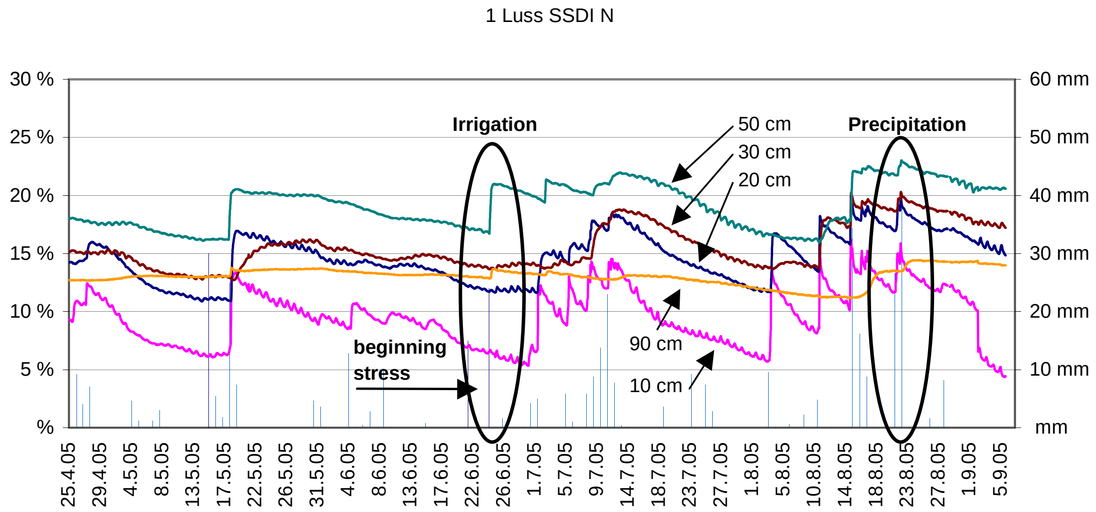

Figure 5. Soil moisture content in different depths of the subsurface drip irrigation system.

Figure 5 shows relative values of the soil moisture in depths of 10, 20, 30, 50 and 90 cm. The bars represent rainfall and irrigation events. In 2005 only a few irrigation events were necessary to avoid dry stress. Irrigation should start when the curves flatten (left cycle). The subsurface drip tubes are installed in a depth of approx. 30 cm. The left cycle marks irrigation; the sensor in 50 cm depth reacts immediately whereas the sensors in 10, 20 and 30 cm do not show any increase in soil water content. In this case it has to be discussed if the capillarity of the soil or other reasons such as lateral depth versus soil type are the causes. During rainfall events the sensor in 10 cm depth is the first one to react, which shows increased values. The oscillations of the curves mainly result from the daily thermal fluctuations.

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SECTION D

RURAL WATER MANAGEMENT
IN DEVELOPING COUNTRIES

Conjunctive Use Planning of Surface Water and Groundwater: A Case Study in the Hirakud Canal Command, Orissa (India)

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ABSTRACT

The canal command of the Hirakud multi-purpose major irrigation project of Orissa, India, is under severe threat of waterlogging in the monsoon season and acute shortage of irrigation water in the non-monsoon season. The water budget of the canal command shows that the available canal water supply during the monsoon season can meet the irrigation requirement only at 10% probability of exceedance whereas during the non-monsoon season, the canal water availability is only 50% of the irrigation water requirement at the same level of exceedance probability. Watertable fluctuation study reveals that during the monsoon season, more than 90% of the canal command remains waterlogged and during the non-monsoon season, the watertable in more than 40% of the area remains within 2-4 m below the ground surface. Hence there is a lot of scope for groundwater development, which can supplement the available surface water resources of the command. Long-run predictive simulation of groundwater table for different cropping sequences in the canal command shows that in order to avoid any undesirable effect, rice should be grown in the whole cultivable command area during the monsoon season followed by rice in the head reach and wheat in the tail reach of the canal command during the non-monsoon season. The entire command area should be left fallow during summer. Area under rice during monsoon and non-monsoon seasons should be reduced by 6% and 16%, respectively, for optimal crop and water resources management of the command.

1. INTRODUCTION

Pre-independence India suffered repeated famines and drought and the country was far from food self-sufficiency because most of the agriculture was mainly rainfed subjected to the vagaries of the monsoon. But the green revolution in the ’60s raised its agricultural production from a mere 50 million tons in 1950-51 to more than 210 million tons at present. Among other factors, the boost in agricultural production is mainly due to creation of irrigation facilities through the major and medium irrigation projects. In the canal command of the Hirakud irrigation project, Orissa (India), which is characterized by sub-humid climate, water is released from the reservoir to the farmer’s field by a large network of unlined canals (Figure 1). Continuous seepage from the canals as well as percolation losses from field irrigation has resulted in groundwater table buildup, which ultimately created the problems of waterlogging during the monsoon season (June to October).

The area receives around 1200 mm of annual rainfall, out of which more than 75% is received during the monsoon season. There are two principal cropping seasons in the area i.e., monsoon season and non-monsoon season (November to March). Rice is the main crop in both the seasons. It is cultivated in almost 97% and 47% of the culturable command area during the monsoon and non-monsoon season, respectively. The irrigation intensity varies between 162 to 175% (100% during monsoon). Other than rice, wheat, sugarcane, pulses, millets, oil seeds, vegetables, and condiments are cultivated in the command area.

2. IRRIGATION WATER SUPPLY AND DEMAND

2.1. Gross Irrigation Requirement

Seasonal gross irrigation requirements (GIR) of crops for the monsoon and non-monsoon seasons at different probability of exceedances were estimated by the method as used by Tyagi (1980) and are shown in Figure 2. For the estimation of reference crop evapotranspiration, Hargreaves formula (Hargreaves and Samani, 1985, Allen et al., 1998) was used. USDA-SCS method (Dastane, 1974) was used for the estimation of effective rainfall. Figure 2 shows that monsoon oilseeds, pulses and millets require a minimum of 70 mm of irrigation at 10% probability of exceedance whereas the monsoon rice requires 338.3 mm of irrigation at the same level of probability. The GIR of the monsoon rice reaches 978.3 mm at 90 % probability of exceedance. During the non-monsoon season, the GIR of crops is very high. It varies from a minimum of 301.5 mm for millets to 1695.9 mm for rice at 10% probability of exceedance. The GIR of the non- monsoon rice reaches 2007.1 mm at 90% probability of exceedance. Sugarcane being an annual crop, its GIR varies from 1424.5 mm to 2400.1 mm at 10% and 90% probability of exceedance, respectively (Figure 2). Based on the above results, for 10% and 90% probability of exceedances, the GIR has been estimated as 734.5 and 2110.3 million m^3 for the monsoon and as 1894.6 and 2335.6 million m^3 for the non-monsoon season, respectively.

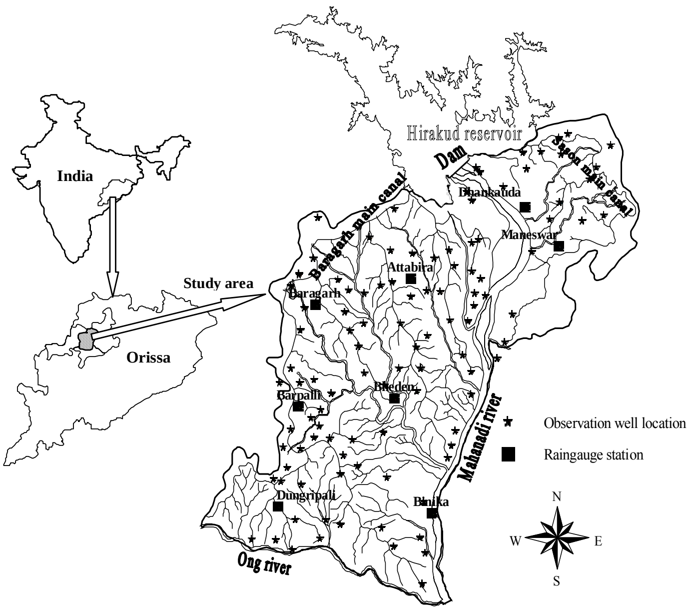

Figure 1. Location map of the study area.

2.2. Irrigation Water Availability

Canal water is the main source of irrigation applied in the command area. From the daily canal discharge data at the head regulator for the years from 1988-89 to 2002-03, the average monsoon and non-monsoon seasons canal water availability has been worked out to be 1172.73 and 1370.0 million m^3, respectively. Considering the canal conveyance efficiency as 70% (Doorenbos and Pruitt, 1977), the availability of canal water at the field head is found to be 820.9 and 959.0 million m^3 for the monsoon and non-monsoon seasons, respectively.

2.3. Deficit

From irrigation water requirement and water availability, it is found that at the present level of cropping, canal water availability during the monsoon season is sufficient to meet the irrigation requirement at 10% probability of exceedance. During the non-monsoon season, irrigation water requirement exceeds the canal water availability by more than 935 million m^3 even at 10% probability of exceedance. Considering the irrigation water requirement at 50% probability of exceedance, the deficits are in the order of 456.3 and 1288.7 million m^3 during the monsoon and non-monsoon seasons, respectively. The mean annual deficit amounts to 1745 million m^3 that is mainly due to rice cultivation in the monsoon and non-monsoon seasons and to a lesser extent due to sugarcane crop.

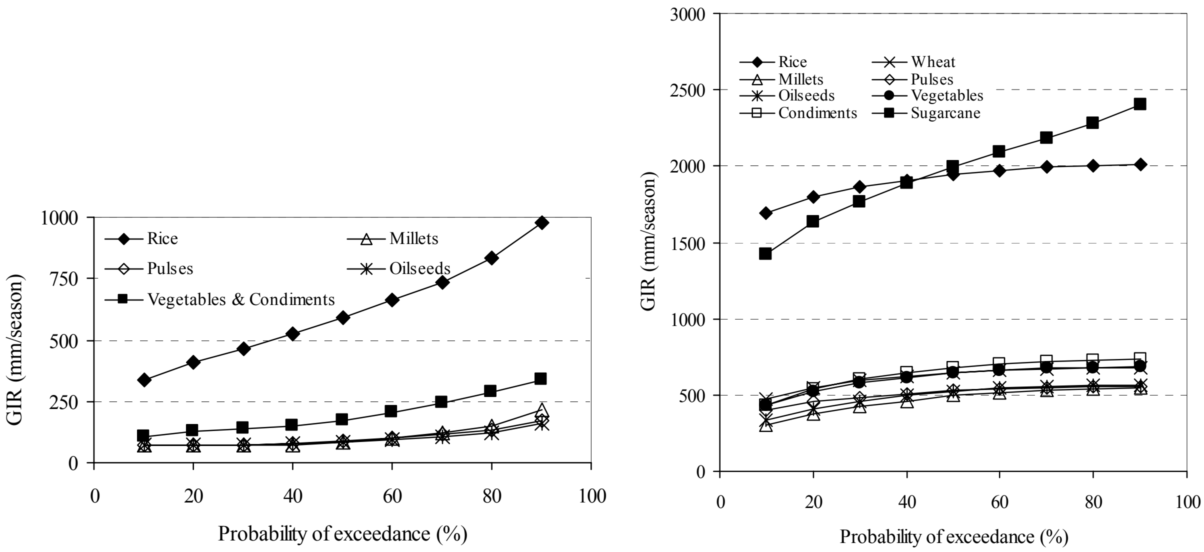

Figure 2. Gross irrigation requirement (GIR) of monsoon (left) and non-monsoon (right) crops (including sugarcane) at different probability of exceedances

2.4. Demand Management

There may be two possibilities of managing water demand, viz, the development of available groundwater resources up to its maximum permissible limit or the reduction of areas under rice and replacing the rice area by low water requiring crops like wheat, pulses, millets, oilseeds, vegetables, and condiments. At 50% probability of exceedance, a rough estimate shows that 5 ha of other monsoon crops can replace 1 ha of monsoon rice and similarly, 3.3 ha of other non-monsoon crops can very well replace 1 ha of non-monsoon rice. Optimal crop and water resources management study was therefore done for maximizing the net annual benefit from the command area. Groundwater simulation study was undertaken to calculate the hydraulic head and groundwater storage changes in the aquifer system due to transient groundwater recharge and discharge processes.

2.4.1 Groundwater Utilization

Watertable fluctuation study was done by the use of SURFER package (Golden software, 2002) and it shows that during the monsoon season, the watertable remains within 2 m below the ground surface in more than 90% of the command area whereas during the peak monsoon months of August and September, it covers the entire area. Just after monsoon, the watertable starts depleting, but during the entire non-monsoon period it remains within 6 m below the ground surface in almost all areas. Hence it is required that the groundwater withdrawal during the non-monsoon period should be increased so that the groundwater reservoir will have sufficient capacity to accommodate the monsoon recharge. Again during the non-monsoon period there is no danger of waterlogging but still there is a lot of scope for groundwater development as in more than 40 % of the area, the watertable remains within 2-4 m below the ground surface.

3. GROUNDWATER FLOW SIMULATION AND CROP SCENARIO ANALYSIS

In order to calculate the hydraulic head and groundwater storage changes in the aquifer system due to transient groundwater recharge and pumping stresses, the groundwater flow simulation model, Visual MODFLOW 3.1 (Waterloo Hydrogeologic Inc., 2003) was used. The model was calibrated for monthly watertable data of 41 observation wells for the year 1993-94, distributed uniformly over the entire area. To predict the system response to future events, predictive simulations were done with the parameters optimized during calibration. The model result shows that there is a lot of scope for sufficient groundwater withdrawal without any undesirable effect. Hence the overall system performance up to 200% cropping intensity was tested and different crop scenario analysis was done.

As it is mentioned earlier that rice is the predominant crop in the area in both the seasons, hence in the proposed scenario, the entire culturable command area is allocated to rice only during the monsoon season. During the non-monsoon season, northern half of the command area (Figure 1), which generally falls in the head end of the main canal, is either allocated to rice or wheat, whereas the southern half is either allocated to rice or wheat or kept fallow. The entire command area is kept fallow during summer. As such four different crop scenarios were tested.

Watertable fluctuation in a long run shows that rice should be grown in the entire cultivable command area during the monsoon season followed by rice in the head reach and wheat in the tail reach of the main canal during the non-monsoon season and the entire command area should be left fallow during summer season.

4. OPTIMAL CROP AND WATER RESOURCES MANAGEMENT

From the optimal crop and water resources management study for maximization the net annual benefit from the canal command (Panda et al., 1996; Sethi et al., 2002), it is observed that out of 158961 ha of cultivable command area, rice may be grown in 144920 ha (91.1 %) during the monsoon season which remains the predominant crop in the area (Table 1). Next to rice, vegetables (4857 ha) followed by pulses (3658 ha) and oilseeds (2391 ha) may be grown that will give more returns. Similarly, non-monsoon rice area should be reduced to 62206 ha (55.8 %) from the present level of 73978 ha. Next to rice, oilseeds (18828 ha) and then pulses (15341 ha) may be grown which will fetch more profit. The net annual profit obtained from optimization solution in the monsoon and non-monsoon season in the command area are 821.9 and 722.2 million Indian rupees (INR), respectively (1 US$ = 48 INR).

Table 1. Optimal parameters in the canal command

Parameters	Monsoon	Non-monsoon
Rice, ha	144920	62206
Pulses, ha	3658	15341
Oilseeds, ha	2391	18828
Vegetables, ha	4857	10808
Sugarcane, ha	1849	1846
Millets, ha	81	914
Fibres, ha	185	-
Wheat, ha	-	944
Other crops, ha	1020	565
Canal water, million m^3	1078.8	995.5
Groundwater, million m^3	346.7	329.4
Net returns (x 10^6 INR)	821.9	722.2

Hence, in total there is a possibility to get 1544.1 million Indian rupees, if the land areas are diverted to different crops in different seasons as proposed. Thus the conjunctive use of both surface and groundwater as available in the command should be utilized judiciously with allocation of different areas to different crops as proposed, which may increase the total returns in the command and change the socio-economic status of the people.

5. CONCLUSIONS

In the Hirakud irrigation project, the temporal variation in canal water supply coupled with the random nature of irrigation water demand particularly from rice cultivation has created an imbalance in the entire agricultural production system. At the present level of cropping and 10% probability of exceedance of irrigation water requirement, canal water availability during the monsoon season is just sufficient to meet the demand whereas during the non-monsoon season, the water demand exceeds the canal water availability by more than 935 million m^3. This needs for conjunctive use management of available surface water and the underutilized groundwater resources. At 50% probability of exceedance level, 1 ha of rice area can be replaced by around 5 ha of other crops during the monsoon season and again in the non-monsoon season 3.3 ha of other crops can replace 1 ha of rice area. Hence area under rice should be reduced to certain extent and low water requiring crops like wheat, pulses, millets, oilseeds, vegetables, and condiments should replace rice. Again during the monsoon season, more than 90 % of the command area remains waterlogged and in the non-monsoon season the watertable remains within 2-4 m below the ground surface in more than 40% of the area. Therefore, there must be sufficient withdrawal of groundwater during the non-monsoon period so that groundwater reservoir can be able to accept more monsoon recharge. Predictive simulation of groundwater table for different cropping sequences in the command area for a long run shows that in order to avoid any undesirable effect, rice should be grown in the whole cultivable command area during the monsoon season followed by rice in the head reach and wheat in the tail reach of the canal command during the non-monsoon season. The entire command area should be left fallow during summer. From optimal crop and water resources management point of view, the area under rice should be reduced by 6% and 16% during the monsoon and non-monsoon season, respectively. Pulses, oilseeds and vegetables should replace rice in those areas for overall system balance.

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Effect of Land Use Change on Hydrological Regime in a Rural Catchment: A Case of River Njoro Catchment, Kenya

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ABSTRACT

Recent studies suggest that the Mau Forest Complex, which serves as the River Njoro headwaters, has decreased by approximately 9% (340 km2) since 1964 due to deforestation. This paper provides an evaluation of the hydrologic response to land use and land cover (LULC) change in the once heavily forested upland portion of the catchment. Rapid conversion from indigenous and plantation forests to small-scale agriculture have occurred in the upland region where agricultural conditions are favourable. Population explosions and migration to areas more suitable for agriculture have contributed to severe land degradation. More profound is the destruction of wildlife habitat due to drastic hydrologic changes brought about by upland deforestation. Several mitigation measures have been recommended to be used to fill the gaps that have so far been identified. Decision support tools for water resources planning and allocation have been proposed and are being tested. Stakeholders are being involved in all aspects of management of the water resources in the catchment in order to ensure sustainability of the water resources.

1. INTRODUCTION

In developing nations where resources are scarce and increased population pressures create stress on resources, an integrated multi-disciplinary approach whereby land use and land cover (LULC) changes can be monitored and correlated with hydrologic, socio-economic, and health changes is necessary for positive change. Remotely sensed imagery coupled with Geographic Information Systems (GIS) and hydrological modelling methods have been employed in the catchment to increase awareness of available resources, and ultimately lead to more informed decisions by policy makers and planners.

The River Njoro is approximately 50 km in length and its catchment covers approximately 270 km^2, with a total human population of about 350,000. Rising from the eastern Mau Escarpment in Kenya's Rift Valley at an altitude of over 3,000 m above sea level, the river flows through forests then mixed agricultural and grazing lands before serving the towns of Njoro and Nakuru. It eventually empties into Lake Nakuru National Park, an inland soda lake and Ramsar site of global significance for its large resident population of flamingos, and Kenya's most visited national park.

Changes in hydrologic response within the catchment as a result of land use changed have had many negative impacts such food insecurity in the region. In addition, the River Njoro though a perennial river, has been drying up or being reduced to a trickle during the dry season at the Lake Nakuru National Park boundary.

1.1. The Study Area

The study area (Fig. 1) lies between latitudes 0° 15' S and 0° 25' S and longitudes 35° 50' E and 36° 05' E and measures about 282 km^2. It lies between an elevation of 1780 and 3420m. Its minimum and maximum average monthly temperatures vary from 5 ^{o}C to 28 ^{o}C. The average annual rainfall ranges from 840 mm to over 1200 mm. The mean monthly rainfall ranges from about 30 mm to over 120 mm with a trimodal pattern having peaks in April, August and November. The topography is predominantly rolling land with slopes ranging from 2 % in the plains to 54 % in the hills. It is mainly covered by the Quaternary and the Tertiary volcanic deposits. The study area was once covered by rich vegetation of highland evergreen forests which extended from the Mau hills and turned into woodland dominated by acacia trees in the Rongai-Njoro plains.

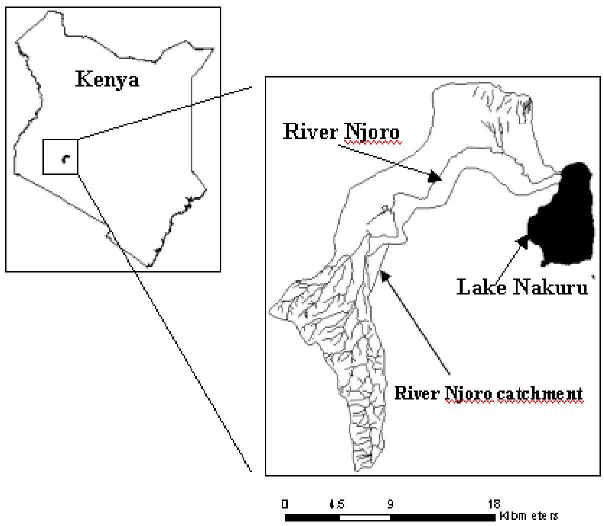

Figure 1. Location of the River Njoro catchment.

2. MATERIAL AND METHODS

Three Landsat scenes (Path 169, Row 60) selected for this study were those for 28th January 1986, 06th February 1995 and 04th February 2003 (Baldyga, 2005). In this study imagery of 30-meter x 30-meter pixel resolution were used. This was considered as an appropriate resolution for a subregional analysis (Campbell, 2002; Lucas *et al.*, 2004). In addition, Landsat was the sensor of choice for this study due to the quality and scale of collected data as well as affordability.

A critical distinction was sought between forested and non-forested areas in an effort to isolate the rapid conversion of forest to small-scale subsistence farming and managed pasture. Distinction in reflectance between forested and non-forested areas is greatest during the dry season, which decreases confusion at forest edges between dense forest vegetation and small-scale agricultural plots (Singh, 1987; Campbell, 1981; Maingi and Marsh, 2001; Tole, 2002). Consequently, images corresponding to a pre green-up period were selected.

The entirety of the watershed and surrounding study area is contained in each individual Landsat scene; however, the scenes were clipped to include only the watershed and parts of the surrounding region included in census districts traversing the watershed as well as Lake Nakuru National Park.

1:50, 000 topographic maps from the Survey of Kenya were used to digitize streams and roads within the River Njoro watershed. Landsat images were geo-referenced using a first order polynomial transformation and a nearest neighbour resampling method, with a resultant 0.14 m root mean square error (Wayman *et al.*, 2001).When overlain on the Landsat scenes, an offset was apparent due to the high topographic relief on the Rift Escarpment. Consequently, 30 ground control points were identified using recognizable and clear features in the Landsat images coupled with stream and road GIS layers.

2.1. Land Cover Classification

Nine information classes, excluding shadow and cloud cover, were identified as relevant for fully quantifying the range of vegetation types and associated transitions across space and time (Table 1). These informational classes represent coarse data aggregates corresponding to basic land management practices occurring within the River Njoro watershed.

Band separability analysis revealed that while plantation forests and dense vegetation had clearly identifiable and unique spectral signatures, land cover types such as small-scale agriculture, urban, sparsely vegetated (i.e., exposed), and managed pastures were spectrally indistinct from one another. This necessitated using a more complex algorithm to refine the data, and a step-wise approach was developed that iteratively used supervised and unsupervised methods.

3. RESULTS AND DISCUSSION

3.1. Results: Classified Land Cover Data at a Range of Scales

Table 1 details land cover changes as a percentage of land cover type at three spatial scales. Land cover changes occurring between 1986 and 1995 are minimal at all three scales; however, significant changes are noted after 1995. It is observed that changes are more significant within the uplands than at the regional or watershed scale (Figure 2).

Table 1. Land cover as percentage of total area.

	Nakuru Region			Watershed			Uplands		
Land Cover Class	1986	1995	2003	1986	1995	2003	1986	1995	2003
Mixed	34.4	36.7	50.6	32.1	32.5	51.2	14.8	14.4	33.4
Dense Vegetation	32.5	31.8	25.5	30.9	27.8	23.6	67.1	60.0	49.8
Plantation Forests	4.6	6.1	4.7	7.8	10.8	6.1	16.6	23.3	13.6
Large-scale Agriculture	18.8	15.8	7.2	18.7	17.4	9.3	1.2	2.2	1.5
Exposed	7.1	7.1	9.5	8.0	8.4	6.1	0.2	0.1	1.6
Urban	0.3	0.4	0.5	2.5	3.1	3.7	0	0	0.01
Water	0.7	0.6	0.7	0	0	0	0	0	0
Algae Bloom	0	0	0	0	0	0	0	0	0

(Source: Baldyga et al., 2005)

There is a distinct increase in mixed grass and small-scale agriculture at all three scales, although the percent increase over the 1986 baseline is most significant in the uplands where a 127% increase occurs in comparison to 47% and 58% increases at the regional and watershed scales respectively. This dramatic change is visually apparent in the uplands maps generated (Figure 2).

An alarming increases in exposed landscape occurred in the uplands (700%) during the same period. These increases in mixed grass and small-scale agriculture and exposed land cover types have come at the expense of forest, which sharply decreased at all scales by as much as 19 – 4%.

Forest losses were significant at a range of scales and occurred almost exclusively after 1995. Total decreases in forested areas were 390 km^2 for the Nakuru region, 24 km^2 for the Njoro watershed, of which 11 km^2 were lost from the uplands. Losses were shared almost equally between the plantation and native forest, which is contrary to a popularly held belief that encroachment is occurring primarily into old plantations.

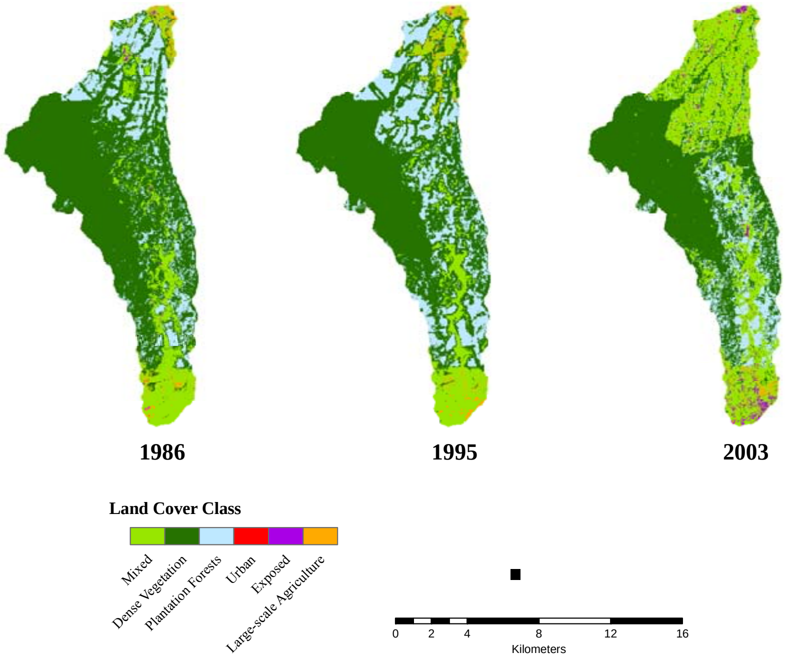

Figure 2. Land cover maps depicting changes in the River Njoro watershed uplands.

3.2. Discussion

It is hypothesized that seasonality is a significant problem when using reference data collected during the dry season resulting in the over prediction of degraded land cover, which is most often confused with the mixed class (Table 1). The images used in this study were chosen primarily to identify the differences between forested and non-forested lands and were taken in January and February, which is the driest period of the year and is usually between harvest and planting. During the dry season many farmers let their fields go fallow, water becomes scarce and irrigation is rare, so it is not unreasonable to have a higher representation of degraded land cover in the images classified for this study. During the rainy season, degraded areas are likely to be under cultivation or managed as pasture. Future research is needed to assess land cover accuracy using the same classification methods to classify a Landsat image from the same season in which reference data were collected.

Classification of land cover using remote sensing data in the Nakuru area revealed significant losses in forest areas with attendant increases in small-scale agriculture. Changes in land cover are present throughout the landscape but analysis revealed the intensity and type of change as a function of geographic position. An iterative method with supervised and unsupervised techniques applied in coordination with spatial analyses was successful in representing the desired classification scheme.

It should be noted that sustainable management of the riparian zones will depend on the collaboration and cooperation of all the stakeholders. In this case therefore, the study proposes future activities where all stakeholders will be brought together to share their experiences and challenges as well as visit the watershed from the source to the lake. One project known as the Sustainable Management of Watersheds (SUMAWA-CRSP) project has embarked on applying the participatory approach whose main focus is sustainable development of the River Njoro Watershed in order to reverse the current declining trends. The approach is motivated by a strong believe that participation by the beneficiaries in any project is fundamental, and that locally selected and serviceable technologies and policies are more likely to succeed unlike complicated, expensive, imported or imposed ones chosen by external decision-makers. This approach also incorporates local values, cultural traditions, local institutions, and local knowledge systems in its attempts to bring science to address local watershed problems. This study builds on the premise that sustainable development must incorporate approaches that communities themselves can manage and control.

4. CONCLUSION

Work presented here provides a baseline for understanding land cover and ecologic changes within the River Njoro watershed and the surrounding region and will be used as an anchor for future studies that explore possible land management scenarios. These data are critical inputs to ecological studies at a range of scales, such as wildlife habitat suitability modelling, fragmentation and patch dynamics. By using a spatially distributed approach, locating areas within the watershed that will most benefit from conservation practices is possible. In a developing nation where financial resources for conservation are stretched, the GIS and remote sensing tools used in this study provide a cost-effective means toward improved land management decision-making.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial support of the Global Livestock Collaborative Science Research Program at the University of California, Davis and the leadership of Scott N. Miller at University of Wyoming and William A. Shivoga at Egerton University on the Sustainable Management of Watersheds Project in Kenya, making this research possible. The results presented in Tables 1 and 2 have been synthesized from the PRA reports prepared by the various PRA teams and several graduate students of the SUMAWA team in Kenya during 2002-2004.

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Irrigation Suitability of the Groundwater: A Case Study on Hand Dug Wells in Debrekidan Watershed, Eastern Tigray, Northern Ethiopia.

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ABSTRACT

This paper assesses the suitability of groundwater for irrigation purpose in Debrekidan watershed, which is located in eastern Tigray, northern Ethiopia. The source of groundwater is hand dug wells. Inventory of hand dug wells through transect walk and in situ measurement of electrical conductivity and temperature were undertaken to determine the number of samples.

By adopting systematic and stratified sampling techniques a total of 36 water samples were collected from hand dug wells that were in use, which corresponds to 10 % of the total available hand dug wells. These samples were collected in two phases: 36 water samples during rainy season and 36 water samples during irrigation season.

To determine the extent of salinity, sodicity and toxicity of specific elements in the groundwater of the area, the water samples were analyzed in the Hydrogeochemistry and Geochemistry Laboratory of the Department of Applied Geology, Mekelle University. The samples were analyzed for major cations and anions (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, CO_3^{2-}, HCO_3^{-}, Cl^{-}, SO_4^{2-} and NO_3^{-}). Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} were measured by using Atomic Absorption Spectrophotometer. Titration method was used to determine CO_3^{2-} and HCO_3^{-} ions. Cl^{-}, SO_4^{2-} and NO_3^{-} were measured using UV Spectrophotometer. EC meter and pH meter were used to determine the electrical conductivity and pH of the water samples, respectively.

Analysis of water chemistry data was carried out by AquaChem 4.0 software, and Piper diagram, Box and Whisker diagram, Stiff diagrams, Wilcox diagram and Radial diagram were used for representing and comparing water quality analysis in the watershed.

In the rain season samples, with the exception of one water samples, which has 5.31 % charge balance error, the charge balance errors of the chemical analyses of all the remaining water samples are less than 5 %. In the irrigation season samples, with the exception of five water samples, the charge balance errors of the chemical analyses of all the remaining water samples are less than 5 %. The charge balance errors of the five samples are 5.82 %, 6.19 %, 7.48 %, 5.47 %, and 5.07 %, respectively. The water type in the study area is Mg-HCO_3, Ca-HCO_3, Mg-Cl, Na-HCO_3, and K- HCO_3. Out of 36 water samples of the rainy season, the dominant water type is Ca-HCO_3 (42 %) followed by Mg- HCO_3 (31%), Na- HCO_3 (22 %), and Mg-Cl and K-HCO_3 (3 %). In the irrigation season samples 69 % is Ca-HCO_3 type followed by Na-HCO_3 (24 %) and Mg- HCO_3 (7 %).

In this study FAO (1985) and Wilcox (1955) guidelines were used to evaluate the suitability of the groundwater of the area for irrigation. Accordingly, the groundwater is suitable for irrigation, where the proportion of water class in rainy season sampling is 11.66 % excellent, 80 % good and 8.34 % permissible, and in irrigation season, the water is classified as 30 % good and 70 % permissible. Besides, the concentration of Na and Cl in the groundwater is normal. Consequently, the groundwater of the area has no specific toxicity effect to grow the dominantly practiced vegetables and field crops in the watershed. However, the groundwater potential of the area has not yet been determined. For sustainable utilization of this natural resource, the groundwater potential of the area should be investigated.

Keywords: Groundwater, Irrigation, Salinity, Sodicity, Toxicity, Water Quality.

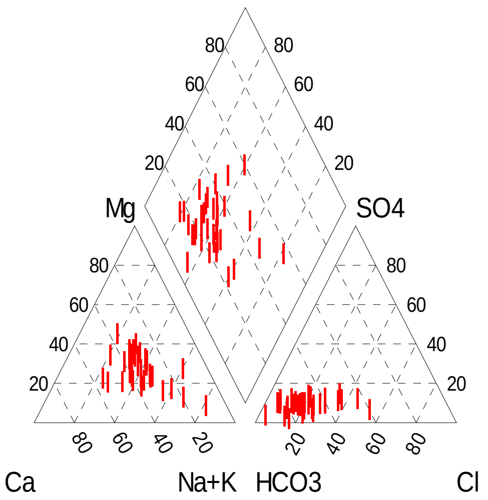

Figure 1. Piper plot for water samples (rainy season samples).

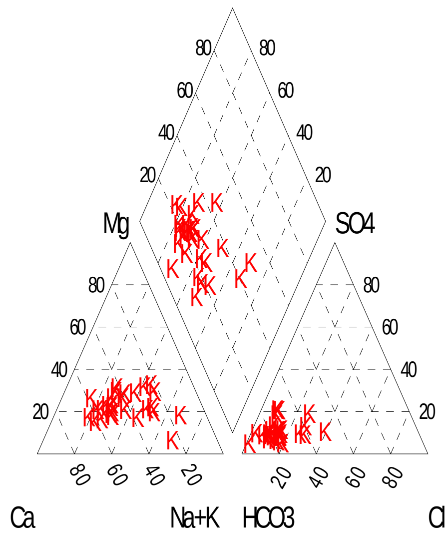

Figure 2. Piper plot for water samples (irrigation season samples).

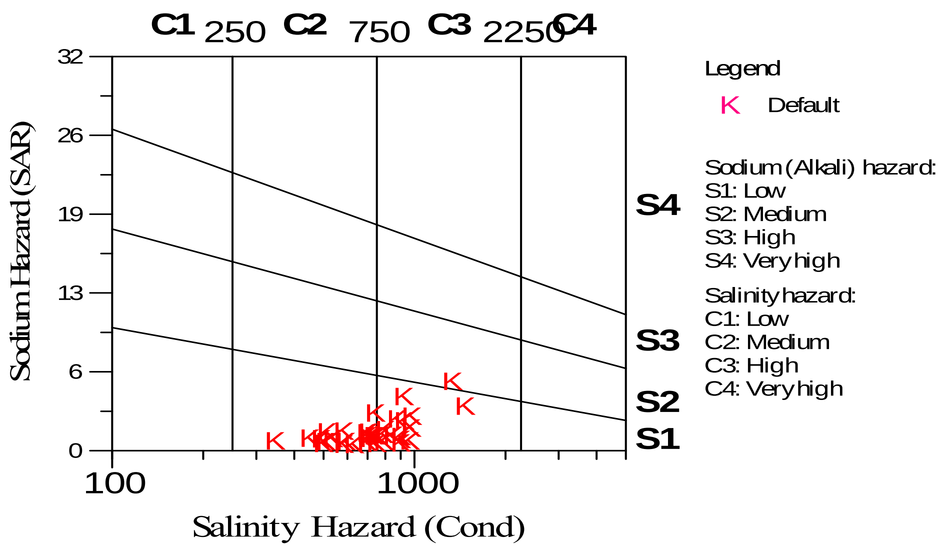

Figure 3. Irrigation water classes using Wilcox diagram (irrigation season samples).

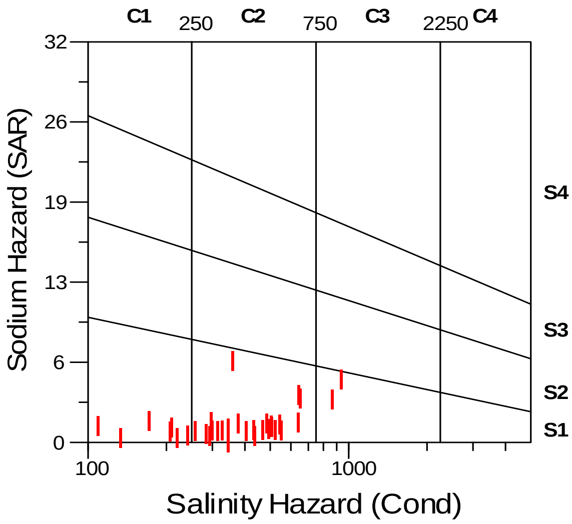

Figure 4. Irrigation water classes using Wilcox diagram (rainy season samples).

Table 1. Class of water in the in irrigation season

EC(dS/)	Mean	STDEV	No wells	Water class (Todd, 1980)	Degree of restriction (FAO, 1985)	%
0.25-0.75	0.59	0.11	11	Class 2, Good	None	30
0.75-2.00	0.99	0.22	25	Class 3, Permissible	Slight - moderate	70
			36			

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Estimation of Peak Direct Runoff and Sediment Yield from the Upper River Njoro Catchment Using AgNPS Model

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ABSTRACT

Design and operation of water resources structures require reliable runoff data. Such data is available from catchments gauged with automatically recording instruments. However, in developing countries, there is lack of data, since such instruments are expensive to acquire and maintain. An application that combined Remote sensing, GIS and AgNPS model was used to estimate peak runoff rate and sediment yield from Upper River Njoro catchment. Remote sensing was used to obtain land cover and associated AgNPS model input parameters. Base flow separation was done so that measured direct peak runoff rate and sediment yield generated by direct runoff could be determined and compared directly with the model simulated results. Peak runoff rates and sediment yield for Upstream (Treetop) and Downstream (Egerton) stations were simulated with EFF of 0.78, 0.69, 0.86, and 0.88 and error of 4.1 %, 5.5 %, 2 %, and 2.5 %, respectively. Information obtained would be useful in better catchment management.

1. INTRODUCTION

Surface runoff and sediment yield data can be obtained from catchments gauged with automatic instruments. However, such catchments are very few in Kenya because of the high cost associated with the procurement, installation and maintenance of these instruments. Infact, of the few gauged catchments, some do not have consistent data records due to lack of proper and continuous maintenance of the gauging instruments. Due to the high expenses involved in automatic gauging, only research catchments are known to have good records.

The Integrated Land and Water Information System (ILWIS) developed by ITC (Meijerink et al., 1988) was used in a GIS-Model link to determine and handle the distributed input and output of the Agricultural Non-Point Source (AgNPS) Pollution model. The distributed model was used to predict sediment yield and runoff for single storm events. GIS capabilities in incorporating catchment data through remote sensing and spatial analysis with hydrological data have been shown to be effective in determining peak flows at various points along a stream channel (Onyando et. al., 2005). The study was necessitated with a need to estimate the catchments sediment yield and runoff volumes for efficient management of the catchment resources currently and in future given that consistent observed data is lacking. This information is important in the development of strategies for efficient and sustainable management of the catchment's land and water resources.

2. STUDY AREA

The River Njoro catchment is part of the larger Lake Nakuru catchment, located approximately 150 km North West of Nairobi, Kenya and one of the rivers originating from the Eastern Mau forest of the Mau Complex and draining into the saline Lake Nakuru, a Ramsar site. The mean annual precipitation is 1200 mm distributed bimodally with peaks in May and October. The study focused on the upper catchment which is approximately 127 km^2 (Fig. 1). It is a high potential area and is under intensive cultivation. The forested hill slopes of the catchment have undergone extensive deforestation, which has led to increased soil erosion, low recharge and remarkable fluctuation in stream flows. Through erosion, the fertile topsoil and the sediment generated are transported by the stream and get deposited in the lower reaches in the river and the Lake. The upper River Njoro catchment has the Egerton gauging station (00.37347^{0}S, 35.94077^{0}E) at 2203m a.s.l as the outlet. The other monitoring station is Treetops gauging station (00.37528^{0}S, 35.92029^{0}E) located at 2285m a.s.l. and 3.7 kilometers upstream of the outlet. The geology and soils of the area is influenced by the volcanic nature of the Rift Valley.

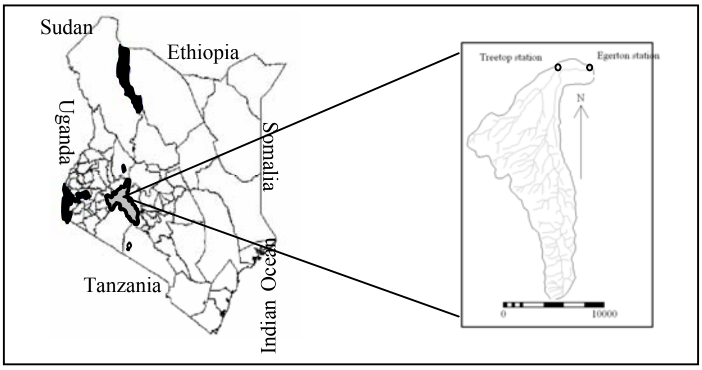

Figure 1. Map of Kenya, and the study area

3. METHODOLOGY

Rainfall data was taken from the readings of non-recording rain gauges of the Egerton University weather station. Eleven storm events were considered in the study. The corresponding stream flows were obtained at two monitoring sites selected for the study.

Runoff sampling was done at the two monitoring sites after storm events for sediment concentration analysis in the laboratory. A depth integrating hand sampler was lowered into the stream and raised to the surface at a constant speed. Three traverses were made across the stream section to come up with the suspended sediment load for the section. The samples were then filtered, oven dried and weighed. Using the direct runoff volume, weight of sediment was converted into a sediment yield in tonnes for a particular storm.

The process of predicting the required outputs via the model-GIS link was then carried out through the following steps: (i) spatial database preparation, (ii) derivation of spatial layers (Fig. 2) and (iii) GIS and model interfacing.

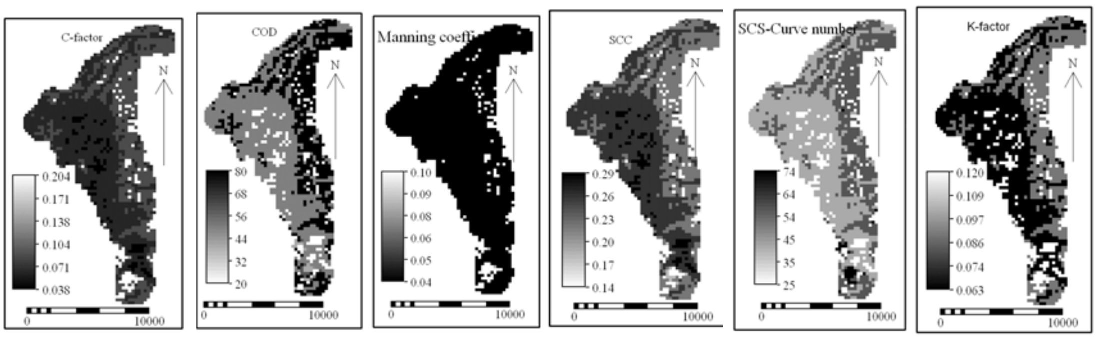

Figure 2. Spatial distribution of land use related parameters

4. RESULTS AND DISCUSSION

The results presented in Table 1 showed the model slightly over and under predicted the peak runoff rates in both the stations. This could be due to fact that some events had complex storms with rainfall following an irregular pattern. For the Upstream station the average percentage error between observed and predicted values was 4.1%. This agreement is confirmed by satisfactory EFF values of 0.78. For Egerton station, there is generally a good correlation between the observed and predicted peak runoff rates. The average percent error between observed and predicted values was 5.5%, and EFF of 0.69.

Table 1. Peak runoff rate (m^3/s) results

Event	Rainfall (mm)	Treetop			Egerton		
		Observed	Simulated	%Error	Observed	Simulated	%Error
15/01/04	40.6	2.966	3.065	-3.3	2.547	2.622	-2.9
11/04/04	42.5	2.981	3.088	-3.6	2.534	2.603	-2.7
23/05/04	45.0	3.055	3.179	-4.1	2.714	2.876	-6.0
22/07/04	37.0	2.267	2.406	-6.1	2.018	2.160	-7.0
11/08/04	28.0	2.843	2.692	5.3	2.543	2.321	8.7
14/11/04	8.4	2.522	2.406	4.6	2.192	2.019	7.9
23/11/04	9.5	2.747	2.617	4.7	2.349	2.191	6.7
25/11/04	17.5	2.521	2.670	-5.9	2.253	2.369	-5.2
16/12/04	25.6	2.910	2.882	1.0	2.887	2.790	3.4
26/01/05	16.5	2.468	2.521	-2.2	2.239	2.352	-5.1
22/03/05	26.5	2.863	2.747	4.1	2.469	2.358	4.5

The statistics presented (Table 1) were found to be consistent with those for similar work involving AgNPS done in other parts of the world. Khoelliker and Humbert (1989) in their work in northeast Kansas found a percent error of 3%, Young et al (1987) in an agricultural catchment in Minnesota had a 1.6% error in their estimations. Suttles et al. (1999) simulation of runoff rate in Georgia coastal plain had an EFF of 0.85, In Hesse, central Germany 3.8% was the error found for runoff simulations.

Sediment yield was also under and over-estimated for the various storms considered (Table 2). The errors for sediment yield were lower than those for the runoff results. This could be attributed to the fact that, all particles were allowed to participate in the channel scouring, and not the AgNPS default that allows only sand particles to erode. For the upstream station the average percentage error between observed and predicted values was 2.0% with an EFF value of 0.88. For Egerton station, there was also a good correlation between the observed and predicted sediment yields. The average percent error between observed and predicted values was 2.5% while for the model efficiency, a value of 0.86 was obtained. The results obtained in the study compared favourably to works using AgNPS by Young et al. (1987), which over predicted sediment yield by 2.5% and had an EFF of 0.95 in the Trevor watershed.

Table 2. Sediment yield (tonnes) results

Event	Rainfall (mm)	Treetop			Egerton		
		Observed	Simulated	%Error	Observed	Simulated	%Error
15/01/04	40.6	326.12	331.51	-1.7	276.21	282.21	-2.2
11/04/04	42.5	335.45	327.62	2.3	288.43	283.33	1.8
23/05/04	45.0	340.66	336.62	1.2	279.57	286.77	-2.6
22/07/04	37.0	290.22	295.14	-1.7	239.38	248.73	-3.9
11/08/04	28.0	331.98	325.44	2.0	264.14	270.06	-2.2
14/11/04	8.4	288.14	295.55	-2.6	239.37	246.72	-3.1
23/11/04	9.5	290.64	296.89	-2.2	241.36	247.14	-2.4
25/11/04	17.5	295.84	306.26	-3.5	266.35	258.34	3.0
16/12/04	25.6	318.88	324.83	-1.9	281.30	275.71	2.0
26/01/05	16.5	307.23	303.34	1.3	248.42	243.51	2.0
22/03/05	26.5	312.00	306.73	1.7	266.11	259.63	2.4

5. CONCLUSION

The stream flow is an integrating measure of all the hydrological processes operating within the catchment. Due to lack of reliable data, AgNPS was used to predict the runoff and sediment yields based on the rainfall information and land use and its related parameters derived using Remote Sensing. The combination of AgNPS, GIS and Remote Sensing has showed to be useful substitute to the *in situ* measurement of runoff and sediment yield for effective catchment management.

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Irrigation Development in the Chi-Mun River Basin, Northeast Thailand: Over-Committing Water Resources in the Name of Development?

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ABSTRACT

More than 50 years of irrigation development have profoundly re-shaped the Chi-Mun river basin in northeast Thailand; the most rural and the poorest region of Thailand. Agricultural development, and with it the expansion of irrigated areas, has ranked high on policy agenda during this period, both in an effort to re-balance regional inequities and to alleviate poverty. This drive to expand irrigation, however, has introduced a host of interrelated problems: loss of wetlands along with the services they provide, the spread of salinization, and – as will be discussed here – water scarcity.

Against popular believe, which, in the most general sense, sees the northeast of Thailand as poorly endowed with natural resources and thus prone to water shortages, I will argue, that water scarcity is not only the result of the regions poor endowment with water resources, but equally a product of an anthropogenic process of overly optimistic assumptions that favored the overdevelopment of irrigation areas, with subsequent supply augmentation being justified by water shortages in these systems. This process (which is neither confined to the Chi-Mun river basin nor Thailand alone), tends to generate environmental problems and leads to poor allocation of public funds.

1. INTRODUCTION

Throughout much of the last century, irrigation development in northeast Thailand has ranked high on the Thai government's policy agenda. From regional integration, to promoting 'development' and 'modernization', to the fight of communism, to poverty alleviation; irrigation development has seen a host of different justifications. What they had in common, however, was the gradual expansion of irrigated areas and the increasing mobilization of water resources for agriculture.

Within a given river basin, however, utilizable resources are of limited nature and when utilizable outflows are fully committed to beneficial uses, river basins are said to be *closed* (Molden, 1997). This, in turn, creates complexities and interconnection at a basin scale and people find their productive activities constrained by water shortages. Moreover, as growing human pressure on water resources brings actual water use closer to potential ceilings, societies usually respond by adopting conservation measures and by reallocating water towards more beneficial uses (Molle, 2003).

Basin closure, and in cases overbuilding, has occurred in many basins across the world. Molle (2006a) listed the Colorado, Yellow River, Amu-Daria/Syr-Daira, Jordan, Cauvery, and river systems of Mexico, Iran as closed river basins, and notes, that the process of basin closure 'seems to be on the way, or compounded, in the Ganges, Indus, Krishna and other river basins'. The mechanisms at work to facilitate over development of water and land resources are, of course, numerous: the political economy of river basin development with convergence of interests of influential actors (state, line agencies, politicians, private companies and development banks), the fuzziness of water rights and double accounting, the malleability of cost-benefit analysis, regional politics (equity and/or 'grab-it-first' strategies), low risks and high subsidies for irrigation developmet, push factors of agrarian pressure and shock events, and finally the lopsided governance of and weak public participation in decision-making (Molle, 2006a)[4]. What becomes increasingly clear, however, is the fact, that the continuing expansion of irrigation areas 'artificially' creates scarcity.

By reconstituting the development trajectory of the Chi-Mun river basin's water resources, and by revisiting the development history of water resources in the basin, I will argue that, against popular believe, water scarcity, which is now driving further investment in irrigation infrastructure, is not merely the sole product of the regions poor endowment in natural resources, notably water, but the creation of demand through a process of overdeveloping irrigation areas in the basin.

2. THE CHI-MUN BASIN, NORTHEAST THAILAND

Northeast Thailand (locally referred to as Isaan) is one of the poorest areas in Thailand; 60 percent of the total poor in the country live in this region and over 70 percent of them are dependent on agriculture for their livelihoods. The largest river basin in northeast Thailand is the Chi-Mun river basin (roughly 120,000km^2 or 2/3 of northeast Thailand), which empties into the Mekong River[5].

Throughout the last 50 years, northeast Thailand has witnessed profound changes: population grew from 3.8 million in 1929 to 20.8 million in 2000, land in farm expanded from 4.3 million ha in 1954 to 9.7 million ha in the late 1990s, forest cover decreased from roughly 90% in 1930s to less than 14% in 2000, and economic activities shifted increasingly away from subsistence farming, and into other economic sectors (particularly during the dry season).

3. A SHORT HISTORY OF WATER RESOURCES DEVELOPMENT IN THE CHI-MUN RIVER BASIN

The Chi-Mun river basin has, over the course of the last 50 years, witnessed various initiatives to augment supply for irrigated agriculture. Starting in the late 1930s, when the Royal Irrigation Department embarked on the construction of small- to medium scale tank systems and run-off-river diversion schemes, the focus soon turned to the construction of medium- to large-scale storage to regulate and capitalize from the natural, and highly seasonal, distribution of run-off.

Being part of the larger Mekong Basin, and its institutional framework, a series of studies was conducted, both for the Mekong and the tributaries, and it was generally concluded that "multipurpose development of water resources was needed for economic development" (USBR, 1965).

Following these recommendations and international mainstream thinking, Thailand raised gross storage in the Chi-Mun Basin by approx. 6,000 Million m^3 from 1965 to 1975, capturing roughly 20% of the annual runoff. Considering the basins flat and undulating topography (along with the resulting lack of viable storage sites) and the contemplated ceilings for medium and large-scale development which ranged from 7,700 Million m^3 (Kambhu, 1963) to about 9,000 Million m^3 (USBR, 1965), this increase in Storage basically meant that all but a few suitable sites for storage[6] have been developed within this period of time (Figure 1).

[4] The above 7 reasons for basin overbuilding do not, as Molle (2006a) stated, indicate "that projects are necessarily unjustified, undesirable, or biased" but "they merely should draw the attention on how project planning may (and tend to) acquire a life of its own, overriding criteria of hydrologic or economic relevance".
[5] The Chi-Mun river basin comprises about 15% of the Mekong basin area, and contributes roughly 6% of the annual flow.
[6] Notably the Upper Chi Tributaries and the Lower Mun Basin

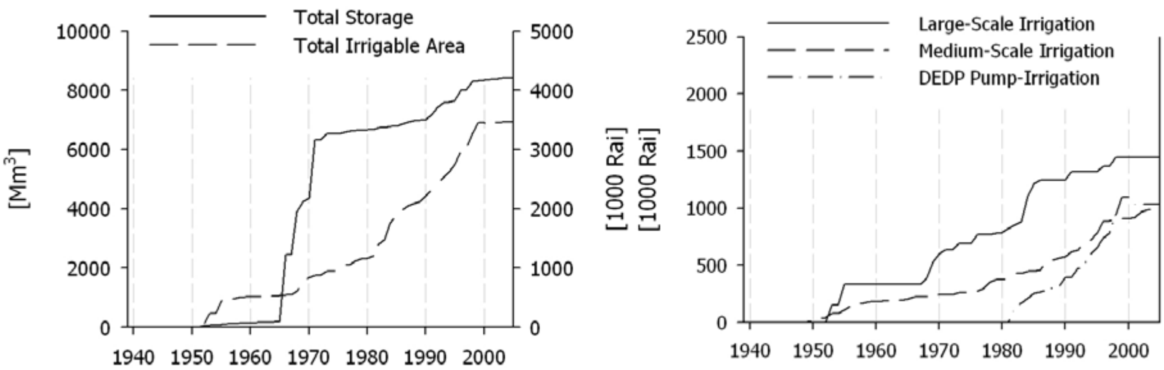

Figure 1. Irrigation Trajectories in the Chi-Mun Basin

Hence, apart from the raise in storage, pump-irrigation became increasingly fashionable. By pointing out the limitations of the existing gravity-based irrigation systems operated by RID, and by arguing that gravity irrigation was unsuited for the topography of northeast Thailand, the Department of Energy Development and Promotion (DEDP) proposed electric pump-irrigation in 1965 (Kamkongsak and Law, 2001).

Since resettlement problems became increasingly important in public discourse, and with most storage sites already being developed, potential irrigable areas served by DEDP Pump-Irrigation systems constantly expanded from the late 1960s to present and passed 1 Million rai (160,000 ha) in 2000. Normally selected where there is enough water throughout the year, and designed in such a way that they do not cause water shortages downstream, it was stated (ESCAP,. 1991), that further construction of storage or flow regulation was not needed for successful operation. This, however, was not undisputed, as it was (already in the early 1980s) increasingly argued that “water requirements of the schemes greatly exceed the unregulated flow”, which, in turn, led to the conclusion that storage is needed (NEDECO, 1982).

Inspired by the concept of floodplain storage[7] and drawing from earlier studies on water import into the Chi-Mun Basin, along with the findings that existing pumping stations are outstripping the unregulated flow, DEDP, in the 1980s, started to study the Khong-Chi-Mun Scheme. Proposed as an interbasin diversion scheme, utilizing both existing storage reservoirs and new storage sites in the floodplains of the lower Chi-Mun river basin, the scheme aimed to promote irrigated agriculture throughout Northeast Thailand, by withdrawing water from the Mekong River and diverting it into significant parts of the Chi-Mun river basin (Sneddon, 2003), supplying water for irrigated agriculture for up to 4.9 million rai (780,000 ha) of farmland (Sombat, 1993). While the Khong-Chi-Mun scheme, so far, has not diverted water from the Mekong mainstream, individual projects have been implemented; amongst others the Hua Na and the Rasi Salai Weirs, both of which caused a considerable outcry by local population and civil society triggered by its impacts on the floodplain ecosystem and the disruption of local livelihoods which depended on it. Irrigation benefits, however, have generally not been accrued from the project, with most designed service areas still being not completed or idle.

[7] The Mekong Secretariat claimed to have introduced this “new concept in the design of flood-control and storage projects, where reservoirs are constructed in the areas affected by annual flooding” (Mekong Secretariat, 1989)

4. CURRENT STATUS AND BRIEF OUTLOOK

In 1995 a study on the Mun basin (RID, 1995) concluded that "water shortages regularly occur in the majority of irrigation schemes during the wet season, even though many of the schemes are only used to 70 percent of their designed command areas", and that "after developing existing schemes to their full potential, and introducing a fully diversified cropping pattern away from the existing dominance of rice, the basin's water resources will be able to support an average of 11 percent dry season cropping". In addition, the report argued, that the potential for agricultural development has "previously been overly optimistic, with an average of less than 5 percent dry season cropping across the basin". Considering that most of the economic appraisals of the last 50 years assumed crop diversification into dry-season cropping to justify economic feasibility, it is hardly surprising that multiple studies on irrigation development in northeast Thailand have pointed to the low economic performance of irrigation development (e.g. Mekong Committee, 1988).

Irregardless of the 1995 findings on resources availability and the lessons learnt from the often poor performance of previous projects, however, there is still a strong drive to expand irrigation areas and to augment supply. The Thai National Mekong Committee (TNMC, 2004) recently claimed, that within the Chi-Mun River Basin some 427 projects with a potential irrigation area of 2.44 Million rai (390,400 ha) might possibly be implemented. Additionally, in 2003, the Thai government announced the Water Grid project[8] a 200 billion baht (US$ 5 billion)[9] venture to bring water to unirrigated farms, notably in the northeast (Molle, 2005), by transferring it from 'wet' areas to parts of Thailand more prone to drought (Hirsch and Jensen, 2006).

5. CONCLUSION

With multiple agencies geared towards supply augmentation, and with project and regional planning mostly irrespective of the implications on a river basin scale, water demand is now regularly outstripping supply, with farmers being asked not to grow a second crop. Overly optimistic assumption regarding potential agricultural production, and frequent double accounting of available water resources, has left irrigation systems short of water. Hence, in most cases, water shortage in irrigation systems is rather induced, than the mere result of the basins low run-off and the region's poor endowment in water resources. These generated shortages, in turn, are now put forward to justify subsequent investments into supply augmentation, notably through interbasin-transfer schemes, propelled by the combined interest of politicians, line agencies and ministries, and segments of the private sector. This general process (which is neither confined to the Chi-Mun basin nor Thailand alone), tends to generate environmental problems and leads to poor allocation of public funds.

[8] A project which, according to Molle (2006b) serves as an example of a project which is supported by political considerations anchored in vague and generic 'positive' objectives: the fight against floods and droughts, and to turn "Thailand into an agricultural powerhouse", with a strong focus on project benefits rather than cost/benefit ratios. This focus is exemplified by Molle (2005), quoting the prime minister to have said that "it would not be a problem if the (water grid) project required a lot of money because it would be worthwhile eventually".

[9] More recently, Hirsch and Jensen (2006) named project costs at 400 billion baht.

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How Important is "Social Competence for an Irrigation Engineer" in Development Co-Operation?

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ABSTRACT

People are the central factor in development co-operation. Successful co-operation is based on mutual trust, the willingness to become acquainted with foreign cultures and technical competence. Social competence is still not considered to that amount as should be. In this paper experiences from project works are integrated to provide the link to reality. Only the recognition and acceptance of the interaction of both, social and technical aspects, creates the prerequisites for the successful work in development co-operation projects.

1. INTRODUCTION

It is the opinion of the authors that social competence is often not adequately considered in technical projects. This may be one of the reasons of the failing of even perfect designed projects. It is essentially to begin first with a definition of social competence and then relate it to the work of an irrigation engineer. What is he meaning of social competence? How can social competence be defined?

Social competence describes the complex of all personal abilities and attitudes which contribute to align the own behaviour to a common action orientated behaviour. "*Socially competent*" behaviour connects the individual goals of persons with the attitudes and values of a group (Wikipedia, 2006a).

Social Competence is prossessing and using the ability to integrate thinking, feeling and behaviour to achieve social tasks and outcomes valued in the host context and culture. Very different social competencies are required and valued in different contexts (Dundee, 2006).

Social competence means skills in the interpersonal sphere. A person is socially competent when their individual skills and abilities allow them adequately to deal with the demands of an interpersonal situation. Appropriate characteristics are capacity for self-assessment, empathy, a willingness to cooperate, the capability to handle conflict and communication. (Beccaria, 2006)

Close related to social competence is the intercultural competence which is the ability for successful communication with people of other cultures. This ability can be existing already at a young age, or be developed and improved thanks to willpower and competence. The bases for a successful intercultural communication are emotional competence, together with intercultural sensitivity (Wikipedia, 2006b)

These definitions have to be set in a context with irrigation engineering work. An attempt is made to quantify the required skills and abilities (Table 1). The most prominent statement is interpersonal relation. For project work in development co-operation this could be read as the ability to deal with contradictions, dissents and conflict in a personally and socially constructive way.

Table 1. Skills and abilities related to "*Social competence*"

Interpersonal relation	Co-operation abilities - institutional level	Leadership qualities	General
Empathy	Teamwork capacity	Responsibility	Knowledge of language
Perception	Conflict management	Self-assertion	Emotional intelligence
Self discipline	Communication	Consequence	Involvement
Tolerance	Mediation	Act exemplary	
Intercultural knowledge	Flexibility	Provide guidance	

The defined enumerators are investigated more closely with respect to successful project realizations. Successful means: The subject of the project, e.g. the irrigation schemes are accepted and maintained by the farmers as it was planned or it has been developed in a beneficial way.

2. ASSESMENT OF SOCIAL ENUMERATORS IN IRRIGATION PROJECTS

2.1. Interpersonal Relations

The work in irrigation projects is characterized by interactions of involved persons. People are the center of the project - the work is carried out with and for people. The regional social structures and environment are especially important in the farmer society. Irrigation engineers and local farmers are conditioned by their respective culture, environment and life situation. In development co-operation the western working oriented society meets unavoidably the traditional African society. In many cases, these cultural differences become visible for the development co-operation employees only on the site. The common goal is to improve or establish irrigation activities to enhance food security and to reduce poverty. Keeping this in mind and affiliate all stakeholders to this are a good start. The interpersonal relations appear on the different project management levels and hence require different skills (Figure 1).

<table>
<tr><td colspan="3">Partner</td></tr>
<tr><td colspan="2">State or regional authorities, farmer communities</td><td>Donors</td></tr>
<tr><td colspan="2">Water association, farmer bodies</td><td>Funding organization, external project management</td></tr>
<tr><td rowspan="2">operational Level</td><td>individual farmers</td><td>irrigation engineer</td></tr>
<tr><td></td><td></td></tr>
</table>

Figure 1. Management levels; Farmer project discussion (Uganda), Team meeting (Ethiopia)

We consider as most sensitive part the on site relations. Ideally, common solutions (participation) are worked out with the aim to establish a better situation for the people. The expression "better situation" is chosen consciously and not catchwords like "rise of the standard" of living, "efficiency increase" or "yield increase" - built on monetary values of the western society.

2.2. Co-Operation Abilities

We have stated before that empathy is one of the key factors for a fulfilling co-operation work. This leads automatically to the next requirement on the operational level, the teamwork, which is an indispensable prerequisite for any project to successfully bring stakeholders of different social background and expectations physically and emotionally together. An irrigation projects involve sociologists, irrigation engineers, economists, health staff etc.. This set up (Figure 2) requires high conflict and communication abilities from all team members. The problem of communication is not only the different foreign languages but also the specific language of disciplines involved and level of education. Theis and Grady summarized this in a triangulation pattern (Figure 2), where the different information flow and communication trajectories are visualised. An irrigation engineer should be capable to interfere with all groups and follow these trajectories.

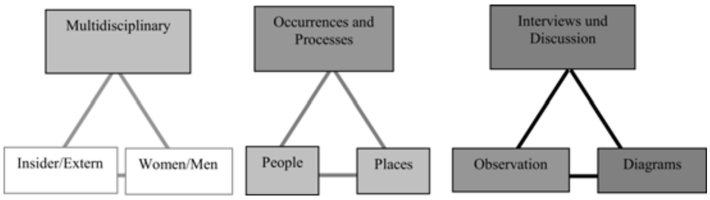

Figure 2. Triangulation Theis, Grady (1991, zit. Schönhuth, Kievelitz, 1993)

Conflicts may appear at different levels and project stages or during operation of an irrigation scheme, within the project group or extern group when for example people are left out for reasons like they are not willing or able to make the requested financial contribution and are not member of a water supply system. We also have to be realistic that not every conflict may be resolved by the project team. A reaction with road blockades and violence and statements like “We will through every dead animal into the river, the water is taken out” is most probably beyond the conflict solution capacity of the irrigation engineer.

Conflicts also evolve when a structure is changed, this could either be a change in the organization or a technical alteration, like an extension of an irrigation scheme. Floch (2004) investigated the consequences of an irrigation extension on water availability in Sri Lanka. He focussed on the inter-sectoral competition in a secondary channel of the existing scheme. Perception parameters are adequacy, flexibility reliability and equity. The well-known perception gradient of head and tail water could be shown empirically. Also the local conflict solving mechanisms were investigated. This is a key information and it is wise when any conflict management is directly linked to existing structures. Cultivators that are not involved in local farmer’s organisations are more vulnerable to conflicts compared to organised farmers.

2.3. Leadership Qualities

Decisions within irrigation projects should be made in participatory way and not independent of the people concerned. The project leader leaves after some time but the people must live with the new situation. This also requires a high degree of flexibility in decision making. Of course, it may look easier for engineers to develop a project without the concerned people and to run it with high financial support. On the other hand it is not satisfactory when an irrigation scheme is not self-sufficient. At the end of the day the irrigation engineer should make himself dispensable and water management should be in the hands of farmers and local communities. One sensitive topic is the gender issue, e.g. work within irrigation projects may be assigned to sexes differently, (women are responsible for irrigation - men are the decision makers and land owners). Water projects should be designed on a regional level to avoid social disparities and integrate the development of technical infrastructure and the necessary institutions for regional management. The involvement of international experts should be reduces to back shopping and monitoring.

From the point of leadership a project is at the end considered successful when all stakeholders have the feeling that their needs are treated adequately.

2.4. General

Besides target group and stakeholder oriented selections of methods and tools additional social principles have to be considered. Work at different levels of social aggregation, i.e. individual, household, group, community, etc. has to be ensured. No ‘hit and run’ studies are performed, but intervention over longer period (repeated visits) are envisaged. Story telling can be an important mean. An irrigation engineer needs within the development co-operation besides engagement also emotional competence. This means, not only the irrigation is important but also the whole environment. A holistic few and systemic approach is becoming more and more a standard and the involvement goes beyond the technical requirements.

3. CONCLUSION

Social competence is one of the columns of interpersonal relations. How much social competence everybody has depends personal experiences and curriculum. In the opinion of the authors social competence can be trained by conscious behaviour and openness. Besides the social competence the technical competence of an irrigation engineer is undisputed. A socially most competent irrigation engineer is useless if the technical basis is missing. Only to recognize and to acceptance the interaction of both, social and technical aspects, creates the prerequisites for the successful work in development co-operation projects. What is the value of the best technical solution, if the concerned people can not accept it? At last openness to know aspects and solutions are a way to success. We close our thoughts with a citation of Bawden (1997): *“If we always see how we’ve always seen, we’ll always be who we’ve always been. Changing the way we collectively construe ourselves means collectively changing the way we think about ourselves, to lead in turn, to changing the way we collectively act”*.

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The Productivity of Shallow Wells Groundwater in Agriculture and Interacting Systems: A Case Study at Debre Kidane Watershed, Eastern Tigray, Northern Ethiopia

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ABSTRACT

Productivity of Water in Agriculture (PWA) is a means of saving water by which farmers can produce more crops per drop of water. This paper assesses current levels of PWA in rain fed and irrigated agriculture, the different water users and their corresponding demands and constraints in the irrigation schemes related to PWA in Debre Kidane watershed, which is located in eastern Tigray, north Ethiopia. Data for the study was obtained from a formal household questionnaire survey, focus group discussion and direct observations on farmer's field. Field experiment was also carried out to know the productivity of water in tomato irrigation. SPSS version 10 was used to analyze the socio economic data.

In the watershed both rain fed and irrigated agriculture water productivity was very low. Rainfall water productivity was highest for mixed crops (0.37 kg/m^3) followed by wheat (0.30 kg/m^3) and barley (0.25 kg/m^3). On the other hand the highest diverted water productivity was for maize (0.24 kg/m^3) and the lowest was for green pepper (0.07 kg/m^3). On the controlled plots high water productivity was obtained for sandy soil (0.1.34 kg/m^3) followed by clay loam soil (0.39 kg/m^3) and silty loam soil (0.28 kg/m^3) whereas on the farmers plot diverted water productivity was highest in silty loam soil (0.08 kg/m^3) followed by sandy and clay loam soils equally (0.06 kg/m^3). The diverted water productivity in sandy soil was 4.474 % of the diverted water productivity in controlled plots, 28.95 % in silty loam soil and 15.23 % in clay loam soil, respectively. Though the productivity of water in the controlled plot was higher than the farmer's plot it is by far less than the potential water productivity in the area which is 25.73 % (sandy soil), 5.29 % (silty loam soil), and 7.55 % (clay loam soil) of the potential water productivity. The economic water productivity of rain fed and irrigation agriculture is highly dependent on the price of the crops and yield that gained. The highest economic water productivity under rain fed condition was obtained for teff (0.229 €/m^3) and the minimum was for maize (0.041 €/m^3). On the other hand, the economic water productivity of tomato was 0.011 €/m^3 (silty loam soil), 0.009 €/m^3 (sandy soil), and 0.008 €/m^3 (clay loam) in farmers' plot and 0.186 €/m^3 (sandy soil), 0.038 €/m^3 (silty loam soil) and 0.055 €/m^3 (clay loam soil) in controlled plots. However, the potential economic water productivity of tomato in the area was about 0.724 €/m^3 of water which is by far greater than the actual one.

In addition to irrigation activities, the farmers used their shallow wells water for domestic and livestock purposes that highly affect the amount of water that must be added to their farmland. Besides, the farmers face problems related to market, storage facilities, absence of transportation, shortage of water and poor water management that highly discourages them not to produce more crops than the present.

Keywords: Groundwater, Interacting Systems, Irrigation, Sallow Wells, Water Productivity.

Table 1. Productivity of Water under Rain fed Agriculture.

Crop Types	[10]P (m^3/ha)	[11]Pe(m^3/ha)	[12]CWR (m^3)	Yield (kg/ha)	[13]MPY (kg/ha)	Productivity of water (kg/m^3)		
						[14]PWP	[15]PePW	[16]PWP
Wheat	4016	2604.1	2989.6	1200	4500	0.30	0.46	1.51
Teff	4016	765.0	2188.2	700	1800	0.17	0.92	0.82
Maize	4016	2374.9	3328.3	800	2500	0.20	0.34	0.75
Mixed crops	4016	2775.9	2830.0	1500	5700	0.37	0.54	2.01
Millet	4016	2550.3	2890.0	900	3500	0.22	0.35	1.21
Barley	4016	2767.4	2933.5	1000	5200	0.25	0.36	1.77
Sorghum	4016	2775.9	2836.3	850	4600	0.22	0.31	1.62

The yield and maximum potential yield data of the area was obtained from the area's Beauro of Agriculture and the yield data was for 2005/06 rain fall season.

Table 2. Productivity of water under irrigated agriculture.

Crop Types	Total amount of water diverted (m^3/ha)	CWR (m^3)	Yield (kg/ha)	MPY (kg/ha)	Crop Water Productivity (kg/m^3)	
					[17]DWP	PWP
Tomato	12891.43	2873.4	1870	15000	0.15	5.22
Onion	17088.00	2143.6	1315	10000	0.08	4.67
pepper	11294.12	2788.6	800	15000	0.07	5.38
Potato	18651.43	2943.3	1600	40000	0.09	13.59
Cabbage	16320.00	2208.2	3600	35000	0.22	15.85
Maize	9984.00	3267.8	2400	2500	0.24	0.77

The yield and maximum potential yield data of the area was obtained from the area's Beauro of Agriculture and the yield data was for 2005/06 irrigation seasons.

Table 3. Productivity of water in tomato plantation in experimental plot.

Soil types	Total amount of water used by the plant (m^3)	Yield (kg/single tomato)	Yield (kg/ha)	Tomato water productivity (Yield/total water diverted) in (kg/m^3)
Sandy soil	1935.48	3.50	2600.00	1.34
Silty loam	8064.52	3.00	2228.57	0.28
Clay loam	6129.03	3.25	2414.29	0.39

Table 4. Productivity of water in tomato plantation on farmers plot.

Soil types	Total amount of water used by the plant (m^3)	Yield (kg/ ha)	Tomato water productivity (Yield/total water diverted) in (kg/m^3)
Sand	30720	1886	0.06
Silt loam	21120	1722	0.08
Clay loam	24960	1476	0.06

[10] P-Total Rainfall:
[11] Pe-Effective Rainfall
[12] CWR-Crop Water Requirement
[13] MPY-Maximum Potential Yield of the area (MPY/CWR)
[14] PWP-Total Rainfall Water Productivity
[15] PePW-Effective Rainfall Water Productivity
[16] PWP-Potential Water Productivity
[17] DWP-Diverted Water Productivity (Yield/total water diverted)

Table 5. Economic Water Productivity under Rain fed Agriculture.

Crop Types	Yield (kg/ha)	Price of Crop (€/kg)	Price of Crop (€/ha)	P (m^3/ha)	Pe (m^3/ha)	18EWP (€/m^3) 19EPWP	20EPeWP
Wheat	1200	0.22	266.42	401.6	2604.1	0.066	0.102
Teff	700	0.25	174.84	401.6	765.0	0.435	0.229
Maize	800	0.12	96.21	401.6	2374.9	0.240	0.041
Mixed crops	1500	0.23	346.90	401.6	2775.9	0.864	0.125
Millet	900	0.18	158.19	401.6	2550.3	0.394	0.062
Barley	1000	0.21	212.77	401.6	2767.4	0.530	0.077
Sorghum	900	0.22	199.81	401.6	2775.9	0.498	0.072

Table 6. Economic water productivity under existing Irrigation practices.

Crop Types	Yield (kg/ha)	Price of Crop (€/kg)	Price of Crop (€/ha)	Total amount of water diverted (m^3/ha)	21EDWP (€/m^3)
Tomato	1870	0.14	259.48	12891.4	0.020
Potato	1315	0.42	547.41	17088.0	0.032
Onion	800	0.46	370.03	11294.1	0.033
Pepper	1600	0.37	592.04	18651.4	0.032
Cabbage	3600	0.06	199.81	16320.0	0.012
Maize	2400	0.12	288.62	9984.0	0.029

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[18] EWP-Economic Water Productivity(Economic return of crop /Total P (Pe)

[19] EPP-Economic Rainfall Water Productivity

[20] EPeP-Economic Effective Rainfall Water Productivity

[21] EDWP-Economic Diverted Water Productivity

SECTION E

SOIL CONSERVATION

A Precipitation Analysis and Conversion Tool (PACT) for Storm Disaggregation

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ABSTRACT

This study presented the results of disaggregated storms derived from rainfall measurement data with high temporal resolution for an agriculturally used watershed at Mistelbach, Lower Austria. The Precipitation Analysis and Conversion Tool (PACT) was used to disaggregate 958 storms covering the time period from 1994 to 2004. The full functionality of PACT includes not only the disaggregation of storms focusing on the parameters: storm duration, storm amount, time to peak intensity and ratio of peak intensity to average intensity but also the possibility of combining measured rainfall data with data from different sources or sensors covering parameters like humidity, solar radiation, wind velocity, wind direction and dew point. The climate input file for the WEPP (Water Erosion Prediction Project) model covering input parameters for one year can be facilitated within one single workflow in an efficient way.

1. INTRODUCTION

Soil erosion and surface runoff models are very useful to simulate erosion and deposition processes on different scale levels. RIST (Rainfall Intensity Summarization Tool, Dabney et al, 2004) was developed to prepare the input files derived from rainfall data for runoff, erosion, and water quality models including RUSLE, WEPP, SWAT, and AnnAGNPS.

The continuous simulation of runoff, erosion and infiltration processes with a physically based model like the WEPP (Water Erosion Prediction Project - Nearing et al, 1990) requires climate date covering at least the time stamp and precipitation with high temporal resolution. These climate data is processed within the climate component of the model. Additional parameters like solar radiation, humidity, wind velocity, wind direction and dew point from different sensors/sources are required to run the crop growth component of the model.

The developed PACT is able to disaggregate storms, to compile data from different sensors or data sources and to integrate all these data into the WEPP climate input file within one single workflow. In this study PACT was used to analyze rainfall data for a 11 years time series starting with 1994 and lasting to 2004. The focus of the investigation was on the (a) storm amount, (b) average intensity, (c) ratio of peak intensity to average intensity, and (d) time to peak intensity.

2. MATERIAL AND METHODS

The study area is located in a 40 ha large agricultural watershed in Mistelbach, Lower Austria.

The climate is dominated by warm summer and cold winter time. Mean average annual precipitation (Table 1) reached 633.5 ± 106.48 mm and mean annual temperature reached 9.6 ± 0.7°C during 11 years time period (1994 to 2004).

Table 1. Summarization of cumulated monthly and yearly precipitation (mm) for Mistelbach study site

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
1994	14	6	31	50	115	164	80	50	14	44	38	36	642
1995	23	19	49	49	54	140	15	8	125	44	38	36	600
1996	43	30	17	85	118	87	67	145	94	56	24	28	794
1997	15	14	45	33	78	64	220	29	15	21	77	27	638
1998	30	2	27	14	55	129	69	31	150	108	32	21	668
1999	16	54	26	43	73	103	142	31	57	12	52	41	650
2000	30	31	71	7	30	18	79	93	65	78	151	53	706
2001	23	5	41	39	38	51	143	44	160	12	53	38	647
2002	9	23	48	36	48	77	105	146	38	82	55	53	720
2003	51	2	1	26	36	32	30	25	45	47	34	62	391
2004	42	55	55	46	44	91	45	41	31	31	29	10	520
mean	26.9	21.8	37.4	38.8	62.6	86.8	90.5	58.5	72.0	48.5	53.0	36.7	633.5
stdv	13.9	18.9	19.4	20.8	30.2	45.2	59.2	47.9	52.5	30.6	359.9	15.2	106.5

The exact location of the rain gauge is latitude 48°34.98’ North and longitude 16°35.22’ East (WGS 84 datum). A tipping bucket rain gauge facilitates the measurement of the rainfall. The collection area of the gauge is 200 cm² and the tipping bucket is triggered after each 0.1 mm of rain. A Starlogger 6004 records the actual rain amount and the actual temperature measured at 1.5 m height with a PT100 sensor in 5 min intervals.

The rainfall data measurement during growing season builds the data source for the rainfall data analysis and storm disaggregation. The storm disaggregation is executed for each single day with precipitation lager than 0.1 mm. This means that all storms within one day are regarded as one single storm and that the number of storms (Table 2) equals the number of days with rainfall during growing season.

The calculation of the normalized time until the peak intensity was based on

$$t_p = \frac{D_p}{D} \tag{1}$$

while D_p was the duration until peak intensity and D the duration of the total storm event.

The normalized peak intensity was calculated

$$i_p = \frac{r_p}{i_b} \tag{2}$$

while r_p was the maximum intensity within the investigated intervals of the storm and i_b was the average intensity of the total storm.

3. RESULTS AND ANALYSIS

The disaggregation of 958 storms showed a mean annual precipitation of 5.15 ± 1.39 mm with a mean annual storm duration of 6.81 ± 1.15 h. The mean annual normalized time to peak showed 0.49 ± 0.04 while the normalized peak intensity showed 10.68 ± 2.05 (Table 2).

Table 2. Compilation of precipitation (mm), duration (h), ip and tp for eleven years (1994 - 2004) time periode

Year	N	Precipitation (mm) Mean	Precipitation (mm) Standard Deviation	Duration (h) Mean	Duration (h) Standard Deviation	ip Mean	ip Standard Deviation	tp Mean	tp Standard Deviation
1994	102	4.97	13.66	5.24	6.17	7.97	10.41	0.51	0.30
1995	85	4.40	11.90	7.33	7.50	14.41	23.65	0.41	0.31
1996	125	4.97	8.07	6.55	7.27	10.30	15.65	0.48	0.28
1997	93	5.32	8.01	7.81	7.43	9.98	12.26	0.51	0.30
1998	76	6.27	10.51	8.02	7.31	10.86	12.91	0.49	0.31
1999	80	6.01	8.18	7.34	7.20	10.78	14.89	0.51	0.28
2000	88	5.85	9.78	7.64	7.11	12.43	15.49	0.49	0.33
2001	120	4.25	5.73	7.26	7.07	11.66	16.28	0.53	0.32
2002	57	8.04	12.95	7.28	7.12	12.08	15.18	0.52	0.29
2003	73	3.05	4.57	4.33	5.22	7.01	11.13	0.50	0.27
2004	59	3.55	5.59	6.10	7.40	9.98	14.04	0.41	0.28
mean		5.15		6.81		10.7		0.49	
stdv		1.39		1.15		2.05		0.04	

The highest normalized annual average intensity was identified with 14.41 ± 23.65 in the year 1995 (Table 4). The lowest normalized annual average intensity 7.01 ± 11.13 was observed in the year 2003. The normalized time until peak intensity (Table 3) showed the lowest average annual value 0.41 ± 0.31 for the year 1995 and the same average annual value with a different standard deviation (± 0.28) for the year 2004. The highest average annual value 0.53 ± 0.32 was observed for the year 2001.

On average 22 ± 6 storms per year either exceeded the 75 % quantile of normalized time until peak intensity or fell below the 25 % quantile of normalized intensity. These specific storms can contribute to high surface runoff rates.

Table 3. Variation of tp over 11 years. N accounts for the total number of observed storms in one year.

Year	Minimum	Maximum	Range	Quantile 25%	Quantile 75%	Mean	Standard Deviation	N
1994	0.006	0.993	0.987	0.38	0.72	0.51	0.30	102
1995	0.001	0.994	0.995	0.10	0.50	0.41	0.31	85
1996	0.001	0.995	0.994	0.25	0.63	0.48	0.28	125
1997	0.001	0.994	0.993	0.22	0.75	0.51	0.30	93
1998	0.012	0.979	0.967	0.22	0.79	0.49	0.31	76
1999	0.008	0.996	0.988	0.25	0.70	0.51	0.28	80
2000	0.001	0.995	0.994	0.15	0.81	0.49	0.33	88
2001	0.004	0.995	0.991	0.25	0.86	0.53	0.32	120
2002	0.006	0.995	0.989	0.36	0.77	0.52	0.29	57
2003	0.015	0.994	0.979	0.25	0.66	0.50	0.27	73
2004	0.008	0.995	0.987	0.12	0.50	0.41	0.28	59

Table 4. The variation of ip over 11 years. N accounts for the total number of observed storms in one year.

Year	Minimum	Maximum	Range	25 %-tile	Quantile Median	75 %-tile	Mean	Standard Deviation	N
1994	1	46.04	45.04	1.00	3.54	9.55	7.97	10.41	102
1995	1	143.88	142.38	1.00	5.80	18.21	14.41	23.65	85
1996	1	102.00	101.00	1.20	4.52	11.70	10.30	15.65	125
1997	1	59.33	58.33	2.00	4.93	12.00	9.98	12.26	93
1998	1	80.37	79.37	3.40	7.54	13.33	10.86	12.91	76
1999	1	72.91	71.91	1.80	4.29	12.10	10.78	14.89	80
2000	1	85.42	84.42	1.84	6.33	18.21	12.43	15.49	88
2001	1	99.11	98.11	1.24	5.00	13.50	11.66	16.28	120
2002	1	69.33	68.33	1.75	5.02	13.00	12.08	15.18	57
2003	1	65.00	64.00	1.00	3.35	7.53	7.01	11.13	73
2004	1	79.71	78.71	1.00	5.50	13.99	9.98	14.04	59

4. CONCLUSION

This study showed that PACT is a useful tool to analyze duration, precipitation, normalized time until peak and normalized intensity of storms. PACT fulfilled the requirement of converting and compiling available climate data with high temporal resolution into a WEPP readable climate input file. The analysis of the whole 11 years period of rainfall data could be achieved within 30 minutes by applying PACT, which was a notable reduction of resources compared to the manual approach. Further improvement of PACT can be seen in the handling of the storm duration as well as the integration of automated calculation of the rain erosivity factor (R-factor).

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The Impact of Land Use on Nutrient Concentration in Upper Water Streams in Slovenia

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ABSTRACT

According to the Water framework directive the EU countries have to define water bodies at risk. The main purpose of this work is to examine if there is any statistical relationship between land use and nitrogen and phosphorus concentration in upper part of 35 Slovene water streams.
We are using advanced data elaboration techniques to cope with GIS oriented data. The data of land use (Corine Land use Cover) were combined with the data of nitrate, ammonium and total phosphate concentration in surface water. Stepwise regression procedure was used in the selection of independent variables for the models. There is a statistically significant relationship between the shares of different land use in the watershed and ammonium, total phosphate and nitrate concentration in surface water on sampling station at the 99% confidence level. This type of analysis could be incorporated in a first rough estimation if water body is at risk.

1. INTRODUCTION

According to the Water framework directive (2000/60/EU) the EU countries have to define water bodies characterised with the same ecological, morphological and water quality characteristics. The main aim of the above mentioned directive is to reach good water status regarding quality and quantity of water by year 2015. The article 5 of the directive among others requires that every EU country makes the analysis of characteristics of watersheds and of the impacts of men's activity in them. Water bodies at risk should be defined as a first step. Water bodies at risk are defined as water bodies for which we are not completely sure that water quality will meet the requirements by year 2015. If someone wants to improve water quality, he should know how different men's activities in the watershed impact to water quality.

Different point and non-point pollution sources can deteriorate the water quality. Agricultural activities have been defined as major sources of non-point pollutants in water (Charbonneau and Kondolf, 1993), even in some cases population with disorganised sewage systems could be the main source of non-point pollutants in water, as well (Aravena et al., 1993). Agricultural land use is supposed to produce the highest amounts of nitrogen (Tong and Chen, 2002), still Fisher et al. (2000) reported that municipal sources of nutrients must be reduced too, to make significant progress in the watershed concerning water quality. There is a strong relationship between land use and the quality of water especially for nitrogen and phosphorus in upland watershed (Gburek and Folmar, 1999). Changing land use and land management practices are one of the main factors impacting runoff water quality (Mander et al., 1998). Current methods on predicting water quality in river catchments based on land-use patterns are still in development (Tong and Chen, 2002).

The main purpose of this work is to examine statistical relationship between land use and nitrogen and total phosphate concentration in upper part of Slovene water streams.

2. MATERIALS AND METHODS

2.1. Land Use

We defined 126 4^{th} range watersheds in Slovenia using a computer-based GIS software system Arc Info. We have chosen 35 water quality-monitoring stations for further analyses based on criteria that they are located in watersheds with the area less than 500 km^2. Accurate watershed area was defined for each water quality-monitoring station.

Land use from Corine land Cover 2000 (CLC 2000) was determined for each water quality-monitoring station watershed area. Resolution, used for land use determination was 25x25 m^2. Land use categories used for this analysis were as follows: urban, forest, fields, orchards and vineyards, grassland and mixed land use. Once the image was classified, the area extent of each land use category was calculated for each watershed area.

2.2. Water Quality

Concentration of nitrate, ammonium and total phosphate in surface water for the period 1998-2002 has been obtained from the state's monitoring program database. The monitoring program has been started in 1986 (ARSO, 2002). We took data from the period around the year 2000, when land use data were determined. Water samples were taken once to ten times per year.

2.3. Statistical Analyses

The question about relationship between land use and water quality has been addressed by applying multiple regression method considering nutrient concentration as dependant variables and the area of land uses as independent variables. Statistical analyses were performed with Statgraphics plus software version 4 (Manugistics®). In most cases non-point pollutants received from contributing watershed can be described in the form of an exponential models (equation 1)

$$npp = \alpha e^{\left(\sum_1^i \beta_i luc_i\right)} \qquad (1)$$

Where: npp is non point pollutant concentration, luc is land use category, α is the intercept, β is a parameter that specifies the direction and strength of the relationships between each land use category and non point pollutant concentration, i is a number of different land use category in a catchment (Basnayat et al., 1999). Following this formula, the dependent variable in the multiple regression analysis was transformed with natural logarithm to reduce asymmetric distribution. Other authors (Tong and Chen, 2002; Fisher et al., 2000) reported the need of log transformation of pollutant concentration data to normalize them and prepare for further statistical estimation.

3. RESULTS AND DISSCUSION

3.1. Land Use

Watershed areas for selected water quality monitoring stations have 183 km^2 in average (range is 7-490 km^2). There is forest in all watersheds and it is the most abundant land use in watersheds in average. It covers 70 % of area in average with minimum and maximum, 28 % and 95 % respectively. Shares of mixed land use, grassland, fields, urban land use and orchards and vineyards follow them. Observed headwater watershed areas have higher share of forest and lower share of agricultural land as they are in Slovenia as a whole, which they are according to CLC 2000 61 % and 25 % respectively. Some land use categories (for example orchards and vineyards or fields) do not exist in all watersheds. Average parcel in Slovenia covers an area less than 0.5 ha. A lot of parcels have dimensions smaller than the chosen resolution for land use determination so the share of mixed land use is quite high.

3.2. Water Quality

Overall average concentration of ammonium, nitrate and total phosphate in surface water in observed monitoring station in the period 1998-2002 were 1.059 (<0.002-19.508), 4.087 (0.433-12.089) and 0.571 (<0.002-11.383) mg/l respectively. Pecárova and Pecár (1996) reported average annual nitrate concentration 1.76-2.78 mg/l in some mountainous catchments of Slovakian surface waters.

3.3. Land Use and Pollutants Concentration in Surface Water Linkage

There is a statistically significant relationship between the shares of different land use in the watershed and ammonium, total phosphate and nitrate concentration in surface water on sampling station at the 99 % confidence level. P-values for all three models from the ANOVA are less than 0.01 (Table 1). Stepwise regression procedure was used in the selection of independent variables for the models.

The relative shares of urban areas, forest, fields, grasslands and mixed land use have an impact on the ammonium and total phosphate concentration in the surface water on the sampling station. Orchards and vineyards, which are not very abundant in the upper watershed areas, do not have a significant impact on concentration of any of the observed pollutants.

Although the observed upper streams supposed to be less populated than the lowland ones in Slovenia, analyses show the most pronounced impact of urban area to ammonium and total phosphate concentration in observed surface water. Also, Fisher et al. (2000) reported that urban areas have huge impact on water quality and that municipal sources of nutrients must be reduced to make significant progress in the watershed. The relative share of urban areas has a statistically significant impact on ammonium and total phosphate concentration in the surface water, but it does not impact the nitrate concentration. The main reason for positively correlated impact of urban area to ammonium (and not to nitrate) in surface water is probably in the form of nitrogen in human excreta. Pecárova and Pecár (1996) reported relatively high phosphate concentration in Slovakian watershed resulting from contribution of municipal sewage, but wastewater was only treated mechanically. Tong (1990) also stated that urban development in the watershed could cause substantial modification on water quality.

Table 1. Multiple regression equations for pollutants concentration depending on land use in the watersheds

Analysis	r^2 (%)	P	Multiple regression equation
Ammonium (mg/l) vs. land use (%)	56	0.0001	$\ln(NH_4^+) = -33.46+1.10\cdot u+0.29\cdot fo+0.31\cdot fi+0.27\cdot g+0.34\cdot m$
Phosphate (mg/l) vs. land use (%)	67	0.0000	$\ln(\text{tot } PO_4^-) = -30.34+0.91\cdot u+0.26\cdot fo+0.29\cdot fi+0.25\cdot g+0.32\cdot m$
Nitrate (mg/l) vs. land use (%)	42	0.0019	$\ln(NO_3^-) = -3.06+0.04\cdot fo+0.06\cdot fi+0.07\cdot g+0.05\cdot m$

Note: u=urban area, fo=forest, fi=fields, g=grassland, m=mixed land use.

4. CONCLUSIONS

Our research showed statistical relationship between land use categories and nutrient concentration in surface water in upper streams. To improve water quality appropriate measures regarding urban land use and agricultural land use should be implemented. Presented methodology can provide a simple but effective tool for planners and policy makers as well as government resource managers for defining the impacts of land use on water resources quality. This methodology could be incorporated into the water bodies at risk defining methodology. It could serve as a first rough estimation if particular water body is at risk or not.

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Present Topics in Applied Soil Water Management Research at the Institut für Kulturtechnik in Petzenkirchen

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ABSTRACT

The "Institut für Kulturtechnik und Wasserhaushalt" (Institute for Soil Water Management Research) in Petzenkirchen is developing methods and measures to decrease the pollution of ground and surface waters and soil erosion. To reach these goals we link extensive field monitoring, soil and water sampling and analyses as well as the application of simulation models together to find sustained solutions to the problem. In this presentation some examples of our current work are given and some problems, which are unsolved so far, will be discussed.

1. REDUCTION OF GROUNDWATER POLLUTION BY MEANS OF APPROPRIATE LAND USE

On an arable site of the pre-Alpine region of Lower Austria, nitrate concentrations of the water leaching to the groundwater has been measured continuously at 110 cm below soil surface since 1990. Starting with October 1994, the traditional local crop rotation was followed by green fallow. Fig. 1 demonstrates the tremendous reduction of the nitrate concentration of the seepage water caused by this modification in land use. While the mean nitrate concentration of the seepage water was about 100 mg NO_3/l for the period 1990 – 1994, it decreased to an average of ~ 12 mg NO_3/l after full plant development (first cut). Although this modification in land use is a radical measure it is at least an appropriate one for catchments of wells for drinking water.

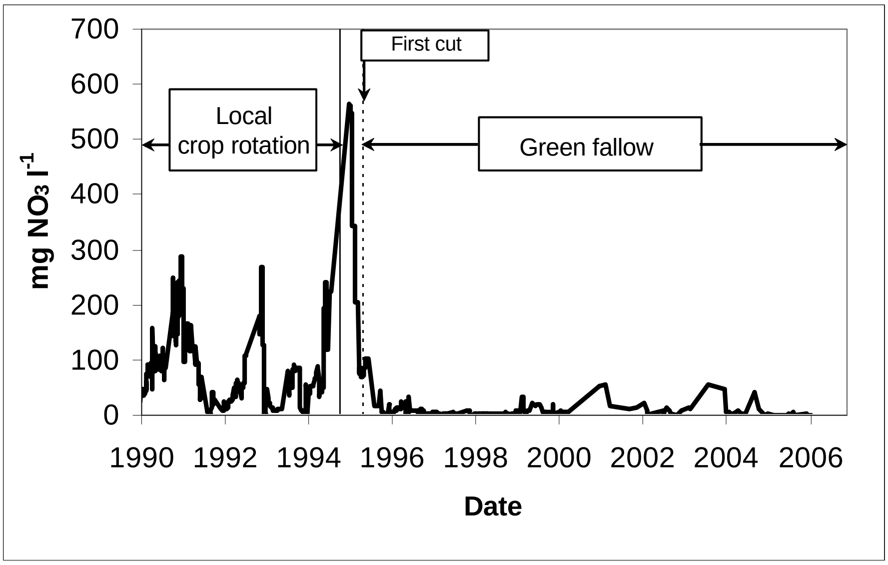

Figure 1. Nitrate concentration of the seepage water for different management practices on arable land.

2. OPTIONS TO REDUCE THE NITRATE CONCENTRATION IN THE GROUNDWATER OF THE MARCHFELD

Pollution of the groundwater by nitrate still is a serious problem in some areas especially in Eastern Austria. In the so-called "Marchfeld" east of Vienna, nitrate concentrations of the groundwater are far too high although most of the farmers take part in the Austrian Program for an Environmental Sound Agriculture (ÖPUL) since several years. Using the model STOTRASIM we now are checking the effect of different agronomic measures to reduce the Nitrate load by systematic changing of the respective input parameters in respect to cropping pattern and fertilization. For a typical Marchfeld soil (Fig.2) the simulations show that input of fertilizer must be drastically reduced to lower the Nitrate concentration of the seepage water to a level of 50 mg/l, which is the threshold value for ground water according to the European water framework directive!

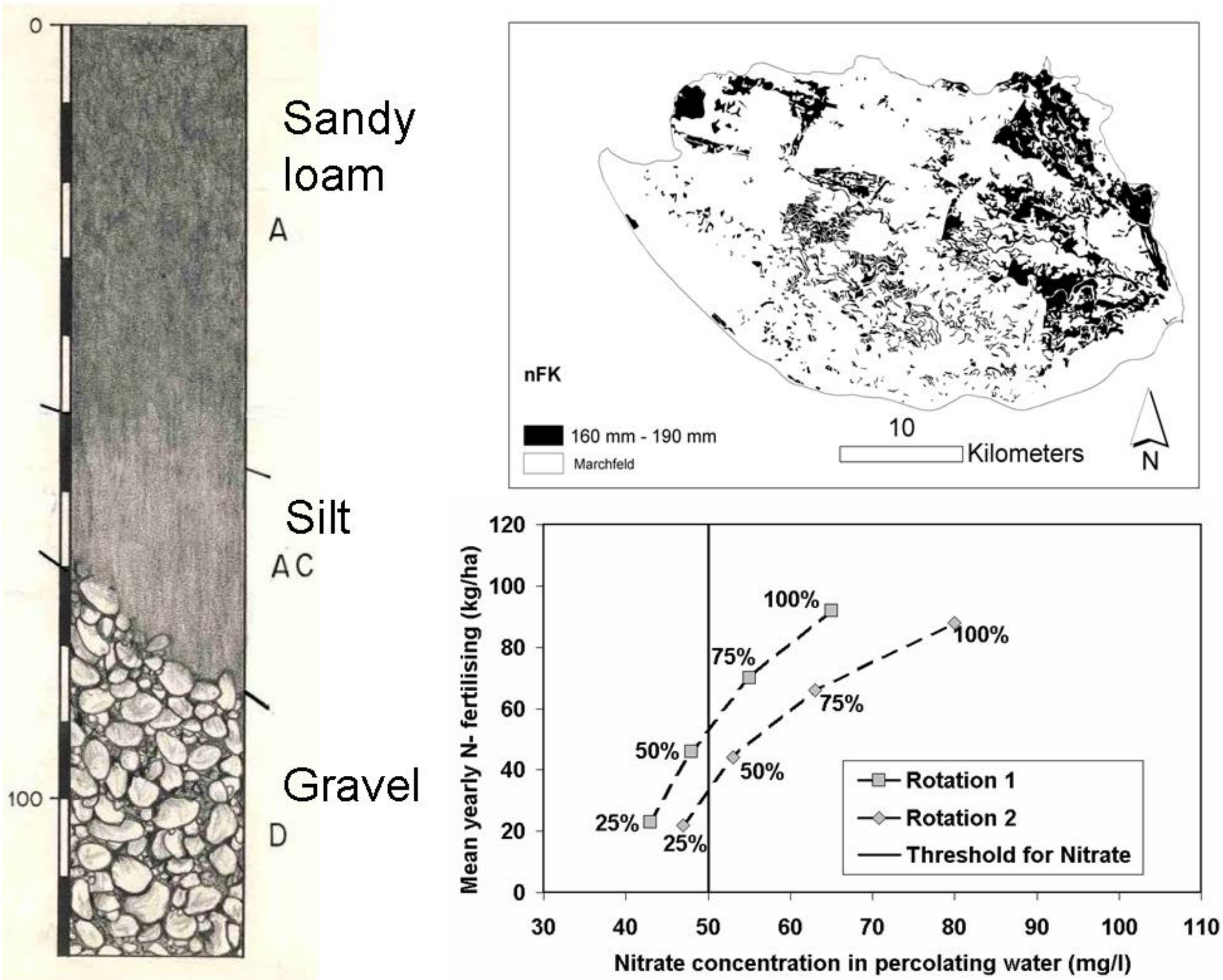

Figure 2. Effect of reduced fertilization on the Nitrate concentration of the seepage water.

3. ASSESSMENT OF THE GROUNDWATER RECHARGE FROM NATIVE GRASSLAND IN THE PANNONIAN CLIMATE

Knowledge of the natural ground water recharge is essential for sustainable use of this valuable resource. In order to calibrate and test the simulation model SIMWASER by which soil water balance may be assessed, we maintain several soil moisture monitoring stations in the "Marchfeld" area. By systematically measuring of the soil water content and soil matric potential throughout the whole soil profile we gather information about temporal changes of the soil water storage as well as the hydraulic gradient at the lower end of the profile. So we are able to estimate percolation flux and to derive actual evapotranspiration from the soil water balance. In the following example the outcome of a soil moisture monitoring station situated in natural grassland at the “Weikendorfer Remise” is shown. In Tab. 1 the results of the measurements and of the simulation are listed as yearly means for the period from November 2002 to May 2006.

Table 1. Measured and simulated soil water balance (mm/a).

	Precipitation	Percolation	Evaporation	Change in storage
measured	640	170	460	10
simulated	640	170	450	20

4. DEVELOPMENT OF A SOIL EROSION MAP OF AUSTRIA

During the last 40 years rather substantial changes in the Austrian agriculture took place. To estimate the effects of such changes erosion models are usually employed. New technical advancements (computer power, GIS) made it possible to compute soil erosion with a high spatial resolution for large geographical data sets. This information is useful for evaluation of agricultural programmes to reduce soil erosion. We therefore used best available data for to compute a soil erosion map for agriculturally used areas in Austria. As a general basis for the evaluation of soil erosion by water the model approach of the well known USLE was chosen. The USLE is an empirical model where a set of erosion influencing factors is numerically evaluated to calculate long term mean annual soil loss. In spite of numerous limitations, the USLE is certainly still the most applied model worldwide. Main reason for this is the lack of suitable datasets in space and time which would be needed for more complex erosion models. Best available basic digital data for our purpose were the Corine data set and agricultural statistics at community level, the digital soil map for Austria (scale 1:25000), a DEM (resolution 10 m) and a map of mean annual rainfall (resolution 7.5 km). In various steps, these data were transformed into the required model input parameters to calculate mean annual soil loss. Austrian wide application of the model reveals areas, which are especially endangered by soil erosion and thus need concentrated efforts for the implementation of control measures such as conservation tillage. As a consequence of the strong relationship between the type of agricultural land use and soil erosion on the one hand, and the distinct land use due to the environmental frame work within Austria on the other hand, agriculturally used areas with increased soil erosion are mainly restricted to the eastern and south-eastern parts of Austria. In terms of political borders, mainly the federal provinces (NUTS level 2 of European classification) of Upper Austria, Lower Austria, Styria, Burgenland and parts of Carinthia may be identified as risk areas.

5. GEOREFERENCED DATABASE FOR SOIL PHYSICAL DATA

Our laboratory is a service sector within the institute supporting our main tasks by providing especially soil physical data such as water retention characteristics, texture or saturated/unsaturated hydraulic conductivity. To manage these data, a georeferenced database has been developed. Supported by GIS, data availability and details for a particular area of interest may easily be recalled as schematically demonstrated by Fig. 3. At present the database contains 470 sites with a total of about 17000 single data sets. This dataset refers to the data that have been generated between 1994 and 2006. In a next step we will add further data originating from earlier years.

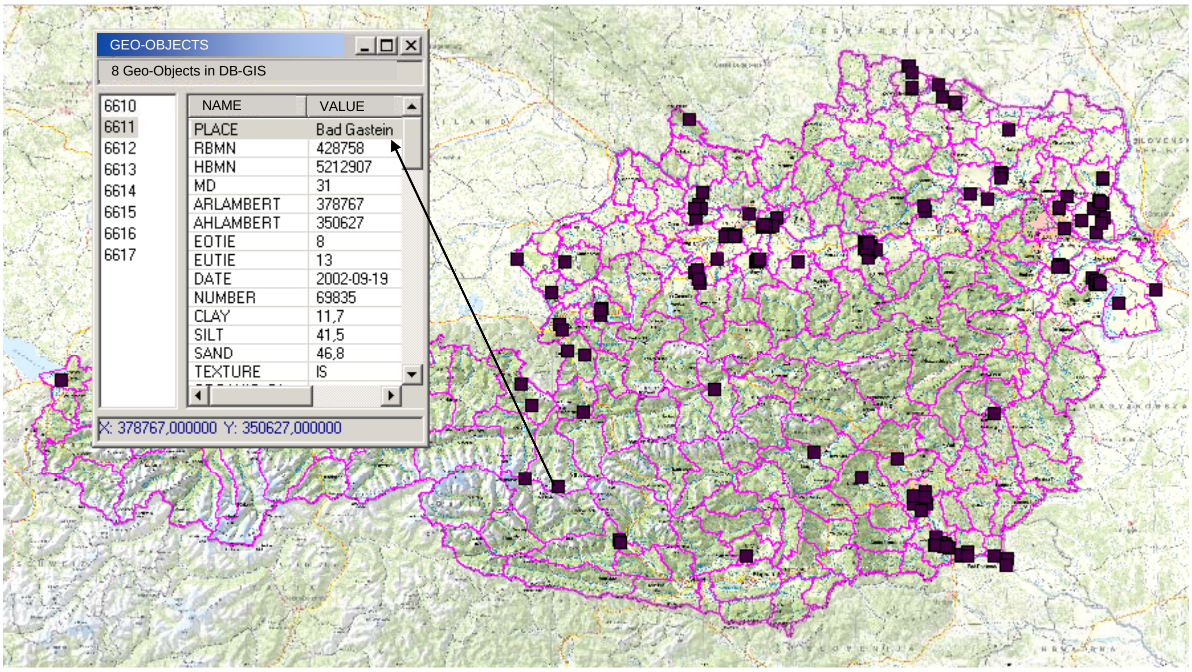

Figure 3. Sites with laboratory data (1994-2006).

6. DISCUSSION

The examples given above may show the ability of applied soil physics in combination with mathematical simulation and geographical information systems in formulating actual problems concerning more sustainable land use here in Austria or elsewhere. Still many details keep unsolved, for instance measurement of water content and soil matric potential in frozen soil as well as getting the "absolute" volumetric water content by using TDR and/or FDR-methods without proper calibration! Application of the "virtual lysimeter" as proposed by Prof. Kastanek in assessing ground water recharge needs very exact knowledge of the unsaturated hydraulic conductivity function, the standard deviation of which still is quite too high for yielding results that would be more reliable than measurements by "real" lysimeters, which are known to be influenced by so many factors. Concerning the assessment of erosion the simple USLE model only can give some rough impression on the areas to which attention should be given in advising the farmers to use suitable agronomic measures and cropping pattern to reduce soil erosion. Refinement of such areas needs better data and other modelling approaches. So there is plenty of work ahead of us!

Effects of Soil Tillage on Carbon Dioxide Emissions

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ABSTRACT

Tillage often decreases soil organic matter content and increases the flux of carbon dioxide (CO_2) from soils. Objective of this field study was to assess the impact of tillage practices on CO_2 emissions from two agricultural used fields. Following tillage treatments were included: 1) conventional tillage (CT), 2) conservation tillage (CS), 3) direct seeding (DS), 4) reduced tillage (RT), and 5) no-till (NT). All systems except CT used cover crops during the winter period.
All reduced tillage practices were able to increase the soil organic carbon (SOC) expressed on a land area basis by 16 to 22 % during a period of 5 to 15 years. Soil respiration led to CO_2-C losses between 0.302 and 0.433 $kg.ha^{-1}.h^{-1}$. Highest releases were always measured from CT. Overall a total amount of 1513 to 2283 kg CO_2-C ha^{-1} were lost from the soil throughout one growing season. On one field, no significant differences between the treatments were observed while on the second field management practices with reduced tillage intensity (RT and NT) had significantly lower carbon losses than CT.

1. INTRODUCTION

Carbon dioxide is an important greenhouse gas (GHG) accounting for 60% of the total GHG effect. Soil is a major source for atmospheric CO_2. In the event of growing threats of global warming due to GHG emissions, reducing CO_2 emissions by sequestering C in the soil is a prime importance. Soil management practices like increasing soil organic carbon content, reduced tillage and mulching can play an important role in sequestering C in soil.

Measurement of soil CO_2 flux for different tillage treatments are important for identifying management practices that may increase this flux and thus affect the global C balance (Post et al., 1990). Some data about carbon dioxide emissions are already available for South (Reschk et al., 2002) and North America (Jacinthe et al., 2002; Reicosky, 1997) as well as for Asia but nearly no information is available for Europe. The objective of this field study was to investigate the effects of different tillage systems on soil respiration and CO_2 emission under Austrian conditions.

2. MATERIALS AND METHODS

Measurements of soil CO_2 flux were carried out from April to November 2005 on two agricultural fields in Pixendorf, Austria (48°17´ N, 15°58´ E, elevation 260 m). Long-term average precipitation amounts to 667 mm, average air temperature 10.8 °C. Soil texture is silt loam with 28 % sand, 62 % silt, 10 % clay and 1.2 % organic carbon content (OC). The whole experiment consisted of an erosion and a tillage experiment. In both experiments the impact of different tillage practices on soil respiration was investigated.

The erosion experiment started in 1997 and included following treatments:

1) Conventional tillage (CT1)
2) Conservation tillage (CS) with cover crop during winter period, and
3) Direct seeding (DS) with cover crop during winter period.

The tillage experiment was initiated in 2000 comparing following tillage practices:

1) Conventional tillage (CT2)
2) Reduced tillage (RT) with cover crop during winter period, and
3) No-till (NT) with cover crop during winter period.

Investigated fields were 4 m wide and about 80 m long with slopes between 3 and 5 %. Each treatment was replicated three times. The soil CO_2 flux was measured with the closed chamber method. In each plot two chambers with a volume of 2 l were inserted 6 cm into the soil, resulting in 6 reps for each treatment. The chambers remained in place during the whole cropping season. The measurements were performed always between 10 am and 2 pm. During the gas sampling the chamber was closed with a lid for 30 min and samples were drawn with a gas-tight syringe through a septum. The increase in CO_2 concentration was corrected with the CO_2 concentration outside the chamber and the air temperature inside and outside the chamber. Concurrent measurements of soil temperature at 2 cm depth and of soil water content in 0-10 cm and 10-20 cm were made at the same time. The gas samples were then brought to the laboratory and analyzed with a GC-TCD (thermal conductivity detection). Precipitation and air temperature were measured in 5 min intervals throughout the whole period.

3. RESULTS

Since 1997 soil loss and surface runoff were measured from 4 m wide and 15 m long erosion plots in the erosion experiment. Long-term average soil loss from the different tilled fields ranged between 0.41 t ha^{-1} a^{-1} (DS) to 3.99 t ha^{-1} a^{-1} (CT1; Table 1; Klik, 2003) with runoff amounts between 15.0 (DS) and 25.4 mm (CS). 5.5 to 44.6 kg organic carbon were lost per hectare and year were lost by these erosion processes (Table 1):

Table 1. Results from long-term erosion experiment (1997-2005).

Parameter	Treatment Erosion experiment CT1	CS	DS
Soil loss ($kg.ha^{-1}.a^{-1}$)	3.99	1.90	0.41
Surface runoff ($mm.a^{-1}$)	23.8	25.4	15.0
OC loss ($kg.ha^{-1}.a^{-1}$)	44.6	21.0	5.4

In 2005 sunflowers were planted on the fields. At the times of gas sampling air temperature ranged from 8 to 21°C and soil temperatures from 5.4 to 25.4 °C. Gravimetric soil water contents (0-10 cm) were between 6 and 26 % (data not shown). Soil water contents were mostly lower in the erosion experiment (CT1, CS, DS) than in the tillage experiment (CT2, RT, NT). Although numerical differences were found between treatments statistical analysis did not shown significant differences in soil moisture (Table 2). In the tillage experiment NT led to a slight increase in bulk density which can be attributed to the low tillage intensity.

The amount of soil organic carbon (SOC) was expressed on a land area basis (Table 2), calculated from the measured OC contents and the dry bulk density. In the erosion experiment reduced tillage practices (CS and DS) were able to increase the SOC amount by around 22 % during eight years. Five years of reduced tillage intensity (RT) improved the level of SOC by about 16 % compared to conventional tillage. No-till practice did not show this positive effect. This can be explained that with conservation tillage plant residues were mixed and partly incorporated in the soil when using the cultivator while with no-till the organic material stayed at the soil surface and was decomposed without being incorporated.

On average, carbon losses between 0.302 and 0.433 kg.ha^{-1}.h^{-1} were measured due to soil respiration (Table 2). Differences between the treatments were not statistically significant in the erosion experiment. In the tillage experiment intensive tillage (CT2) led to significantly higher carbon losses than no-till. Reduced tillage was not significantly different from CT2 and NT.

Table 2. Average values of soil water content, dry bulk density, soil organic carbon and CO_2 emissions during investigation period

Parameter	Treatment					
	Erosion experiment			Tillage experiment		
	CT1	CS	DS	CT2	RT	NT
Soil water content (%)	14.4 [a]	16.0 [a]	15.8 [a]	17.0 [a]	18.7 [a]	18.6 [a]
Dry bulk density (g. cm^{-3})	1.372	1.381	1.375	1.352	1.34	1.412
SOC (t. ha^{-1}.a^{-1})	22.19	26.81	27.11	34.20	38.92	32.36
CO_2 emission (kg C ha^{-1}.h^{-1})	0.308 [a]	0.317 [a]	0.302 [a]	0.433 [a]	0.343 [ab]	0.331 [b]

[a] values followed by the same letter are not statistically significant different ($p < 0.05$)

Fig. 1 shows the temporal distribution of the soil respiration measurements in the tillage experiment (Fig. 3). In addition daily rainfall and air temperature values as well as soil temperatures at sampling are displayed. Overall higher CO_2-fluxes were measured in the tillage experiment than in the erosion experiment (data not shown). High fluctuations and a seasonal trend with higher values in summer can be observed. The study showed that soil temperature had a higher impact on CO_2 fluxes ($R^2 = 0.4326$) than soil moisture or organic carbon content.

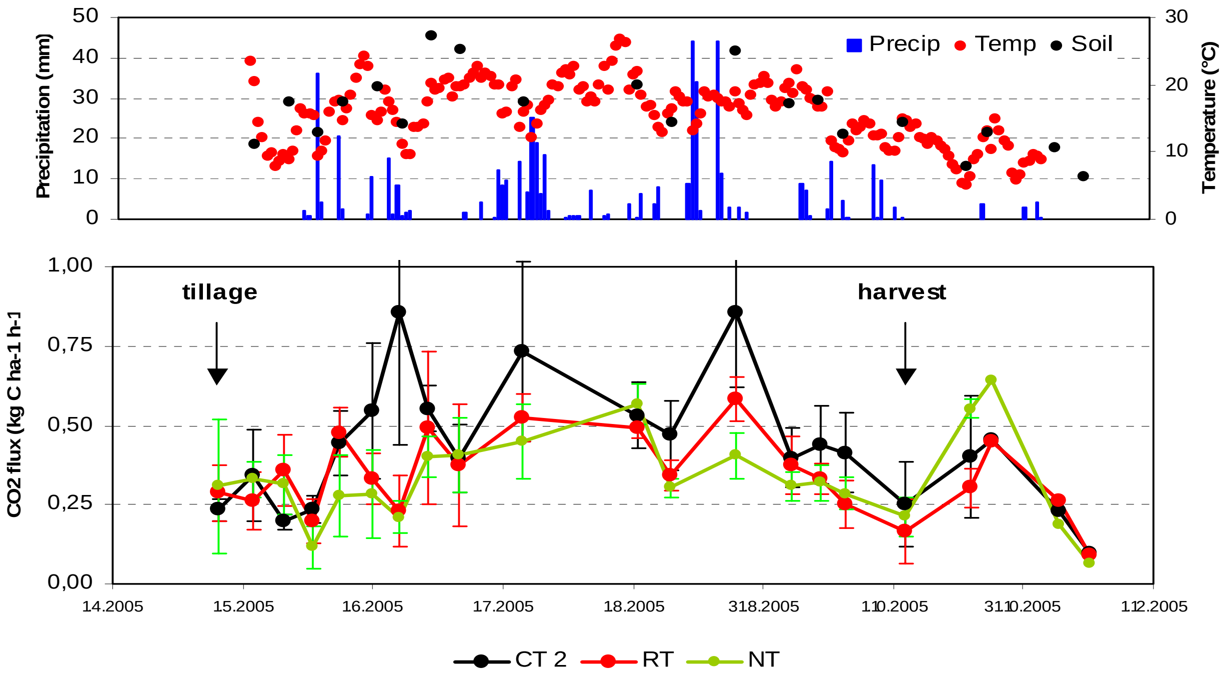

Figure 1. Temporal distribution of CO_2-C flux from soil surfaces of the tillage experiment

Overall, between 1513 and 2283 kg C were lost per hectare during the growing season (middle of April until middle of November). In the erosion experiment differences between the tillage treatments were not significant. In the tillage treatment, the type of tillage affected significantly the release of CO_2-C from the soil. Reduced tillage intensity led to significant reductions of soil respiration and therefore contributed to carbon sequestration. Due to conventional tillage 6.7 to 7.2 % of the OC stored in the 0-10 cm soil depth were lost during the investigation period by soil respiration. Corresponding values for CS, DS, RT and NT were 6.0, 5.6, 4.6 and 5.4 %, respectively. Nevertheless, the data show that site specific conditions like soil temperature and soil moisture greatly influence the emission rates.

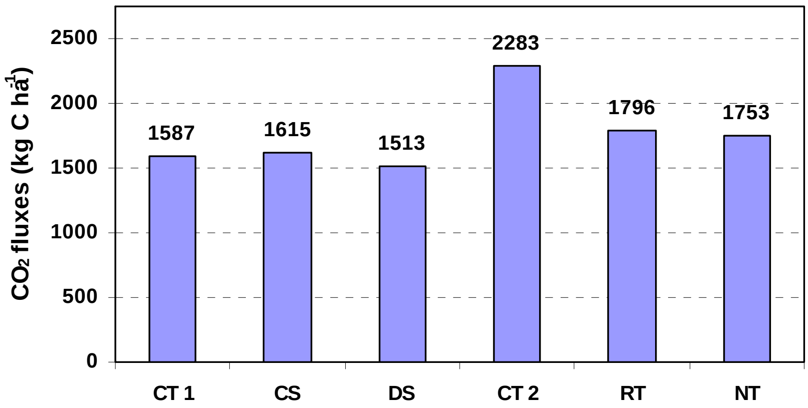

Figure 2. Seasonal losses of CO_2-C from investigated tillage treatments (April 25-November 16, 2005)

4. CONCLUSIONS

Soil respiration releases CO_2 and contributes to greenhouse gas emissions. The field study showed that CT often leads to higher carbon dioxide losses while soil management systems with reduced tillage intensity like conservation or no-till are able to reduce this losses significantly and to improve carbon sequestration. Nevertheless, site specific conditions like actual soil temperature and soil water content mainly affect this process.

ACKNOWLEDGEMENT

The study was partly funded by the Hochschuljubiläumsstiftung of the City of Vienna.

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Application of Geostatistics Concept in Agri-Environmental Sciences: A Case Study Addressing Soil and Organic Matter Redistribution by Erosion Processes to Assess Soil Fertility and Establish Sediment Budget

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ABSTRACT

The spatial correlation of ^{137}Cs (Bq m^{-2}), organic matter content (%) and soil erosion-sedimentation patterns was estimated in a 2.6 ha field using geostatistics coupled with a Geographic Information System (GIS). The spatial variability of different agroenvironmental parameters was characterized through geostatistical method in the field localized in the southern part of the Boyer River watershed, in Eastern Canada. Semivariograms were produced to take into account the spatial structure present in the data. A good autocorrelation and reliable variograms were found for each parameter tested ($0.87 \leq R^2 \leq 0.95$ and $0.7 \leq$ Scale/Sill ≤ 0.96). Soil organic matter spatial redistribution was correlated to soil erosion and sedimentation as shown by the significant relationship ($R = 0.8$; $p \leq 0.01$; $n = 42$) in the first 20 cm between ^{137}Cs and organic matter. The net sediment production was estimated for the whole field as 7.8 t ha^{-1} yr^{-1} with a sediment delivery ratio of 96 %. These results show that due to erosion processes and especially snow melt erosion, most of the sediment mobilized was transported out of the field.

1. INTRODUCTION

In environmental studies and resource assessment, the objective of a sampling is to ensure sufficient sample numbers for interpolation, in order to attribute values for areas not exhaustively sampled and to develop patterns. Therefore, the spatialisation of data is an important component in soil and water management. Variography can be used to quantify and to model the spatial correlation (also called structure) between locations and to characterize the spatial behaviour of the data. It is possible to model the relationship between the sample values and the distance that separate them. In the 1960s, geostatistics were used in the mining industry and later were extended to many other topics and sciences like geomorphology, geology, hydrology, geography. Despite the fact that this approach was developed some 50 years ago, this concept has not reached the managers and surveyors for whom it was intended. The main utility of geostatistics, likewise variography, in assessing soil erosion-sedimentation using fallout radionuclides (FRN) is not only to spatialise the redistribution and establish a budget of FRN but also to spatialise soil movements using conversion model and to estimate sediment budget using '*area weighted mean*' as well as to improve sampling survey.

The Boyer River watershed drains a 217 km^2 territory, in eastern Canada, Quebec. Over the last decades, the agricultural activities taking place in the watershed have specialized and intensified. At the same time, a quantitative and qualitative degradation of the soil and water resources of the watershed was noticed. Continuous degradation of water quality, particularly from high levels of suspended solids and phosphorus and high sedimentation rates have been identified as the most probable causes for the decline of the Rainbow Smelt fish population. These facts suggest that soil erosion is an important factor in this environment.

In the last five years, the magnitude of soil erosion in the Boyer River watershed has been investigated using ^{137}Cs measurements. This technique was used at different scales, in Canada and in other regions (Mabit et al., 2002; Ritchie and Ritchie, 2005). In the Boyer River watershed, the magnitude of soil erosion was investigated using a GIS oriented sampling strategy for ^{137}Cs measurements in selected fields representing the main soil-slope-land use combinations encountered in the watershed (Mabit et al., 2006).

The present paper reports on the use of geostatistics to assess soil redistribution, as indicated by ^{137}Cs measurements, and its spatial relationship with some soil parameters, particularly organic matter (OM) content. The main goal of this project was to determine at the field scale the structure of spatial dependence of different soil chemical properties, to map soil movements and to establish a sediment budget using the information provided by geostatistical approach.

2. MATERIALS AND METHODS

A typical 2.6 ha field, located in the upstream part of the Boyer River watershed was investigated. The slope does not exceed 2%. The soil is a sandy loam, with an average composition of 54% sand, 33% silt and 13% clay. The average organic matter content is 4.3%. Soil samples were collected along seven parallel transects laid down the dominant slope. On each transect, the distance between sampling points was adjusted to take into consideration the micro-topography. A total of 42 points were sampled at 0-20, 20-30 and 30-40 cm depths. Bulk density, ^{137}Cs activity (Bq kg^{-1}), organic matter content (%) and particle size distribution of each soil sample were measured in the laboratory. Soil samples were dried and sieved at 2 mm. The ^{137}Cs measurements were done on the fine fractions (< 2 mm) by gamma spectroscopy. Counting times ranged between 10 000 and 50 000 seconds, depending on the ^{137}Cs activity of the soil. This was sufficient to obtain a counting error less than 10% at the 95% confidence level. ^{137}Cs activities (Bq kg^{-1}) were converted to areal activities (Bq m^{-2}) using the bulk density of each sample. The conversion of the areal activities of ^{137}Cs into soil movement (t ha^{-1} y^{-1}) was done using the Mass Balance Model 2 (MBM 2) developed and updated for IAEA by Walling and He (2005). For the particle size factor and the relaxation depth, default values were used. The proportional factor was preset as 0.8 due to frozen period and field condition.

The spatial distribution of ^{137}Cs, organic matter content and soil movement was analyzed and described using geostatistics and variography concepts. Geostatistical and spatial correlation analysis was performed by GS$^+$ version 7 software (Gamma Design Software, 2004). Afterwards the different variographic parameters and fitted models were introduced in the GIS software Surfer 8.00 (Golden Software., 2002). A spatial soil movement distribution was produced through mapping, using Kriging interpolation. On the basis of the resulting map, a sediment budget was also produced, using the Surfer 8 package.

3. MAIN RESULTS AND DISCUSSION

The organic matter content of the soil ranged from 2.3 to 7.3 % with an average of 4.3 ± 0.4 % (average ± 95% confidence interval). The mean value of the ^{137}Cs reference sites was estimated at 2970 ± 110 Bq m^{-2} with a coefficient of variation of 4 % (n = 9). The ^{137}Cs activity in the agricultural field varied from 531 to 4180 Bq m^{-2} with a mean value of 2034 ± 745 Bq m^{-2}(mean ± SD). On the average, around 65 % of the total inventory of ^{137}Cs (Bq m^{-2}) was concentred in the 0-20 cm depth increment, 25 % in the 20-30 cm and less than 10% in the last increment (30-40 cm) under the plough layer.

The relationship between the measured parameter was tested. The correlation matrix showed that the values of the different variables tend to be unrelated. Effectively, no clear and significant relationship was found between soil texture parameters, organic matter content and the ^{137}Cs total areal activity. Therefore, another test was done on the top surface. This reveals a significant relation between organic matter and ^{137}Cs surface inventory for the first 20 centimetres. A positive power correlation was established:

$$Y = 0.0867 \cdot X^{0.5487} \qquad (n = 42;\ r = 0.8;\ p \leq 0.01) \qquad (1)$$

with Y = organic matter content in % and X = ^{137}Cs areal activity in Bq·m^{-2}.

A high erosion rate, indicated by a low ^{137}Cs inventory, translates into a high loss of organic matter, as indicated by the positive power correlation between these two parameters If soil degradation is not obvious, it generally does not significantly influence farmers in their decision to adopt soil conservation practices. However, soil quality degradation constitutes a more convincing argument. Soil erosion is a selective process and so consequently the spatial redistribution of soil should be translated into soil quality depletion in eroding areas and into enrichment in sedimentation areas. Similar results were found in a previous study in a 180 ha watershed located in North of France (Mabit and Bernard, 1998). Therefore, physical degradation of soils through erosion is coupled with a soil quality degradation that will decrease crop productivity.

Experimental variograms for ^{137}Cs and organic matter content were fitted to theoretical models using their average semivariance of four distance values (11, 25, 41, 55 m) estimated with 36, 41, 131 and 100 pairs respectively. The geo-statistical and key parameters determined by the variogram analysis for OM, ^{137}Cs, soil movement are presented in Table 1.

Table 1. Spatial dependence and key parameters of the different variograms.

	Active lag distance	Lag interval	Type of model	Range	Sill	Nugget
^{137}Cs activity	70 m	16	Isotropic Spherical	30 m	408 KBq m^{-2}	17 KBq m^{-2}
OM (0-20 cm)	70 m	16	Isotropic Spherical	38 m	1.99 %	0.362 %
Soil Movements	100 m	20	Isotropic Spherical	65 m	197 t ha^{-1} y^{-1}	39 t ha^{-1} y^{-1}

The experimental variogram for soil movements, after conversion of the ^{137}Cs activity using the MBM 2, were fitted using the average semivariance of five distance values (11, 32, 48, 71, 89 m) estimated with 42, 87, 158, 156, and 100 pairs respectively. All semivariograms are well structured with a small nugget effect. Effectively, each variogram showed a good autocorrelation for soil movements (R^2= 0.87; 'nugget-to-sill' ratio of 20 %), for ^{137}Cs activity (R^2=0.91; 'nugget-to-sill' ratio of 4 %) as well as for organic matter (R^2=0.95; 'nugget-to-sill' ratio of 18 %).

The estimated soil movement rate for individual sampling points ranged from a loss of 62 t ha^{-1} yr^{-1} to a deposition of 17 t ha^{-1} yr^{-1}. After interpolation and taking into account the structure of the data, a complete soil movement budget was calculated for the whole field. The net loss or the net output from the field was estimated at 7.8 t ha^{-1} yr^{-1} using Kriging. The gross erosion reached 8.1 t ha^{-1} yr^{-1}. The sediment delivery ratio (SDR) that corresponds to the ratio of the net output to the net erosion rate represents 96 %. This means that 96 % of the sediment mobilized in the field effectively leaves it. This high SDR reflects the fact that erosion area represents 98 % of the field surface and the sedimentation only 2 %. The soil movement classification rates in this agricultural field clearly showed that around 75 % of the field is affected by a low erosion of 0-10 t ha^{-1} yr^{-1} and less than 10 % of the area is affected by an erosion greater than 10 t ha^{-1} yr^{-1}.

In the present study, the high value of the SDR could be explained by the join effect of the snow melt erosion, water erosion and tillage erosion.

Soil texture analysis reveals no significant variation between sampling points affected by erosion and sedimentation processes. So a clear protocol is needed to estimate soil selectivity processes for using conversion model. This aspect of the use of Fallout RadioNuclides techniques for estimating soil erosion and sedimentation need to be improved. This item is under investigation through an experimental erosion test which was already started and conducted by the authors under controlled conditions in a greenhouse, using ^{134}Cs labeled soil and a rainfall simulator (Mabit and Bernard, 2006).

4. CONCLUSIONS

This study confirms that the ^{137}Cs technique coupled with geostatistics and variography can be a reliable complement to more conventional methods for assessing erosion and sedimentation. Geostatistical techniques can be applied to soil parameters, such as ^{137}Cs, OM as well as soil movement processes and then be used to optimise in a realistic way the spatial interpolation of data. The correlation found for the soil subsurface between ^{137}Cs and organic matter content highlights the relationship between soil erosion and spatial redistribution of organic carbon. The spatialisation of soil movement variability is a first step for an efficient resource management policy and to implement successfully conservation actions.

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SECTION F

SPECIAL TOPICS

The Hydrographic Monitoring-Network of the Unsaturated Zone in Austria (UZ-Network)

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ABSTRACT

Beginning in 1997, a monitoring-network subsequently has been established using continuous gauging of the main quantitative parameters of water-dynamics within the buffer-zone between atmosphere and groundwater. Soil-moisture, water-tension and temperature are registered by data-loggers at 4 to 6 different profile depths.. The idea was to continuously gain punctual groundwater recharge and actual evapotranspiration data at the measuring-site from the gauge data and to derive regional results by applying regional parameters taken from the Austrian soil-map to the punctual established algorithms. Today eleven measuring stations are in operation and selected soil-moisture and water-tension data, perhaps starting in 2002 but more likely in 2004, are about to be published.

1. LEGAL AND ORGANISATIONAL FRAMEWORK

The UZ-network is embedded in the hydrographic subject “Subsurface Water”, which contains the quantitative water balance elements "groundwater, springs and unsaturated zone". “Quantitative” means not concerning any chemistry or biology aspects– just water pressures and tensions, fluxes, soil-moistures, temperatures, in the case of springs, conductivity (solutes) and eventually turbidity is added. The Austrian Hydrographic Survey dealing with the subsurface water consists of 4 federal employees (including myself) and 1 to 4 colleagues in each province. We operate 3,000 groundwater stations, 100 springs and 11 unsaturated-zone-sites involving the construction and sensor/data-logger-equipment of the gauges, the observation, manned also by external and paid observers, the maintenance of the networks, the data-processing, data-base-management and the data/result-publication.

To make the overview about the Hydrographic Survey in Austria more complete, there are about twice as many colleagues dealing with surface-water (including solids) and half as many dealing with the atmosphere (not included is the ZAMG). Our federal mean annual subsurface-water-budget amounts to approximately 40,000 € plus 30,000 € paid to the observers in each province. The countries add about half up to twice.

In 1997 a measuring-network of the unsaturated zone, containing 45 sites, is explicitly mentioned in the “Hydrography Law" for the first time. In 1995 Dr. Pramberger (my predecessor in office) and DI Feichtinger (BAW, IKT Petzenkirchen) drafted a network, consisting of 8 to 10 sites, equipped with lysimeter, tdr-profiles, tensiometer-profiles and gypsum block-profiles and about 35 to 37 sites equipped with just profiles (without lysimeters). The profile-measuring-depths were defined at 10, 30, 60, 90, 120 and 150 cm below surface. Drafts of the federal measuring network never contain exact locations, as we depend on the interest, personnel and financial aid of the provinces to a great extent and also on new measuring-projects like the UZ-network.

2. THE PUNCTUAL GROUNDWATER-RECHARGE DERIVED FROM TENSION AND MOISTURE-PROFILES

Already in the early 1990's the interest in time-series of groundwater-recharge increased significantly – reducing, for example, the interest in temperature-profiles. Nowadays the groundwater-recharge of groundwater-bodies (and even groups of groundwater-bodies) is in the centre of sustainability consultations, due to the water-framework-directive. Rough estimations of groundwater recharge are based on surface runoff and/or from mean annual precipitation. Verifications of those estimations are desired and can be derived from our measuring sites.

The main idea of the UZ-network is to gain groundwater recharge with reasonable accuracy by

- calculating field- and lab-pf-curves
- calculating the capillary conductivity-function using e.g. MILLINGTON & QUIRK
- calculating the recharge with the help of tension differences in the deepest layer
- if possible, calculations with software SIMWASER to verify the calculated recharge
- if possible, plausibility check with a nearby groundwater- and precipitation gauge

The main problem we are encountered with now is the huge difference between laboratory- or literature-pf-curves and our measured field-pf-curves – especially in the deeper layers. The reason is that our soils contain fractions of course particles up to 60-70 %. Such soils are – precautiously speaking – a great challenge to soil moisture sensors. A moisture measuring control programme with TRASE-measuring two to four times per year and manual verification by disturbed soil samples and laboratory analysis was started.

In the meantime, we have reduced our project ambition in many ways. Instead of 45 sites we are happy when 11 of our sites work without breaks. At the moment we are confronted with interruptions of up to 40 % at our problematic sites, even if professionally (Fa. UMS) maintained. Perhaps we will try to establish two new sites within the next 3 years. In the early 2000's we thought we could forget the equipment with additional lysimeters, as we thought we could derive all results from the profiles. In the last 2 years we had to face the fact that continuous UZ-profile-measuring is not only extremely expensive to maintain (concerning personnel and financial resources) and even incomplete, but also the measured data are extremely unreliable. Furthermore you can not rely on such small amount of data (mainly soil moisture), even if they look reasonable.

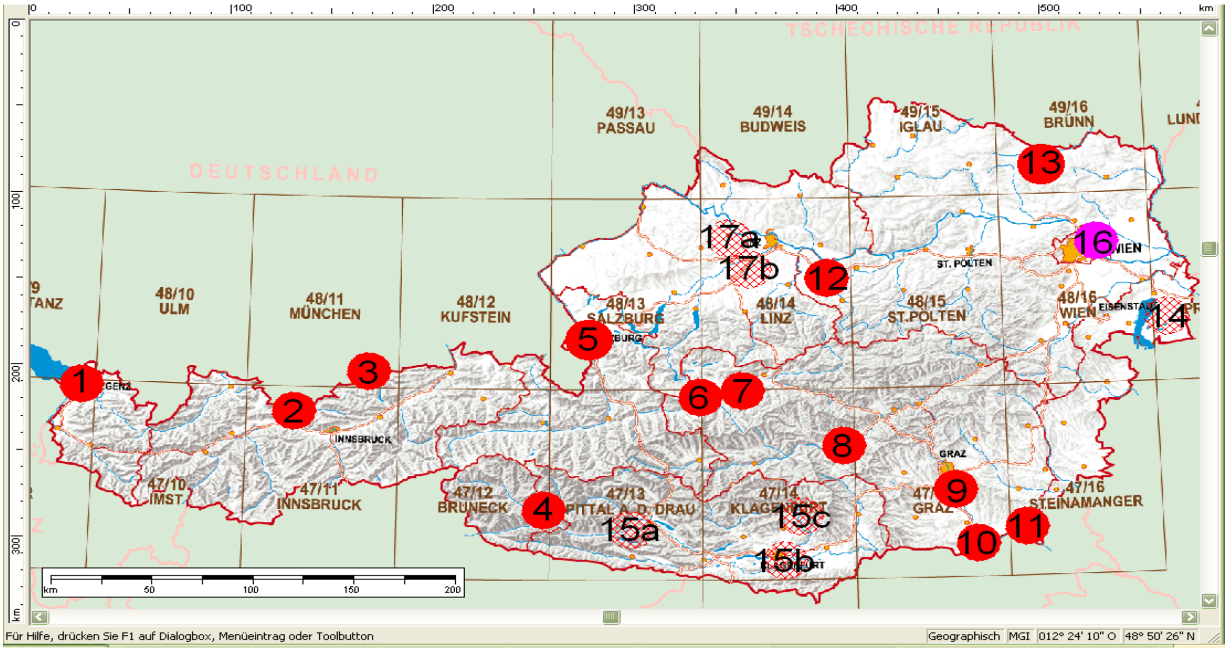
That´s why we have started to equip 3 or 4 sites with additional lysimeters as it was proposed in 1995.

We don´t insist any more on being able to compute the recharges ourselves before publishing any parameter time series. Up to now we have not been able to formulate general data-correction algorithms. With the help of our 2 research Institutes accompanying the UZ-network – Dr. Stenitzer from the BAW, IKT Petzenkirchen and Prof. Klik and his team from the Institute of Hydraulics and Rural Water Management – we are now able to see a solution, but the implementation of the algorithms into our hydrographic software system (AZUR, Company aqua_plan) is causing huge numerical or performance problems.

We – especially those provinces, whose site(s) work(s) quite well – look forward to the final go ahead of the publication of water-tension and soil-moisture data.

3. OVERVIEW OF THE MEASURING-SITES

The following illustration (Figure 1) shows the most important key data of the UZ-network: Location, start of measurement (year), name, altitude, additional remarks.



1 from 02-2005 Lauterach (400 müA) – Twin-profil ; Computation 2005
2 from 01-1998 Leutasch (1135 müA) –lysimeter since 2006; Computation 2006
3 from 09-1997 Achenkirch (850 müA; forest) – quadruple profil; cooperation with BFW
4 from 04-1999 Zettersfeld (1820 müA) – Twin-soil-moisture-profil; tensiometer-equipment 2006
5 from 05-2002 Elsbethen (428 müA); Computation 2006
6 from 08-2005 Stoderzinken (1890 müA) - Twin-profil – cooperation with BAL; With lysimeter
7 from 07-2004 Gumpenstein (690 müA) – cooperation with BAL; only lysimeters with soil-moisture-equipment; sensor-equipment outside lysimeters and tensiometer-eqipment 2007
8 from 04-2000 Stadlmoar (670 müA)
9 from 11-2001 Kalsdorf (330 müA) – Twin-profil plus ADCON-Test; Parameteranalysis 2004 existing
10 from 07-2002 Hochgraßnitzberg (500 müA) ADCON-Test) not working; 2007 perhaps 1 ADCON+
11 from 07-2002 Zaraberg (300 müA) ADCON-Test) +tension-profile in that region projected
12 from 01-1999/2000 Wolfsbach (340 müA) - Twin-profil
13 from 10-1997 Schalladorf (238 müA)– pilote ! Computation existing; Regionalization existing
14 Seewinkel – extension-project Burgenland; perhaps 2008
15a oberes Drautal – extension project K
15b Klagenfurter Becken - -„-
15c Krappfeld - -„-
16 from 1995 Hirschstetten – AGES Lysimeter; projected data-transfer and publication
17a Südliches Eferdinger Becken – extension-project-variant Oberösterreich
17b Traun-Enns-Platte - -„-

BFW: Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft
BAL: Höhere Bundeslehr- und Forschungsanstalt für Landwirtschaft

4. SELECTED PICTURES FROM GAUGES, DATA AND COMPUTATION

The following pictures should provide some closer views how

- our sites are constructed
- punctual and regional recharge is computed
- we manage the data (site-data and time-series)

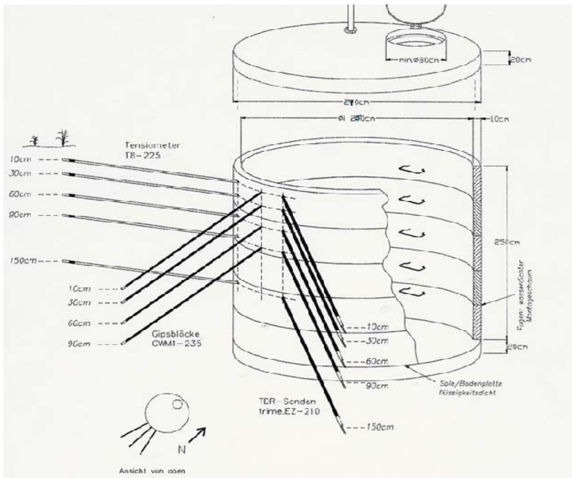


Figure 1. Location Elsbethen left: Datalogger right: Installation scheme

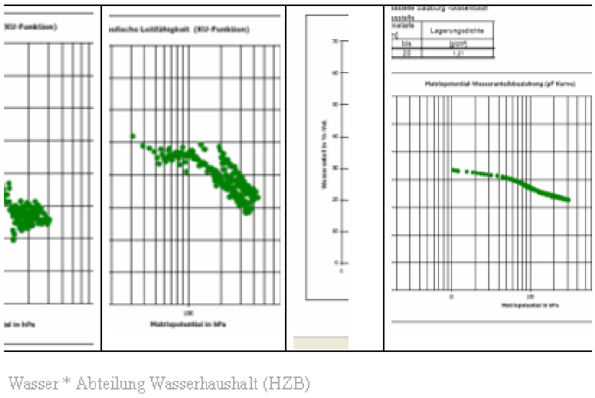


Figure 2. Location Elsbethen left: Sensors right: labor-analysis (ku, pf)

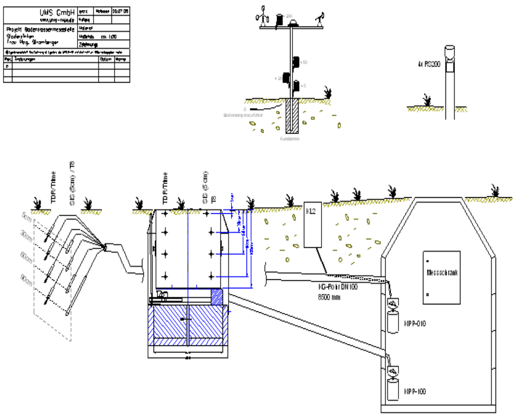


Figure 3. left: Installation scheme Stoderzinken right: Location Leutasch

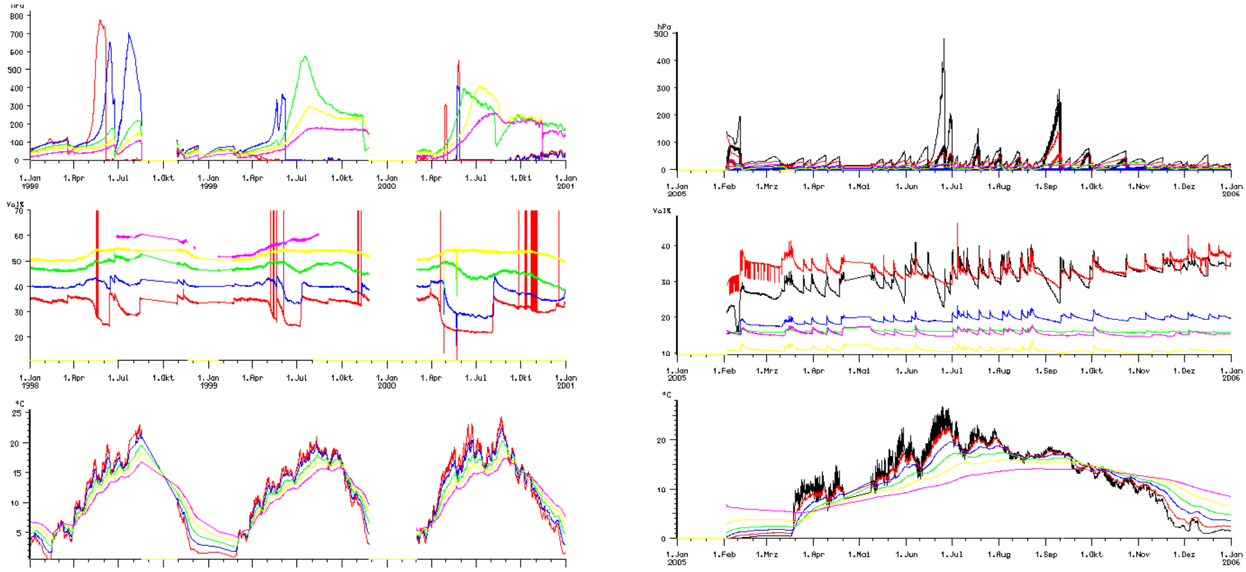


Figure 4. Raw-data Schalladorf: water tensions, soil moistures and temperatures (1998–2000) right: Raw-data Lauterach North (2005)

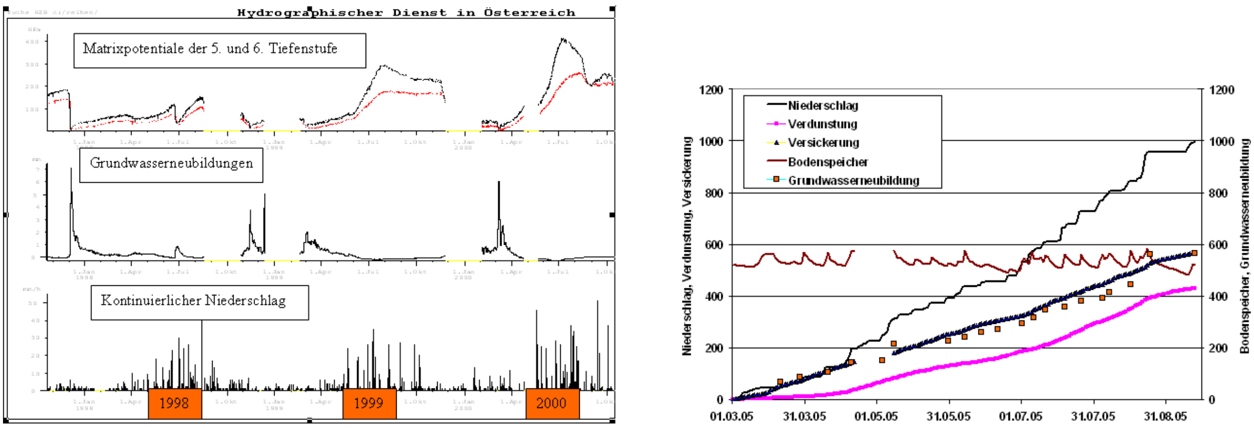


Figure 5. Schalladorf; AZUR-computed recharge – implementation of algorithms and k-functions after Feichtinger (Schalladorf-report, 2003) right: Lauterach North; EXCEL-computed recharge; Stenitzer, 2005

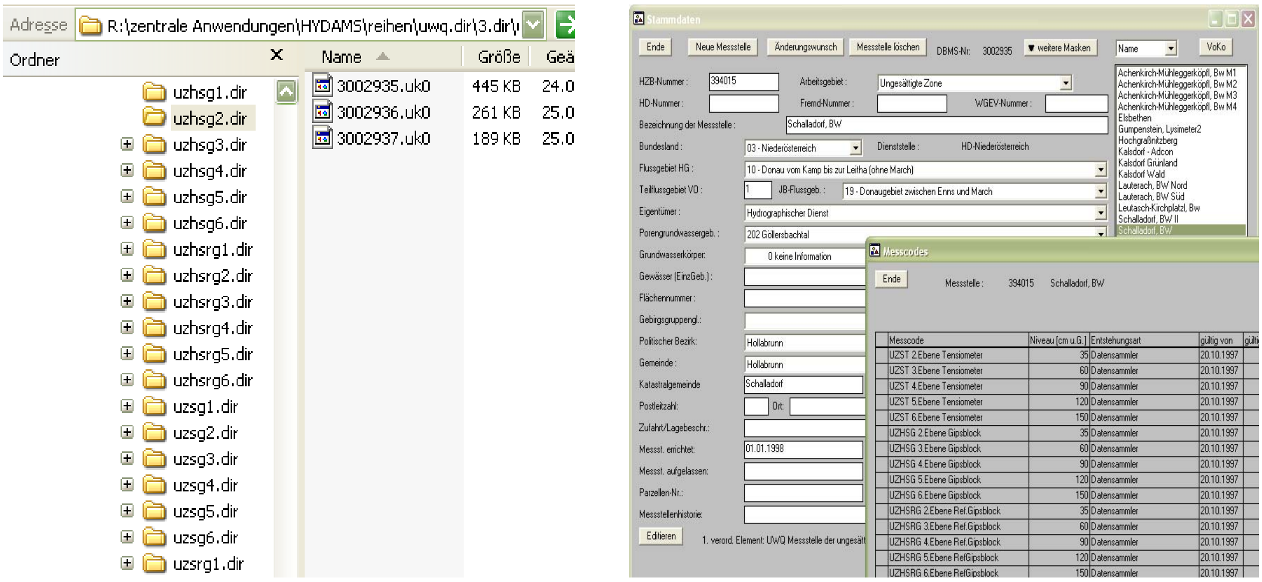


Figure 6. Organization of time-series right: Station-data

Figure 7. The AZUR-UZ-software: modules and details

New Interactive Tool for Educational and Training Provision in SIA

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ABSTRACT

ATLAS project brought together the experts of the leading European research, education and training institutions in the area of land use and sustainability impact assessment, combining innovative research efforts and practical experiences, enabling an educational breakthrough required to meet the ambitions of the current research priorities. It resulted in ability of the coordination and dissemination of educational practice and the development of future training initiatives for policy and practice in this area throughout Europe by concrete results as:

– Creation of baseline description (on-line database) of the status of educational provision at practitioner's, professional, undergraduate, Master's and PhD levels, within Europe;
– A SWOT-analysis (strengths, weaknesses, opportunities, threats) of the extent to which this provision meets current needs, with clear recommendations for improvement; and,
– A ***'RoadMap'*** for training in land use sustainability assessment providing better European organisation of the educational provision leading to appropriate professional qualifications.

1. INTRODUCTION

The fragmented nature of education and training provision in sustainability impact assessment for land use planning is a major barrier to the management of rapid land use change that is now occurring in Europe.

Project is a targeted co-ordination action designed:

1. to assess the status of educational and training provision in the area of land use change, and develop a tool (on-line data base) for the training possibilities;
2. to analyse the sustainability impact assessment process and the obstacles to its successful implementation in the field of land use policies in Europe, and make recommendations aimed at finding solutions for improvement in terms of training and education on SIA; and
3. to develop a 'road-map' as an interactive web-based training tool for sustainability impact assessment primarily aimed at policy makers

ATLAS will produce an assessment of current user needs in both public and private organisations, including industrials, throughout Europe. To allow clients and stakeholders to choose the appropriate educational facilities for their demand, ATLAS will generate an analysis of the current educational provision on the basis of:

- what is available in the European Research Area in the field of sustainability impact assessment of land use policies in terms of:
  - contents (subjects, educational targets, education level, interdisciplinarity)
  - knowledge transfer (information, innovation and communication technologies, learning methods and tools),
  - accessibility (language, previous education required, costs), and
  - relevance to needs of key user groups
- how the existing knowledge could be better organised to gain an added European value.

2. METHODS

One of the objectives was to survey the existing education and training provision in the field of land use and sustainability impact assessment in Europe and classify them according to pre-set criteria. This was achieved by the development of a web-based database of courses at universities, polytechnics, professional training organisations and others dealing with courses on PhD, Master-level, Bachelor level, Post-Doc, Professional training, and Other (including summer schools). A hierarchal approach was used for the priority of topics:

1. Sustainability Impact Assessment (SIA), Strategic Environmental Assessment (SEA) and Environmental Impact Assessment (EIA) for land use change.
2. Land use and sustainability (including land use policy).
3. Modelling and scenario analysis.
4. Landscape (including landscape architecture, agriculture, ecology, nature conservation, forestry etc.), if these courses were considered to be related to land use changes and sustainability.

Educational institutes, organizations and courses were identified through Internet searches and by the use Internet portals for higher education and environmental organisations. Due to a low response rate on initial contacts to the organizations ATLAS members themselves collected the information and filled in the forms. Until present 2059 courses have been entered in the database. These were distributed between 9 subject areas: Agriculture and forestry (9 %); Architecture and landscape design; Economy and law (7 %); Environmental Modelling and Scenario Analysis (2 %); Environmental protect ion and Sustainable Development (20 %); Environmental Science And Technology (inc Ecology) (24 %); Landscape planning and management (18 %); Sociology or social impact (5 %). University courses were clearly predominant part. English was the most common language for teaching (796 courses). The most commonly used of 77 keywords were: Environmental Management (541 entries), Environmental Impact Assessment (257), Ecology (250), Land-use Planning (236), Sustainable Development (223), Environmental Protection (211), and Landscape Planning (173). Most courses were on Master and Bachelor levels.

The database shows that that the supply of courses in the field is well developed and rapidly increasing in most European countries. While 10 % of the course supply is dealing with Environmental assessment and strategic impact assessment; the rate of courses that are dealing with Sustainability Impact Assessment in its strict sense is nearly non-existing in all countries. As expected, the situation in course supply varies in general over the European countries. The database represents a comprehensive overview of European courses. It will provide a good base for the SWOT analysis and the Roadmap (Figs. 1, 2) within the ATLAS project. For this the accuracy and updating of the database is crucial.

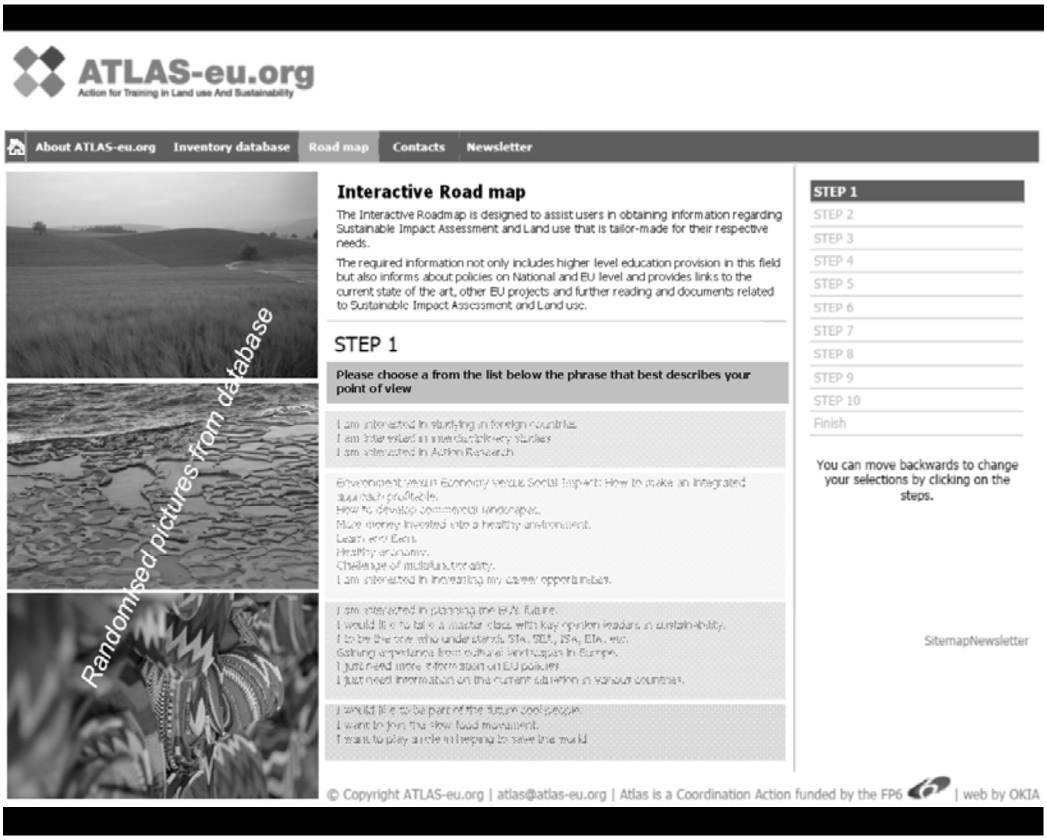

Figure 1. Draft design of the first step of RoadMap on ATLAS website.

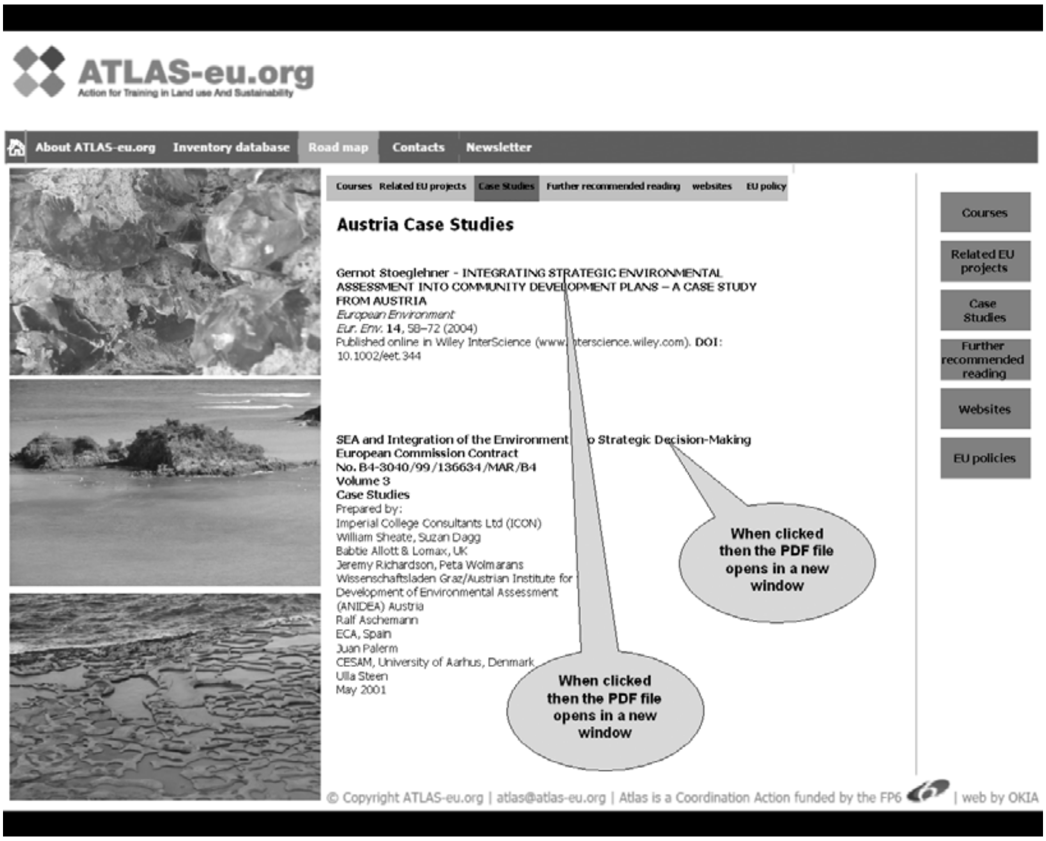

Figure 2. Draft design of the RoadMap – example of a result page.

3. RESULTS AND CONCLUSIONS

Currently the database represents a comprehensive overview of European courses. It will provide a good base for the SWOT analysis and the Roadmap within the ATLAS project. For this the accuracy and updating of the database is crucial.

In the process of conducting the interviews it became clear that many people, although they were all familiar with a range of impact assessment (IA) tools, they (with the exception of a few researchers) did not know the term SIA. It was apparent that SIA is a relatively new concept and the term has had little exposure. As a result of these trials, the focus was often directed to asking questions relating to Impact Assessment (IA) or Strategic Environmental Assessment (SEA), terms which were considered to be more familiar to the targeted study groups. To reach the different players in the field of sustainability impact assessment the education and training offered should be multiform and involve different providers, universities as well as consultants or NGOs. By making use of modern technologies like the internet to disseminate recent developments and public case studies for comparison a wide audience can be reached. Portals on the internet can prove to be most useful for quickly finding relevant information. Conferences as organised by the IAIA are good platforms for exchanging of experiences on a scientific level and creating informal networks. Universities can attract more professionals by adjusting their curriculum to be more practically orientated and in shorter time span. They could also offer more possibilities for schooling their own staff. In some cases universities have links with business schools that especially organise courses for professionals. For policy makers the incentive for doing a course is often related to the developments in legislation and should therefore be mostly tailor-made, which can be provided by consultant firms. NGOs can play an important in creating awareness on sustainability with the general public.

This study was financially supported by EU FP6 project No. 018543 ATLAS „*Action for Training in Land use And Sustainability*“.

More information available at http://www.atlas-eu.org/

Climate Change Impacts on Yield and Crop Water Use in Austria Using Crop Models

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ABSTRACT

The impact of climate change on crop production in Austria was investigated in several studies by using dynamic crop models. Complex effects on crop growth and yield can be simulated directly. The simulation of soil and crop water balance is a crucial point in dynamic crop growth models. The effect of water balance parameters and water stress on winter wheat production in north-east Austria and under different climate change scenarios using the CERES-Wheat and WOFOST model is presented. There is strong evidence that, especially for soils with low soil water storage capacity or no groundwater impact to the rooting zone, irrigation or water-saving production techniques (e.g. by indroducing mulching systems, adapting crop rotation), will remain important requirements under future climates in central European agricultural regions for the attainment of the yield potential of crops.

1. INTRODUCTION

The impact of climate change on crop production was investigated in several studies by using mainly dynamic crop models (e.g. Downing et al., 2000). The approach of analysing the effect of climate change on agroecosystems using dynamic crop models has the advantage to include all relevant impact factors of the soil-crop-atmosphere system over short time periods. Complex effects on crop growth and yield can be simulated directly. The simulation of soil and crop water balance is a crucial point in dynamic crop growth models (Eitzinger et al., 2004). However, the potential impacts of climate change on agricultural crop production are manyfold and complex in general, and containing many uncertainties. Therefore many studies are limited to specific aspects such as crop yields or yield risks under defined circumstances such as various climate scenarios, land use and management scenarios (e.g. Downing et al., 2000; Parry, 2000). Often it is not feasible to consider all influential environmental factors, crop management or socio-economic feedbacks because of lack of data, methods and information.

2. RESULTS

Several studies in Austria investigated maize and wheat production because of its economic relevance. For example, the effect of water balance parameters and water stress on winter wheat production in north-east Austria under different climate change scenarios (Fig. 1) was investigated e.g. by Eitzinger et al. (2001, 2003) and Alexandrov et al. (2002) using the CERES-Wheat and WOFOST models.

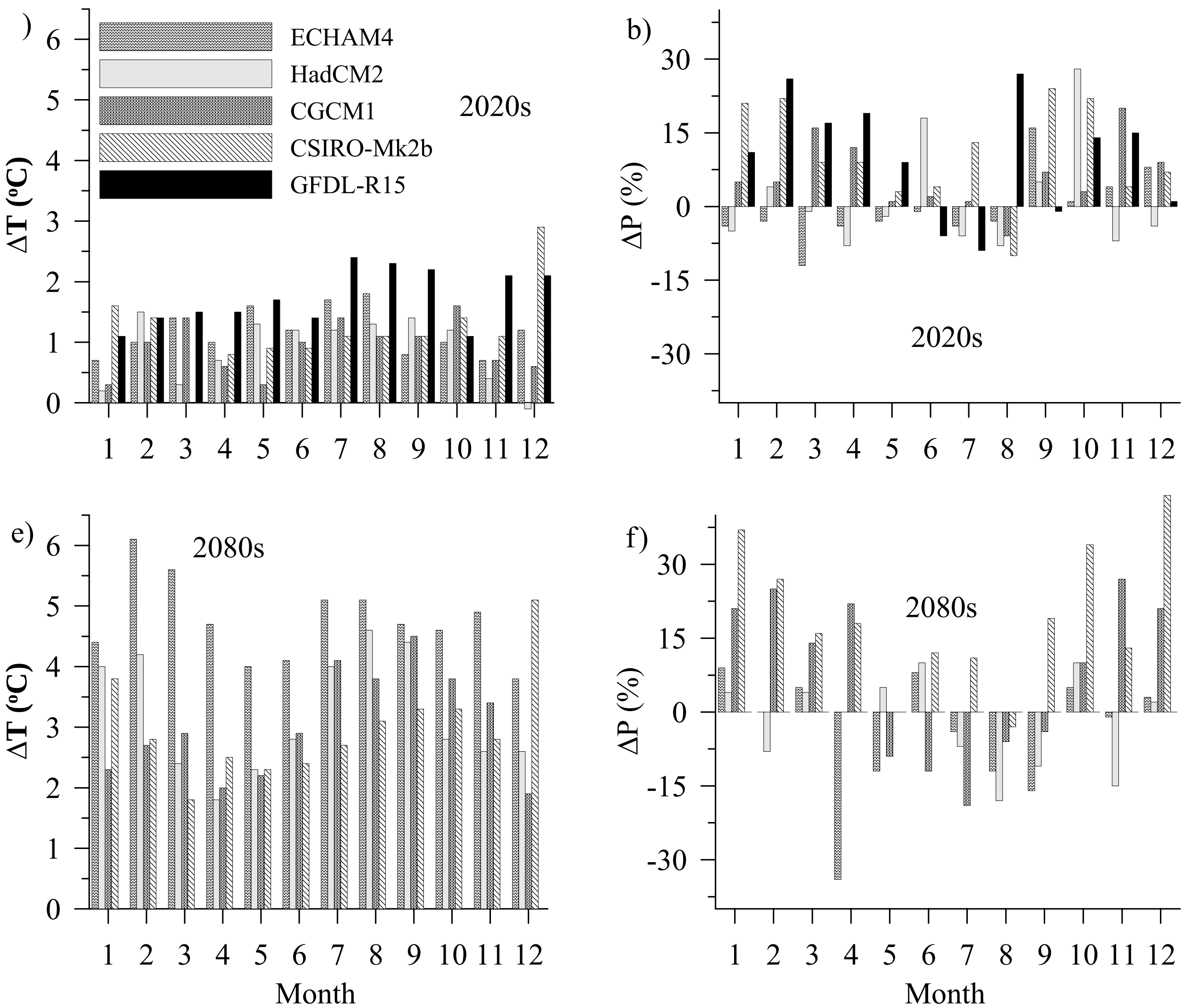

Figure 1. Various climate scenarios (for Temperature T and Precipitation P) for north-east Austria, used in the climate change impact studies in relation to the base period of 1961-1990.

The studies on winter wheat and barley (Alexandrov et al., 2002) show increasing yields under the future climate scenarios in Austria (Fig. 1). Despite expected high air temperatures during the 2080s, the projected increases in wheat yield were between 3 and 20 % due to the fertilization impact of the increased CO_2 level (Fig. 2). Similar results were found for spring barley yield. Despite higher yield levels, crop transpiration and water stress dropped significantly compared with current conditions through the simulated increase in water-use efficiency and reduced total potential evapotranspiration of the growing period (caused by shortened growing period) under the applied $2xCO_2$ climate scenarios (no change in climate variability assumed). A study (Eitzinger et al., 2003) shows that up to about 40 per cent of evapotranspiration was provided by groundwater at a site with groundwater impact.

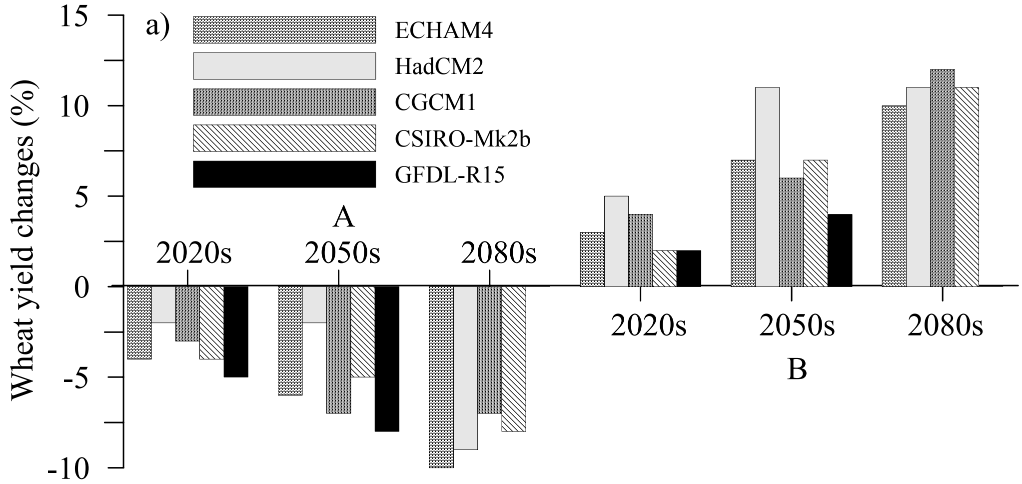

Figure 2. Simulated yield changes under different climate scenarios without (A) and with (B) the direct CO2-effect.

Sensitivity analyses showed that soil water storage capacity plays an important role in yield levels and yield variability under current climate as well as expected climatic change, where ‘light’ soils show a lower increase in winter wheat yields and higher yield variability than the standard ‘medium’ and the ‘heavy’ soil types (e.g. Eitzinger et al., 2004; Alexandrov et al., 2002). Additionally, yields and yield variabilities were significantly different between the climate scenarios as a result of the differently predicted amount and distribution of precipitation over the vegetation period, which therefore remains a main source of uncertainty. Similary, the soil water content in autumn will have an significant impact on crop water availability and yield of winter cereals (Fig. 3). Mulching systems and other measures for saving soil water resources will therefore be important.

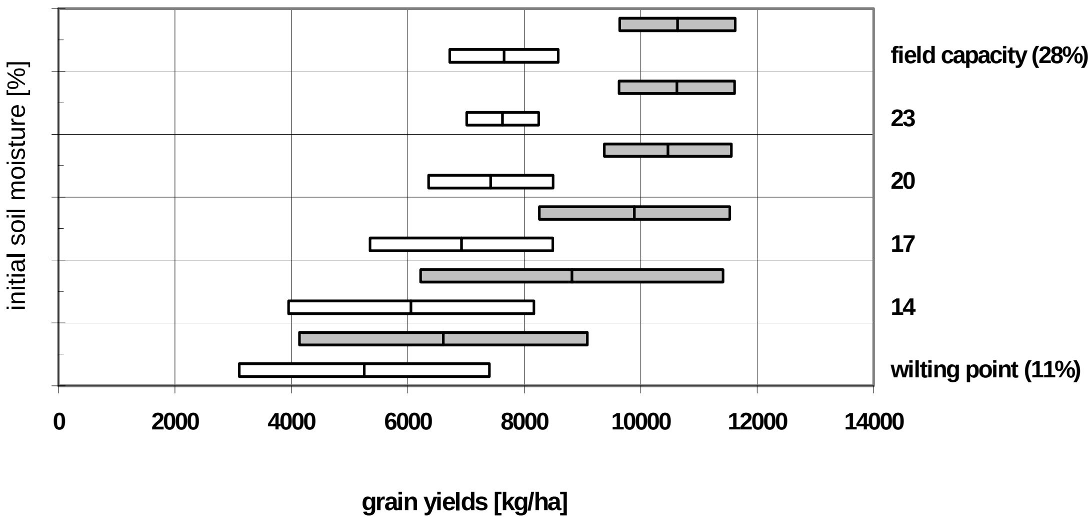

Figure 3. Effect of initial soil water content in autumn on a medium soil type effect on the yield of winter wheat (bar presents mean ± std, white bars represent present weather, gray bars represent changed weather and 2xCO_2 concentration).

A change in extreme weather events in future climates such as the pattern of drought periods, which are not considered in the climate change scenarios, could significantly reduce the predicted yield levels. Crops grown on soils with low soil water storage capacity, such as sandy soils and soils with shallow potential rooting depth, or crops with shallow rooting systems are much more vulnerable to changes in precipitation patterns.

3. CONCLUSIONS

Despite of higher expected yield levels and increased water use efficieny by many crops due to climate warming, the presented studies show that there is a strong evidence that, especially for soils with low soil water storage capacity or no groundwater impact to the rooting zone, irrigation or water-saving production techniques (e.g. by introducing mulching systems, adapting crop rotation), will remain important requirements under future climates in central European agricultural regions for the attainment of the yield potential of crops. Further they conclude that if the frequency and duration of droughts and heat waves will increase as recent studies indicate or soil- and groundwater reserves decrease (e.g. by decreasing summer river flow from Alpine region) drought damages affecting yields will increase. Apparently the most productive agricultural regions (i.e. typically lowland in the warmest (and also driest) part of Austria are especially in risk. Summer crops will be even more vulnerable and dependent on soil water reserves, as the soil water or higher ground water tables during the winter period cannot be utilized as much as by winter crops. Evapotranspiration losses during summer due to higher temperatures would increase significantly.

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New Methods Calculating the Risk Potential of Hydrocarbon Deposits

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ABSTRACT

In Austria drilling activities for exploration of hydrocarbons started already in 1938. Even today, more than 60 years later, a considerable number of oil and gas wells are still producing.
It's a fact that the standards for producing, collecting and treatment of hydrocarbons changed significantly over the last 60 years.
In the early "pioneer days" of hydrocarbon exploration, it was normal to use earth drains to conduct the mixture of oil and water to the collecting points also consisting of earthly constructions. Environmental protection in those days was not a critical issue.
Today it has to be the main responsibility of each oil and gas producing company to find the balance between historical pollution and environmental protection based on today's legal requirements. Therefore calculating the risk potential of historical oil deposits represents a key technology for environmental protection of today's oil and gas industry.
Based on this background OMV as the leading Austrian oil company started in 1985 to evaluate proper technologies for calculating the risk potential of oil contaminated areas using geophysical techniques mainly based on direct current surveys.

1. PRINCIPALS OF GEOPHYSICAL SURVEYS

The applicability of geophysical methods for investigating the structure of an oil contaminated area depends on measurable geophysical contrast between the oil contaminated soil itself and the undisturbed surrounding. The geophysical contrast can be expressed in different values for the geo-electrical resistivity.

To get information of the distribution of electric resistivity values in the subsurface two outside electrodes (Fig. 1) submit direct current hemispherical to the subsoil. Vertical to the hemispheric current lines the potential lines are running and voltage can be detected with two centre electrodes.

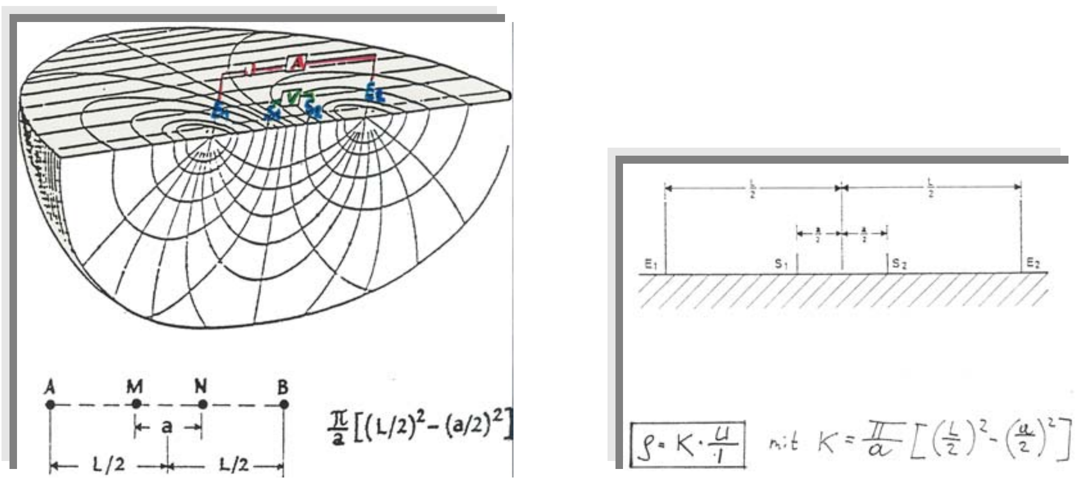

Figure 1. Electrode – configuration

The apparent specific electric resistivity can be calculated according to the equation

$$\rho_a = \frac{U}{I} \cdot K. \quad (1)$$

„*K*“ is a factor that takes care of the configuration of electrode-spacing. In Figure 1 the so called “Schlumberger - Electrode-Spacing” is shown.

The information obtained depends on different parameters like petrographic sequence of layers, the ionic and metallic conductivity, the pore volume and the interstitial filling.

So, why can this method be used to detect oil contaminated areas like oil field deposits, and why is there a resistivity contrast between an oil deposit and the undisturbed surrounding area. To answer this question it is necessary to know the typical composition of an oilfield waste disposal.

The waste products of a typical oil field deposit consist with more than 50 % out of mostly chlorinated drilling mud and about 25 % are represented by demolition waste due to abandonment activities. The remaining rest fraction mainly consists out of soil contaminated with hydrocarbons. To picture it out an oilfield waste disposal can be compared with an electrolytic saturated sponge, therefore an infiltration of chloride ions into the subsoil would decrease the values for the electrical resistivity. In case of a leaking oilfield waste disposal geo-electrical surveys will provide a quick overview of infiltration area and can help to find the right way for further restoration. But also other methods of geo-electrical surveys like INDUCED POLARIZATION “IP” are qualified to get a better picture of oil contaminated soil.

What does induced polarization mean?

The IP effect can be illustrated by a simple model consisting of an ohmic resistivity and a capacitor connected in parallel. If a potential is applied, current flows through the resistance and the capacitor is charged, based on the fact that in the subsoil there exist always two kinds of “conductors” the metallic and the electrolytic. As soon as current is stopped the capacitor will be discharged via the resistance. The shape of the potential dropping curve is a function of the capacitor’s ability to be polarized, due to the physical and chemical effects across the boundaries of metallic and electrolytic conductors.

The frequency effected polarisation compares the difference of resistivity at two different frequencies as a function of poor or highly mineralized (contaminated) rock.

2. FIELD EXAMPLES

2.1. Investigation of Geological Structure of an Oil Deposit and the Surrounding Area

The example demonstrated in Figure 2 shows the application of geo-electrical surveys to get a better understanding of the geophysical composition of an oil deposit and its surrounding.

As the waste disposal was located in a ground water sensitive area, it was necessary to found out whether the oil disposal has a good water barrier between two ground water layers or not!

Geo-electrical surveys based on direct current method in combination with a few number of slim hole core drilling projects could give answer to this question as illustrated in Figure 2 by a plotted profile of resistivities along an selected cross section. The results were summarized in geological 3D model with a trustful relief of a water barrier as shown in Figure 3.

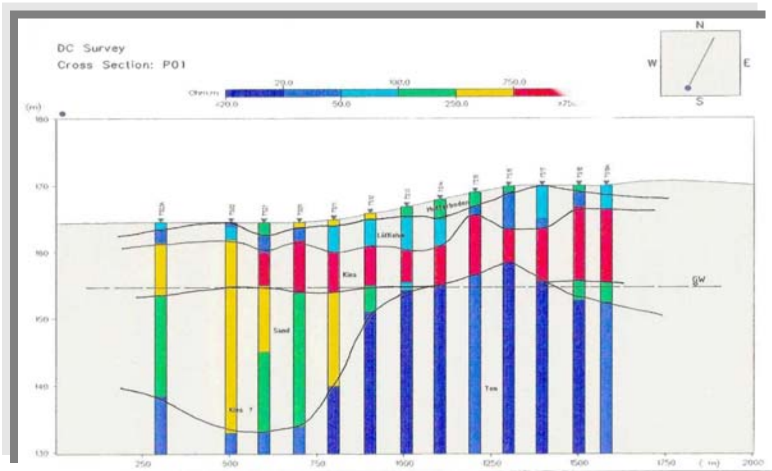

Figure 2. DIRECT CURRENT SURVEY – cross Section

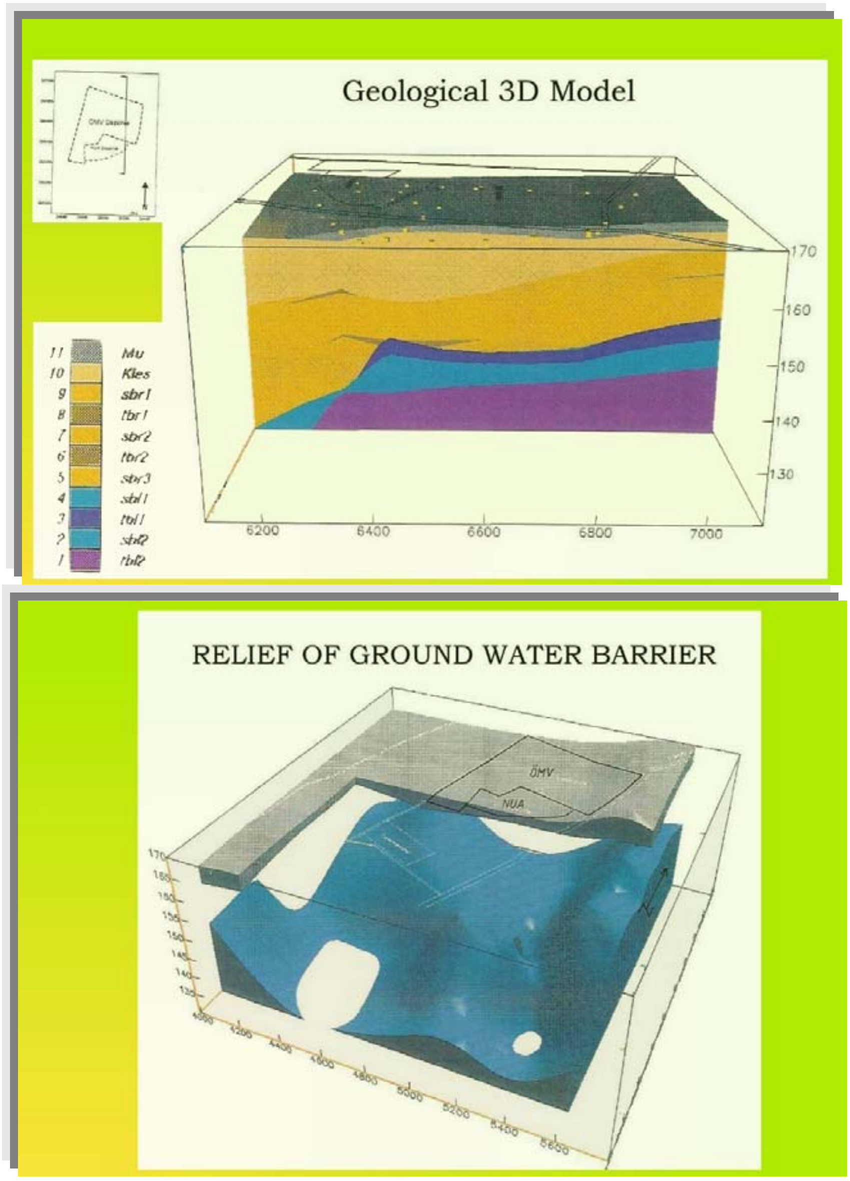

Figure 3. Geological 3D MODEL. North-east cross section (top) and relief of ground water barrier (bottom)

2.2. Investigation of a Leaking Oil Field Disposal

The second example illustrates the assist of geo-electrical surveys for detecting a leaking waste disposal. The history of this waste disposal started with an excavation for coarse gravel. After this process was finished a pit in nature was existing. This was an excellent opportunity for the population of this area to deposit all their waste in the existing pit. Of course no one took care that there was no sealing existing to prevent infiltration of ground water level with leakage water out of the rubbish pit dump. Figure 4 very significantly demonstrates the influence of leakage water to subsoil and ground water by a dramatic reduction of resistivity values. S3 – S6 profiles representing the resistivity distribution of the waste disposal and the underlaid sediments show a significant reduction of resistivity values in the dry and water saturated gravely soil. This example confirms the ability of geo-electrical surveys as a quick shot for calculating the risk potential of waste dumps.

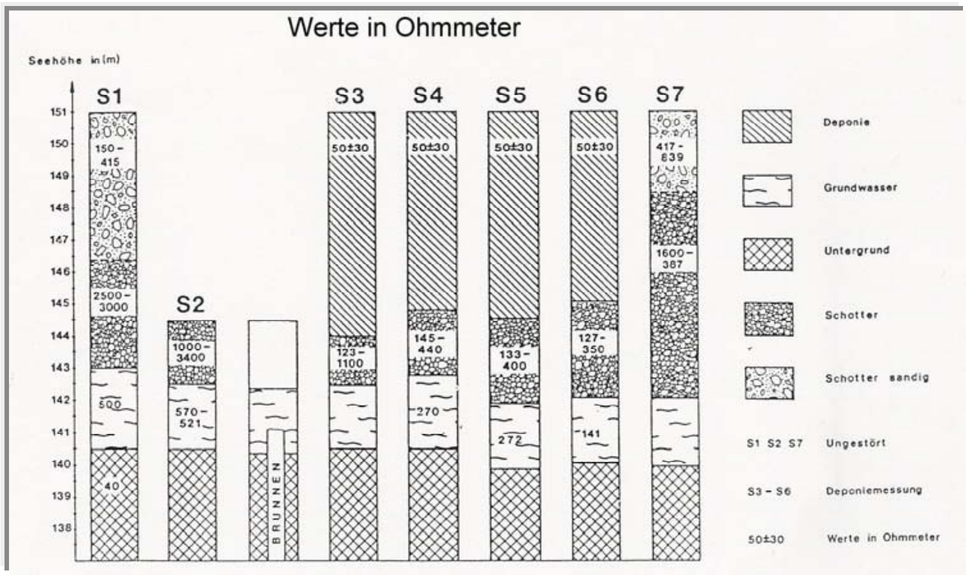

Figure 4. Geoelectrical surveys for detecting a leakting waste deposal

Spatial Uncertainty Assessment of Soil Electrical Conductivity Using Sequential Gaussian Simulation

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ABSTRACT

The general purpose of this paper is to assess spatial uncertainty of electrical conductivity (EC) of soil. In many irrigation and drainage systems, it is necessary to know the uncertainty of electrical conductivity in unknown locations in addition to regional estimates of EC (For example the probability of EC being above salinity limit in a set of points). Most traditional mapping algorithms, including kriging, aim towards local uncertainty and they fail to reproduce patterns of spatial continuity, and do not provide any measure of spatial uncertainty. Stochastic simulation allows drawing several equiprobable realizations all honoring the same initial data at their locations. Spatial features observed consistently on all simulated images may be considered as reliable, i.e. representatives of the true reference map, whereas features present on some simulations only would be deemed unreliable. In this study sequential Gaussian simulation (sGs) is carried out on a data set of 635 electrical conductivity (EC) measurements in southeast of Iran.

Multiple quantitative measures of spatial uncertainty in order to identify saline area are established. For instance, the probability of exceeding 4 and 20 ds/m of electrical conductivity is mapped.

Keywords: Geostatistics, spatial uncertainty, sequential Gaussian simulation, and spatial electrical conductivity.

1. INTRODUCTION

Soil electrical conductivity (EC) is one of the parameter affecting groundwater condition and solute transport. Also, spatial variation of EC of soil is used in complex non-linear models to investigate the impact of a given scenario, such as a particular land reclamation process in environmental decision-making. In many cases spatial uncertainty of salinity may be more critical than local accurate estimation of mean values. In such cases, there is a need to create maps, which provide an assessment of joint spatial uncertainty of EC.

In the last two decades, geostatistics has been used as a means to describe spatial patterns of many attributes. There exists necessarily uncertainty about the attribute value at an unsampled location. The conventional geostatistical approaches e.g. Kriging are just able to model local uncertainty by computing a minimum error variance estimate and the associated error variance. Stochatic simulation such as sequential Gaussian simulation (sGs) is become popular in the last decade as an alternative to overcome the drawback of Kriging for assessing spatial uncertainty. In fact they generate alternative realizations that all honor the data, therefore it looks more realistic. Differences between several realizations provide a measure of spatial uncertainty.

Geostatistics has been widely used to predict soil EC (e.g. Gallichand et al. 1992, Utset et al. 1998, Bishop et al. 2001 and Walter et al. 2001). Nevertheless, few studies have addressed the spatial uncertainty assessment of EC of soil.

The objectives of this study are to assess spatial uncertainty of EC_e to produce a probability map of exceeding a given threshold and throw p-quantile maps in southeast of Iran by using stochastic simulation.

2. MATERIALS AND METHODS

2.1. Study Area and Data Set

This study conducted on some parts of sistan plain called Shib-Ab and Posht-Ab Payeen, in southeast of Iran. The study area covers about 47000 ha and it is located between 30° 40′ to 31° 20′ N latitude and 61° 15′ to 61° 50′ E longitude. The data set was about 600 electrical conductivity measurements of the saturated paste extract (EC_e) determined at three depth intervals (0- 50cm, 50-100cm and 100-150 cm).

2.2. Geostatistical Approach

Geostatistics is a useful tool, which considers the randomized and structured nature of spatial variables and the spatial distribution of the samples (Oliver, 1987).

In this study, Geostatistical stochastic simulations are used to model the uncertainty of EC_e prevailing jointly at N locations u_i. This requires generating a set of L realizations $\{z^{(l)}(u_i), i=1,..,N\}$, $l=1,...,L$ by sampling the N-variate or N-point conditional cumulative distribution function (ccdf)(Goovaerts, 1997):

$$F(u_i,...,u_N; z_1,..., z_N \,|(n)) = Prob\{Z(u_i) \le z_1,..., Z(u_N) \le z_N |(n)\} \tag{1}$$

Where $z^{(l)}(u_i)$ is lth realization of random variable $Z(u_i)$ at location u_i.

2.2.1. Semivariogram Estimation and Modeling

The semivariogram is the main instrument in all geostatistical approaches. It quantifies spatial correlation between the data points to make predictions (using kriging) at unsampled locations. The experimental semivariogram $(\bar{\gamma}(h))$ for a given lag vector h is estimated as:

$$\bar{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[z(u_i) - z(u_i + h) \right]^2 \tag{2}$$

Where $N(h)$ is the number of data pairs within the class of distance and direction used for the lag vector h. A continuous function must be fitted to $(\bar{\gamma}(h))$ in order to compute semivariogram values for any possible lag h required by prediction algorithms. There are different types of model, which could fit to different experimental. The most important of them is the spherical model realized also as the best model fitted to EC_e data in this study. The form of the spherical model is

$$\gamma(h) = \begin{cases} C_0 + C_1 \left[\frac{3}{2}\frac{h}{a} - \frac{1}{2}\left(\frac{h}{a}\right)^3 \right], & h \le a \\ C_0 + C_1 & h \succ a \end{cases} \tag{3}$$

Where $\gamma(h)$ is the spherical semivariogram, C_0 is the nugget effect, C_1 is the structural variance, h is lag distance and a, is the range of spatial continuity.

2.2.2. Sequential Gaussian simulation (sGs)

The sequential simulation algorithm requires the determination of a ccdf at each location being simulated (Goovaerts, 1997). The conditioning data consist of all original data and all previously simulated values available within a neighborhood of the location considered. This method needs a regularly spaced grid, covering the region of interest and utilizes a random path through the grid, such that each node is visited in sequence only once. At each unsampled location, the expected value is simulated according to a conditional distribution. In fact it generates alternative realizations that all honor the data. Sequential Gaussian simulation (sGs) is a sequential simulation with a multiGaussian Random Function (RF) model, which typically requires a prior normal score transform of data to ensure that at least the univariate distribution (histogram) is normal. The normal score ccdf then undergoes a back transform to yield the ccdf of the original variable (Goovaerts, 2001).

2.3. Assessment of Spatial Uncertainty

After generating many equiprobable stochastic images of the EC_e distribution multiple quantitative measures of spatial uncertainty may derivate. A probability map is one measure of spatial uncertainty providing probability of being lesser (or greater) than any given threshold in a series of points. Another measure of uncertainty is p-quantile map. It provides a joint assessment of attribute estimation and the accuracy of that estimation in a single map.

In this study all the geostatistical simulations have been done by GSLIB (Geostatistical Software Library), developed by Deutsch & Journel (1998), at the University of Stanford.

3. RESULTS AND DISCUSSION

3.1. Summary Statistics of EC_e

A brief statistics of EC_e is reported in Table1. As it is clear from this table, EC_e in Shib-Ab and Posht-Ab Payeen has a highly positively skewed distribution especially in the first depth interval where the mean is more than twice the median.

Table 1. Basic statistics of EC_e (ds/m) in Shib-Ab and Posht-Ab Payeen

Depth	Min.	Max.	Mean.	Median	Variance	cv[a]	skewness	Kurtosis
0-50	0.65	158.75	15.85	7.22	553.87	148.45	2.93	9.71
50-100	0.37	53.7	8.39	5.85	56.22	89.39	1.69	3.86
100-150	0.17	41.6	7.94	5.75	47.12	86.4	1.43	2.13

a : cv refers to coefficient of variation

3.2. Probability Map of EC_e:

Stochastic simulation is performed with a conditional sequential Gaussian technique, using 5876 nodes of a regular 500 m × 500 m grid. 100 equiprobable realizations are simulated for EC_e in the three depth intervals. Post processing of these images provides probability and p-quantile maps of EC_e. Figure 1 shows (a) the probability that EC_e is greater than 4 ds/m (FAO limit of salinity) and (b) the probability that EC_e exceeds 20 ds/m (the limit of salinity to have a 50 % reduction of crop). Dark areas (high probability) on these maps are areas where EC_e is high.

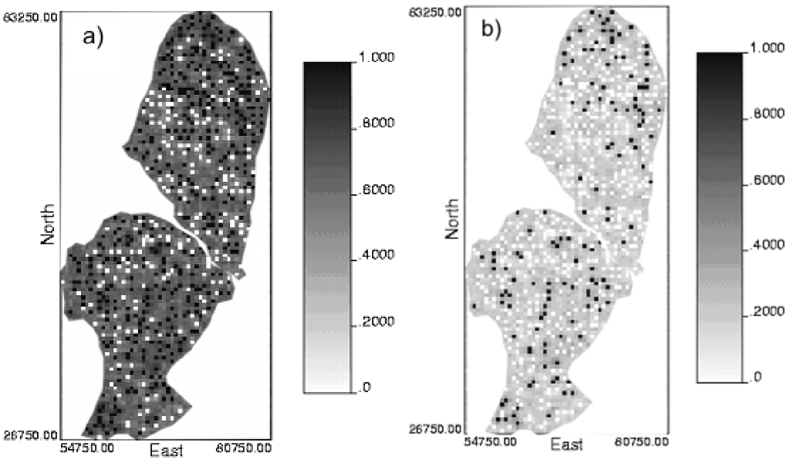

Figure 1 Probability map of exceeding 4 (a) and 20 (b) ds/m of EC_e in depth of 0-50 cm.

3.3. P-Quantile Map of EC_e:

Fig. 2(a) provides a low (0.1) quantile map; more precisely, the map of the EC_e value that is exceeded by 90 % of the simulated values at the same location. Therefore, a location appearing high (dark) in Fig. 2(a) has a high probability (90 %) to exceed the EC_e value there. Also, Fig. 2(b) shows a high (0.9) quantile map; more precisely, the map of the EC_e value that is higher than 90 % of the simulated values. Therefore, a location appearing low (light gray) in Fig. 2(b) has a high probability (90 %) to be actually lower than EC_e value there.

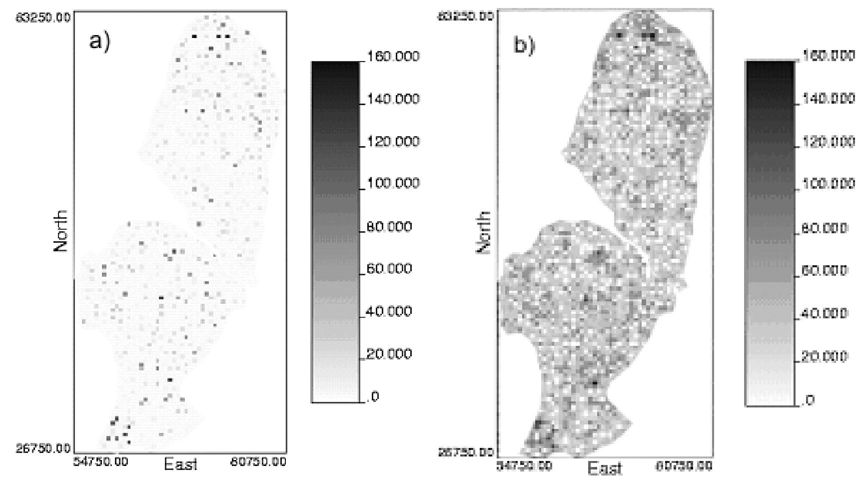

Figure 2. 0.1-quantile (a) and 0.9-quantile (b) maps of EC_e in depth of 0-50 cm.

4. CONCLUSIONS

The aim of this study is not the estimation of soil salinity but rather to assess spatial uncertainty of estimates through geostatistical analysis of stochastic simulation. In contrast to the conventional kriging, which is unable to detect any measure of spatial uncertainty, sequential Gaussian simulation appears to be a very strong tool to create a visual and quantitative measure of spatial uncertainty. Therefore it is suggested that the very strong and capable conditional stochastic simulation such as sGs, as presented in this study, be more introduced and available to soil scientists and users of geographical information systems.

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Surface Scanning on Hydraulic Sedimentation Models

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ABSTRACT

On an investigation of solids transport at the confluence reach of a channel flow, the Moire mapping method is introduced. The method has been adapted and successfully applied as a new device for optical surveying and mapping of entire 3-D deposition surface on the hydraulic scale model, during the running experiment. Various techniques of optical surface mapping – like single point measurement and image interpretation are being discussed. Several techniques of Moire mapping – like shadow Moire and projection Moire are presented. Finally, application of this method under the water is presented.

1. INTRODUCTION

One of the main tasks by the morphological experiments on the hydraulic scale models is to map the surface changes by the simulated process of sediment deposition, erosion etc. The classical devices and methods are the depth point gauges, woolen threads and photogrammetry. All the mechanical methods suffer under a disadvantage that that they are surface destructive and extremely time consuming. The optical methods, on contrary, are non invasive, while functioning without surface (water, sediment) disturbance. They are also more efficient, because they allow at least some automatisation of the process and demand less time for the measurement itself. The decision, which method would be the optimal one, for a specific task, may be done respectively following criteria: measurement accuracy, time demand for measurement, characteristics of the surface to be measured (color, texture, reflection, form, size), existing devices, option of measurement during the running experiment, option of measurement under water.

2. OPTICAL SURVEYING METHODS FOR IRREGULAR SURFACES IN EXPERIMENTAL HYDRAULICS

The optical measurement methods can distinguish between single point measurement and image interpretation. Single point measurement is mostly very accurate, delivering numerical results, which may be visualized. These procedure is often very slow and do not function simultaneously with the running experiment. Image interpretation is based on photography. The acquisition works are generally quick, nevertheless a post-processing is needed. The result can be in form of a photo, graphics and/or 3-D coordinates table.

2.1. Single-Point Measurement

The single-point measurement runs automatically. Measuring facility is mostly computer driven (Nachtnebel et. al, 1997). The elevation of the predetermined plan position is measured by a laser ray. It is reasonable to place the measuring points as a plan raster and if necessary to add some other significant points.

2.2. Image Interpretation

Image interpretation methods are photogrammetry and Moire topography. Here are the photos made that are later being processed. By this methods appears the distortion. Firstly the camera recording includes a central perspective projection. This leads to a spatial distortion. Through the orthogonal exposure could the distortion be minimized, but not eliminated. By orthogonal recording it comes to displacements of measuring points positioned on different levels. This is the result of the difference between the perspective and orthographic projection. Those distortions may be easily compensated by adequate methods.

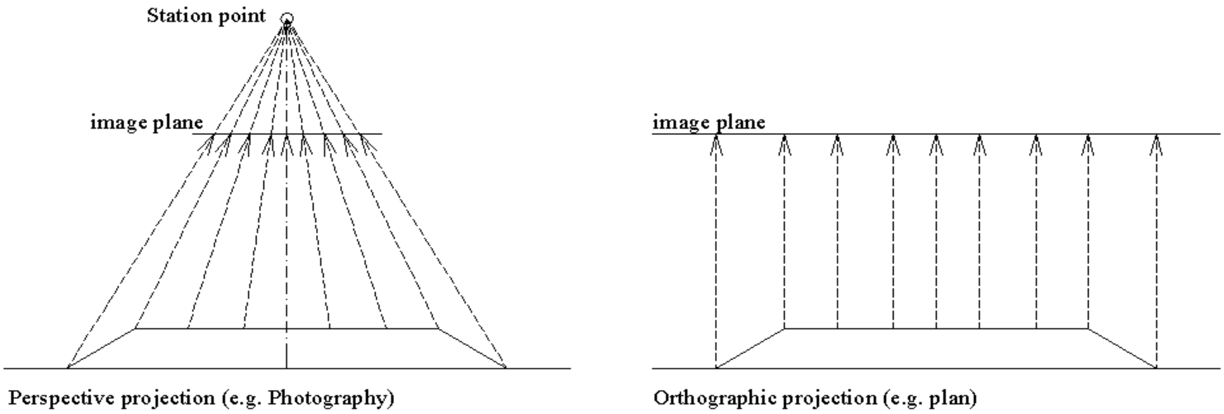

Figure 1. Projective rays of perspective and orthographic projection

Photogrammetry

By this method the measured object is being photographed from different angles. Nowadays, no special metric camera for this task is needed. The objective distortion may be calculated and corrected by the known control points. The position of the camera has not to be known. Having just two equalized photos from different angles, this stereo pair of photos can be viewed three-dimensional and processed. By sufficient contrasts the resulting processing, follows by the computer automatically.

The total processing (measuring control points, elimination distortion effects and stereoscopic processing) is very time consuming and does not function under water. Sophisticated software and skilled personnel are needed. The results are good.

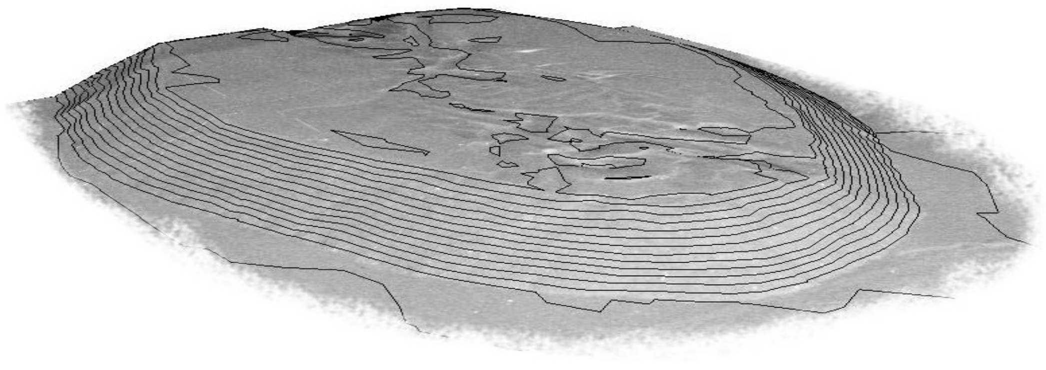

Figure 2. Result of the photogrammetry.

Moiré Topography

The word originates from 12.th century and holds in Arabic culture, known for material woven out of Mohair-wool (Neugebauer H., 1998). 3-D surface acquisition in experimental hydraulics by means of the Moire fringes is relatively new. In 2000, Müller (Müller et. al 2001) made the first experiment on scour by a bridge pier.

The Moire topography is an optical method of the image interpretation, with intention to get the information of the 3-d form of an object. In contrary, to the photogrammetry, here is just one photo needed. There are many possibilities of technical implementation. There are always two similar periodic systems overlaid, that generate moire pattern. A correct description of this effect come by Cloud (1998). In order to build out this striped pattern of the Moire fringes, must the projection center be placed orthogonally to the lines. This may be done by arrangement of the illumination and of the camera, or through two projectors. By a suitable arrangement of the reference plane (a grid) the resulting Moire fringes represent the contour lines.

In order to realize this theoretical basis, Post (1994) introduced various methods how to do this.

Shadow Moiré

The essence of this method is a flat grid. The object is being illuminated through the grid from the side. The observer through the grid, recognizes the surface that is covered by a Moire pattern.

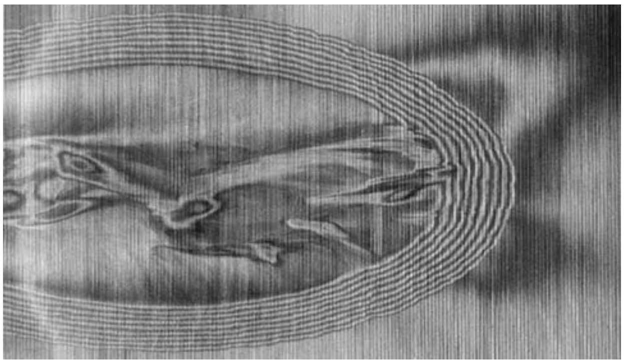

Figure 3. Delta deposition - Photo with the shadow moiré effect.

This pattern is formed while the dark and bright fields alternate. As bright, appear the sectors, which are illuminated through the grid and may be visualized. As dark, appear the sectors that are either not illuminated, or are covered by the grid. Weather a field is dark or bright may depend, by a constant position of the observer, camera and light source, only on the distance of the object surface from the grid (the reference plane).

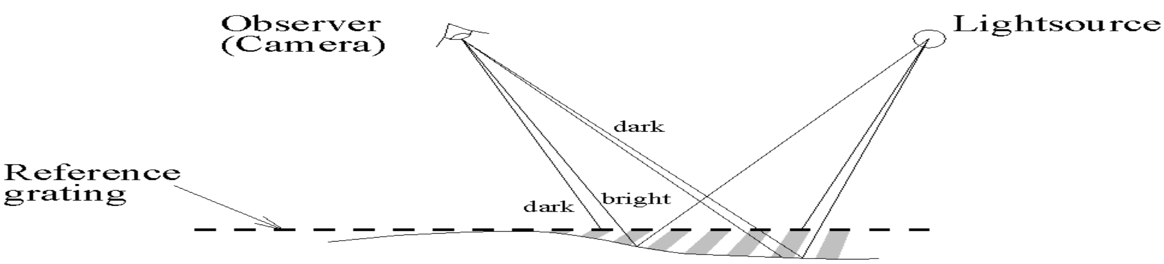

Figure 4. Principle of the shadow moire method

The level difference between the neighboring contour lines Δh_{iso} may be determined by the following equation:

$$\Delta h_{iso} = \frac{L \cdot S}{D} = \frac{S}{\tan \alpha} \tag{1}$$

Where L is the vertical distance between the light source or camera from the grid, S the reference grating pitch and D is the distance between the camera and the light source. α is the angel between the observer and the light source.

2.3. Measurement under Water

Measurement under water, during the test performance, has not been possible till now, by optical methods, although such a permanent monitoring would be of a great value. The methods of the single point measurement do not reach the object under water, because the laser ray reflects on the water surface. Besides this methods are, due to their time consume, unsuitable for the current measurements. Photogrammetric processing is due to the light reflection not possible. Just by the help of the Moire topography is a continuous monitoring of a ongoing current investigation under water surface possible. Yet, the consequences of the light refraction have to be considered.

Through the light refraction on the water surface, the elevation difference between the Moire lines is larger, what results with a smaller number of layers. The new distance between the Moire lines may be easily calculated while taking into account refraction angle δ :

$$\Delta h_{iso} = \frac{S}{\tan(\alpha - \delta)}, \tag{2}$$

The distortion effect caused by the refraction may be compensated parallel with the special perspective equalization.

3. SUMMARY

Optical methods of the surface scanning in the experimental hydraulics are absolutely non-invasive and allow a quick recognition of the surface. Here especially the Moire topography should be stressed. With help of this simple method it is possible to record 3-D surfaces of an object even under the water. The scanning follows without any contact with the surface and flowing water. The result may be visualized immediately. Above all, the surface recording during the running test, without any disturbance of the test, is unique and promising. The tests performance may be “live” followed and documented.

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Riverbank Hydrology and Channel Width Adjustment: The Importance of Matric Potential in Monitoring and Modelling Riverbank Erosion Processes – Case Study at the Drau River, Austria

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ABSTRACT

The aim of this work is to predict the amount of bank retreat due to different hydrological conditions at the gravel-bed river Drau. The investigated riverbanks consist of imbricated gravel with interstitial sand overlain by several layers of sandy silt and sand deposits. Riverbank retreat is caused by erosion due to fluvial forces and, in the upper portion of the bank, by mass failures. As matric suction is an important factor for the shear strength of the riverbank material, it is necessary to investigate the bank hydrology to understand the processes involved in mass failures. In order to calibrate and verify a model, which combines the riverbank's hydrology and its stability against failure, the hydrology and the geometry of a selected riverbank are monitored.

1. INTRODUCTION

The Austrian reach of the River Drau was historically characterized as partially braided, aggrading channel system. High floods at the end of the 19th century and especially in the 1960's required solutions for flood control and minimizing the riverbed. In order to achieve these objectives a number of regulations and bank protection measures have been accomplished. These local and sectional measures in combination with catchment-wide changes like torrent control structures in tributaries, land use changes and also intensive gravel dredging caused a deficit of sediment load, which led to economical and ecological problems (Habersack and Nachtnebel, 1998).

The EU-LIFE Project "Auenverbund Obere Drau" realised extensive restoration measures to improve the ecological integrity of the river-ecosystem, in order to stop riverbed degradation and ensure flood protection. The removal of bank protection structures initiated self-dynamic side erosion at the River Drau, f. e. in the side-arm built in the year 2002, where the monitoring site is situated. Lack of process understanding makes it difficult to estimate river widening in advance.

Bank retreat results from a complex combination of processes of fluvial erosion and mechanisms of mass failure (Casagli, 1999). At the Drau River mass failures occur in the upper part of the bank, which consists of several layers of sandy silt and sand deposits. In these materials the matric potential causes a so called apparent cohesion which increases the shear strength, even in originally cohesionless materials like sands. Hence the bank's stability varies due to changes of matric potential (e.g. Rinaldi and Casagli, 1999; Casagli et al., 1999; Rinaldi et al., 2004). The riverbanks remain stable at steep angle over long periods of time, until flow events, rainfall or snowmelt reduce the matric potential of the bank material. Consequently the shear strength is reduced and failure may occur. After failure fluvial erosion at the toe of the bank again leads to oversteepening.

Figure 1. Restoration measure at the Drau River at Kleblach-Lind, Austria.

In order to develop a model which takes into account parameters and variables involved in mass failure processes, intensive monitoring of bank hydrology and geometry is necessary. This work focuses on processes involved in mass failure, but further research on fluvial erosion of riverbank material will follow to finally couple fluvial erosion, seepage and mass failure models in one simulation (Dapporto and Rinaldi, 2003).

2. MATERIALS AND METHODS

2.1. Experimental Setup

Three tensiometers and five matrix sensors were installed in one profile illustrated in fig. 2, to monitor the bank hydrology. The matrix sensors are situated close to the bank surface as they are less sensitive to mechanical forces regarding bank failure. Also they are able to measure higher matric suctions. The tensiometers were installed in depths where their measuring range would not be exceeded. To prevent damages they were installed further behind the bank surface, even though values measured by tensiometers would be most interesting closer to the bank surface, as tensiometers are expected to be very reliable in indicating real conditions and fast in reaction. In the case of submergence, they are able to indicate the elevation of the groundwater table. Temperature of the soil is measured by tensiometer nr. 3 (fig. 2) and another temperature sensor installed in 0.5 m depth. In an observation well the groundwater level is measured; another sensor monitors the river stage. Rainfall is registered by an ombrometer. All data is saved every 15 minutes. After every event causing changes to the geometry the riverbank is surveyed with reflectorless measurement. In order to obtain the time of failure and to be able to notice if more failures are involved in the riverbank retreat during one event, a remote-controlled camera takes pictures at optional time intervals (fig. 3).

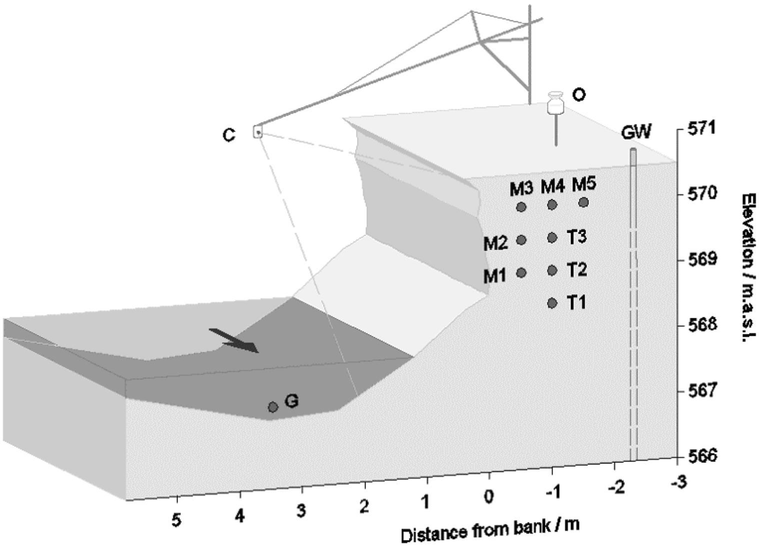

Figure 3. (left). Picture taken by the remote-controlled camera. Figure 2 (right). Arrangement of measurement devices installed at the monitoring site. Key: T1, T2, T3, tensiometers; M1, M2, M3, M4, M5, matrix sensors; G, gauge; GW, ground water level sensor; O, ombrometer; C, camera. A temperature sensor is installed next to M3 and in the same depth.

2.2. Methods

A riverbank representative for the site was selected where steep banks promised further side-erosion in the near future. In order to investigate the depth of the underlying gravel layer and to see if the stratigraphy visible at the bank surface remains constant in the horizontal direction, penetration tests will be done.

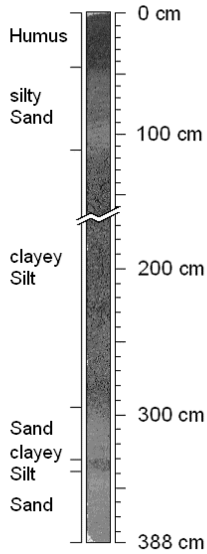

Figure 4. Soil profile.

When the groundwater level sensor was installed, a continuous soil column was obtained which showed the great variety of different soil layers (fig. 4). Undisturbed soil samples were taken from the exposed bank and from a hand-made trial pit for conductivity tests and to obtain the soil-water characteristic curves and grain size distributions in the laboratory. These tests are not completed yet and therefore the soil profile in fig. 4 is a crude estimation. Additionally the field-saturated hydraulic conductivity will be measured in situ with a guelph permeameter. Hydraulic conductivity functions will be estimated.

The geotechnical characterization of the materials is done on disturbed and undisturbed samples. Several methods have been evaluated to investigate the influence of matric potential on the shear strength of the soil. Common triaxial tests on undisturbed soil samples are very difficult to perform due to the fact that the matric potential should be the same at every point of the probe. Many series of tests have to be done to obtain the desired non-linear relation between matric potential and shear strength. This turned out to be too consuming in terms of time and material. Finally direct shear tests under different testing conditions were performed on undisturbed and homogenised samples. The first test series were performed with a constant volume of undisturbed samples to obtain the effective shear parameter ϕ' and c'. Non-planar shear surfaces, which varied from sample to sample, made the interpretation of results difficult.

In the next test series the soil samples were homogenised and fully saturated to simulate worst conditions and to determine the lowest possible friction angle and cohesion.

Tests at different water contents will follow to obtain the apparent cohesion at different matric suctions. The results will be compared with formulae like the one introduced by Vanapalli et al. (1996) which estimates the matric suction-shear strength curve from the effective shear parameters and the soil-water characteristic curve:

$$\tau = c' + (\sigma - u_a)\tan\phi' + (u_a - u_w)\left(\frac{\theta_w - \theta_r}{\theta_s - \theta_r}\right)\tan\phi', \quad (1)$$

where τ = shear strength, c' = effective cohesion, σ = total normal stress, u_a = pore air pressure, ϕ' = friction angle in terms of effective stress, u_w = pore water pressure, θ_w = actual water content, θ_s = water content at saturation, θ_r = residual water content.

The results of the laboratory tests are used as input parameters for a saturated and unsaturated transient 2D-seepage simulation with the numerical model SEEP/W from GEO-SLOPE International, Ltd. The groundwater table and the distribution of matric suctions in the unsaturated zone are used as initial conditions; the stage hydrograph and/or rainfall event as time-stepped boundary conditions. Measured and computed values will be compared. Using the pore water distribution and river stage of every time step a stability analysis (SLOPE/W from GEO-SLOPE International, Ltd.) is performed to calculate the most probable slip surface of rotational and slabtype failures and its associated factor of safety. Therefore some adaptions are required, as SLOPE/W uses the slice method and cannot operate on geometries containing overhanging sections. The factor of safety concerning cantilever failures will be calculated with a spread sheet using the distribution of matric potential along verticals, where the normal stress is zero and the shear strength depends only on the cohesion (Rinaldi, 2006). Most failures occur a few hours after the peak of the hydrograph during rapid drawdown, when the bank stability is lowest because of: decreasing or even zero matric suction and consequently loss of apparent cohesion; loss of confining pressure of the river stage and of lift force; increased weight due to a higher water content acting on steep critical slip surface (fig. 5). Depending on the permeability of the bank material excess pore-water pressures can also occur during rapid drawdown, but are not required for mass failures (Simon, 1999).

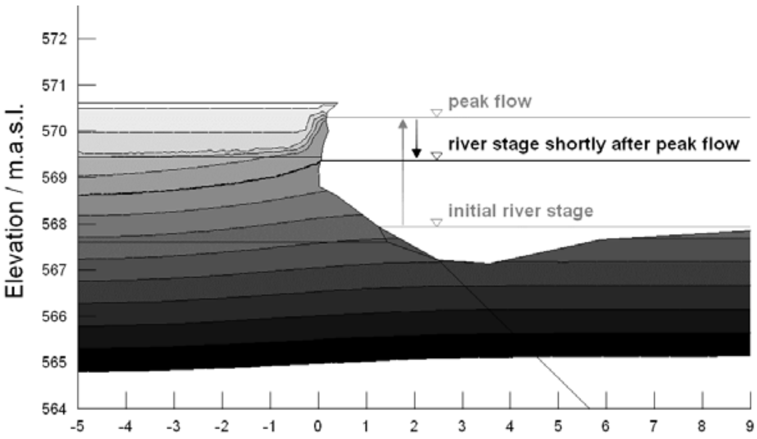

Figure 5. Seepage modelling with simplified soil properties and user-defined hydrograph, indicating the pore water pressure distribution shortly after peak flow. Hydrograph leaving behind weakened soil near the bank surface.

3. PRELIMINARY RESULTS

From the time of installation on the 18th of July 2006 until the 10th of August the matrix sensors M2-M5 had no good contact to the soil, so that they didn't react to changes of soil water conditions, except for one rainfall event. On the 10th of August they seemed to get in good contact with the soil. From then on, M2-M5 showed fast reaction to rainfall events. The data recorded by M1 corresponds well to the trend of the data recorded by T2. The tensio-meters were working well from the very beginning. On the 2nd of August the river gauge has been installed as the last device of the setup. Shortly after its installation a limited flow peak in the night from 3rd to 4th August led to submergence of the deepest tensiometer T1 (fig. 6). As expected the tensiometer then measured positive pore water pressure.

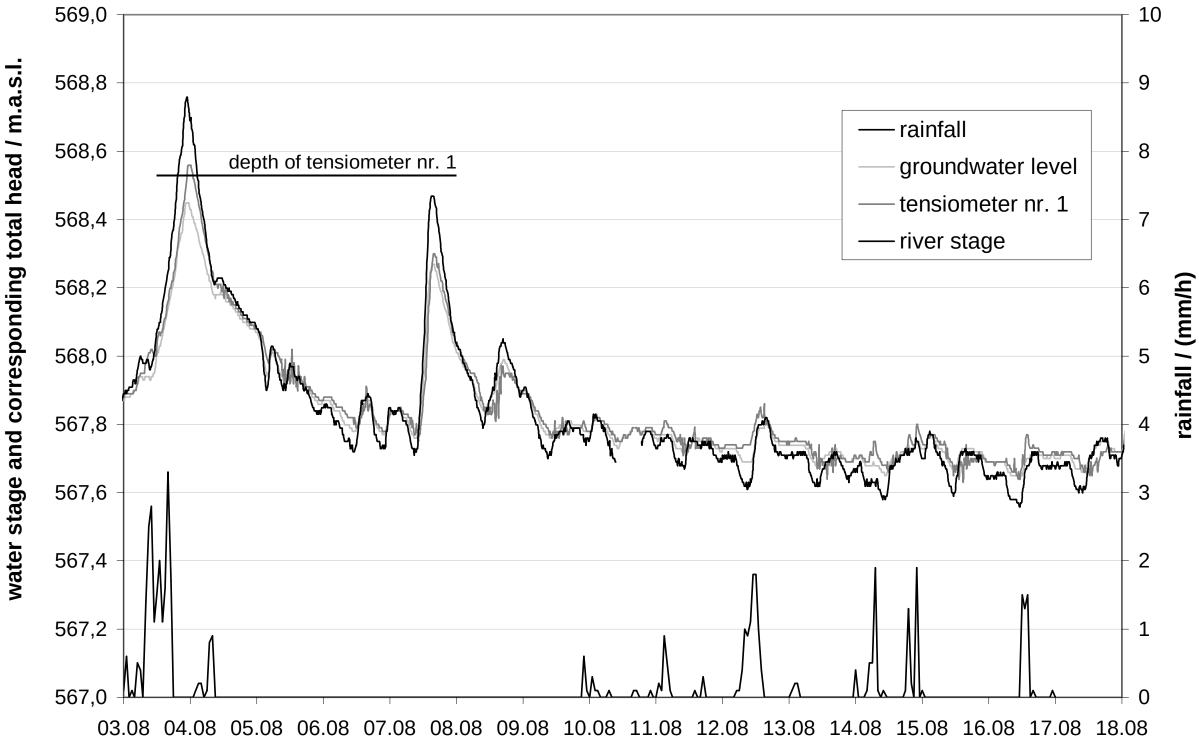

Figure 6. Reaction of groundwater level sensor and tensiometer nr. 1 on river stage and rainfall.

4. PROSPECTS

After having determined all soil parameters, the values measured during rainfall and flow events can be compared to results obtained from the seepage model. Additionally the factor of safety concerning mass failure will be calculated for every time step. If mass failure occurs, time, type and geometry of the failure can be compared to the model results. The next step will be to include the process of fluvial erosion into the simulation. Vegetation effects on riverbank stability will be investigated and methods of their implementation into models are going to be evaluated. Finally insight into the basic model parameters conditioning maximum river width is expected.

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An Insurance Drought Model

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ABSTRACT

The drought model of the Austrian hail insurance is based on a water balance model. The water balance is determined for each crop type as the difference of precipitation and evapotranspiration on a daily basis for a 1 km x 1 km grid. The calculation of the reference evapotranspiration is based on the Penman-Monteith method recommended by the FAO. The Penman-Monteith equation contains the meteorological parameters radiation, humidity, temperature and wind speed. All meteorological parameters are made available through the Central Institute for Meteorology and Geodynamics (ZAMG). To obtain the evapotranspiration for each crop type on a specific place the reference evapotranspiration is multiplied by a crop coefficient (K_c) derived from the historical meteorological data of the last 35 years. Due to changes in vegetation the K_c factor changes during the growing period and three values (for the initial, mid-season and late season stage) are required depending on the phenological growth stages.

1. DATA BASE

1.1. INCA (Integrated Nowcasting through Comprehensive Analysis) Data

The meteorological data used for the calculation of the water balance (precipitation, temperature, humidity, wind speed, radiation) are based on INCA analysis data (Haiden, 2006) processed by ZAMG. The current domain of the INCA system consists of an area of 600 km x 350 km at a resolution of 1 km and covers the eastern Alps and alpine forelands. Figure 1 shows the precipitation analysis of 7 August 2006.

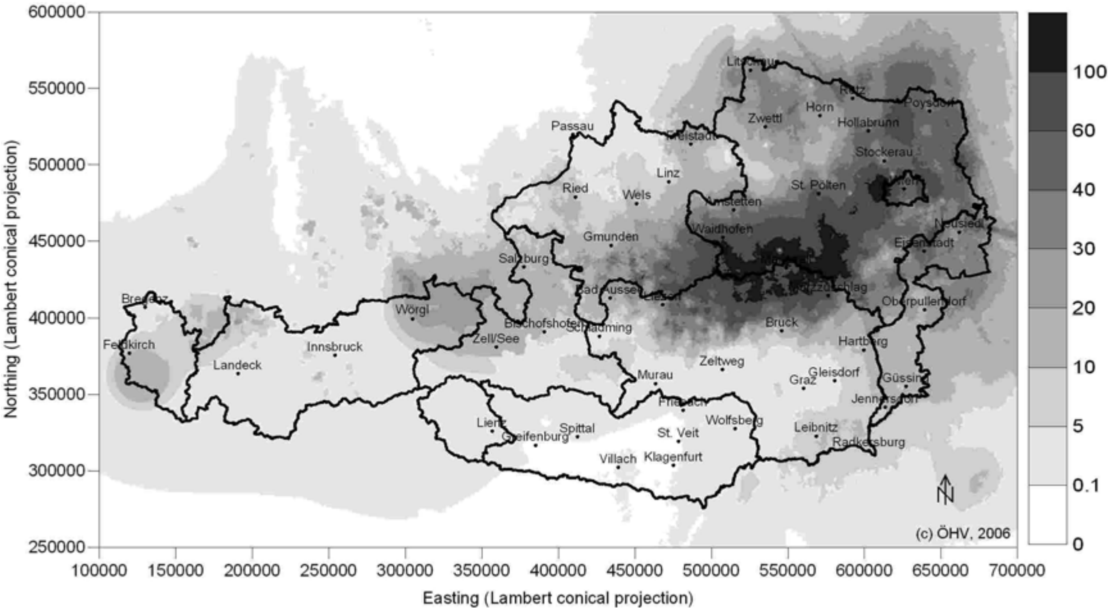

Figure 1. INCA precipitation analysis of 7 August 2006.

The most important data source for the INCA system are the ~ 140 automated stations (TAWES) of the ZAMG and the radar data from the Austrian radar network operated by the civil aviation administration (Austrocontrol). For the precipitation analysis additionally the data from the stations of the hydrological services (~ 600) are implemented (not in real-time).

For the reconstruction of former water balances and the calculation of the so called historical K_c factors (next chapter) the data from the digital climate atlas (ZAMG, 2002) for the period 1971 to 2000 containing 170 stations was used.

1.2. Phenological Growth Stages

Selected phenological growth stages (planting date, stem extension, flowering, ripening) are observed by employees of the Austrian hail insurance for each crop type at up to 80 different locations. To spread this information on the 1 km x 1 km INCA grid a simple plant growth model based on the photothermal unit (PTU) is used (Stenitzer, 1988). The PTU is calculated using equation 1 and accumulated through the growing period of each crop type:

$$PTU = (T - T_{bas}) * DAYLGT \quad [°C\ h] \tag{1}$$

PTU = photothermal unit [°C h], T = mean daily air temperature [°C], T_{bas} = 5 °C, DAYLGT = daylength [h]. Figure 2 shows the accumulated PTU until 7 August 2006.

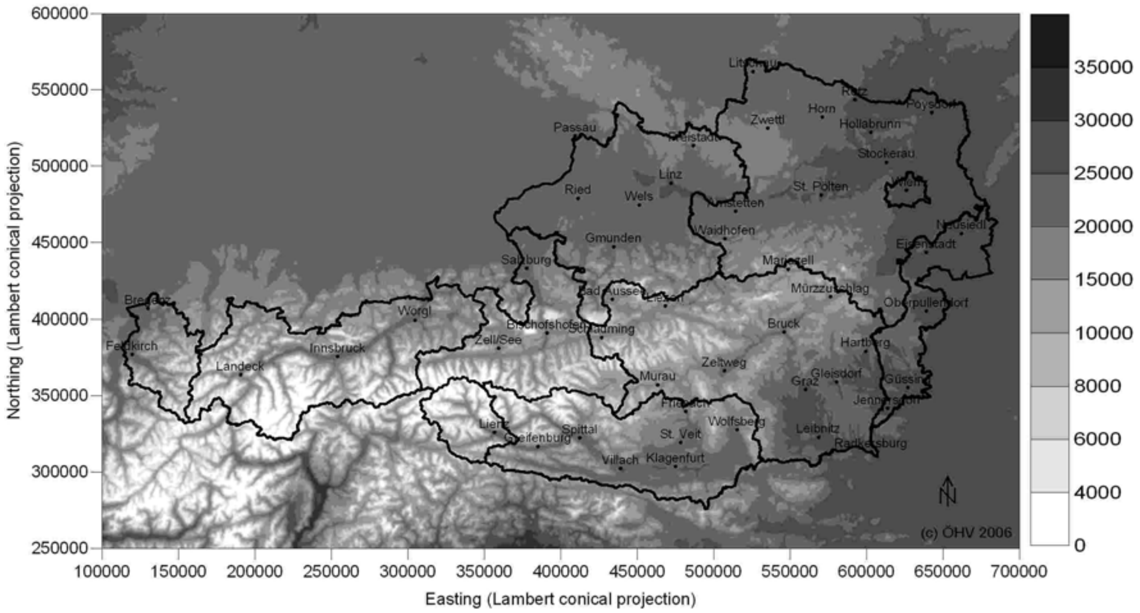

Figure 2. Accumulated PTU until 7 August 2006.

2. WATER BALANCE CALCULATION

The water balance (equation 2) is determined for the crop types wheat (winter and summer), barley (winter and summer), rye, triticale, oats, maize, peas, sunflower, potato, soybeans and pumpkin on a daily basis:

$$WB = NS - ET_c \quad [mm/day] \tag{2}$$

WB = water balance [mm/day], NS = precipitaion [mm/day] and Et_c = crop evapotranspiration [mm/day].

The FAO (Food and Agriculture Organization of the United Nations) Penman-Monteith equation (Allen, 1998) to determine the reference evapotranspiration (ET_0) is shown in equation 3

$$ET_0 = \frac{0.408\Delta(Rn - G) + \gamma(\frac{900}{T + 273})u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \text{ [mm/day]} \quad (3)$$

with ET_0 = reference evapotranspiration [mm/day], Rn = net radiation at the crop surface [MJ/m^2day], G = soil heat flux density [MJ/m^2day], T = mean daily air temperature at 2 m height [°C], u_2 = wind speed at 2 m height [m/s], e_s = saturation vapour pressure [kPa], e_a = actual vapour pressure [kPa], Δ = slope vapour pressure curve [kPa/°C] and γ = psychrometric constant [kPa/°C].

The effects of characteristics that distinguish the cropped surface from the reference surface are integrated into the crop coefficient (K_c). The calculation of the crop evapotranspiration (ET_c) is shown in equation 4.

$$ET_c = ET_0 \cdot K_c \quad \text{[mm/day]} \quad (4)$$

Therefore the growing period is divided into three distinct growth stages. The initial stage from planting date to stem extension, the mid-season stage from stem extions to flowering and the end-season stage from flowering to ripening. The crop coefficients were calculated (equation 5) for each stage and crop type by reconstructing the reference evapotranspiration with data from the digital climate atlas using equation 3, setting WB = 0 in equation 2 and using equation 4:

$$K_c = \frac{(NS - WB)}{ET_0} \quad (5)$$

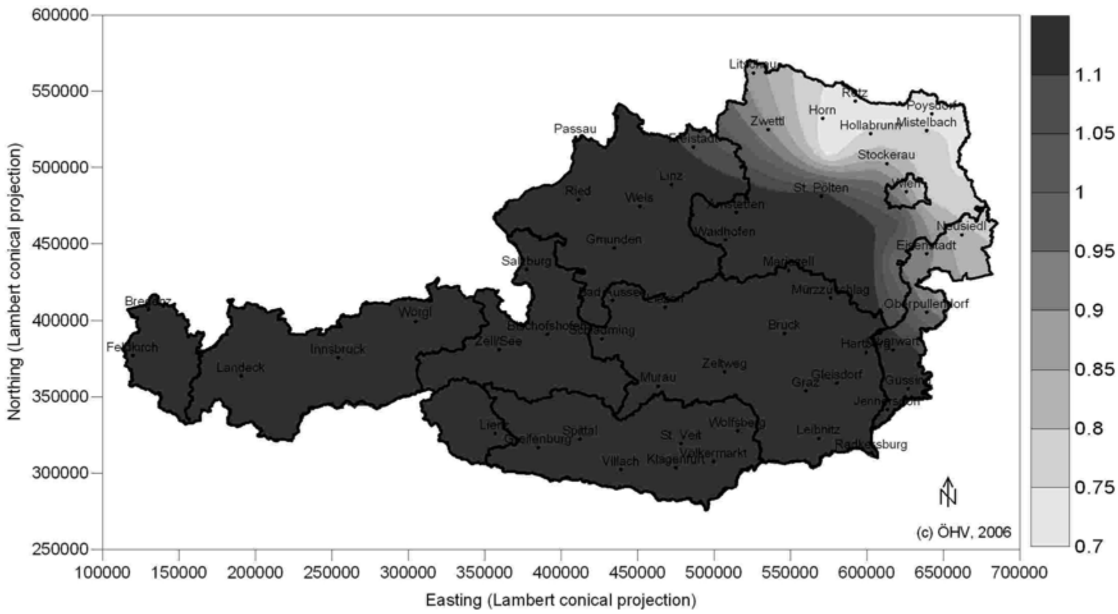

Figure 3. The crop coefficient for winter wheat in the mid-season stage.

With this assumption we link the mean yield to the climatological situation at a specific place. And our calculated crop coefficients were compared to the K_c values recommended by the FAO (Allen, 1998) and cannot exceed these values for the mid-season stage. In Figure 3 the crop coefficient for winter wheat in the mid-season stage is shown on the INCA grid.

For contributing to different soil types the accumulated water balance cannot exceed 60 mm for fields with low drought risk and 20 mm for fields with high drought risk. The insurant decides about having a low or high drought risk.

The water balance for maize in the mid-season stage 2006 is shown in figure 4.

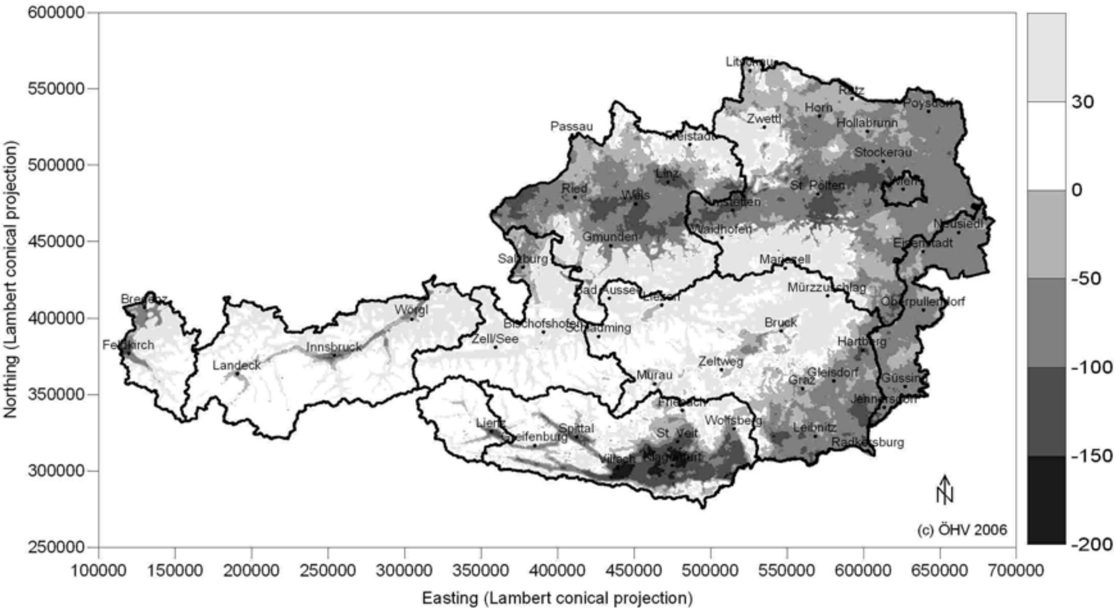

Figure 4. Water balance of maize (in mm) in the mid-season stage 2006.

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Climate Change Analysis Based on Accumulating Curves of Precipitation and Temperature Distance Away from Averages: a Case Study of Xifeng Town, Gansu Province, China

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ABSTRACT

Climate change plays a very important role in agriculture and rural water management. Accumulating curves of the measured data distance away from averages could show the change of climate factors clearly. The regression of accumulating curves could descript the stages of climate change. The climate change is analyzed based on the precipitation and temperature data from 1951 to 2001 in Xifeng Town, Gansu Province, China. The annual precipitation increased before 1976, and decreased after 1976. The mean annual temperature and mean lowest temperature increase significantly. There are four clear stages including cool and dry stage, cool and wet stage, warm and wet stage and warm and dry stage. The monthly precipitation and temperature change differently. Precipitation increases in winter and early spring while it decreased in July, August and September. The monthly mean temperature and mean lowest monthly temperature increase significantly. The warm and wet trend is clear in winter. In the wet period of summer and early autumn, climate change has a warm and dry trend. Climate change is one of the core topics in research of environment evolvement (Wang and Dong 2002). It affects not only the vegetation growth, agriculture, stock rising and so on (Zhang and Zhang 2002; Li et al 2002; Wang 2002), but the change of regional water resources (Zhang et al 2003). Some research showed that the precipitation varied in the periods of 8.5 years and 3-4 years (Wang and Dong 2002). Furthermore, it showed that the climate change warmer and drier (Yan 1999), and the change ranged varied in different seasons. Because the change is complex in period and seasons, a method is put forward to discover the change. Xifeng Town is located in the transition of arid and semiarid area with deepest loess cover (Qian 1991), and the climate change is sensitive. The precipitation and air temperature data in Xifeng Town are analyzed to show the climate change.

1. DATA AND METHOD

The dataset is from 1951 to 2001 measured in Xifeng Weather Station, Gansu Province. The precipitation data includes of annual, monthly and flood period precipitation depth, and the air temperature includes of mean, highest and lowest monthly air temperature. The annual mean, highest and lowest monthly air temperatures are the averages of relative values of every month.

Accumulating curves of the measured data distance away from averages are used when to analyze the change of precipitation and temperature. The values of abscissa (X axis) are years and the values of coordinate (Y axis, P_i) are calculated by equations below:

$$K_i = K_{ic} - k_a \qquad (1)$$

$$P_1 = k_1 / k_a^* \cdot 100\,\% \qquad (2)$$

$$P_i = P_{i-1} + k_i / k_a^* \cdot 100\,\%, \qquad i > 1 \tag{3}$$

In the equations, k_a is the average values of precipitation and air temperature; K_{ic} is the measured value of the first year; k_i is the measured data distance away from averages in year i; P_1 and P_i are the percentage of measured data distance away from averages of the first year and year i respectively, %. The measured data distance away from averages could discover the change efficiently.

2. RESULTS

2.1. Climate Change of Annual Data

According to the analyses, the annual mean precipitation and air temperature are 513.5 mm and 8.48 °C during 1951-2001. In Figure 1 and the all other figures below, y1, y2, y3 and y4 are mean, highest and lowest monthly air temperature respectively. It is showed that the annual precipitation changed greatly in the last 50 years. Before 1976, the annual precipitation increased and then decreased after 1976. The air temperatures increased steadily that the linear correlation coefficient of annual mean and lowest air temperatures are 0.5907 and 0.6805 respectively, and the significances are 0.001 (51 samples). The annual highest increased gradually after 1975.

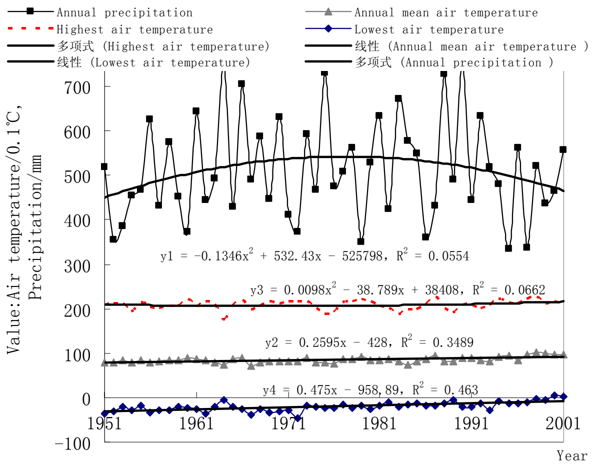

Figure 1. Precipitation and temperature change from 1951 to 2001

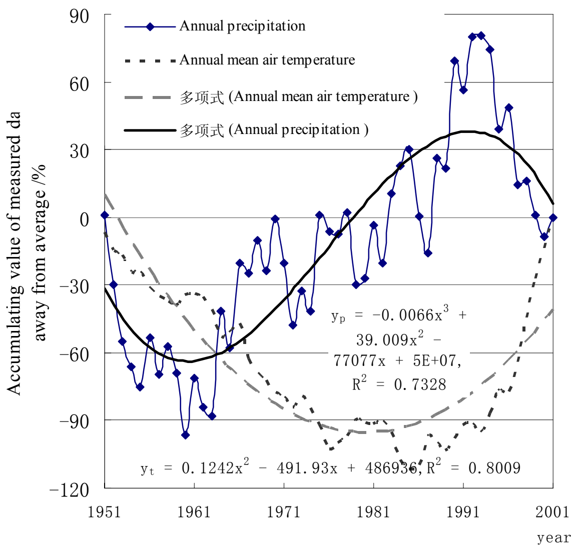

Figure 2. Accumulating curves of precipitation and temperature away from averages from 1951 to 2001

2.2. Stages of Climate Change

It is showed in Figure 2 that the Accumulating curves of the measured data of annual precipitation and air temperature distance away from averages change greatly in the research period respectively. The change process of them had some differences. The non-linear regressions showed that a cubic equation and a quadratic equation can show the change process of climate change significantly (significances is 0.001, 51 samples). In the last 51 years, there are four stages on precipitation and air temperature change in Xifeng Town (See Table 1).

Table 1. The average annual precipitation and temperature of different stages

Stage	Period	Average annual precipitation		Average annual temperature	
		Period(mm)	Annual change(mm/a)	Period(°C)	Annual change(°C/a)
Cool and dry stage	1951-1963	478.62	-	8.213	-
Cool and wet stage	1964-1984	540.71	2.965	8.211	-0.0001
Warm and wet stage	1985-1993	546.50	0.724	8.599	0.0485
Warm and dry stage	1994-2001	461.76	-10.592	9.491	0.1114

Note: Annual change means the average annual precipitation or temperature change compared with that of next stage

Table 2. Linear coefficient of monthly precipitation and temperature with year

Month	Precipitation	Average temperature	Highest temperature	Lowest temperature
Jan	0.6215***	0.4221**	0.0715	0.5567***
Feb	0.5813***	0.2611*	0.1253	0.3829**
Mar	0.5344***	0.0795	-0.1191	0.1287
Apr	0.0409	0.3075*	-0.0443	0.2112
May	-0.1027	0.3535*	0.0723	0.4356**
Jun	0.1148	0.0155	-0.1408	0.3783**
Jul	-0.1246	0.2728*	0.1681	0.2552*
Aug	-0.0225	0.2080	-0.0981	0.2459*
Sep	-0.1074	0.4341**	0.4496**	0.3272*
Oct	0.0845	0.2225	-0.0322	0.0764
Nov	0.1484	0.2579*	0.1445	0.2083
Dec	0.3603	0.3972**	0.2565*	0.2491*
Whole year	0.0401	0.5907***	0.1774	0.6805***

Note: ***, **, * means the significant coefficient being 0.001, 0.01and 0.1 respectively.

2.3. Monthly Climate Change

The linear coefficient of monthly precipitation and temperature with year is showed in Table 2. In general, the precipitation in winter and the beginning spring have a increasing trend, the linear coefficients of monthly precipitation in January, February, March and November with year are 0.6215, 0.5813, 0.5344 and 0.3603 respectively, and the significant is more than 0.01; The precipitation in July, August and September decreased slightly. The non-linear regression showed that precipitation increased before 1975 and then decreased.

The air temperature increased in each month, and in January, September and October, the increasing is significantly (significance more than 0.01) The significance of increasing in February, April, May, July and November is 0.1 that showed the increasing trend of temperature change. The highest air temperature of five months (March, April, June, August and October) decreased faintly. The highest air temperature in September and December increased significantly. The lowest air temperature increased evidently in each month. The linear coefficients in January, February, May and June are less than 0.01, but that in July, August, September and December are less than 0.1.

2.4. Climate Change in Different Seasons

It showed that there was a higher temperature and more precipitation in winter (December and the next January and February), and the annual mean and lowest air temperature increased (Table 2). In the first two months of spring (March and April), the highest air temperature decreases. In the flood season (summer and autumn, from May to September), the trend of climate change is warming and drying. The linear coefficients of monthly precipitation with year are negative, but the mean and lowest temperature increased significantly.

3. DISCUSSIONS

It showed that the annual precipitation increased before 1976 and then decreasing, and the annual mean and lowest air temperature increased directly. The result is different from that of Wei (Wang and Dong 2002) . Wei showed that the period in 1950s and the beginning of 1960s is lacking of precipitation, and in the period from the middle of 1960s to the beginning of 1990s, there was more precipitation, and then, precipitation decreased. The drying process is very clear when comparing the warm and dry stage and warn and wet stage.

The same as climate change in Weihe Velly, the trend, warming in winter and summer and drying in summer and autumn, is very clear in Xifeng Towm (Yan 1999). There are four stages, such as Cool and dry stage, Cool and wet stage, Warm and wet stage and Warm and dry stage. The climate change is not just a simple warming and drying trend and the change is complex.

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