Auswirkungen unterschiedlicher Bewirtschaftungsmaßnahmen im Feldgemüsebau beurteilt anhand des EPIC Modells unter besonderer Berücksichtigung des Nitrataustrags

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Kurzfassung

Computermodelle werden zunehmend zur Untersuchung und Vorhersage von Umweltauswirkungen verwendet. In dieser Arbeit wird das Modell EPIC (Environmental Policy Integrated Climate) zur Abschätzung der Auswirkungen unterschiedlicher Bewirtschaftungsmaßnahmen im Gemüsebau verwendet. Im Eferdinger Becken ist der Feldgemüsebau ein wichtiger landwirtschaftlicher Produktionszweig. Aufgrund von Schwellenwertüberschreitungen bei Nitrat im Grundwasser wurde ein Sanierungsprojekt zur Minimierung der Nitratverlagerung im Gemüsebau durchgeführt. Die Maßnahmen beinhalteten unter anderem die Reduktion der Stickstoffdüngung um 30% oder den Anbau von Zwischenbegrünungen. An zwei Standorten in der Region wurden Lysimeter zur Sammlung des Sickerwassers installiert. Die Nitratverlagerung wurde anhand von Messungen des Nitrats im Sickerwasser beurteilt. EPIC Simulationen wurden durchgeführt, um Langzeiteffekte dieser Maßnahmen abzuschätzen. Dazu wurde das Modell anhand der Messdaten von den Untersuchungsstandorten kalibriert. Ein Vergleich der Simulationsergebnisse mit Messergebnissen zeigt, dass Erträge, Sickerwasseranfall und Nitratverlagerung mit EPIC wiedergegeben werden können. Simulationen über 20 Jahre ergaben eine Verringerung der Nitratverlagerung bei reduzierter Düngung und bei Zwischenbegrünung. Entgegen der Erwartungen kam es bei reduzierter Bewirtschaftungsintensität zum Ansteigen der Nitratverlagerung bis zum ca. zehnten Simulationsjahr. Deshalb wird ein Beobachtungszeitraum von mindestens 10 Jahren zur Beurteilung der Umweltauswirkungen von Bewirtschaftungsmaßnahmen empfohlen. Aufgrund der unterschiedlich starken Auswirkungen von Niederschlag und Temperatur auf Umweltparameter soll in Simulationsexperimenten die Abhängigkeit ausgewählter Parameter von Wetterschwankungen untersucht werden.

Abstract

Computer models are increasingly used to analyse environmental impacts of management measures in agricultural land uses. The Eferding basin is a major vegetable production region in Austria, where steadily rising nitrate concentrations in groundwater have been observed over the last decades. A sanitation program has been launched with management measures that reduce nitrogen fertilization rates by 30 %, or integrate cover crops. In this study, field measurements on seepage water, nitrate leaching, and crop yields are used for calibration of the bio-physical process model EPIC (Environmental Policy Integrated Climate). The performance testing of EPIC indicates that the model is able to predict yields, seepage water, and nitrate leaching. EPIC simulations over 20 years show decreased nitrate leaching from management measures that have reduced fertilization or introduce intercropping. Positive effects of cover crops on yields and soil condition could not be verified by modelling results. Nitrogen losses by leaching and ammonia volatilization significantly increase after 5 years (volatilization) and 10 years (leaching). Therefore, longer time analysis should be carried out to better evaluate the environmental impacts of alternative management measures. In addition, a simulation experiment is recommended to analyse the stochastic environmental effects due to the high variability of parameters directly affected by precipitation and temperature.

Einleitung

Biophysikalische Prozessmodelle werden zunehmend zur Analyse von Umwelteffekten eingesetzt, da zum einen die Datenmenge, -güte, und -verfügbarkeit steigen und zum anderen komplexe Wechselwirkungen besser berücksichtigt und dargestellt werden können. In der vorliegenden Arbeit wird ein Modell zur Abschätzung von unterschiedlichen Bewirtschaftungsmaßnahmen im Feldgemüsebau eingesetzt. In Produktionssystemen mit hohem Anteil von Gemüse in den Fruchtfolgen kommt es teilweise zu großen Stickstoffverlusten, da der Feldgemüsebau durch hohe Düngungsintensitäten und großen Mengen an stickstoffreichen Ernterückständen charakterisiert ist. Deshalb enthalten die Böden am Ende einer Vegetationsperiode häufig große Mengen an Nitratreststickstoff, der über den Winter in das Grundwasser ausgewaschen werden kann. Weitere Verluste erfolgen in die Atmosphäre als molekularer Stickstoff oder Lachgas als Folge von Denitrifikation oder über Ammoniakverflüchtigung (Krug et al., 2002). Molekularer Stickstoff findet sich zu ca. 87 % in der Atmosphäre und ist somit unbedenklich. Emissionen von Lachgas und Ammoniak sind wirken sich jedoch in negativen Umwelteffekten aus. Lachgas aufgrund seiner hohen Treibhausaktivität. Ammoniak kann zu Lachgasbildung führen als auch zu Eutrophierung und Versauerung der Gewässer sowie zu Bildung von Feinstaub beitragen. Diese Arbeit beschäftigt sich vordergründig mit Emissionen von Nitratstickstoff, die zu Eutrophierung führen und im Falle von Auswaschung ins Trinkwasser ein toxikologisches Problem darstellen kann.

Grundlage dieser Arbeit stellt ein in der Region Eferding durchgeführtes Projekt zur Reduktion von Nitratauswaschungen im Feldgemüsebau dar (Dietrich et al., 2002). Das Eferdinger Becken ist ein bedeutendes Frischgemüseanbaugebiet, in dem bei einigen Messstellen die mehrmalige Überschreitung des Schwellenwertes von 45mg NO_3/l im Grundwasser gemessen wurde. Aufgrund dessen wurde ein Sanierungsprogramm eingerichtet. Unterschiedliche Bewirtschaftungsmaßnahmen wurden auf Ertrag, Qualität, Nitratverlagerung und Sickerwasseranfall geprüft. Die Maßnahmen beinhalten eine Düngung nach dem KNS-System, eine Reduktion der Stickstoffdüngung um 30 % des KNS-Sollwerts und den Anbau von abfrostenden und nicht abfrostenden Zwischenfruchtbegrünungen, die den im Oberboden verbleibenden Stickstoff über den Winter teilweise binden sollen. Im Wesentlichen zeigten die Untersuchungen über drei Jahre, dass die Düngung nach KNS-System zu keinen Qualitäts- und Ertragseinbußen führte. Die Reduktion der Sticktoffgaben um 30 % führte bei einigen Sorten zu Verminderungen von Qualität und Erntemenge. Zwischenbegrünung, vor allem nicht abfrostende, ergab bei optimaler Einarbeitung positive Effekte für Ertrag und Bodenzustand (Liebhard et al., 2003). Messdaten von knapp vier Jahren und zwei Standorten im Eferdinger Becken wurden zum Vergleich mit Simulationsergebnissen von EPIC (Environmental Policy Integrated Climate) verwendet. EPIC wurde in den 80er Jahren zur Bewertung des Zustandes von Böden und Gewässern in den USA entwickelt (Williams et al., 1984). Seitdem wurde das Modell fortlaufend ausgebaut und in seinen Anwendungen verfeinert (Williams 1995; Izaurralde et al., 2006).

EPIC ermöglicht den Vergleich verschiedener Bewirtschaftungssysteme und deren Auswirkungen unter anderem auf Hydrologie, Erosion und den Kreisläufen von Stickstoff, Phosphor und Kohlenstoff. Die wichtigsten Komponenten in EPIC bilden Simulation von Wetter, Hydrologie, Sedimentation und Erosion, Nährstoffzyklen, Pestizide, Pflanzenwachstum, Bodentemperatur- und Feuchte und Bodenbearbeitung. Für die Simulation einiger P rozesse w ie E vapotranspiration ka nn zwischen verschiedenen Algorithmen gewählt werden. Die Anwendung des Modells erfordert eine Vielzahl von Daten und die Qualität der Resultate hängt stark von der Qualität der Eingangsdaten ab. Dabei ist zwischen Daten die notwendig sind und solchen, die zusätzliche Informationen zur Erreichung genauerer Ergebnisse liefern, zu unterscheiden.

Das Ziel der vorliegenden Arbeit ist eine Beurteilung, inwiefern sich das Modell EPIC eignet, Erträge, Sickerwasseranfall und Nitratverlagerung im Gemüsebau über längere Zeiträume abzuschätzen.

Im ersten Teil der Arbeit „***Comparison of f ield measurements and E PIC s imulations of nitrate leaching under different vegetable production systems in the Eferdinger Becken, Austria***“ wird das Modell anhand der Messdaten an eine Bewirtschaftungsvariante eines Standortes kalibriert und eine Validierung der Simulationsergebnisse mit den übrigen Bewirtschaftungsvarianten und dem zweiten Standort durchgeführt.

Im zweiten Teil „***EPIC long-term simulations of vegetable production systems with sensitivity analysis of the weather generator***“ wird anhand eines Simulationsexperimentes untersucht, wie sich die unterschiedlichen Bewirtschaftungsmaßnahmen über eine Periode von 20 Jahren auswirken. EPIC beinhaltet ein Programm zur Generierung unterschiedlicher Witterungsverläufe. Die langjährigen Wettersimulationen dienen, sowohl die stochastischen als auch dynamischen Effekte in der Bewertung von Bewirtschaftungsmaßnahmen zu berücksichtigen.

Im Anhang befinden sich Beiträge für Veranstaltungen, die zur Erarbeitung der Diplomarbeit verfasst wurden:

- ***Impacts of al ternative management measures in v egetable production s ystems on nitrate leaching in the Eferdinger Becken, Austria*** - eine Kurzpublikation zu einem Vortrag beim Symposium „Soil Physics and Rural Water Management" (SoPhyWa), Wien, September 2006
- ***Long-term C & N simulations with EPIC for estimating ecosystem functioning under different management practices in the Marchfeld watershed*** – ein Posterbeitrag zur Konferenz "Reduced Nitrogen in Ecology and the Environment", Obergurgl, Oktober 2006
- ***Evaluation of alternative management measures in vegetable production systems by field measurements and EPIC simulations*** – ein Posterbeitrag zum "14th International Poster Day, Transport of Water, Chemicals and Energy in the Soil-Plant-Atmosphere System", Bratislava, November 2006.

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Comparison between field measurements and EPIC simulations of crop yields and nitrate leaching under different vegetable production systems in the Eferdinger Becken, Austria

1. Introduction

Intensive production systems with major shares of vegetables in the crop rotations often lead to high nitrate emissions. In the Southern Eferding 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. Vegetables are produced in an area of 500 ha (Eschlböck, 2000). Because nitrate concentrations in the groundwater are exceeding the threshold of 45 mg NO_3 /l at different monitoring sites, a sanitation program to reduce nitrate leaching was launched (Liebhard et al., 2003). In the region approximately 240 ha need sanitation due to high nitrate emissions. Nitrate leaching of different management systems was evaluated by collecting seepage water in field lysimeters that have been installed on representative farms in the region, and by measuring nitrate concentrations of seepage water. The investigated management measures are intercropping systems with different cover crops over the winter period, and reduction of nitrogen fertilizer rates. The effects on yields, seepage water, and nitrate concentration of seepage water were estimated for evaluation of alternative management measures. Several studies have shown that cover crops can increase soil quality and may decrease nitrate leaching (McCracken et al., 1994; Weinert et al., 2002; Jackson et al., 2004; Thorup-Kristensen, 2006). Weinert et al. (2002) reported that winter cover crops in potato cultivations reduce the potential for nitrate leaching by absorbing and storing nitrogen in plant tissue during winter months and by absorbing and transpiring water, therefore lessening water percolation. Incorporation of cover crop biomass in fall released more nitrogen during winter months than incorporation of cover crops in spring time (Weinert et al., 2002). Cover crops can have positive effects on soil fertility and may raise the availability of nitrogen for cash crops which could increase crop yields (Paustian et al., 1992). Nevertheless, for some crops as lettuce intercropping might enhance diseases (Jackson et al., 2004).

Field measurements were carried out for almost four years. As field measurements are cost and time intensive, short time measurements are often used to predict long-term effects. However, several effects change over longer time periods and cannot be evaluated by short-time measurements. Therefore, computer modelling becomes increasingly important to evaluate environmental impacts of alternative agricultural systems on soil and water resources. Computer models allow us to change management or environmental parameters in order to study their influences. Model calibration using measurements is necessary to test the model performance and reliability of simulation outputs. In this study, field measurements are compared with simulation results from the bio-physical process model EPIC (Environmental Policy Integrated Climate). EPIC can be used to compare management systems and their effects on crop yields as well as on water, nitrogen, phosphorus, pesticides, organic carbon, and sediment transport, on organic carbon sequestration, and eventually on greenhouse gases emissions. Several studies have shown that EPIC is capable of predicting vegetable yields and nitrogen losses. An overview of EPIC applications is given in Gassman et al. (2004). Calibration of the model was carried out with lysimeter measurements from the base-run (control) management of one farm. The calibrated model is used to test the performance with alternative management measures from the same site as well as from the other site on the second farm in the region.

2. Material and Methods

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). Seepage water samples were taken and measured once per week. Figure 1 gives a schematic description of the lysimeters used. Data from April 1998 to December 2001 are used to calibrate EPIC and test its performance. Figure 2 shows precipitation and temperature from the observed time period. Annual precipitation is about 795 mm. Weather data were obtained from the meteorological station in Aschach/D, which is close to the sampling sites (Dietrich et al., 2002).

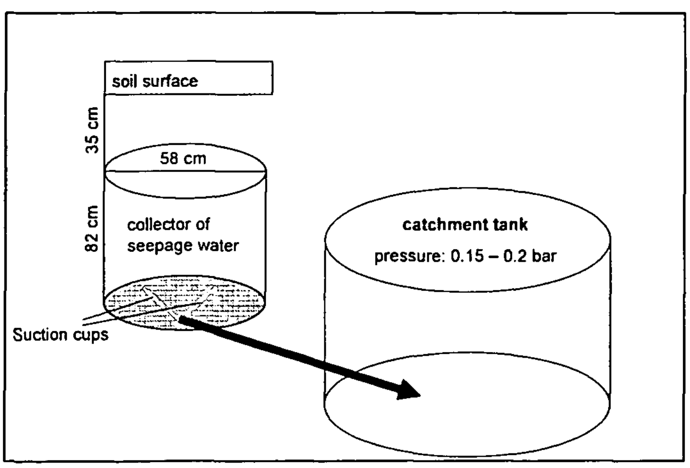

Figure 1: Schematic description of the lysimeter

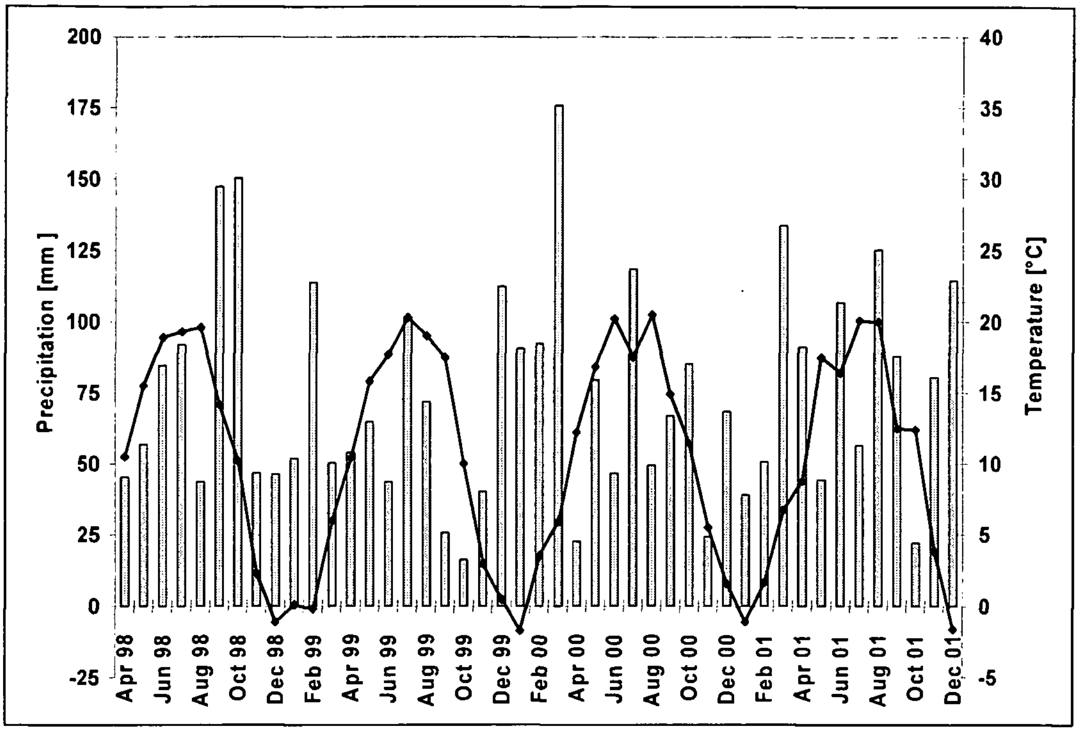

Figure 2: Precipitation (bars) and temperature (line) over the period of measurements (with changes from Dietrich et al., 2002)

The site in Wörth is characterised by soil texture of loamy sand (Table 1), humus content in top soil (0-30 cm) of 1.7 %, and a pH of 7.1. Soil texture of the site in Seebach can be classified in loamy sand to sandy loam, humus content in top soil is 2 %, and the pH is 7.0. The amount of coarse material in horizon C is very high in Wörth and rather low in Seebach (Dietrich et al., 2002). Bulk density and hydrological parameters as field capacity, wilting point and usable field capacity are slightly higher in the soil in Wörth, and decrease with soil depth. Pore volume is higher in the soil in Seebach and increases with soil depth. However, for horizon C (lower than 100 cm in Wörth and 120 cm in Seebach) only data on density and texture are available.

Table 1: Physical parameters of soils (with changes from Dietrich et al., 2002)

	horizon	depth	texture	density	bulk density	total pore volume	field capacity	wilting point	usable field capacity
		[cm]		[g/cm^3]	[g/cm^3]	[%]	[%]	[%]	[%] or [mm/dm]
Wörth	Ap	0-25	lS	2.7	1.7	38.7	37.6	12	25.6
	B1	25-60	lS	2.74	1.6	41.9	33.2	9.8	23.4
	B2	60-100	lS	2.75	1.5	47.1	29.5	5.6	23.9
	C	100- [200]	cS	2.7	no data	no data	no data	no data	no data
Seebach	Ap	0-30	lS/sL	2.71	1.6	43	33.2	10.6	22.6
	B1	30-80	lS/sL	2.75	1.5	45.9	36.5	11.6	24.9
	B2	80-120	sS/lS	2.76	1.4	49.6	39.6	4.3	35.3
	C	120-[200]	cS	2.72	no data	no data	no data	no data	no data

lS/sL: loamy Sand/sandy Loam
sS/lS: silty sand/loamy Sand
cS: coarse Sand

Contents of selected nutrients are shown in Table 2. With exception of MgO nutrient content in Seebach is slightly lower than in Wörth. The reduction of P_2O_5, K_2O, and MgO in Seebach is explained b y lack o f fertilization dur ing c ultivation o f w inter w heat in t he l ast y ear before measurements were taken. In Wörth, only the content of K_2O is reduced after the sampling period. The other nutrients are either increased or similar as in the beginning of measurements depending on the management alternative. Details on measurements can be found in Dietrich et al. (2002). The two soils are representative for approximately 75 % of the soils in the region (the soil in Wörth for about 23 %, and the one in Seebach for about 50%).

Table 2: Selected nutrient content of soils (with changes from Dietrich et al., 2002)

[mg/100g soil]	Wörth					Seebach			
		2002					2002		
	1998	V1	V2	V3	V4	1998	V1	V2	V3
total N	109	120	120	110	108	125	107	112	105
P_2O_5	51	61	64	54	53	33	33	30	26
K_2O	27	20	22	20	20	20	16	19	13
MgO	9	9	8	7	7	17	14	14	12

Crop rotations and management measures

The sampling site in Wörth is separated in four neighbouring parcels with a total area of 3 000 m^2. Every parcel consists of four vegetable beds. Crop rotations include potatoes, Chinese cabbage, celery, cauliflower and green salad. In fall 2000 a cover crop – either phacelia (variations 1 and 2) or a green rye and phacelia mixture (variations 3 and 4) – was planted on all variations. In the last year of measurements winter wheat was planted following green salad.

Table 3: Crop rotations and nitrogen fertilization rates (N in kg/ha in brackets) for the four alternatives at the site in Wörth (with changes from Dietrich et al., 2002)

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

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). Irrigation and pesticides were applied depending on the crop (Dietrich et al., 2002). Information on crop rotations and fertilization of the sites in Wörth are summarized in Table 3. Further details on the management can be found in Dietrich et al. (2002).

The sampling site in Seebach is separated in three neighbouring parcels with a total area of 2 000 m^2 corresponding to four rows of salad each. Fertilization was carried out following the N_{min} target values system (KNS) for all variations. In Seebach green salad was grown with either green rye or phacelia as cover crops on two variations. N inputs are shown in Table 4. Further details on the management can be found in Dietrich et al. (2002).

Table 4: Crop rotations and nitrogen fertilization rates (N in kg/ha in brackets) for the four alternatives at the site in Seebach (with changes from Dietrich et al., 2002)

Year		Variation 1	Variation 2	Variation 3
1998	**1st crop**	Green salad (110)	Green salad (127)	Green salad (127)
	2nd crop	Green salad (90)	Green salad (61)	Green salad (61)
	3rd crop	Green salad (86)	Green salad (50)	-
	Cover crop	-	Green rye	Phacelia
1999	**1st crop**	Green salad (128)	Green salad (131)	Green salad (126)
	2nd crop	Green salad (67)	Green salad (89)	Green salad (85)
	3rd crop	Green salad (84)	Green salad (84)	-
	Cover crop	-	Green rye	Phacelia
2000	**1st crop**	Green salad (122)	Green salad (130)	Green salad (127)
	2nd crop	Green salad (88)	Green salad (76)	Green salad (75)
	3rd crop	Green salad (40)	Green salad (73)	Green salad (79)
	Cover crop	Winter wheat	Winter wheat	Winter wheat

The model

The bio-physical process model EPIC allows simulation of many processes important in agricultural land use 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 E PIC inc lude w eather s imulation, hy drology, e rosion-sedimentation, nut rient 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 hundr eds 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. The PET equations are the Penman-Monteith

(Monteith, 1965), Penman (Penman, 1948), Priestly-Taylor (Priestley-Taylor, 1972), Hargreaves (Hargreaves and Samani, 1985) and Baier-Robertson (Baier and Robertson, 1965). The erosion/sediment yield equations are the USLE (Wischmeier and Smith, 1978), the Onstad-Foster modification of the USLE (Onstad and Foster, 1975), the MUSLE (Williams, 1975), two variations of MUSLE (one for small watersheds and one for steep slopes), a MUSLE structure that accepts input coefficients and an additionally user specified MUSLE variant that interacts with other EPIC components (MUST is used in this analysis). The equations are identical except for their energy components. The USLE depends strictly upon rainfall as an indicator of erosive energy. The MUSLE and its variations use only runoff variables to simulate erosion and sediment yield. Runoff variables increase the p rediction accuracy, eliminate the need for a delivery ratio (used in the USLE to estimate sediment yield), and enable the equation to give single storm estimates of sediment yields. The USLE gives only annual estimates. The Onstad-Foster equation contains a combination of the USLE and MUSLE energy factors. Runoff rate can be calculated by the curve number method (USDA-Soil Conservation Service, 1972), or three variations of the Green and Ampt methodology (Green and Ampt, 1911). The optional Green and Ampt infiltration equation simulates rainfall excess rates at shorter time intervals (0.1 h). For calculation of nutrient and carbon cycling soil organic matter is split into three compartments: microbial biomass, slow humus and passive humus (existing in subsurface layers only). Organic residues added to the soil are split into a metabolic or structural litter compartment which is distinguished into lignin and non lignin fraction (Izaurralde et al., 2006). The structural litter is assigned a fixed C:N ratio (Parton et al., 1987). Microbial biomass receives carbon and nutrients from non-lignin components of structural litter, metabolic litter, slow humus, passive humus and inorganic ions. Potential transformations of C, N, and P are calculated based on substrate-specific rate constants, temperature and water content whereas some are also affected by lignin content and soil texture (Izaurralde et al., 2006). Demand for N or P is calculated by the potential C transformation of the source compartment and the N:C or P:C ratio of the receiving compartment which varies with substrate and soil conditions (Parton et al., 1994). Actual transformations are calculated based on the supply available from each potential transformation. If N or P demand exceeds the mineral N or P available, EPIC calculates a proportional reduction in the net demand and each potential transformation. Biomass turnover and death adds C and N to the compartments of slow and passive humus, leached material and the gases CO_2 and NH_3 (Izaurralde et al., 2006). N leaves the soil system either b y c rop r emoval or through N losses in percolation w ater, s ub surface flow, runoff, sediment, ammonia volatilization.

In this study, EPIC is calibrated to base-run data from variation 1 in Wörth. The calibrated model is then applied to different management alternatives and to the sites in Seebach.

3. Results and discussion

The sanitation program

The results of the sanitation program showed that management measures, which aiming at reducing nitrate leaching into groundwater, could decrease nitrate leaching between 10 kg N/ha. and year and 80 kg N/ha and year. 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; Liebhard et al., 2003).

Comparison of measurements and simulations

Comparisons of EPIC simulations and measurements for crop yields are shown in Figure 3. In general, good agreements between simulated 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, variation 1). Chinese cabbage can also achieve high yields depending on the variety. Average yields of Chinese cabbage are around 70 t per ha (Wonneberger and Keller, 2004). The coefficient of correlation (R^2) ranges between 0.7 and 0.9 (Table 5).

Table 5: Coefficient of determination (R^2) between simulated and measured yields

	Variation 1	Variation 2	Variation 3	Variation 4
Wörth	0.715	0.822	0.851	0.813
Seebach	0.899	0.755	0.840	-

Several studies have shown that EPIC is able to reproduce crop yields and nitrogen losses (Cavero et al., 1996; Chung et al., 2001; Wang et al., 2005). An overview is found in Gassman et al. (2004). The results of this study demonstrate that mean values and variability of percolation water and nitrogen leaching can be reasonably reproduced by the model during the calibration procedure (Figure 4, Wörth). In Wörth 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).

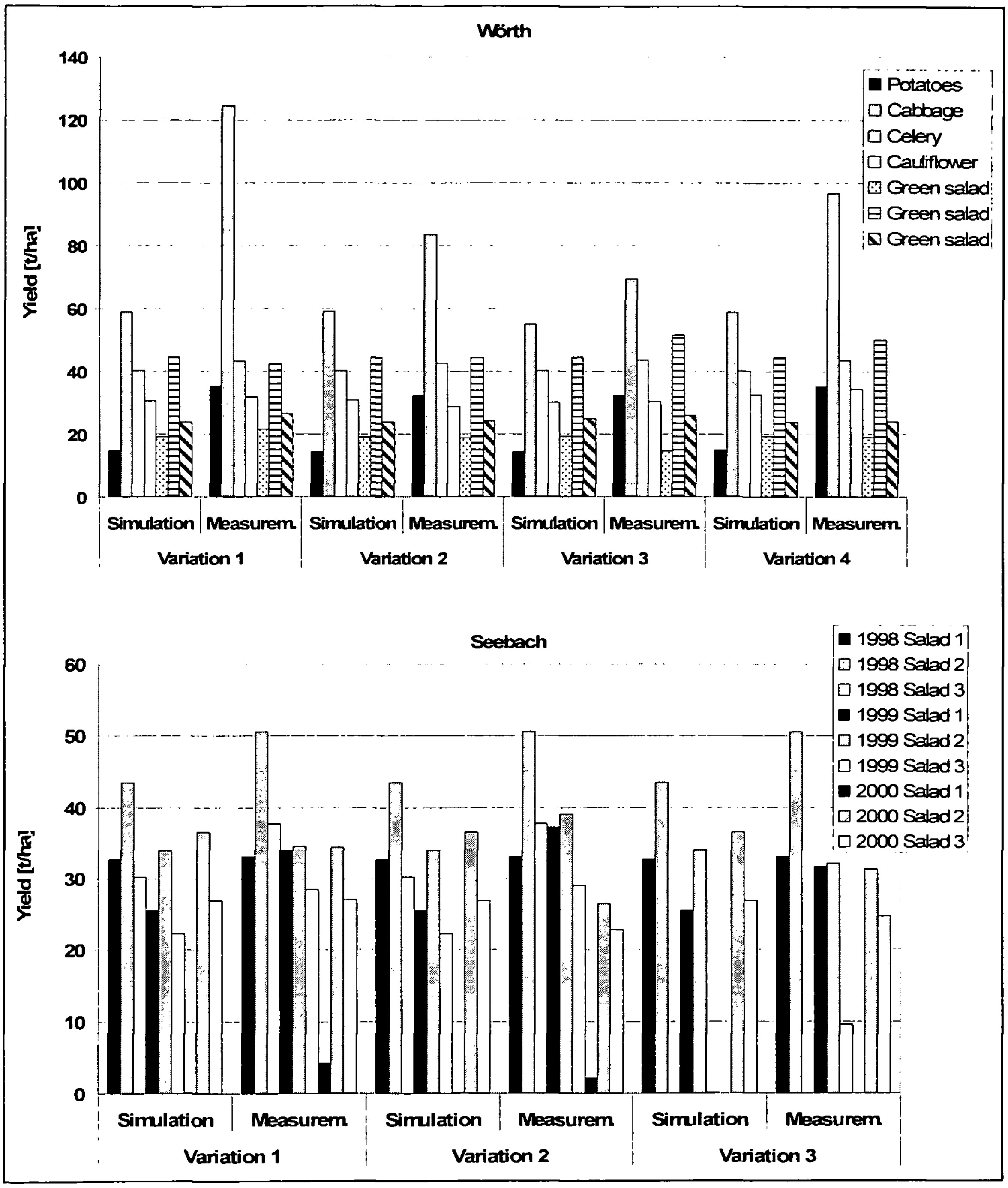

Figure 3: Simulated and measured fresh weight crop yields in t per ha and year

Simulation results and measurements are much less correlated in Seebach (variation 1 is shown in Figure 4). In the beginning of the sampling period measured peaks could not be reproduced by the calibrated model (based on the site in Wörth). Extraordinary differences occur in March 1999 and March 2000 with high peaks in the simulations that cannot be explained by the measurements. Variation 2 in Seebach shows similarly poor performance as variation 1. In variation 3 simulation results are closer to the measurements than in variation 1 and 2. (data not shown). Therefore, more information on management history as well as potential differences in hydrology or N dynamics may help to improve simulation results. Given the similarities in soil and weather conditions between the two sites, it is surprising that in the field measurements the high peak in March 2000 only occurs in Wörth and not in Seebach (Figure 4).

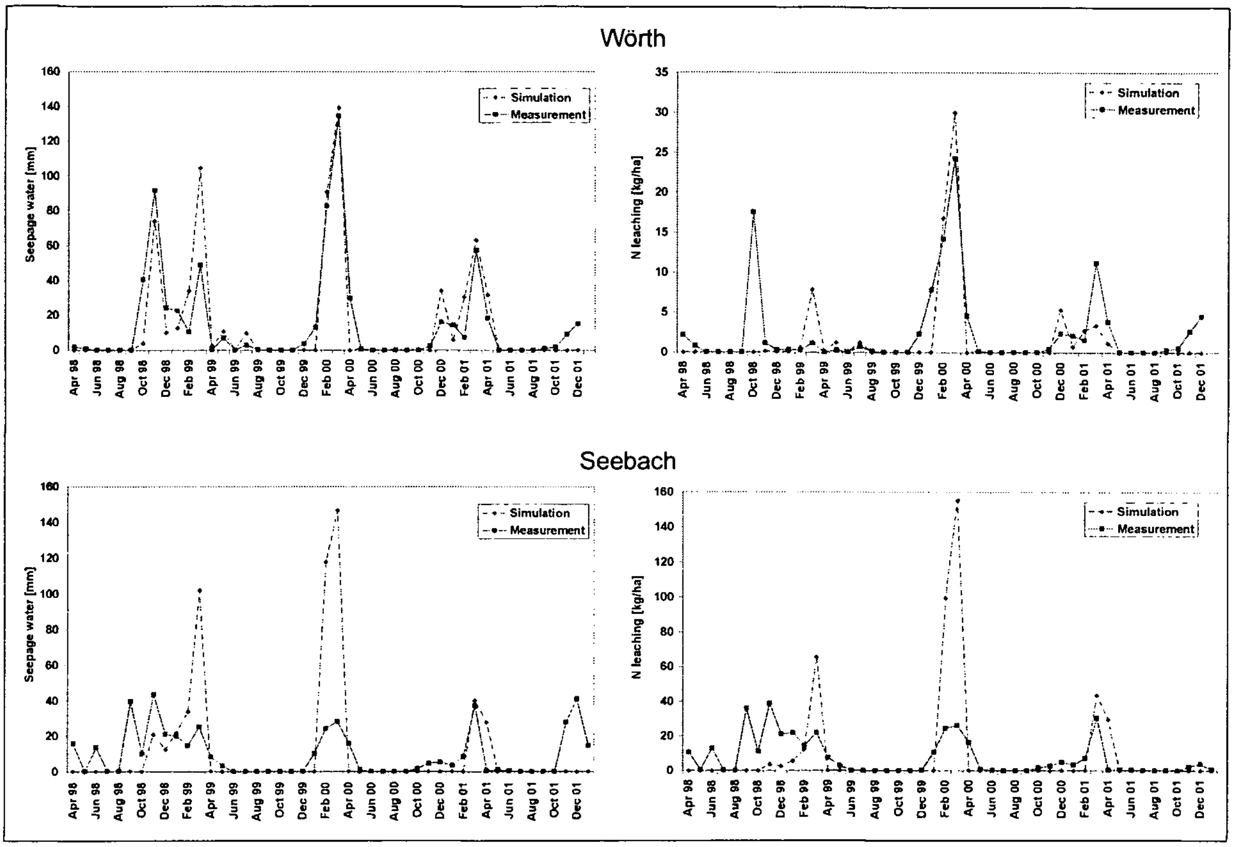

Figure 4: Simulation and measurements of monthly seepage water (in mm) and N leaching (in kg/ha) at 1.2 m soil depth of variation 1 in Wörth and Seebach

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)[1] calculated following Liu et al. (2007) and presented in Table 6. 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.

Table 6: Coefficient of determination (R^2) and index of agreement (d) between simulated and measured percolation water and nitrogen leaching

	Variation 1		Variation 2		Variation 3		Variation 4		Variation 1		Variation 2		Variation 3	
	R^2	d	R^2	d	R^2	d	R^2	d	R^2	d	R^2	d	R^2	d
seepage water	0.81	0.95	0.25	0.7	0.4	0.79	0.18	0.66	0.2	0.51	0.29	0.25	0.63	0.6
N leaching	0.57	0.86	0.05	0.49	0.05	0.48	0.05	0.45	0.24	0.5	0.03	0.33	0.47	0.72

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

Variations 2, 3 and 4 show similar agreement with R^2 for seepage water between 0.2 and 0.4 and d between 0.7 and 0.8. R^2 for N leaching is in all variations 0.05, d around 0.5. R^2 and d for Seebach variation 1 (and 2) prove bad agreement which is already indicated by Figure 4. The model overestimates nitrogen leaching in Seebach.

4. Conclusions

This study shows that EPIC is capable of reproducing vegetable yields. Seepage water and N leaching is fairly reproduced by the model if site calibration is carried out. Therefore, EPIC can be used to analyze environmental impacts of alternative management practices. The study sites in this analysis were in the same region and therefore characterized by similar weather and soil conditions. Nevertheless, high correlation between measurements and modelling results of seepage water and N leaching was obtained for the site used for calibration. Further analyses are needed to trace and understand the differences in N dynamics or hydrology between the two sites.

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EPIC long-term simulations of vegetable production systems with sensitivity analysis using a weather generator

1. Introduction

Crop rotations with high percentage of vegetables often lead to environmental problems related to nitrogen losses. In Austria, the Southern Eferding basin is a region where intensive vegetable production systems are applied. The nitrate concentrations in the groundwater are exceeding threshold values at different monitoring sites in this region. Therefore, a sanitation program had to be implemented that provides farmers different management measures to reduce nitrate leaching (Liebhard et al., 2003). Environmental impacts of different production systems are often predicted by computer models as field measurements are time and cost-intensive and are often carried out over shorter time periods. Bio-physical process models enable us to analyse long-time effects of different management measures or to assess effects of environmental changes on certain indicators. In this study, the EPIC (Environmental Policy Integrated Climate) model has been applied to predict the short- and long-term effects of alternative crop management measures in the Eferding basin. The EPIC model can be used to analyse different crop management systems and their impacts on crop yields as well as on horizontal and vertical movements of water, nutrients, pesticides, organic carbon, and sediment. The management components that can be changed in EPIC are crop rotations, crop/grass mixes, tillage operations, irrigation scheduling, drainage, furrow diking, liming, grazing, burning operations (e.g., on prairies), tree pruning, thinning and harvest, manure handling (e.g. lagoons), and fertilizer and pesticide application rates and timing. Several studies have shown that EPIC is capable in predicting vegetable yields and nitrogen losses. An overview of EPIC applications is given in Gassman et al. (2004). For instance Cavero et al. (1998) applied EPIC in tomato cultivations that received nitrogen from commercial fertilizer and/or green and turkey manures. The authors concluded that EPIC could predict the evolution of inorganic nitrogen in different soil layers and above ground biomass.

In this study, EPIC is used to evaluate the long-term effects of four different management measures that have been promoted in the sanitation program. Among the management measures are a reduction of the nitrogen fertilizer rates and the planting of cover crops during the winter period. Several studies have shown that cover crops increase soil quality and decrease potential for nitrate leaching (McCracken et al., 1994; Weinert et al., 2002; Jackson et al., 2004; Thorup-Kristensen, 2006). Weinert et al. (2002) report that winter cover crops in potato cultivations reduce the potential for nitrate leaching by absorbing and storing nitrogen in plant tissue during winter months and by absorbing and transpiring water, therefore lessening water percolation. Incorporation in fall released greater nitrogen during winter than incorporation of cover crops in spring (Weinert et al., 2002). Cover crops have been reported to increase crop yields, because of the positive effects on soil quality and increased availability of nitrogen for cash crops (Paustian et a l., 1992), b ut for s ome crops as l ettuce int ercropping m ight e nhance dis eases (Jackson et al., 2004).

Long-term actual weather data was not available for the sites in the Eferding basin. EPIC provides a program that generates weather data based on s tatistical parameters for monthly precipitation, minimum and maximum temperature, and solar radiation. The objective of this study is to analyse the stochastic and dynamic effects of different long-term weather seeds on crop yields, percolation, and nitrogen leaching.

2. Material and Methods

2.1. Site characteristics

Simulations are based on typical vegetable production systems in the Southern Eferding basin in Upper Austria Crop rotations are characterised by high percentages of vegetables as green salad, potatoes, cabbage, cauliflower, etc. with interruptions of corn or winter wheat following every two to four years of vegetables. Fertilization is carried out mainly by mineral fertilizer. Average N input amounts to approximately 200 kg/ha and year. Model calibration was carried out with data from field lysimeters measuring percolation water, nitrate concentrations, and crop yields. Percolation water samples were taken and measured once per week over a period of almost four years. Detail site description and measurement equipment and design are documented by Dietrich et al. (2002).

Data on weather, topography and soil from the calibration site (Site 1, Soil 1) and a slightly different site (Site 2, Soil 2) were used as basis for the simulations. The sites are characterised by annual precipitation of 795 mm, a soil texture of loamy sand for Site 1, and a loamy sand to sandy loam for Site 2, as well as high soil water storage capacity (Dietrich et al., 2002). The two soils are representative for approximately 75 % of the soils in the region (Soil 1 for 23 %, Soil 2 for 50%).

2.2. Model description

EPIC (Environmental Policy Integrated Climate) is a biophysical process model that is mainly used for simulation of natural processes important in agricultural land management. It was developed by an USDA modelling team in the early 80s to asses the status of U.S. soil and water resources (Williams et al., 1984; Jones et al., 1991). EPIC compounds various components from CREAMS (Knisel, 1980), SWRRB (Williams et al., 1985), GLEAMS (Leonard et al., 1987) and CENTURY (Parton et al., 1994, Izaurralde et al., 2006) and has been continuously expanded and refined (Williams et al., 2000). Current research efforts are focusing on model algorithm that addresses greenhouse gases emissions (e.g. N_2O, CH_4). The major components in EPIC are weather simulation, hydrology, erosion-sedimentation, nutrient and carbon cycling, pesticide fate, plant growth and competition, soil temperature and moisture, tillage, cost accounting, 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 (PET) equations, seven erosion/sediment yield equations, two peak runoff rate equations, etc., which allow reasonable model applications in very distinct natural areas.

The PET equations are the Penman-Monteith (Monteith, 1965), Penman (Penman, 1948), Priestly-Taylor (Priestley-Taylor, 1972), Hargreaves (Hargreaves and Samani, 1985) and Baier-Robertson (Baier and Robertson, 1965). The erosion/sediment yield equations are the USLE (Wischmeier and Smith, 1978), the Onstad-Foster modification of the USLE (Onstad and Foster, 1975), the MUSLE (Williams, 1975), two variations of MUSLE (one for small watersheds and one for steep slopes), a MUSLE structure that accepts input coefficients and an additionally user specified MUSLE variant that interacts with other EPIC components (MUST is used in this analysis). The equations are identical except for their energy components. The USLE depends strictly upon rainfall as an indicator of erosive energy. The MUSLE and its variations use only runoff variables to simulate erosion and sediment yield. Runoff variables increase the prediction accuracy, eliminate the need for a delivery ratio (used in the USLE to estimate sediment yield), and enable the equation to give single storm estimates of sediment yields. The USLE gives only annual estimates. The Onstad-Foster equation contains a combination of the USLE and MUSLE energy factors. Runoff rate can be calculated by the curve number method (USDA-Soil Conservation Service, 1972) or three variations of the Green and Ampt methodology (Green and Ampt, 1911). The optional Green and Ampt infiltration equation simulates rainfall excess rates at shorter time intervals (0.1 h).

For calculation of nutrient and carbon cycling, soil organic matter is split into three compartments: microbial biomass, slow humus and passive humus (existing in subsurface layers only). Organic residues added to the soil are split into a metabolic or structural litter compartment which is distinguished into lignin and non-lignin fraction (Izaurralde et al., 2006). The structural litter is assigned a fixed C:N ratio (Parton et al., 1987). Microbial biomass receives carbon and nutrients from non-lignin components of structural litter, metabolic litter, slow humus, passive humus and inorganic ions. Potential transformations of C, N and P are calculated based on substrate-specific rate constants, temperature and water content, whereas some are also affected by lignin content and soil texture (Izaurralde et al., 2006). Demand for N or P is calculated by the potential C transformation of the source compartment and the N:C or P:C ratio of the receiving compartment which varies with substrate and soil conditions (Parton et al., 1994). Actual transformations are calculated based on the supply available from each potential transformation. If N or P demand exceeds the mineral N or P available, EPIC calculates a proportional reduction in the net demand and each potential transformation. Biomass turnover and death adds C and N to the compartments of slow and passive humus, leached material and the gases CO_2 and NH_3 (Izaurralde et al., 2006). N leaves the soil system either by crop removal or as losses through percolation water, sub-surface flow, runoff, sediment transport, or ammonia volatilization.

EPIC file structure

EPIC is a compiled FORTRAN program and therefore a specific format and file structure is crucial. An **U**niversial **T**ext **I**ntegrated **L**anguage (UTIL) has been developed to support EPIC and help the user to create his or her own data sets. UTIL provides additional information on each single input variable in EPIC. The data and file structure for EPIC have been arranged in a relational database type format to reduce data duplication. For a given study, weather, soil, field, and operation schedule data are only entered into a file one time. Then another file specifies which weather, soil, field, and operation schedule are used for each run. An overview of the files and data flow is given in Figure 1. For a given study, the major data elements to be developed by a user include descriptions of sites (fields), soils, operation schedules, weather stations, and constant data. The file structure arrangement of these is now briefly discussed.

The EPIC file structure consists of six functional file groups (Figure 1). The executing file runs the model. The control files set and configure execution of the simulation runs. The file "epicrun.dat" contains information on the run number or run name and ID numbers to code site, weather, wind, soil and operation schedule files. The ID numbers are connected to corresponding input files in the index files, e.g. to the index file "soil3060.dat" different soil files can be listed. Therefore, execution of different runs with variable management, weather, soils, etc. can be carried out easily by changing the corresponding parameters in the "epicrun.dat" file.

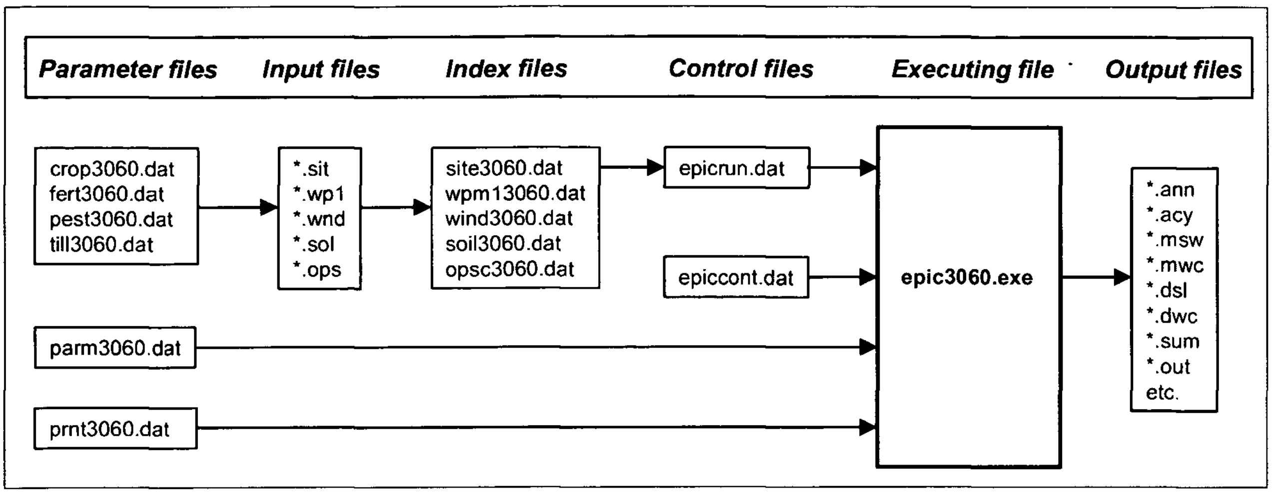

Figure 1: The EPIC file structure

The input files contain ID numbers e.g. for crops identified in parameter files (crop3060.dat) that are established by USDA. However, these parameters can be changed if specific information for instance on certain crop varieties are available.

The parameter file "parm3060.dat" contains parameters of functions that specify natural processes (partition coefficients, exponents, etc.).

In the "prnt3060.dat" file, one can select output variables, which are reported on daily, monthly, and annual time scales.

The control file "epiccont.dat" controls data items that are constant over the runs, such as simulation period, information if weather is generated or read in, CO_2 concentration in the atmosphere, NO_3 concentration in rainfall or several factors regarding erosion, runoff etc. Equations for PET, ersosion/sediment yield and runoff have to be selected in the "epiccont.dat" file.

Input files

The quality and completeness of input data are essential for producing reliable modelling results. The major input data components are topography, weather, soil, and crop management. It can be distinguished between mandatory data which comprise the minimum of information that is needed for the simulations and a range of optional data that can be input to increase prediction accuracy.

Site

The file "*.sit" carries site specific information on topography as size of drainage area, altitude, longitude, latitude, slope, etc. and crop management related issues such as specifying automatic fertilization or irrigation. Moreover, the file for data on daily weather records is indicated here as well. The drainage area is generally a field-size area up to 100 ha. In this drainage area topography, weather, soil and crop management are assumed to be homogenous.

Weather

The weather variables, necessary for running EPIC, are precipitation (in mm), minimum and maximum air temperature (in degree Celsius), and solar radiation (in MJ/m^2). If the Penman methods are used to estimate potential evapotranspiration, wind speed (in m/sec measured at 10 m height), and relative humidity (in %) are also required. If measured daily weather data is available, it can be directly input into EPIC. In addition, monthly statistics of this daily weather (mean, standard deviation, skew coefficient, probabilities of wet-dry and wet-wet days, etc.) need to be computed and input in the model. EPIC provides a support programme to compute the statistics of relevant weather variables based on daily weather records. Consequently, long historical daily weather records (20-30 years) for all weather variables are desirable for statistical parameter calculations. Based on the statistics of the weather variables, EPIC can generate weather patterns for long-run analyses (over 100 years), or as indicated above, daily weather records (e.g. from world climate models with downscaling procedures) can be input directly. There is also an option of reading a sequence of actual daily weather and use generated weather afterwards within a simulation run.

In the control file "epiccont.dat" can be determined if weather is generated or read in or if only specific variables shall be generated or read in. The file name for daily weather input is stored in the site file as mentioned above. If weather is generated the required variables are stored in the input file "*.wp1" and eventually wind variables in "*.wnd".

The weather generator allows to automatically run multiple weather seeds, the number of which is set in the "epiccont.dat" control file. The weather generator draws weather seeds for precipitation, minimum and maximum temperature, radiation and relative humidity.

Soil

The file "*.sol" contains a large number of physical and chemical soil parameters describing general soil characteristics (pH, texture, bulk density,etc.), nutritional status (mineral and organic N, P, C contents, cation exchange capacity, etc.), and soil hydrology (initial soil water content, depth to water table, field capacity, saturated conductivity, etc.). Some parameters (e.g. bulk density) represent essential variables for running EPIC, while others give additional information for the simulations but are not mandatory input data.

Each soil has to be assigned to a hydrological soil group indicating the runoff potential (1 to 4) and to a soil group factor differentiating between kaolinitic, mixed and smetitic soils. Soil profile can be split in up to 15 soil layers. Therefore, a range of soil parameters have to be provided for each soil layer. The number and thickness of soil layers are set in the file "*.sol".

Management

In the file "*.ops" is all information on crop management operations. A wide range of management scheduling allows flexibility in modelling different cropping and tillage systems including crop rotations and inter-cropping systems. Timing of operations can be input by the model user, or automatically scheduled by fractioning of daily heat unit accumulation which is the basis of phenological crop development. The heat unit schedule may be input by the model user or provided by EPIC.

The management file includes:

- Date of operations, or the earliest date of operations
- Crop ID and associated variables such as potential heat units needed to reach maturity, amount of plants per square meter, crop sequence i.e. crop rotations, etc. (crop ID is provided in the parameter file "crop3060.dat")
- Type of planting, harvesting and tillage operation (equipment ID is provided in the parameter file "till3060.dat")
- Amount and type of irrigation (equipment ID)
- Amount and type of fertilizer (fertilizer ID is provided in the parameter file "fert3060.dat"), and
- Amount and type of pesticide (pesticide ID is provided in the pesticide file "pest3060.dat").

Information on crop parameters of more than 100 of annual and perennial crops and trees is provided by USDA and listed in "crop3060.dat". In this file, a range of crop specific parameters are stored that can be altered if more detailed information for instance on crop varieties is available. These variables describe crop characteristics as optimal and minimal temperature, maximal crop he ight, N fraction i n yield, i f t he c rop is a nnual o r p erennial, w arm o r c old seasonal, etc.. In addition, a range of growth related parameters that change during different stages of maturity as lignin fraction, root to biomass partitioning coefficient or N fraction in root vs. biomass is provided. A harvest index which partitions the fraction of yield to biomass is adjusted during each year of simulation. The harvest index and the harvest efficiency influence the actual amount of crop yield. The harvest efficiency is dependent on the kind of harvester and indicates what portion of the harvested material actually leaves the field. This parameter is stored in the file "till3060.dat". The parameter "harvest index override", also stored in "till3060.dat" is needed for a second harvest, for instance to differentiate between grain and straw harvest.

2.3. Input data

In this study four different management operations and two soils corresponding with two sites were combined and simulated with five different weather seeds for a simulation period of 20 years. In the following, relevant information on the input data is provided. For calculation of PET the algorithm from Hargreaves (Hargreaves and Samani, 1985) produced best results during calibration procedure. Sediment yields were estimated using MUST and runoff rates were estimated by the Green and Ampt method (Green and Ampt, 1911).

Site

Input parameters were adjusted to the sites for the field measurements. Some characteristics of the site file are shown in Table 1.

Table 1: Selected variables of the site input file

	watershed drainage area [ha]	latitude of watershed	longitude of watershed	average watershed elevation	upland slope length [m]	upland slope steepness [m/]
Site 1	0.01	48.13	14.1	330	20	0.010
Site 2	4.5	48.13	14.1	330	25	0.015

Soil

Both soils used for the study have low runoff potential and are assigned to kaolinitic soils. Some soil layer specific parameters from two soils in the Eferding basin are shown in Table 2. In Soil 2, silt content increases with depth, whereas silt strongly decreases and sand increases in Soil 1. Therefore, field capacity is lower in deeper soil layers of Soil 1, and higher in Soil 2.

Topsoil organic carbon is slightly higher in Soil 1 than in Soil 2. The pH in both soils is almost constant at 7.2. In all simulations, Soil 1 refers to Site 1 and Soil 2 to Site 2.

Table 2: Selected layer specific soil parameters from two sites in the Eferding basin

Layer Nr.	Depth to bottom of [m]	Bulk density [t/m³]		Wilting point [m/m]		Field capacity [m/m]		Sand content [%]		Silt content [%]		pH	Organic carbon [%]		$CaCO_3$ content [%]
	Soil 1 & Soil 2	Soil 1	Soil 2	Soil 1	Soil 2	Soil 1	Soil 2	Soil 1	Soil 2	Soil 1	Soil 2	Soil 1 & Soil 2	Soil 1	Soil 2	Soil 1 & Soil 2
1	0.15	1.568	1.473	0.120	0.106	0.376	0.332	41.9	45.1	45.3	39.9	7.2	1.27	1.03	9
2	0.45	1.511	1.416	0.098	0.116	0.332	0.365	43.1	36	43.2	49	7.2	0.55	0.66	12
3	0.8	1.387	1.321	0.056	0.043	0.295	0.396	60.1	44	33.9	51	7.3	0.20	0.20	18.5
4	1.2	0.855	1.188	0.028	0.038	0.155	0.398	99	84	0.8	15	7.3	0.01	0.01	21

Weather

Statistical parameters for the EPIC weather generator were calculated based on 12 years of interpolated daily MARS weather data (using MARS grid number 52065). The following statistical climate parameters were calculated: monthly means for temperature minimum und maximum, precipitation, and solar radiation, monthly standard deviations for temperature minimum und maximum, a nd precipitation, skew coefficients for monthly precipitation, the probabilities of a wet day after a dry day as well as the probability of wet day after a wet day, and average rainy days per month. In order to analyse the stochastic effect of weather on crop yields and N leaching five weather seeds were generated. One seed contained weather data for 20 years.

Table 3: Crop rotation and nitrogen fertilizer application rates in kg/ha and year for the base-run management (ops 1)

Year	Crop	N input [kg/ha]
1	Corn	160
2	Potatoes	140
	Chinese cabbage	91
3	Celery	154
4	Corn	160
5	Cauliflower	255
6	Green salad 1	91
	Green salad 2	97
	Green salad 3	98

Management

A crop rotation with two years of different vegetables following one year of maize was set up for six years. After six years the crop rotation was repeated. Dates of tillage operations were manually input. The crop rotation and management operations are typically for the Eferding region. Information on the crop rotation and nitrogen input for the base management (ops1) is shown in Table 3. Fertilizer is applied in one to three rates depending on the crop. Simulations were run for three further management variations (ops2-4). In ops2 and 3 nitrogen input was decreased by 30 % and in ops3 and 4 green rye was planted in fall after vegetable harvest as cover crop. Two weeks before planting in spring green rye was mown and incorporated.

3. Results and Discussion

3.1. Alternative management measures

Crop yields

Reduced N application did not decrease yield quantity. However, the model does not directly provide information on yield quality. Crop yields from simulation of Soil 1 and the base-run management (ops1) are shown in Figure 2. Only marginal differences in crop yields were simulated between the two soils and between different management systems.

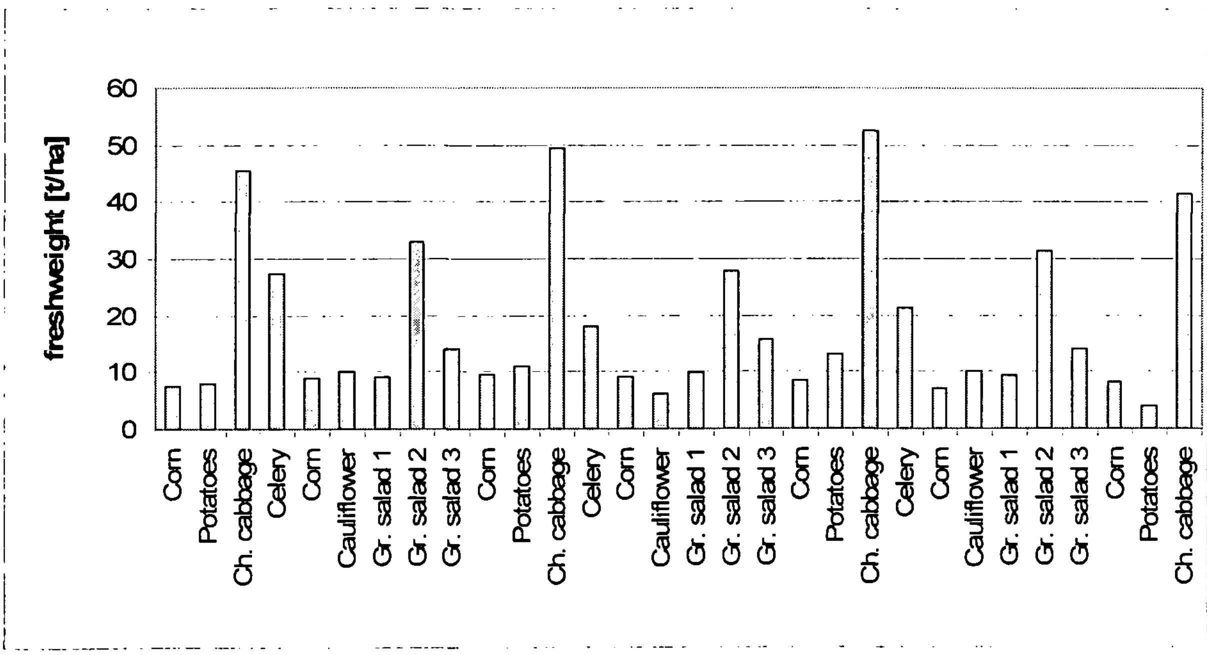

Figure 2: Crop yields of Soil 1 and base-run management (ops1) in freshweight t/ha

N losses

Average N leaching are ranging between 40 and 80 kg/ha and year depending on the management. Mean ammonia volatilizations have been simulated between 20 and 30 kg/ha and year. Average N losses by runoff are around 10 to 15 N kg/ha, by sediment transports about 10 kg/ha, and by sub-surface flow between 1 and 1.8 kg/ha and year. N harvested by crop yields are 50 kg/ha and year on average, which ranges between 12 kg/ha for green salad and 160 kg/ha for corn.

T-tests were carried out to reveal significant differences between the two soils and the four management variations. Between the soils no significant differences can be observed. Differences between management variations are shown in Figure 3.

A reduction of N application rates could significantly decrease nitrate leaching and losses by ammonia volatilization. Mean values of N leaching are lower for systems with cover crops (Figure 4). However, T-tests did not prove significant differences between N leaching of crop rotations with cover crops and those without cover crops (no differences between ops1 and 4 or between ops2 and 3, Figure 3). Increased evapotranspiration and decreased water percolation caused by intercropping as reported by Weinert et al. (2002) cannot be verified by modelling results as no significant differences have been tested.

Soil 1
N percolation, N in subsurface flow and ammonia volatilization

	ops1	ops2	ops3	ops4
ops1	-	-	-	-
ops2	■	-	-	-
ops3	■		-	-
ops4		■	■	-

Soil 2
N percolation

	ops1	ops2	ops3	ops4
ops1	-	-	-	-
ops2	■	-	-	-
ops3	■		-	-
ops4			■	-

Soil 2
ammonia volatilization

	ops1	ops2	ops3	ops4
ops1	-	-	-	-
ops2	■	-	-	-
ops3	■	■	-	-
ops4	■	■	■	-

Soil 2
N in subsurface flow

	ops1	ops2	ops3	ops4
ops1	-	-	-	-
ops2	■	-	-	-
ops3	■		-	-
ops4		■	■	-

Figure 3: Results of T-tests of N losses between management variations. Black fields represent significant differences, grey fields no significant differences

Ammonia v olatilization is inc reased w hen c over c rops a re p lanted. A s ignificant dif ference between management measures with and without cover crops can be observed in both soils, particularly in Soil 2 (significant differences between ops1 and ops4 and between ops2 and ops3). Ammonia volatilization reaches maximum values of 52 kg N/ha and year (Soil 2, ops4, year 14). Although nitrate in groundwater poses a much more discussed and immediate problem, losses by ammonia should not be neglected.

A significant positive effect of intercropping on organic carbon contents in topsoil or erosion could not be verified by the modelling results.

Development of N losses over 20 years

N leaching and ammonia volatilization over the simulation period of 20 years in Soil 1 are shown in Figure 4. N leaching is highest for the base management (ops1) and reaches maximum values of more than 200 kg/ha in year 15, when celery is grown. This means that more N is lost by leaching than is input by fertilizer in this year. Peaks of N leaching occurred in years when corn was grown or in the following year. Consequently amounts of N fertilization should be reduced for corn. Low values of N leaching coincide with years when potatoes and cabbage (years 8, 14), celery (year 9) or green salad (year 18) were grown. For some extreme values coherence with ammonia volatilization can be observed. For instance low N in percolation water in year 14 coincides with relatively high volatilization. The opposite effect is displayed in year 17.

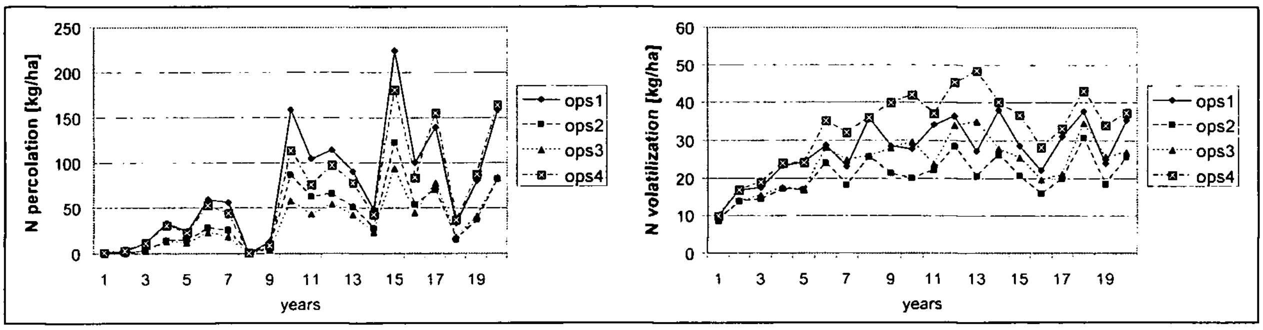

Figure 4: N losses by percolation water and volatilization of Soil 1 and the different management variations (ops1-ops4) in N kg/ha and year

T-tests of N losses between different periods revealed that ammonia volatilization significantly increases after five years and N leaching after approximately 10 years. Although mineral N can be very mobile and quickly converted, long-term effects from intensive management practices seem to be important to consider. Therefore, monitoring programs over a few years are too short to predict non-linear future developments of N losses. Consequently, analyses on long-term effects are needed to evaluate certain management measures.

3.2. Sensitivity analysis of the stochastic weather generator

Simulations of five different weather seeds are carried out to investigate the stochastic effects on nitrogen losses over 20 years. A comparison between mean values of five years for precipitation, minimum and maximum temperature and five different weather seeds are shown in Figure 5.

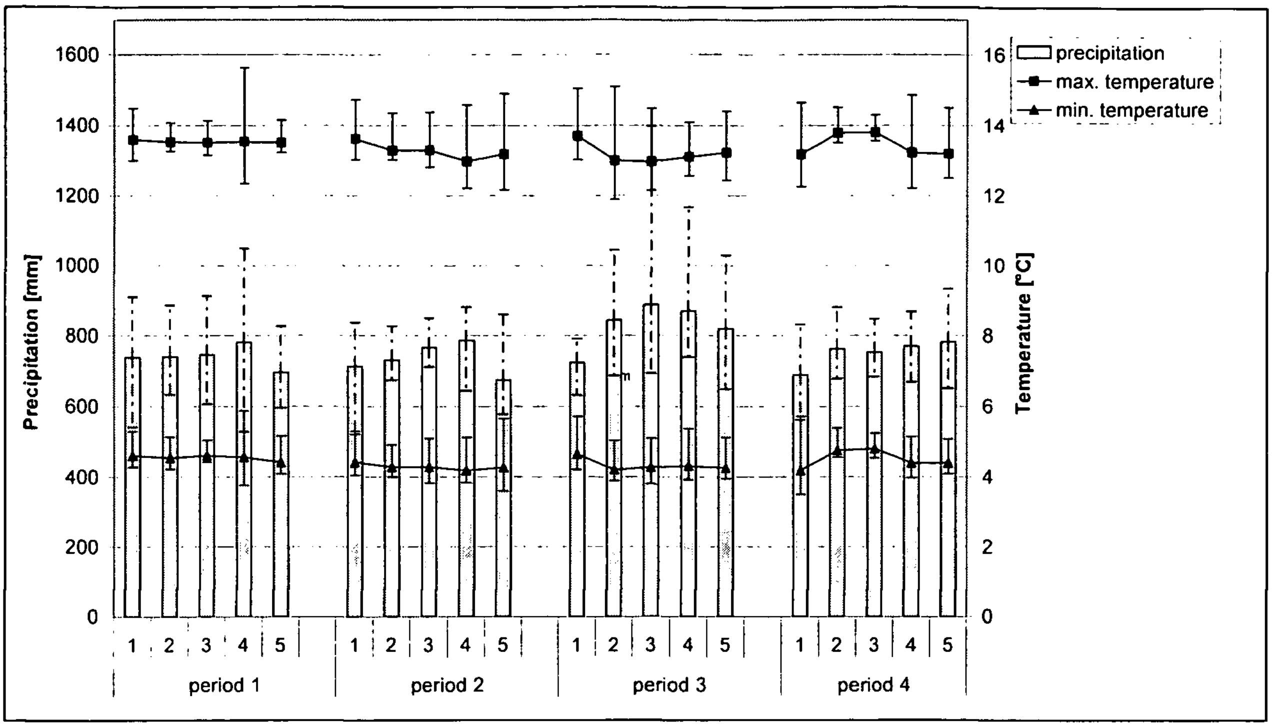

Figure 6: Mean values of five years for precipitation (bars), minimum (triangles) and maximum (squares) temperature and the five generated weather seeds (1 to 5)
Note: The range bars give minimum and maximum values

Average annual precipitation ranges from 675 mm (simulation of weather seed 5 in period 2) to 888 mm (seed 3 in period 3), mean minimum temperature from 4.2°C (seed 4 in period 2 and seed 1 in period 4) to 4.8°C (seed 3 in period 4) and mean maximum temperature from 13.0°C (seed 3 in period 3) to 13.8°C (seed 3 in period 4). The effects of stochastic weather on some hydrological parameters (e.g. evapotranspiration, runoff; in Figure6) can be quite substantial.

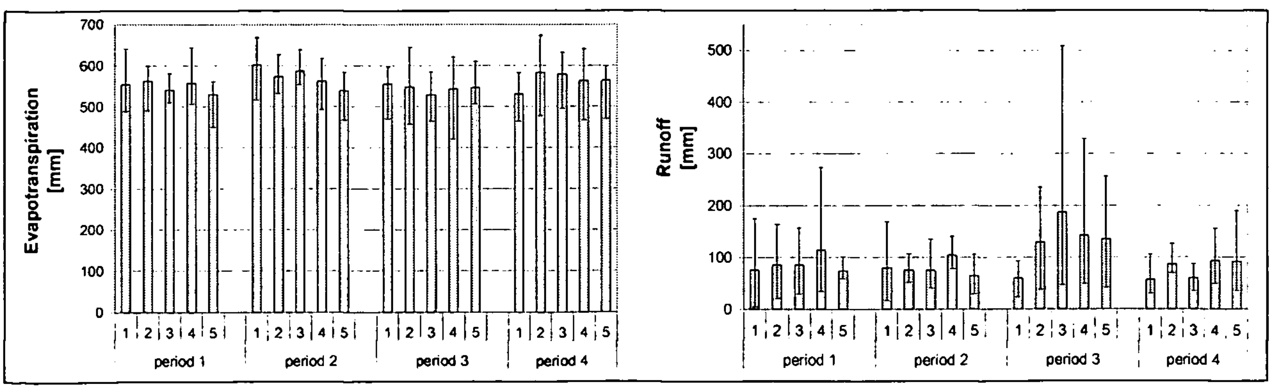

Figure 5: Mean values of five years for evapotranspiration and runoff and for five weather seeds (1 to 5) based on Soil 1 and base-run management (ops1)
Note: The range bars give minimum and maximum values

For instance the highest mean runoff rate in period 3 is three times higher than the lowest one (Figure 6). The variation of evapotranspiration can be 10 % of average evapotranspiration and also ranges substantially between weather seeds (1 to 5) (e.g. period 2). Figure 6 shows results from simulations of Soil 1 with base-run management (ops1).

Variability between different management systems

The influence of the stochastic weather is different between the analysed management measures. For instance, N losses with percolation water and runoff show different variability. Results of Soil 1 and Soil 2 are shown in Table 4 and Table 5. In general, variability seems to be higher if N losses are lower as the highest differences between weather seeds can be observed for ops3 and ops2. For example, in period 2 and ops3, N percolation of seed 3 is approximately three times higher than of seed 1.

Concerning N in runoff, differences between weather seeds are also highest for ops2 and ops3. Considerable differences occur in period 1 between seed 1 and seed 4 or in period 4 between seed 5 and seed 3 (ops2 and ops3, Table 4 and Table 5).

N percolation and runoff mean values over the whole simulation period of 20 years show considerably less variability than 5 years mean values. However, the range between minimum and maximum values is very high (Figure 7).

Table 4: Nitrogen in percolation water and runoff in kg/ha from Soil 1 and four management variations (ops1 to 4) and five weather seeds (seed 1 to 5)

N percolation					**N run off**				
Soil 1					**Soil 1**				
period 1	**ops1**	**ops2**	**ops3**	**ops4**	**period 1**	**ops1**	**ops2**	**ops3**	**ops4**
seed 1	14	6	6	13	seed 1	5	4	3	5
seed 2	10	6	6	10	seed 2	8	5	5	8
seed 3	21	12	11	19	seed 3	7	5	4	7
seed 4	18	10	8	15	seed 4	13	9	9	13
seed 5	14	7	6	12	seed 5	12	9	8	12
period 2					**period 2**				
seed 1	57	29	21	44	seed 1	15	11	10	15
seed 2	81	43	32	63	seed 2	14	10	9	14
seed 3	110	66	59	101	seed 3	15	10	9	14
seed 4	109	64	58	102	seed 4	13	9	8	12
seed 5	69	38	30	56	seed 5	19	13	12	18
period 3					**period 3**				
seed 1	116	65	51	95	seed 1	13	8	8	13
seed 2	143	77	76	143	seed 2	17	12	12	17
seed 3	133	75	76	138	seed 3	28	19	19	28
seed 4	135	75	72	129	seed 4	21	14	14	21
seed 5	122	64	58	116	seed 5	24	16	16	23
period 4					**period 4**				
seed 1	102	51	53	105	seed 1	16	10	10	15
seed 2	80	45	43	80	seed 2	14	9	8	14
seed 3	64	31	27	56	seed 3	10	6	6	10
seed 4	82	43	37	74	seed 4	15	10	9	14
seed 5	114	67	66	114	seed 5	25	17	16	23

Table 5: Nitrogen in percolation water and runoff in kg/ha from Soil 2 and four management variations (ops 1 to 4) and five weather seeds (seed 1 to 5)

N percolation					N run off				
Soil 2					**Soil 2**				
period 1	**ops1**	**ops2**	**ops3**	**ops4**	**period 1**	**ops1**	**ops2**	**ops3**	**ops4**
seed 1	13	10	10	12	seed 1	12	8	7	11
seed 2	11	8	7	11	seed 2	14	9	8	14
seed 3	18	12	11	16	seed 3	13	9	8	13
seed 4	15	9	8	13	seed 4	19	13	13	19
seed 5	12	8	7	10	seed 5	13	9	9	13
period 2					**period 2**				
seed 1	53	32	21	36	seed 1	22	15	15	22
seed 2	71	43	32	54	seed 2	21	15	14	21
seed 3	96	62	54	86	seed 3	21	15	14	20
seed 4	107	67	58	95	seed 4	20	14	13	19
seed 5	73	44	35	57	seed 5	19	13	12	18
period 3					**period 3**				
seed 1	110	64	47	83	seed 1	18	12	12	19
seed 2	145	84	78	137	seed 2	24	17	17	26
seed 3	136	80	79	135	seed 3	34	24	24	36
seed 4	135	83	73	121	seed 4	29	19	19	30
seed 5	128	76	66	116	seed 5	35	23	23	36
period 4					**period 4**				
seed 1	105	58	57	104	seed 1	22	14	14	21
seed 2	89	52	50	86	seed 2	21	13	12	21
seed 3	69	39	34	61	seed 3	18	11	11	18
seed 4	88	50	46	81	seed 4	20	13	13	20
seed 5	104	63	60	103	seed 5	30	21	20	30

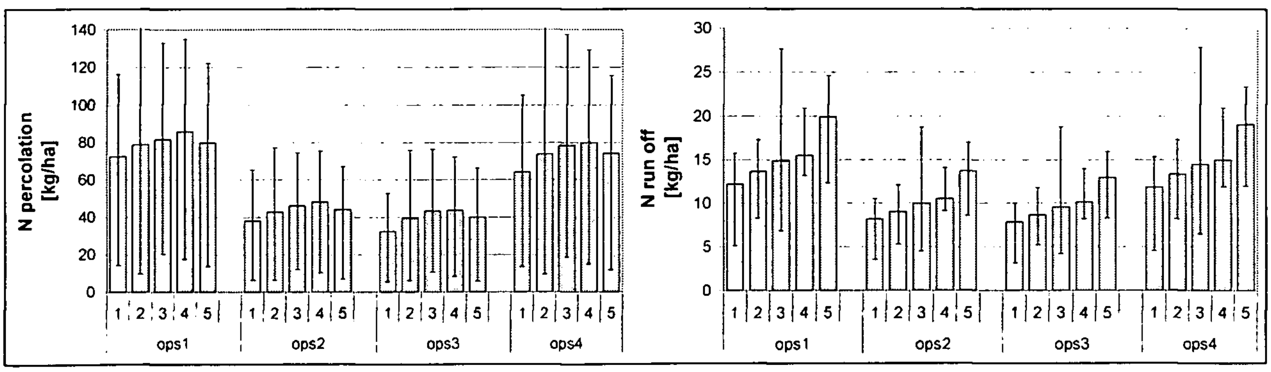

Figure 7: Mean values of N in percolation and in runoff in kg/ha for Soil 1 over the whole simulation period of 20 years, four management variations (ops1 to 4), and five weather seeds (1 to 5)
Note: The range bars give minimum and maximum values

Variability between soils

Mean values of N leaching and N in runoff over the simulation period of 20 years hardly show any differences between the two soils. However, between periods of five years, some differences between the soils can be observed. Figure 8 and Figure 9 show N losses by percolation water and runoff as percentage of weather seed mean values from both soils and the four management variations for the first and last period. Differences in the variability pattern can be observed between the soils. In Soil 2, differences in weather seeds result in less variability between management variations than in Soil 1. For instance, the N percolation in period 4, ops3, and seed 5 exceeds with 140 % the mean value in Soil 1 and in Soil 2 with 120 %.

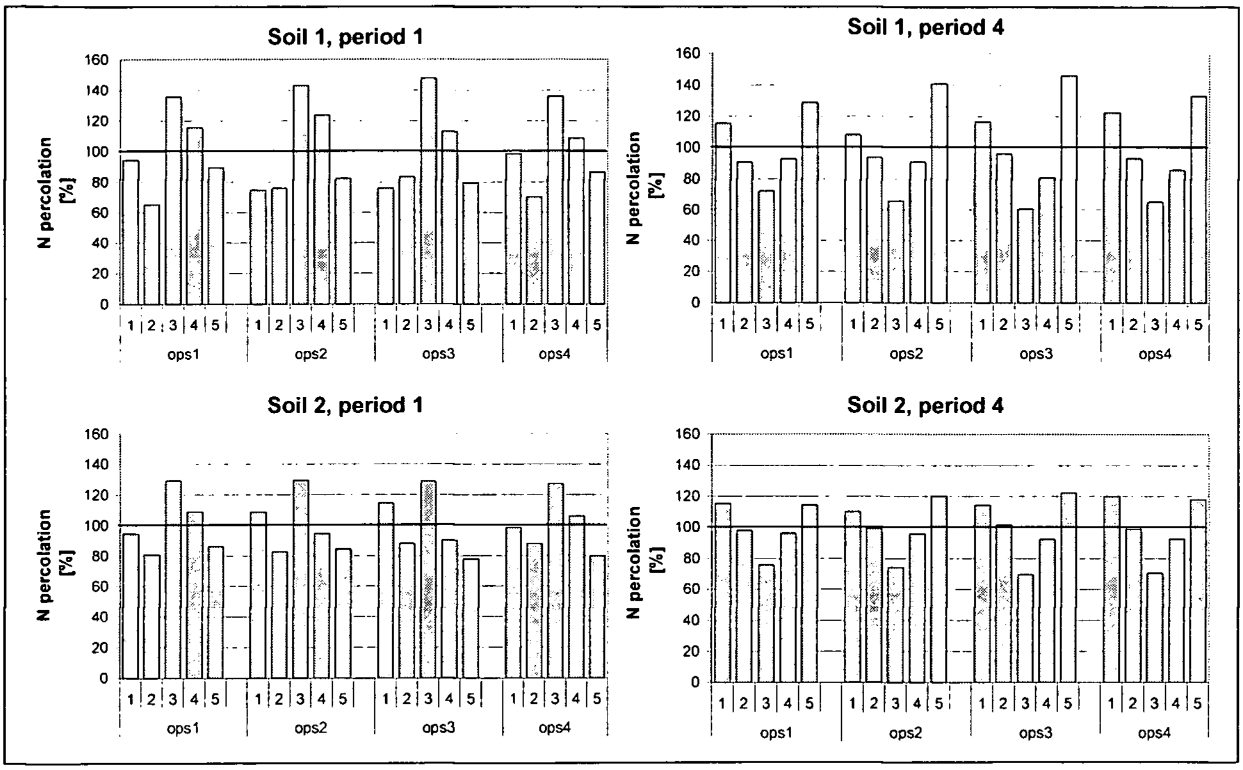

Figure 8: N percolation as percentage of weather seed mean values (1 to 5) for Soil 1, Soil 2, four management variations (ops1 to 4), and period 1 and 4

An other example of different variability between the soils is given by N in runoff (Figure 9). for instance in period 1, seed 5 reaches nearly 140 % of the seed mean value in Soil 1, in Soil 2 of the same period remains under the mean value for all management variants (ops1 to 4).

Other parameters for N losses as subsurface flow or ammonia volatilization show less variability between weather seeds (data not shown).

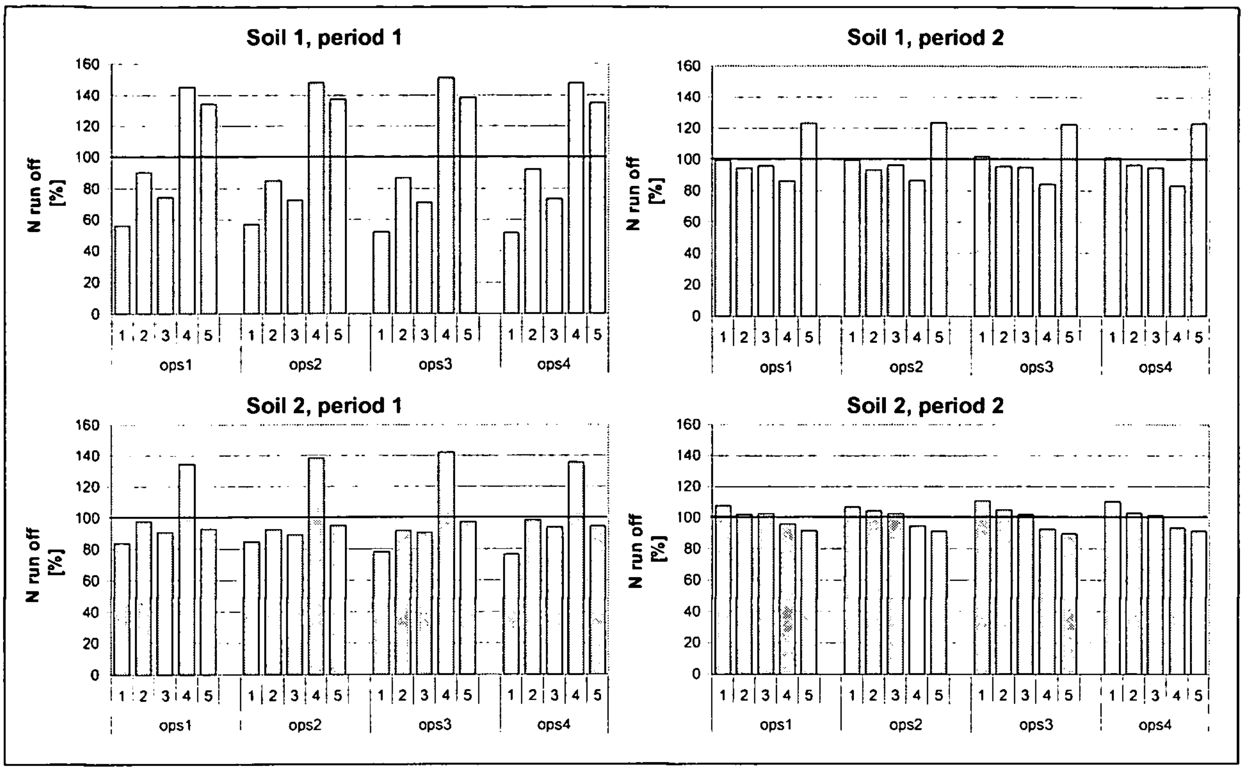

Figure 9: N in runoff as percentage of weather seed mean values for Soil 1, Soil 2, four management variations (ops1 to 4), and period 1 and 2

4. Conclusions

The reduction of N fertilizer application rates could significantly decrease N leaching in both soils but did not decline crop yields. Cover crops have proved a potential in reducing N leaching although no significant differences could have been revealed. The increase of ammonia volatilization caused by cover crops is not negligible. Positive effects on crop yields by incorporating cover crop biomass in spring could not be confirmed as in previous studies (e.g. Paustian et al., 1992). The analysis has shown that there are stochastic and dynamic effects, which should be considered in evaluating the environmental impacts of management measures.

Some parameters directly affected by precipitation and temperature as N leaching and runoff can r eact very sensitively to s mall changes in precipitation o r temperature. Al though m ean values of these parameters do not show significant differences over longer time periods, a high range of environmental impacts from different weather seeds is simulated. Certainly, the effects vary with other environmental conditions such as soils and management measures. Nevertheless, stochastic analysis of production and environmental effects from multiple weather seeds is necessary if short time periods are investigated.

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Zusammenfassung und Diskussion der Ergebnisse

Ziel der Arbeit ist eine Beurteilung, inwiefern sich das biophysikalische Prozessmodell EPIC eignet, Erträge, Sickerwasseranfall und Nitratverlagerung im Gemüsebau abzuschätzen. Dazu wurden Messdaten mit Simulationsergebnissen verglichen.

EPIC ermöglicht die Abschätzung der Effekte von Bewirtschaftungsmaßnahmen über längere Zeiträume (Schmid et al., 2006). Anhand von Simulationsexperimenten wurde untersucht, wie sich unterschiedliche Bewirtschaftungsmaßnahmen über eine Periode von 20 Jahren auf Umweltparameter wie Nitratverlagerung und Ammoniakverflüchtigung auswirken. Langjährige Wettersimulationen wurden durchgeführt, um stochastische als auch dynamische Effekte in der Bewertung von Bewirtschaftungsmaßnahmen zu berücksichtigen.

Die Kalibration von EPIC ergab, dass Mittelwerte und Variabilität der Messdaten von Sickerwasser und Nitratverlagerung reproduziert werden können. Ein Vergleich der Erträge zeigt überwiegend gute Übereinstimmung zwischen Simulationen und gemessenen Erträgen, mit Ausnahme von Kartoffel und Chinakohl. Allerdings war die Kartoffelernte für diesen Standort in dem Versuchsjahr außergewöhnlich hoch. Bei Chinakohl werden verschiedene Sorten angebaut, die sich in den Ertragsleistungen stark unterscheiden können.

Die höchste Korrelation zwischen Messung und Simulation des Sickerwasseranfalls und der Nitratverlagerung wird am Kalibrationsstandort Wörth mit der Grundbewirtschaftungsvariante (Düngung nach KNS-System und ohne Zwischenbegrünung) erzielt. Die übrigen Varianten am Standort Wörth ergaben geringere Korrelation, wobei der Sickerwasseranfall eine bessere Übereinstimmung zeigt als die Nitratverlagerung. Der zweite Standort Seebach, an dem das kalibrierte Modell angewendet wurde, weist allgemein geringere Übereinstimmung als der Kalibrationsstandort Wörth auf. Zwei der drei Bewirtschaftungsvarianten (Variation 1 und 2) von Seebach korrelieren übermäßig gering zwischen Simulations- und Messergebnissen. Sickerwasseranfall, sowie Nitratverlagerung werden in diesen Varianten vom Modell überschätzt. Obwohl die beiden Standorte sehr ähnlich bezüglich Boden und Klima sind, kommt es in Seebach zu kleineren Mengen an Nitratauswaschung als in Wörth. Vor allem Extremauswaschungsmengen, die in Wörth gemessen wurden, konnten in Seebach nicht gemessen werden, was EPIC jedoch simulierte. Um dennoch bessere Simulationsergebnisse zu erzielen, wäre es notwendig, einerseits die Vorgeschichte des Standorts und andererseits die Hydrologie sowie die Stickstoffdynamik noch genauer zu untersuchen.

Die Simulation verschiedener Bewirtschaftungsmaßnahmen über einen Zeitraum von 20 Jahren ergab keine Unterschiede hinsichtlich der zu erwartenden Ertragsmengen. Dies bedeutet, dass erstens kein negativer Effekt der reduzierten Stickstoffdüngung und kein positiver Einfluss der Zwischenbegrünung auf die Ertragshöhe, wie sie in anderen Studien beobachtet wurden (z.B. Paustian et al., 1992), gegeben ist. Es ist aufgrund der Simulationsergebnisse jedoch nur bedingt möglich, Aussagen über die Qualität der Erträge zu machen.

Bezüglich der Nitratverlagerung ergaben T-Tests signifikante Unterschiede zwischen Varianten mit Stickstoffdüngung nach KNS-System und solchen mit 30% reduzierter Stickstoffdüngung. Die jährliche Nitratverlagerung der Varianten mit Zwischenbegrünung ist über den Verlauf der 20 Jahre zwar geringer als in Varianten ohne Begrünung. Es konnten jedoch keine signifikanten Unterschiede festgestellt werden. Durch die Zwischenbegrünung steigen die Stickstoffverluste über Ammoniakverflüchtigung an. Dies ist dadurch zu erklären, dass größere Mengen an Stickstoff im und über dem Boden zurückgehalten werden und sich dadurch das Potenzial von Ausgasungen erhöht. Die gesamten Verluste von Stickstoff sind dennoch bei Varianten mit Zwischenbegrünung geringer als bei solchen ohne Begrünung. Signifikante Auswirkungen der Zwischenbegrünung auf Sickerwasseranfall und Evapotranspiration wurden, wie aufgrund anderer Studien erwartet (z.B. Weinert et al. 2002), nicht beobachtet. Ebenso konnten keine Effekte auf den Gehalt des organischen Kohlenstoffs oder auf die Erosion verzeichnet werden. Im Zuge der Feldversuche wurden jedoch positive Auswirkungen auf die Bodenfruchtbarkeit festgestellt (Liebhard et al., 2003).

Die Simulation der Nitratverlagerung und der Ammoniakverflüchtigung über 20 Jahre zeigte einen signifikanten Anstieg bis zu einem Zeitraum von ca. 10 Jahren bei der Nitratverlagerung bzw. fünf Jahren bei der Ammoniakverflüchtigung. Daher ist zur besseren Beurteilung von Bewirtschaftungsmaßnahmen notwendig, längere Zeiträume zu berücksichtigen.

Ein Simulationsexperiment über stochastische Wetterverläufe ergab, dass Variationen von Wetterparametern unterschiedliche Auswirkungen auf die Nitratverlagerungsmengen zwischen verschiedenen Bewirtschaftungssystemen und den beiden Standorten haben. Diese sind vor allem auf den Einfluss von Niederschlag und Temperatur zurückzuführen. Deshalb sollten bei der Evaluierung von Bewirtschaftungsmaßnahmen die stochastischen Effekte von Wetterparametern berücksichtigt werden.

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Anhang

- ***Impacts of al ternative management measures in v egetable production s ystems on nitrate leaching in the Eferdinger Becken, Austria***

  Symposium: Soil Physics and Rural Water Management (SoPhyWa), Wien, September 2006.

- ***Long-term C & N simulations with EPIC for estimating ecosystem functioning under different management practices in the Marchfeld watershed***

  Konferenz: Reduced Nitrogen in Ecology and the Environment, Obergurgl, Oktober 2006.

- ***Evaluation of alternative management measures in vegetable production systems by field measurements and EPIC simulations***

  14th International Poster Day, Transport of Water, Chemicals and Energy in the Soil-Plant-Atmosphere System", Bratislava, November 2006.

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.

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.

MATERIAL AND METHODS

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.

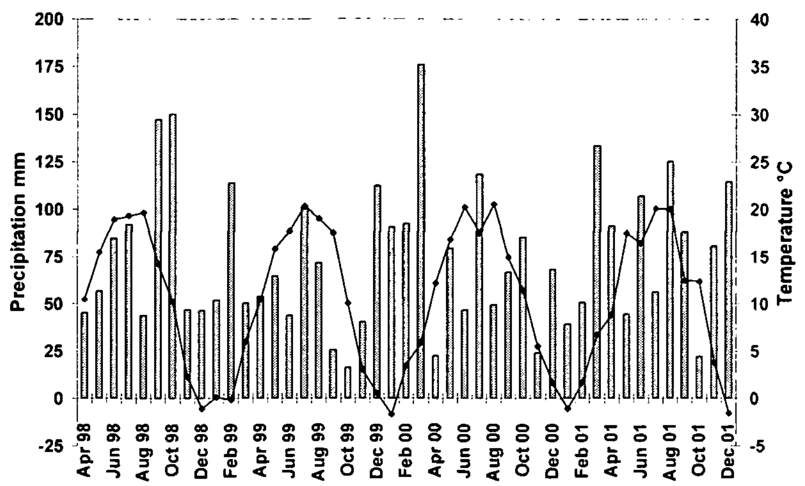

Figure 1. Precipitation (bars) and temperature (line) over the period of measurements.

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

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.

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 simulated 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 t 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)[1] 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

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

agreements than results from Seebach. Especially nitrogen leaching from Seebach shows poor performance due to overestimation of the model (data not shown), which will be further investigated.

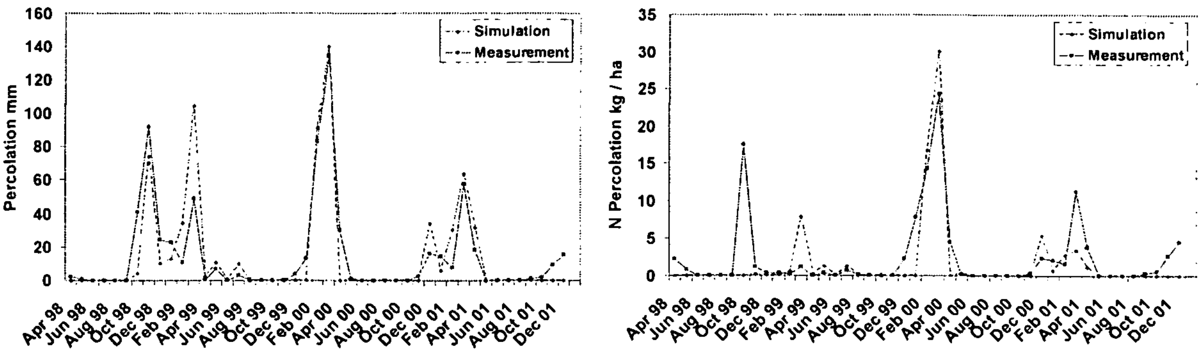

Figure 2. Simulation and measurements of water percolation (in mm) and N leaching (in kg ha-1) in Wörth (variation 1) at 1.2 m soil depth.

Table 3. Coefficient of determination (R^2) 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	
	R^2	d	R^2	d	R^2	d	R^2	d	R^2	d	R^2	d	R^2	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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Long-term C & N simulations with EPIC for estimating ecosystem functioning under different management practices in the Marchfeld watershed

Brigitte Müller and Erwin Schmid

Problem statement

The Marchfeld region is located East of Vienna and North of the river Danube. Intensive agricultural production has led to increased nitrate levels in the groundwater of the Marchfeld causing conflicts with the local supply of drinking water. The area has a size of approximately 1.000 km2 of which about 75.000 ha are used for agriculture. The depth to the shallow groundwater aquifer ranges from less than 1 m close to the river Danube to more than 10 m in small areas in the North. A mean annual precipitation of about 530 mm during the last 30 years has made the Marchfeld to one of the driest regions in Austria, where evapotranspiration usually exceeds precipitation from May to October. Major crops are cereals, vegetables, and sugar beets. As there is hardly any livestock farming, nitrogen input is mainly supplied by mineral fertilizers. In order to evaluate the long-term effects of different forms of nitrogen input, computer simulations are carried out.

Material and Method

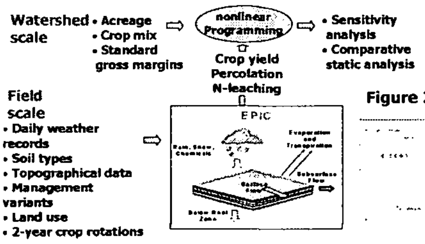
The model

The bio-physical process model EPIC (Environmental Policy Integrated Climate) was used for this simulation exercise. EPIC can be used to describe C, N, and P cycles in managed and unmanaged ecosystems and their effects on water, nitrogen, phosphorus, pesticides, organic carbon, sediment transport, and eventually on green house gas emissions. For evaluation of effects on N dynamics EPIC generates output parameters as N fixation, mineralization, percolation, ammonia volatilization or N loss by sediment and subsurface flow. The drainage area considered by EPIC is generally a field-size area - up to 100 ha - where weather, soil, topography, and management systems are assumed to be homogeneous. The major components in EPIC are weather simulation, hydrology, erosion-sedimentation, nutrient and carbon cycling, pesticide fate, plant growth and competition, soil temperature and moisture, tillage, cost accounting, and plant environment control. EPIC operates on a daily time step, and is capable of simulating hundreds of years if necessary (Figure 1).

Data aggregation and calibration

For the simulation, data aggregation was necessary. Therefore, the 75,000 hectare watershed was divided into statistically derived hydrological response units (HRU) by cluster analysis with respect to weather, soils, crop mixes and rotations, management practices, and topographies based on county-level survey data. Clustering crops, crop mixes, and soil types combined with daily weather records for ten years provides spatial and temporal representation of the watershed (Figure 2). For the calibration means of 4 measurements per year from 1992-1999 and approximately 90 sites were used. Results of the calibration are shown in Figure 3.

Figure 1: Environmental Modeling System



In a second step, the model is used for simulations over 30 years with following variations in the amount of nitrate and ammonia nitrogen:
"Base run": NO3:NH3 = 50:50; "NO3": NO3:NH3 = 100:0; "NH3": NO3:NH3 =0:100
Further simulations were carried out with compost fertilization. Compost contains of 1.6% total N of which 1.4% are organic. Ammonia amount to 87% of the mineral N and nitrate 13%.

Figure 2: Crop mix and soil clusters for each county in Marchfeld

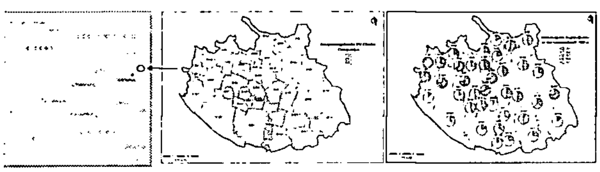
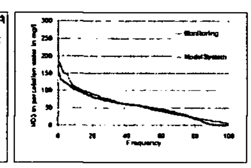


Figure 3: Calibration



Results and Discussion

Simulation over 30 years resulted in average nitrate concentration in percolation lowest value for "NH3" (52 mg/l), and the highest value for "NO3" (68 mg/l), and for the base run 58 mg/l. Ammonia volatilization is increased for "NH3" with 34.6 kg/ha per year in comparison to the base run with 29.6 and with "NO3" 24.8 kg/ha per year. Total N losses including leaching, volatilization, erosion, surface and subsurface flow have mean values from 45 kg/ha for "NO3" to 52 kg/ha for "NH3". Small changes can be observed in organic carbon in topsoil (<30 cm) with 61.5 t/ha in the base run, 61.2 t/ha in the "NO3" and 61.7 t/ha in the "NH3" scenarios. Annual mean dry matter crop yield production resulted in 5.0 t/ha for the base run, 5.1 t/ha for "NO3" and 4.91 t/ha for "NH3" (Figure 4). Mann-Whitney-U-Tests were carried out for N percolation, volatilization, organic carbon and yields. Significant differences between the variations were obtained for all parameters except for crop yields which only showed a significant difference between "NO3" and "NH3", but not between the two variations and the base run. In summary, fertilization with NH3 reduced N loss in percolation by 1 kg/ha in comparison to the base run and by 3 kg/ha in comparison to fertilization with NO3. However, volatilization increased by 5 kg/ha in comparison with the base run and by 9.8 kg/ha in comparison with NO3 fertilization. Results of the compost fertilization cannot be directly compared with the other variation due to mineralization of organic N over the years. However, mean values show lower nitrate leaching due to reduced nitrate concentrations of compost. Volatilization and total N losses are increased. Positive effects can be observed on organic carbon in topsoil which is increased in comparison to the other variations (Figure 4).

Figure 4: Mean of crop yields, organic carbon and nitrogen losses

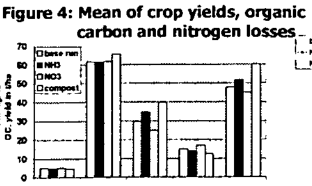
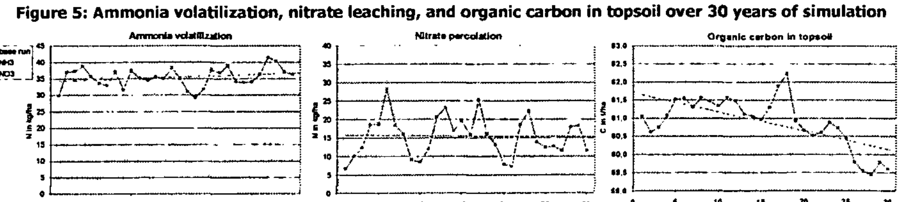


Figure 5: Ammonia volatilization, nitrate leaching, and organic carbon in topsoil over 30 years of simulation



Over 30 years of simulation volatilization shows regular fluctuations with a slight increase in mean values. Nitrate percolation is characterized by larger fluctuations but rather steady mean values. Organic carbon decreases in all variations, whereas differences between the variations increase over time (Figure 5). The study showed that a shift to ammonia fertilization would reduce nitrate leaching by 1 - 2 kg/ha in comparison to mixed fertilization or only nitrate containing fertilizers. Consequently, fertilizers high in ammonia would reduce negative impacts on groundwater. However, fertilizing with ammonia results in high nitrogen losses by ammonia volatilization that outweigh reduced nitrate leaching. Moreover, yields were slightly decreased with ammonia fertilization. Therefore, a shift towards high amounts of ammonia nitrogen cannot be recommended from the results of this study.

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Material and Method

The model

The bio-physical process model EPIC (Environmental Policy Integrated Climate) can be used to describe C, N, and P cycles in managed and unmanaged ecosystems. The drainage area considered by EPIC is generally a field-size area - up to 100 ha - where weather, soil, topography, and management systems are assumed to be homogeneous. The major components in EPIC are weather simulation, hydrology, erosion-sedimentation, nutrient and carbon cycling, pesticide fate, plant growth and competition, soil temperature and moisture, tillage, cost accounting, and plant environment control. EPIC operates on a daily time step, and is capable of simulating hundreds of years if necessary (Figure 1).

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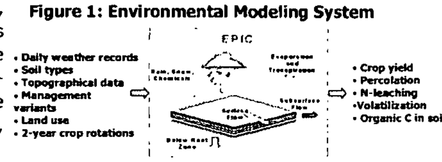

Field Measurements

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Figure 2: Measurements of the lysimeters

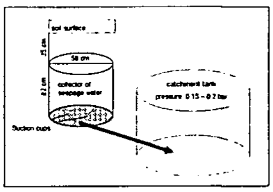

Figure 3: Precipitation (bars) **and temperature** (line) **of the sites**

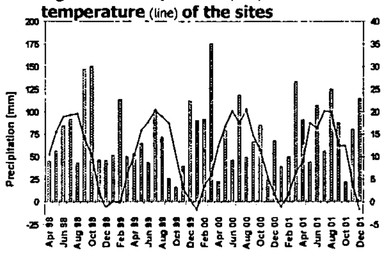

Table 1: Management of the farm in Wörth (numbers show N fertilization in kg/ha)

Year		Variation 1	Variation 2 (-30% N)	Variation 3 (-30% N)	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)
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The management measures could decrease N emissions between 10 kg/(ha·y) and 80 kg/(ha·y). The fertilization rates based on the KNS-system did not reduce quantity and quality of vegetables yields. Reduction in N 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).

Good agreements between simulated and measured crop yields were reached in all variations (figure 4). The biggest differences occurred for potatoes and Chinese cabbage yields of which measured yields were extraordinary high. Model calibration with data from variation 1, Wörth demonstrates that mean values and variability of percolation water and N leaching can be reasonably reproduced (figure 5). In general, percolation water shows better correlation than N leaching, which is evident by the coefficient of determination (R^2) and index of agreement (d) calculated following Liu et al. (2006) (figure 6). The index of agreement ranges between 0 and 1, and a value of 1 implies perfect agreement. Model results from Wörth perform better agreements than results from Seebach. Especially nitrogen leaching from Seebach shows poor performance due to overestimation of the model (data not shown), which will be further investigated. Differences between modeling and measurements can have several reasons of which some are variability of parameters in the soil system, unknown uncertainty of simulations and measurements, especially by extrapolating measured data to whole fields or poor adaptation of the model. For the future data uncertainties should be estimated and further model improvement should be carried out. Despite that the results of this study still show that EPIC can be used to analyse environmental impacts of management practices. Therefore, the simulations are a starting point for evaluating long-term effects of these management measures and for analysis of further management practices.

Figure 4: Simulated and measured fresh weight crop yields

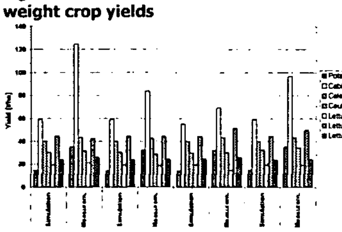


Figure 5: Simulation and measurements of water percolation and N leaching in Wörth (variation 1) at 1.2 m soil depth

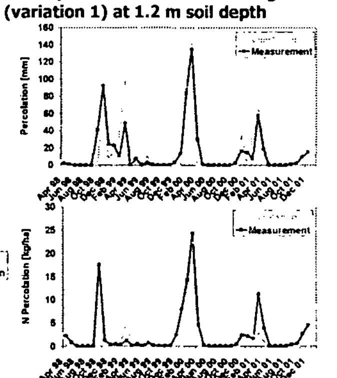
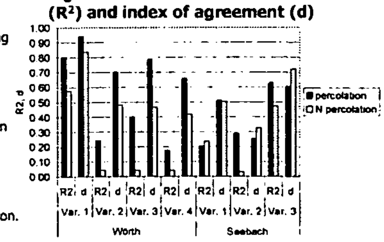


Figure 4: Coefficient of determination (R^2) and index of agreement (d)



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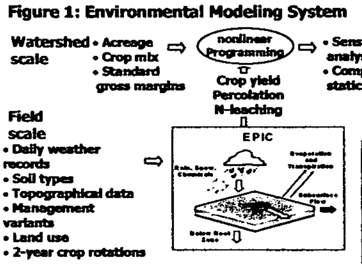
The bio-physical process model EPIC (Environmental Policy Integrated Climate) was used for this simulation exercise. EPIC can be used to describe C, N, and P cycles in managed and unmanaged ecosystems and their effects on water, nitrogen, phosphorus, pesticides, organic carbon, sediment transport, and eventually on green house gas emissions. For evaluation of effects on N dynamics EPIC generates output parameters as N fixation, mineralization, percolation, ammonia volatilization or N loss by sediment and subsurface flow. The drainage area considered by EPIC is generally a field-size area - up to 100 ha - where weather, soil, topography, and management systems are assumed to be homogeneous. The major components in EPIC are weather simulation, hydrology, erosion-sedimentation, nutrient and carbon cycling, pesticide fate, plant growth and competition, soil temperature and moisture, tillage, cost accounting, and plant environment control. EPIC operates on a daily time step, and is capable of simulating hundreds of years if necessary (Figure 1).

Data aggregation and calibration

For the simulation, data aggregation was necessary. Therefore, the 75,000 hectare watershed was divided into statistically derived hydrological response units (HRU) by cluster analysis with respect to weather, soils, crop mixes and rotations, management practices, and topographies based on county-level survey data. Clustering crops, crop mixes, and soil types combined with daily weather records for ten years provides spatial and temporal representation of the watershed (Figure 2). For the calibration means of 4 measurements per year from 1992-1999 and approximately 90 sites were used. Results of the calibration are shown in Figure 3.

Figure 1: Environmental Modeling System



In a second step, the model is used for simulations over 30 years with following variations in the amount of nitrate and ammonia nitrogen:
"Base run": NO3:NH3 = 50:50; "NO3": NO3:NH3 = 100:0; "NH3": NO3:NH3 =0:100
Further simulations were carried out with compost fertilization. Compost contains of 1.6% total N of which 1.4% are organic. Ammonia amount to 87% of the mineral N and nitrate 13%.

Figure 2: Crop mix and soil clusters for each county in Marchfeld

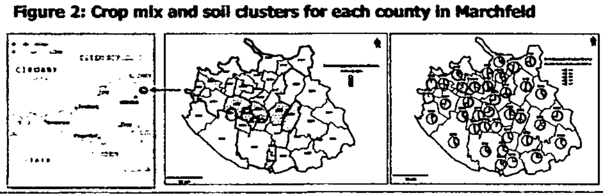
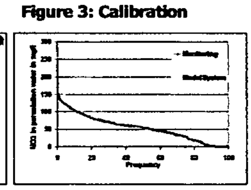


Figure 3: Calibration



Results and Discussion

Simulation over 30 years resulted in average nitrate concentration in percolation lowest value for "NH3" (52 mg/l), and the highest value for "NO3" (68 mg/l), and for the base run 58 mg/l. Ammonia volatilization is increased for "NH3" with 34.6 kg/ha per year in comparison to the base run with 29.6 and with "NO3" 24.8 kg/ha per year. Total N losses including leaching, volatilization, erosion, surface and subsurface flow have mean values from 45 kg/ha for "NO3" to 52 kg/ha for "NH3". Small changes can be observed in organic carbon in topsoil (<30 cm) with 61.5 t/ha in the base run, 61.2 t/ha in the "NO3" and 61.7 t/ha in the "NH3" scenarios. Annual mean dry matter crop yield production resulted in 5.0 t/ha for the base run, 5.1 t/ha for "NO3" and 4.91 t/ha for "NH3" (Figure 4). Mann-Whitney-U-Tests were carried out for N percolation, volatilization, organic carbon and yields. Significant differences between the variations were obtained for all parameters except for crop yields which only showed a significant difference between "NO3" and "NH3", but not between the two variations and the base run. In summary, fertilization with NH3 reduced N loss in percolation by 1 kg/ha in comparison to the base run and by 3 kg/ha in comparison to fertilization with NO3. However, volatilization increased by 5 kg/ha in comparison with the base run and by 9.8 kg/ha in comparison with NO3 fertilization. Results of the compost fertilization cannot be directly compared with the other variation due to mineralization of organic N over the years. However, mean values show lower nitrate leaching due to reduced nitrate concentrations of compost. Volatilization and total N losses are increased. Positive effects can be observed on organic carbon in topsoil which is increased in comparison to the other variations (Figure 4).

Figure 4: Mean of crop yields, organic carbon and nitrogen losses

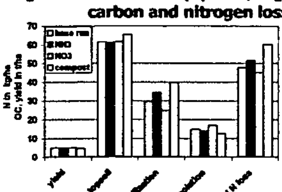
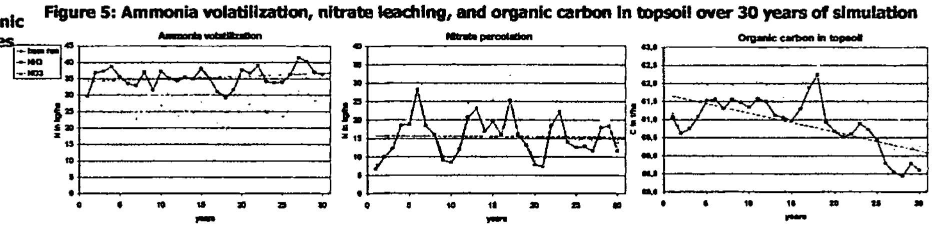


Figure 5: Ammonia volatilization, nitrate leaching, and organic carbon in topsoil over 30 years of simulation



Over 30 years of simulation volatilization shows regular fluctuations with a slight increase in mean values. Nitrate percolation is characterized by larger fluctuations but rather steady mean values. Organic carbon decreases in all variations, whereas differences between the variations increase over time (Figure 5). The study showed that a shift to ammonia fertilization would reduce nitrate leaching by 1 - 2 kg/ha in comparison to mixed fertilization or only nitrate containing fertilizers. Consequently, fertilizers high in ammonia would reduce negative impacts on groundwater. However, fertilizing with ammonia results in high nitrogen losses by ammonia volatilization that outweigh reduced nitrate leaching. Moreover, yields were slightly decreased with ammonia fertilization. Therefore, a shift towards high amounts of ammonia nitrogen cannot be recommended from the results of this study.

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Evaluation of alternative management measures in vegetable production systems by field measurements and EPIC simulations

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Problem statement

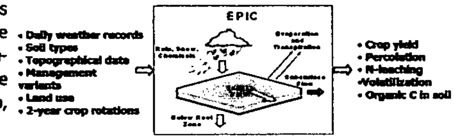
Intensive production systems with major shares of vegetables in the crop rotations often lead to high nitrate emissions. In the Southern Eferdinger basin the vegetable growing sector is of economic importance and produces a variety of field vegetables. Because nitrate concentrations in the groundwater are exceeding the threshold of 45 mg NO3 per litre at different monitoring sites, management measures to reduce nitrate leaching need to be implemented (Liebhard et al., 2003). In order to evaluate different management measures seepage water was collected in field lysimeters and nitrate concentrations analysed. Especially for evaluation and prediction of environmental long-term effects computer models are increasingly used. Model calibration to specific sites is necessary for performance testing and reliability of simulation outputs. In this study lysimeter measurements are used for comparison with computer simulation results.

Material and Method

The model

The bio-physical process model EPIC (Environmental Policy Integrated Climate) can be used to describe C, N, and P cycles in managed and unmanaged ecosystems. The drainage area considered by EPIC is generally a field-size area - up to 100 ha - where weather, soil, topography, and management systems are assumed to be homogeneous. The major components in EPIC are weather simulation, hydrology, erosion-sedimentation, nutrient and carbon cycling, pesticide fate, plant growth and competition, soil temperature and moisture, tillage, cost accounting, and plant environment control. EPIC operates on a daily time step, and is capable of simulating hundreds of years if necessary (Figure 1).

Figure 1: Environmental Modeling System



Field Measurements

Two representative farms in the villages Seebach and Wörth were chosen for the installation of seven field lysimeters (figure 2) (three in Seebach and four in Wörth). Data from April 1998 to December 2001 are used for calibrating EPIC and performance testing. The sites are characterised by soil texture of loamy sand till sandy loam (Seebach), and loamy sand (Wörth) and high soil water storage capacity. Figure 3 shows precipitation and temperature from the observed time period. In Seebach, one field was cultivated with green salad only, two other fields included green rye, phacelia and high mallow as cover crops. Fertilization was carried out following the Nmin target values system (KNS). N 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 2: Measurements of the lysimeters

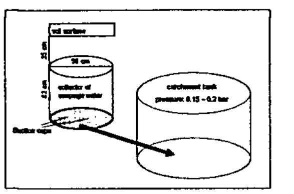


Figure 3: Precipitation (bars) and temperature (line) of the sites

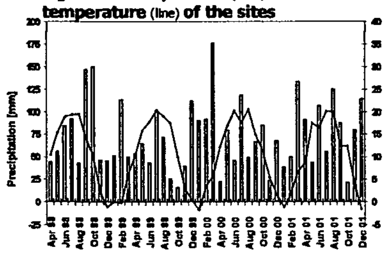


Table 1: Management of the farm in Wörth (numbers show N fertilization in kg/ha)

Year		Variation 1	Variation 2 (-30% N)	Variation 3 (-30% N)	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	Lettuce (91)	Lettuce (84)	Lettuce (90)	Lettuce (96)
	2nd crop	Lettuce (97)	Lettuce (60)	Lettuce (49)	Lettuce (98)
	3rd crop	Lettuce (98)	Lettuce (51)	Lettuce (49)	Lettuce (87)
	Cover crop	Winter wheat	Winter wheat	Winter wheat	Winter wheat

Results and Discussion

The management measures could decrease N emissions between 10 kg/(ha·y) and 80 kg/(ha·y). The fertilization rates based on the KNS-system did not reduce quantity and quality of vegetables yields. Reduction in N 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).

Good agreements between simulated and measured crop yields were reached in all variations (figure 4). The biggest differences occurred for potatoes and Chinese cabbage yields of which measured yields were extraordinary high. Model calibration with data from variation 1, Wörth demonstrates that mean values and variability of percolation water and N leaching can be reasonably reproduced (figure 5). In general, percolation water shows better correlation than N leaching, which is evident by the coefficient of determination (R^2) and index of agreement (d) calculated following Liu et al. (2006) (figure 6). The index of agreement ranges between 0 and 1, and a value of 1 implies perfect agreement. Model results from Wörth perform better agreements than results from Seebach. Especially nitrogen leaching from Seebach shows poor performance due to overestimation of the model (data not shown), which will be further investigated. Differences between modeling and measurements can have several reasons of which some are variability of parameters in the soil system, unknown uncertainty of simulations and measurements, especially by extrapolating measured data to whole fields or poor adaptation of the model. For the future data uncertainties should be estimated and further model improvement should be carried out. Despite that the results of this study still show that EPIC can be used to analyse environmental impacts of management practices. Therefore, the simulations are a starting point for evaluating long-term effects of these management measures and for analysis of further management practices.

Figure 4: Simulated and measured fresh weight crop yields

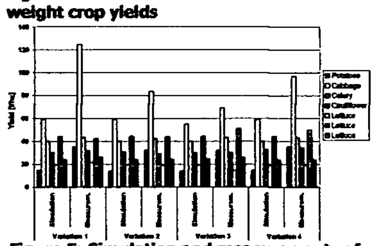


Figure 5: Simulation and measurements of water percolation and N leaching in Wörth (variation 1) at 1.2 m soil depth

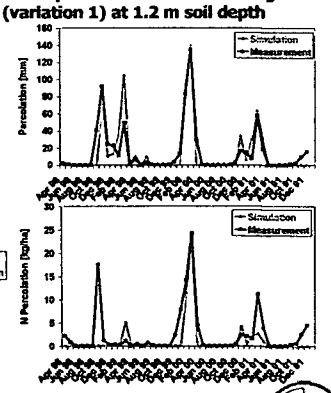
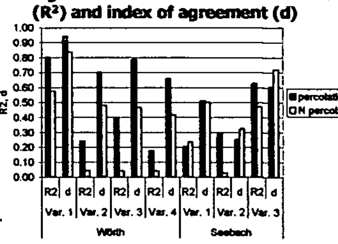


Figure 4: Coefficient of determination (R^2) and index of agreement (d)



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