Chapter 6

Modelling Impact of Adjusted Agricultural Practices on Nitrogen Leaching to Groundwater

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Additional information is available at the end of the chapter

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Abstract

The aim of the research was to determine how changes in the management of agricultural land (cultivation techniques, fertilisation, type of crop and crop rotation) influence on the leaching of nitrogen from the soil profile. Research was conducted in the Drava River plain in Slovenia. The impact of 31 different scenarios of potential change in agricultural land management was evaluated using the Soil and Water Assessment Tool (SWAT) model. The research was located on the shallow aquifer with alluvial bedrock composite from carbonate and silicate layers, which is the main source of drinking water in the area. The results of the SWAT model version 2009 showed that with the constant climate and land management technology, the magnitude of nitrogen leaching from the soil profile is mainly influenced by soil properties. The most drastic effect on the increase of nitrogen leaching showed vegetable production technology, followed by cereals (corn, wheat and barley). Vegetable production even in ecological production by Slovenian standards can result in similar leaching potential as conventional farming, due to unfavourable conditions originating from soil properties (shallow soil profile). Effects of grassland production may lead to 76–98% reduction in nitrogen loss from soil profile in comparison to current practices.

Keywords: nitrogen balance, leaching, agriculture, SWAT, environment

1. Introduction

The purpose of this paper is to present the scientifically based starting point in the development of sustainable farming in water protection areas. The issue of proper agricultural management on water protection areas is very complex since two, in management of the environment, quite different ecosystem services (water and food providing) have to coexist [1].

After the 1950s, the area of arable land and the quantity of used mineral fertilisers worldwide and in Europe increased sharply [2]. Intensive agricultural production and greater density of animals have influenced on increased input of nitrogen on land and leaching into water bodies causing deterioration of groundwater and surface water resources quality. From the first serious attempt to change the impact of agriculture on water quality in Europe, with the adoption of the Nitrate Directive (91/676/EEC), it has been 25 years. Therefore, the main objectives of the expert community are to determine the transport and balance of nitrogen from agricultural land and its impact on water bodies and changing agricultural practices towards sustainable agriculture. The results of higher environmental awareness accompanied with measures adopted in agriculture policy can be seen in substantial gradual drop in consumption of mineral fertilisers in European Union (EU) member states [3]. These results were achieved through many different actions such as political decision of EU to act, designation of nitrate-vulnerable zones (NVZs) and establishment of Codes of Good Agricultural Practice for farmers on voluntary basis, establishment of action programmes to be implemented by farmers within NVZs, and establishment of national monitoring and reporting system every 4 years for each member state [3]. To be more precise, there are some measures within cover action programmes which are crucial for the success, such as regular education of farmers, subsidy payments, cross-compliance in agriculture, implementation of new crop varieties, organic and no-till farming, promoting a 3-year rotational scheme, promoting nitrogen fixation plants, green manure plants and nitrogen catch crops, and so on.

In Slovenia, groundwater accounts for 98% of all sources of drinking water supply, so the effective protection of groundwater quality is of the utmost importance for the health of the population [4, 5]. But unfortunately, main areas of groundwater resources such as Drava Plain in Slovenia spatially coincide with the most intensive agricultural areas. Therefore, is nitrogen in these areas together with the plant protection products the main groundwater pollutant? Coincidence of natural geological and climate conditions, development in agriculture production management and past inappropriate decisions by authorities caused that many of drinking groundwater sources are at a high risk or even not suitable for use [6]. While Slovenia assigns the whole country as nitrate-vulnerable zone by Nitrate Directive and almost all farmers implemented Codes of Good Agricultural Practice, areas of additional special protection of drinking water groundwater resources are defined as water protection areas (WPAs). The basic function of WPA is conservation of drinking water quality of all water resources, which are intended for the supply of the population. Each of the EU member states committed themselves to the Water Framework Directive (2000/60/EC) with aim to implement a variety of environmental measures and maintain or improve good quantitative and chemical status of all groundwater and surface water bodies [7]. On this basis, each member state had to prepare river basin management plans and define water bodies' quality status and actions to achieve ultimate WFD goal of good water quality. All actions and quality status are carefully monitored and reported to European commission. In the case that member state in not fulfilling its own plan European Commission begins process of determining liability which could lead to the imposition of a fine to member state. One of the reporting activates of each member state is also annual report on gross nitrogen budget (GNB) and net nitrogen budget (NNG) which is prepared on the basis of Eurostat/OECD methodology [8]. The GNB is calculated as the balance between inputs (consumption of fertilisers, manure input, atmospheric deposition, biological fixation, seed-sand planting materials and crop residues) and outputs (crop harvest, harvest and grazing of fodder, crop residues removal and stock changes of N in soil) of nutrients to the agricultural soil [9]. The GNB serves as a measure of the total potential threat of nitrogen surplus or deficit in soils to the environment. Long-term deficit means loss of agriculture land productivity and excess means higher potential for pollution and eutrophication of water resources.

In the EU, WFD is proposed to use different modelling strategies to define the most cost-effective and especially environmentally effective actions with a purpose of finding balance between preserving water quality and sustaining food production. The European Commission has been in pursuit of the best model suitable for modelling nutrient losses from agricultural systems in European condition funded by the EUROHARP project [10]. Among the large ensemble of models was Soil and Water Assessment Tool (SWAT) together with NL-CAT, TRK and EveNFlow proved to be one of the best for hydrology and water quality modelling. However, researchers emphasise that there is no single model which could be used in all conditions and produce reliable results. Soil and Water Assessment Tool model is one of the open source models capable of fast and effective evaluation of agricultural practices impact on water bodies [7, 11, 12]. In the first place, it was developed to model best management practices (BMPs) in agriculture. Although these seem to be an easy task, the model requires large amount of data on management practices and water quality measurements to produce reliable results. BMPs in agriculture are one of the most often modelled scenarios; however, a combination of local hydrology, terrain, soil, land use, climate and management practices makes them constantly attractive [12–15]. BMPs in agriculture can also be described as agri-environmental measures (AEMs) introduced by farmers due to practical and cost-effective reasons. They influence on erosion processes and sediment transport, fertilisers and plant protection products transport and leaching. Based on their efficiency, they prevent pollutants to enter water bodies and conserve drinking water supply and water habitats while maintaining agricultural production [13, 14].

The aim of the paper is to investigate the impact of different adjustments in the management of agricultural land (cultivation techniques, fertilisation, type of crop and crop rotation) on the nitrogen leaching from the soil profile. For this, 31 different BPM scenarios of potential changes in agricultural land management were evaluated using Soil and Water Assessment Tool model.

2. Materials and methods

2.1. Study area

The River Drava Plain (Dravsko polje) aquifer study area (293.2 km^2) is located in the north-eastern part of Slovenia (**Figure 1**). The Drava Plain altitude is relatively small and ranges between 200 and 250 m without any distinct slopes. The plain is divided on four alluvial terraces. The agricultural land lies above an intergranular aquifer with specific soil characteristics which are the result of the deposition of river sediments. The river Drava deposited sediments of Quaternary sand and gravel in the area which forms extensive alluvial aquifer. The aquifer is very well permeable with the permeability coefficient of about 5 × 10^{-3} m/s. The aquifer is unconfined and exposed to the intake of pollutants from the surface. The area is suitable for intensive agriculture (grain production) due to the favourable terrain and structure of land ownership. According to data on land use prevails arable (44%) followed by the forest (20%), urban (19%) and grassland (9%). Other land-use classes are represented by 1% or less. Soils are shallow and contain many sand particles and larger rocks. Due to continental climate with spring rainfall and hot and relatively dry summers, drought often occurs on these soils.

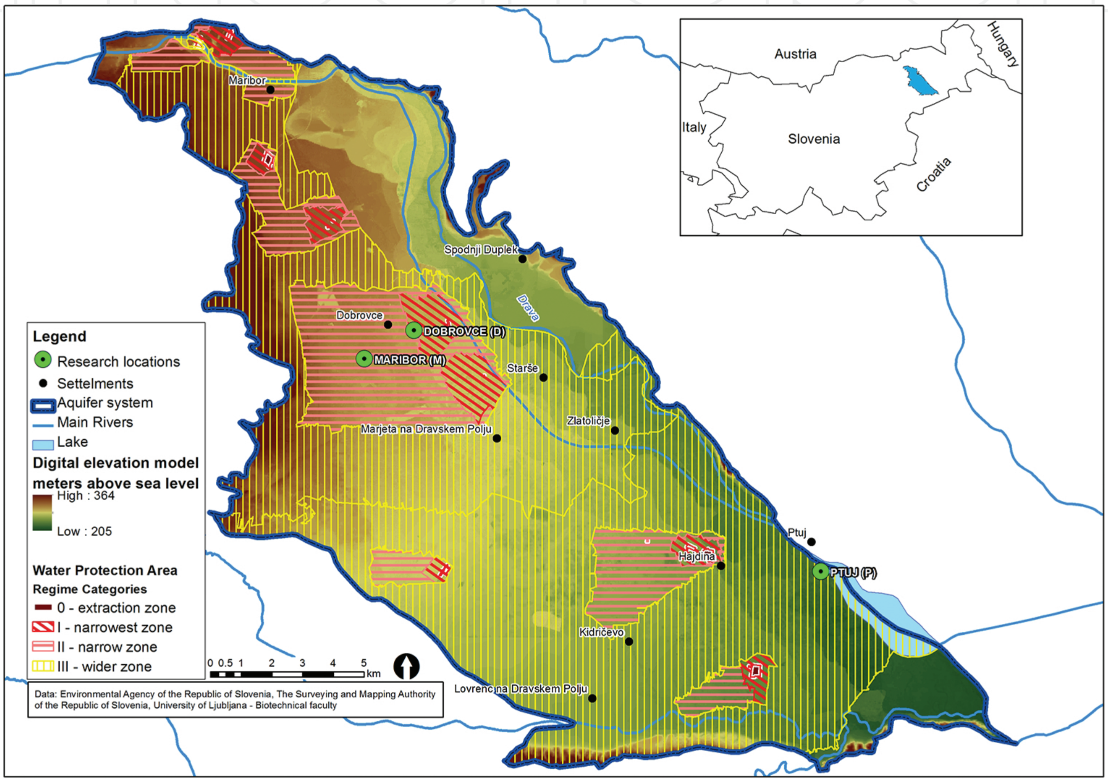

Figure 1. The river Drava Plain study area land use, elevation and water protection area.

Geographically speaking, the Drava Plain area is located in sub-Pannonian Slovenia, which is characterised by continental to sub-continental climate, with lowest rainfall quality in winter and spring months (January to April) and the highest in the summer months (June to September) due to typical stormy rainfall events. The average annual rainfall amounts (1981–2010) measured at the Maribor Airport and Ptuj were 935 and 959 mm, respectively. The average annual minimum temperature measured at the Maribor Airport was 5.3°C and maximum 15.3°C. The average minimum temperature for the meteorological winter (December to February) was −3.8°C and meteorological summer (June-August) 25.4°C.

In the area of the river Drava Plain, two regulations on water protection areas are in force, which protect the aquifer as the primary source of drinking water in the area. The measured concentration of nitrate (NO_3^-) in groundwater is at many monitoring points, in excess of the WFD-recommended concentrations for drinking water (50 mg NO_3^-/l) (**Figure 2**).

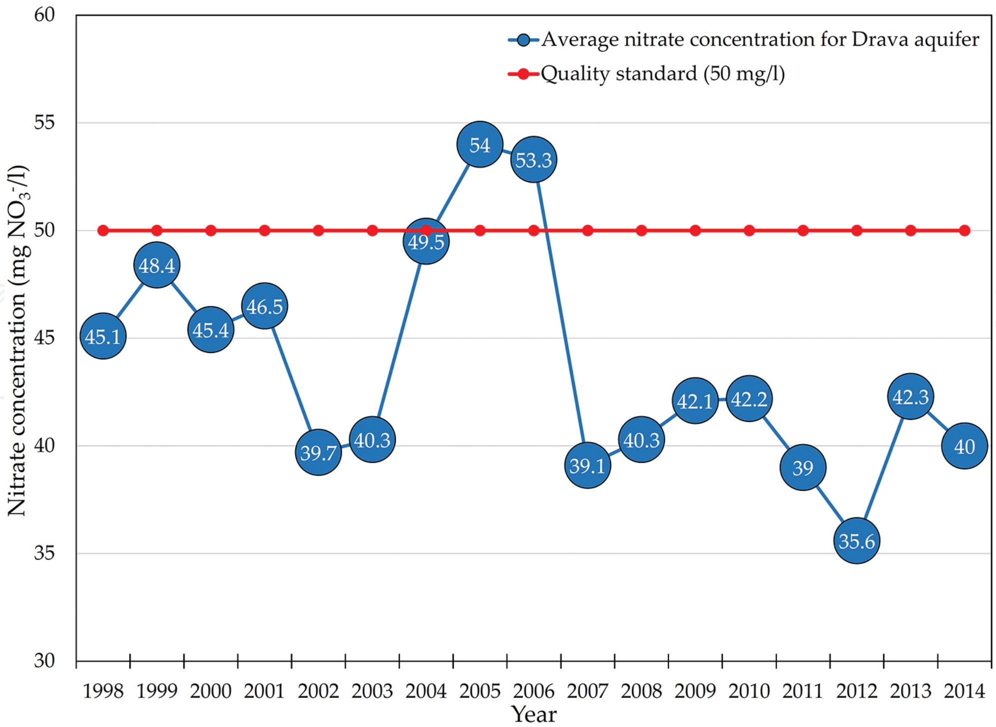

Figure 2. Average annual nitrate concentration (mg NO_3^-/l) for Drava aquifer between 1998 and 2014 calculated by Slovenian Environmental Agency on the basis of several monitoring points.

Three research locations were included in the study (**Figure 1**): Dobrovce (253 m.a.s.l.) mostly vegetable horticultural production, narrowest WPZ zone I (1.53 ha); Maribor (262 m.a.s.l.) with a grain crop rotation, narrow WPZ zone II (15.12 ha); Ptuj (218 m.a.s.l.) mixed crop rotation for seed production, wider WPZ zone III (2.25 ha) (**Figure 1**).

2.2. SWAT model description

Processes in the unsaturated zone were modelled with the Soil and Water Assessment Tool model ArcSWAT version 2009.10.1 [16]. The model was developed to assist water managers in evaluating the impact of agricultural activities in the river basins. The core of the model was developed in the early 1990s under the United States Department of Agriculture (USDA). The model was at the beginning called SWRRB and was created by joining three existing models CREAMS, EPIC and GLEAMS [12].

The SWAT model has the capability to predict the impact of land use and land management on the water quality and quantity and transport of sediment and soluble materials from agriculture in large river basins with the complex heterogeneous topography, soils, land use and land management conditions over long periods of time [12]. It is capable of modelling numerous agricultural management practises, agri-environmental measures, climate changes, scenarios of future land-use development, plant growth and biomass development. It operates on annual, monthly, daily and even on hourly time scale. Its open source code enables scientists to connect the model with others such as APEX, ALMANAC and MODFLOW and upgrade it for better performance such as SWIM and SWAT-G [12, 17, 18].

Diffuse sources of nutrients and their transport routes are in the SWAT model strongly linked to the water cycle, which is influenced by water and solar energy. When precipitation falls on the soil, it may follow different preferential pathways such as surface runoff or shallow subsurface runoff (transfer of N and P) and vertical leaching into the shallow aquifer (transfer of N). The nitrogen balance in the soil and groundwater depends on many factors (biological, climatic and physico-chemical properties of the soil). Detailed explanation of the SWAT model strengths, weaknesses, opportunities and threats in catchment modelling is given in preceding book chapter [19].

2.3. Database

For the preparation of the model, data were collected ranging from spatial data (digital elevation model (DEM) map, land-use map and classification and soil map and its properties), time series (weather such as daily precipitation, temperature, solar radiation, wind speed, relative humidity; crop rotations such as type of farmed culture, crop rotation sowing and harvesting dates; tillage such as the type of tillage and machines, the time of basic soil preparation, cultivation during growth and after; fertilisation such as the type, time of use, quantity and nutrient content), attribute data (soil parameters such as thickness of horizons, hydrological group, bulk density, texture, colour, rocks, organic matter, hydraulic conductivity, plant available water and soil erosivity—MUSLE; plant growth such as leaf area index, the development of dry biomass and average yield) to data for model calibration (soil water content (SWC)) (**Table 1**). Information about the type, quantities and dates of the use of fertiliser was obtained from Agricultural Extension Service (Chamber of Agriculture and Forestry of Slovenia—Unit Maribor) and farmers. Data acquisition began in early July 2011, and lasted over the entire period of the survey until 2013. When the data were collected, they were during the research gradually entered in the SWAT model to prepare a base scenario of the base current agricultural practices in all three research locations. This was a base for further development of scenarios of potential crop rotations including good agricultural practices for protecting water protection zones (WPZs) in the Drava Plain area.

2.4. Agricultural land management scenarios

The scenarios were developed with the aim to determine how changes in agricultural practices (crop rotation, fertilisation rate and type of plant varieties) influence the leaching of nitrogen below the plant roots from the soil profile. In designing the scenarios, we relied on the guidelines for the scientifically grounded fertilisation, issued by the Ministry of Agriculture, Forestry and Food [20], own expertise and information from agricultural producers (farmers) in the study area.

Depending on the availability of data, we prepared a total of seven sets of scenarios with 31 possible combinations of alternative rotations and managements (A. Basic rotations with modified fertilising norms, B. Basic rotations with introduced new crops, C. Grassland use, D. The most common rotations in the research area, E. Adapted the most common rotations, F. Organic rotations, G. Water protection zones regime rotations) (**Table 2**). Scenarios can serve only as indicative information as actual future development of agricultural land management is impossible to predict. EU Common Agricultural Policy (CAP) changes at least once in 7 years with possible mid-term changes in each of the member states after evaluation of the national Rural Development Programmes (RDPs). Agricultural policy can throughout financial stimulants dictates simultaneous sustainable agriculture and protection of water resources. In designing the scenarios, we relied on the guidelines for professionally justified fertilisation, issued by the Ministry of Agriculture, Forestry and Food [20], own expertise and on information from farmers.

Climate	**Data source**
Precipitation, avg., min. and max. temperature, relative humidity, energy of global solar radiation, average wind speed	Slovenian Environmental Agency (ARSO), Meteorological station Maribor Airport, Precipitation station Ptuj
Soil	
Digital soil map, the number and depth of horizons, rooting depth, soil-bulk density, field capacity, wilting point, saturated hydraulic conductivity, soil colour, organic matter, texture (clay, silt, sand), erosivity soil—MUSLE	Ministry of agriculture, forestry and food (MKGP), field measurements, pedotransfer functions, laboratory measurements, calculations
Land-use management practices	
number of rotation years, crop type, time of sowing, planting and harvesting, time of fertilisation, type of fertiliser, the method and depth of applications, time of tillage, type of machines and tillage depth, rooting depth, height of plants, plant nutrient content, the biomass development, the potential yield, harvest index, LAI	Farmers, Chamber of Agriculture and Forestry of Slovenia (KGZS)—Unit Maribor, SWAT database
Terrain, land use	
Digital elevation model (DEM), land-use map, land-use classification	Ministry of agriculture, forestry and food (MKGP), The Surveying and Mapping Authority of the Republic of Slovenia (GURS)

Table 1. Model input database.

Scenario/location		**Crops in rotation**	**Elemental fertiliser (kgN/ha per year)**		
Base	Dobrovce	ca-tn/on/po/pe/po	120-0/27/100(organic)/75/174		
	Maribor	or-cl/co/ww-cl/co/wb-cl/co/ww	150-0/111/109-0/111/109-0/111/109		
	Ptuj	ww-bw/ww-cl/fp/ww-cl/cas	161-0/161-0/27/161-0/122		
Scenarios of adjusted agricultural practices			**Average fertiliser application (kg elemental N/ha per year)**		
			Dobrovce	**Maribor**	**Ptuj**
Base scenarios			127	135	130
A.	1	Medium-stocked soil for a high yield	–	171	152
	2	Medium-stocked soil for average yield	–	114	90
	3	Medium-stocked soil for a low yield	–	69	60
	4	Without livestock manure	103	–	–
	5	With livestock manure	–	180	150

Scenarios of adjusted agricultural practices			Average fertiliser application (kg elemental N/ha per year)		
			Dobrovce	Maribor	Ptuj
B.	6	without corn (and with soya)	–	76	–
	11	Integrated vegetable crop rotation 1	162	–	–
	12	Integrated vegetable crop rotation 2	213	–	–
	13	Integrated vegetable crop rotation 3	122	–	–
C.	7	Grassland—four-cut-BMP			182
	8	Grassland—three-cut-BMP			122
	9	Grassland—two-cut-BMP			47
	10	Grassland—one-cut-BMP			0
D.	14	Average cattle rotation			183
	15	Average pig rotation			170
	16	Average arable crop rotation			160
	17	Average permanent grassland			434
E.	18	Cattle rotation no livestock manure			147
	19	Cattle rotation no maize (with soya)			87
	20	Pig rotation no livestock manure			153
	21	Pig rotation no maize (with soya)			37
F.	22	Organic vegetable rotation			47
	23	Organic field crop rotation			60
G.	24	WPZ I—cattle			134
	25	WPZ II/WPZ III—cattle			177
	26	WPZ I—pig			144
	27	WPZ II/WPZ III—pig			170
	28	WPZ I—arable crop			142
	29	WPZ II/WPZ III—arable crop			160
	30	WPZ I—permanent grassland			191
	31	WPZ II/WPZ II—permanent grassland			415

Key: ca, cabbage; tn, turnip; on, onion; po, potatoes; pe, peppers; or, oilseed rape; cl, clover; co, corn; ww, winter wheat; wb, winter barley; bw, buckwheat; fp, field peas; cas, cabbage for seeds; BMP, best management practices according to guidelines for the scientifically grounded fertilisation [20]; WPZ, water protection zone; I, narrowest WPZ zone (stricter regime); II, narrow WPZ zone; III, wider WPZ zone.

Table 2. Agricultural land management scenarios.

In the first set (A.) are three scenarios for Maribor and Ptuj, where fertilisation of basic rotation changed depending on the quantity of yield (A. Scenarios 1–3) and one with organic fertiliser (cattle slurry) introduced in to rotation with strictly mineral fertilisers (5). For the location of Dobrovce, organic fertilisers are replaced by mineral (Scenario 4). In the second set (B.) is one scenario for the Maribor rotation, where soya replaced corn (Scenario 6) and three scenarios for Dobrovce with alternative vegetable rotations, with one legume as a main crop and winter greening (Scenarios 11–13). In the third set (C.) are four scenarios including four-cut, three-cut, two-cut and extensive one-cut (no fertilisers) grassland (Scenarios 7–10). In the fourth set (D.) are average cattle/dairy, pig, arable rotation and for the research area typical permanent grassland management (Scenarios 14–17). In the fifth set (E.) are two variations of modified cattle/dairy and pig rotations, one without organic fertilisers (Scenarios 18 and 20) and the other with soya replacing corn (Scenarios 19 and 21). In the sixth set (F.) are average horticultural (vegetable) and organic rotation (Scenarios 22 and 23). In the seventh set (G.) are average cattle/dairy, pig, arable rotation and permanent grassland management with included fertilisation rates required in WPA (Scenarios 24–31). The results of the alternative scenarios were compared with the baseline scenarios (business as usual).

2.5. Calibration process and data analysis

Model-testing procedures were carried out on daily level for all three research locations. Simulation period was split on warm-up, calibration and validation period. Warm-up period was excluded from comparison due to model setting up the water and nutrient cycle balance. Model calibration and validation were performed with comparison of measured and simulated soil water content data at research location. These were the only available data for testing whether water cycle in the soil profile is functioning adequately. Calibration and validation periods are as follows: Ptuj December 2011-March 2012 and April-May 2012, respectively, Maribor November 2011 and December 2011, respectively, and Dobrovce July-August 2011 and August to September, respectively. Parameters for automated and manual calibration were selected based on sensitivity analysis tool in ArcSWAT [21] and expert knowledge of the research area. Ten parameters were selected, including CN2, ESCO, GW_REVAP, REVAPMN, CANMX, FFBC, SOIL_BD, SOL_AWC, SOL_K and SOL_ALB. Sensitivity analysis, calibration and validation procedures for these three locations are in-depth explained in previous publication [22].

Model performance was determined with comparison of measured and simulated time series via graphical or visual comparisons and objective function called percent bias (*PBIAS*) [23]. It measures the average tendency (higher or lower) of simulated values to be different than observed ones. Negative *PBIAS* values mean excess water in simulation and positive values mean lack of water in simulation. Visual comparison was used due to important share of rocks in the soil which impact probes measurements of soil water content at the research locations. Simulated values were acceptable if they fall within minimum- and maximum-measured values.

To obtain useful and informative results, simulation of base and alternative management scenarios was run for a period of 12 years (2000–2011) for all three locations. The first three warm-up years (2000–2002) were excluded from result analysis. Results were analysed on the basis of hydrological response unit (HRU) obtained from SWAT OUTPUT.HRU data file on daily, monthly and annual level for the period of 9 years (2003–2011). Results include analysis of nitrogen balance for base and alternative agricultural land management scenarios. The main model output variables for nitrogen balance are nitrogen fertiliser applied (N_APP), N added to soil profile by rain (NRAIN), N fixation (NFIX), fresh organic to mineral N (F-MN), active organic to mineral N (A-MN), active organic to stable organic N (A-SN), denitrification (DNIT), plant uptake (NUP) and N leached from the soil profile (NO3L). All variables are expressed as kilograms of N per hectare (kg N ha^{-1}).

Wilcoxon rank-sum non-parametric test was used for the detection of significant differences between base and alternative scenarios. We compared the average annual values of two independent samples of equal size ($n1 = n2 = 9$). The results of alternative agricultural land management scenarios are statistically significantly different from base situation, if the Wilcoxon test value exceeds 62 at $\alpha = 0.05$ or 70 at $\alpha = 0.20$.

3. Results and discussion

3.1. Calibration

Water that enters the soil profile can move by several possible routes. Soil water can be removed from the soil by plant uptake or evaporation (evapotranspiration) or may percolate vertically through the soil horizons below the bottom of the soil profile, or laterally as surface runoff and interflow. The majority of the soil water is removed through evapotranspiration. Correct preparation of soil parameters is verified by soil water content and plant growth rate results.

PBIAS statistical test shows that simulated SWC at all three research locations is within a reasonable range and in good agreement with measured values (**Table 3** and **Figure 3**). The results fall within the very good category [23]. From **Figure 3**, SWC is well seen declining during prolonged periods of drought and the rise of SWC after precipitation events.

Parameter	Default	Range	Ptuj		Maribor		Dobrovce	
			SAR	FCV	SAR	FCV	SAR	FCV
Cn2	D*	±25%	4	+5	3	+10	6	+25
Esco	0.95	0.5–1	3	0.87	5	0.85	4	0.80
Gw_Revap	0.02	0.02–0.20	10	0.10	9	0.09	10	0.06
Revapmn	750	0–1000	8	760	10	634	9	530
Canmx[a]	0	0–20	7	2.3	4	2.5	5	2
FFBC	0	0–1	6	0.93	8	0.94	7	0.95
Sol_Bd	D*	±25%	5	+2	6	+10	3	+21
Sol_Awc	D*	±25%	1	+8	1	+12	1	+18
Sol_K	D*	±25%	2	0	2	−5	2	−10
Sol_Alb	D*	±25%	9	+1	7	−2	8	−3
Calibration	0 = optimal		−7.59		4.33		9.61	
Validation	+ values (%) = underestimate – values (%) = overestimate		4.76		−8.73		−7.64	

SAR, Sensitivity Analysis Rank; FCV, Final Calibrated Value; [a], forest, permanent crops, grassland + arable; D*, depends on soil type, land use and modeller set-up; Cn2, SCS runoff curve number for moisture condition II; Esco, soil evaporation compensation factor; Gw_Revap, groundwater “revap” coefficient; Revapmn, threshold depth of water in the shallow aquifer for “revap” to occur; Canmx, maximum canopy index; FFBC, Initial soil water storage expressed as a fraction of field capacity water content; Sol_Bd, moist bulk density; Sol_Awc, available water capacity of the soil layer; Sol_K, saturated hydraulic conductivity; Sol_Alb, moist soil albedo.

Table 3. Sensitivity analysis and daily time-step soil water content (SW) calibration and validation performance statistics for the Ptuj, Maribor and Dobrovce research locations.

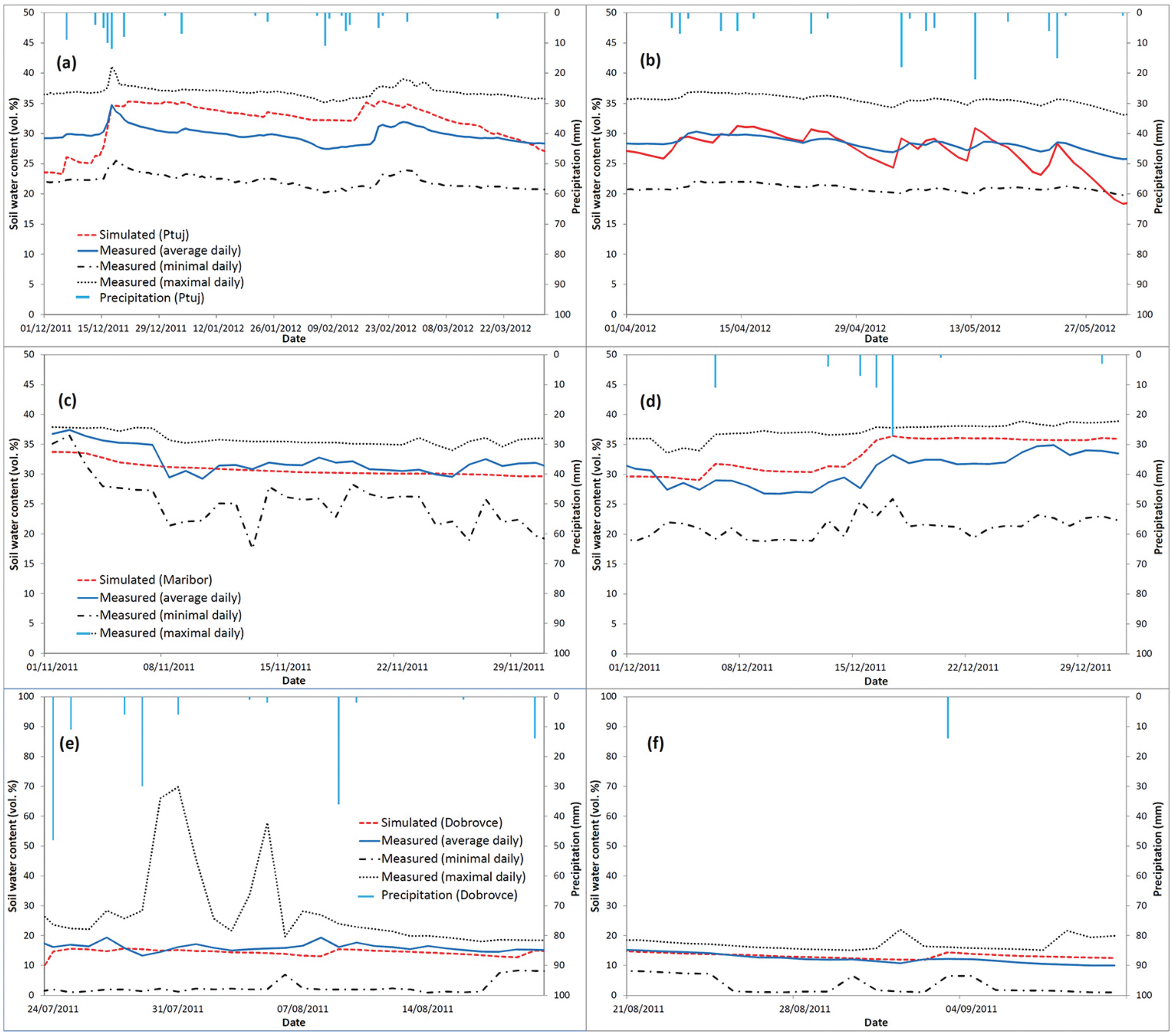

Figure 3. Visual comparison of soil water content calibration and validation at various periods for Ptuj (a and b), Maribor (c and d) and Dobrovce (e and f) research locations.

Based on the results of PBIAS test and visual comparison of the simulated and measured values of SWC, we can argue that the SWAT model is well enough calibrated to be suitable for carrying out simulations of SWC and nitrate leaching from the soil profile. It is necessary to be cautious in interpreting the results because the period of SWC measurement was short and calibration and validation periods do not cover all possible weather and land management events.

3.2. Nitrogen balance

3.2.1. Base scenarios

The base scenarios show a high average annual variability in nitrogen leaching from the soil profile (**Table 4**). Comparison of base rotations from practice between themselves showed that production technologies with higher N intake have negative impact on the balance of N causing higher leaching. Results of the model show that the same technology (rotation) is not suitable for all soil types (**Table 4**). As shown in the example from Maribor with rotation suitable for relatively deep soils, can this rotation cause from two to three times greater N leaching if used on shallow soils of Dobrovce. Measures for controlling nitrogen fertilisers' application are not defined on the basis of soil properties, according to the current regulation for the WPA of the Drava Plain. Areas of regimes I, II and III have been determined in order to prevent microbiological contamination of drinking water wells. The results show that for the purpose of preventing the negative N balance, the WPA zones and regime should be designed according to the soil properties. This is even more important because Water Framework Directive obliges member states to improve the water quality status of the entire aquifer and not only that part in the vicinity of wells.

Research location	**Nitrogen leached from the soil profile(kg N ha^{-1} year)**											
	Rotation											
	Ptuj				**Maribor**				**Dobrovce**			
↓Soil↓	**avg**	**StDv**	**min**	**max**	**avg**	**StDv**	**min**	**max**	**avg**	**StDv**	**min**	**max**
Ptuj	51.3	43.4	1.2	109.1	32.4	17.5	0.7	56.2	71.4	50.1	13.2	152.8
Maribor	71.1	76.0	4.0	180.9	59.9	27.5	22.2	103.9	85.5	49.7	8.8	159.0
Dobrovce	91.5	105.5	6.0	267.6	97.5	62.3	12.3	208.4	91.1	56.1	4.9	188.3

avg, average; StDv, standard deviation; min, minimal; max, maximal; shaded cells, results of rotation management and soils type from the same research location.

Table 4. Average annual nitrogen leaching (kg N ha^{-1}) from the soil profile (model SWAT) for all three base rotations of the three research locations Ptuj (P), Maribor (M) and Dobrovce (D) for the research period 2003–2011.

3.2.2. Agricultural land management scenarios

Current base fertilisation rates at the Maribor research locations are higher than the rates for the average yield are (Scenario 2) (**Table 5** and **Figure 4**) [20]. On replacing part of the organic fertiliser with the mineral (Scenarios 4 and 5) and vice versa, organic animal fertilisers were shown to cause higher excess N in the balance (**Table 5** and **Figure 4**). It is necessary to invest in the education of producers and to strengthen the control of fertilisation plans. Analysis of soil properties is required to check how much fertiliser can soil hold and how much can be applied at given soil conditions to achieve optimum yields and to avoid excessive N leaching.

Comparison of Dobrovce base rotation similar to organic and conventional integrated horticultural rotation (Scenarios 11–13) with fertilising norms for optimal production of vegetables has shown that outdoor horticultural production in Dobrovce shallow and sandy soils with gravel parent material is probably not the optimal use of agricultural land from the water protection point of view (**Table 5** and **Figure 4**). Much better results for N leaching were archived by organic field crop rotation (Scenario 23) with N-leaching yields lower from base rotations (**Figure 5**). Organic farming in WPZ is, beside water quality, also in pursuit of other goals, such as increased biodiversity, animal welfare and ban of synthetic plant protection products.

Nitrogen (kg N ha^{-1} per year)

	Scenario						
	Base*	**1**	**2**	**3**	**4**	**5**	**6**
Applied	130:135:127	170	112	67	101	157	88
P – leached	51	50	43	41		66	
M – leached	60	85	44	24		83	24
D – leached	91				87		

	Base	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Applied	130:135:127	172	122	43	0	144	220	144
P – leached	51	1	2	5	4			
M – leached	60	5	8	9	9			
D – leached	91	26	26	18	14	68	146	89

	Base	**Cattle**			**Pig**			**Grassland**
		14	**18**	**19**	**15**	**20**	**21**	**17**
Applied	130:135:127	178	146	39	180	152	40	433
P – leached	51	38	33	38	56	53	50	12
M – leached	60	62	53	58	79	74	69	21
D – leached	91	96	79	76	110	101	88	74

	Base	**16**	**22**	**23**
Applied	130:135:127	166	47	13
P – leached	51	52	65	47
M – leached	60	63	79	59
D – leached	91	79	91	69

	Cattle			**Pig**			**Arable**			**Grassland**		
	14	**24**	**25**	**15**	**26**	**27**	**16**	**28**	**29**	**17**	**30**	**31**
Applied	178	139	173	180	125	180	166	127	166	433	190	415
P – leached	38	5	37	56	6	56	52	38	52	12	1	8
M – leached	62	16	61	79	19	79	63	47	63	21	4	19
D – leached	96	44	94	110	41	110	79	58	79	74	21	68

*Applied amount of nitrogen fertilisers: Ptuj (P) – 130 kg N ha^{-1}; Maribor (M) – 135 kg N ha^{-1}; Dobrovce (D) – 127 kg N ha^{-1}. Leached – nitrogen leached past the bottom of the soil profile
1 – fertilising for large yield; 2 – fertilising for average yield ; 3 – fertilising for small yield; 4 – base rotation/no organic fertilisers; 5 – base rotation/only organic fertilisers: 6 – soya replaces corn; 7 – grass/4 cuts; 8 – grass/3cuts; 9 – grass/1 cut only ; 10 – grass/1 cut no fertilisers; 14 –cattle/dairy cows rotation; 15 – pigs rotations; 16 –arable rotation; 17 – average grassland; 18 – cattle rotation/no organic fertilisers; 19 – cattle rotation/soya replaces corn; 20 – pigs rotations/ no organic fertilisers; 21 – pig rotation/soya replaces corn; 22 – organic vegetable rotation; 23 – organic field crops rotation; 24 – 14 with WPZ I regulations; 25 – 14 with WPZ II and III regulations; 26 – 15 with WPZ I regulations; 27 – 15 with WPZ II and III regulations; 28 – 16 with WPZ I regulations, 29 – 16 with WPZ II and III regulations; 30 – 17 with WPZ I regulations; 31 – 17 with WPZ II and III regulations

Table 5. Comparison of average annual applied fertiliser (mineral and organic) and nitrogen leaching from soil profile (kg N ha^{-1}) between base and alternative scenarios for the research locations Ptuj (P), Maribor (M) and Dobrovce (D) in the research periods 2003–2011.

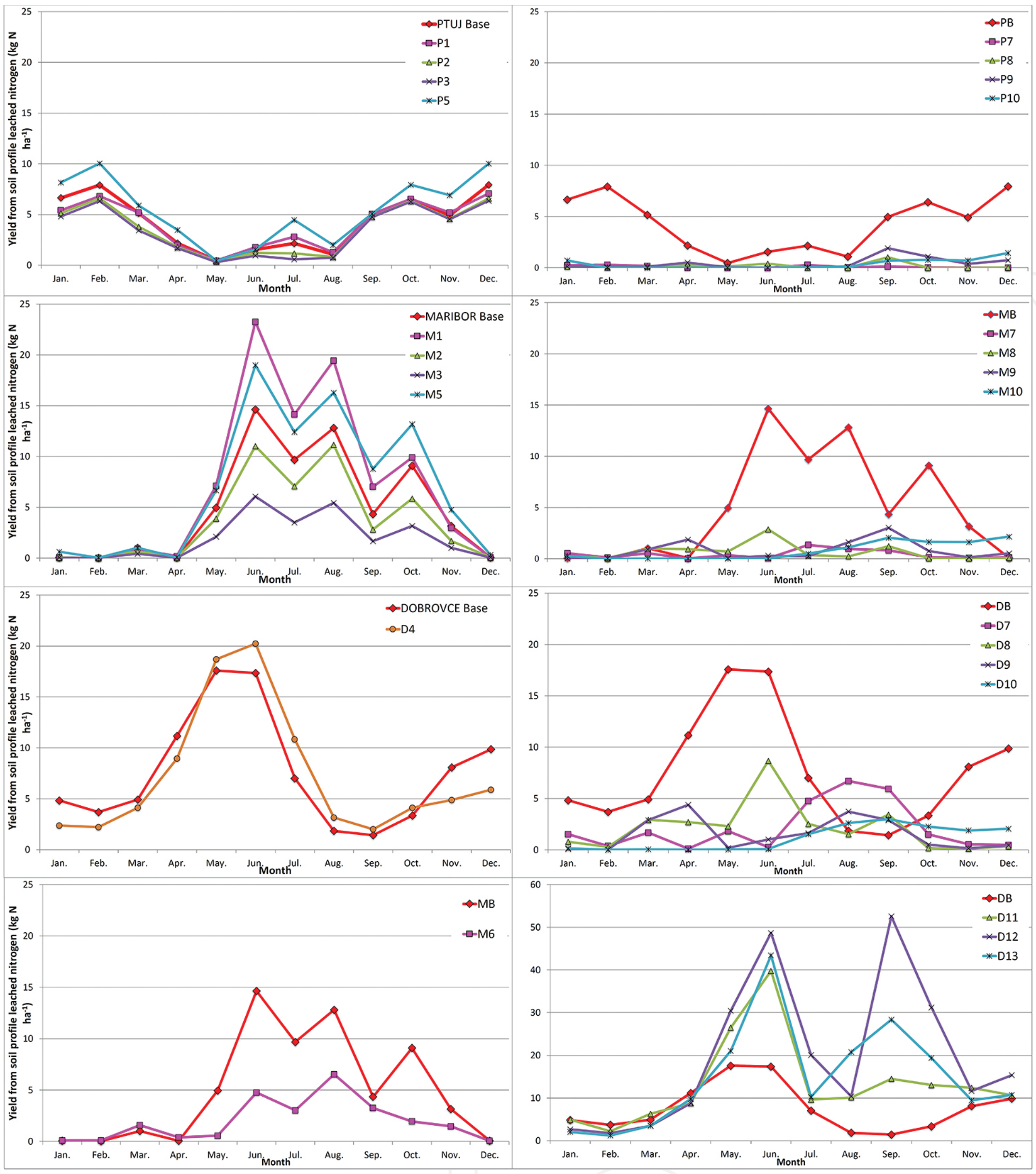

Figure 4. Comparison in simulated average monthly nitrogen leaching (kg ha^{-1}) between base and alternative agricultural management (Scenarios 1–13) for research locations Ptuj (P), Maribor (M) and Dobrovce (D) in the period between 2003 and 2011 (Scenarios key in **Tables 2** and **5**).

Grassland land use and management proved to be an extremely beneficial for soil N balance (Scenarios 7–10). Interestingly, the four-cut intensive grassland without excessive use of animal manure contributes to a drastic reduction in N leaching (**Table 5** and **Figure 4**). Through the process of modelling permanent pasture with average production technology, it was found that farmers on average spread slurry three times per year (in some cases even more) in addition to that they spread mineral fertilisers (Scenario 17). This practice causes on shallow soils such as in Dobrovce heavy losses of N, which are comparable to those in the arable fields. This shows that regulation on banning the organic fertilisers especially liquid animal manure (slurry) in the WPA I is appropriate and eligible measure. Awareness of this is even more important as currently a major part of slurry is applied on arable land as part of corn field fertilisation and not on the grassland areas.

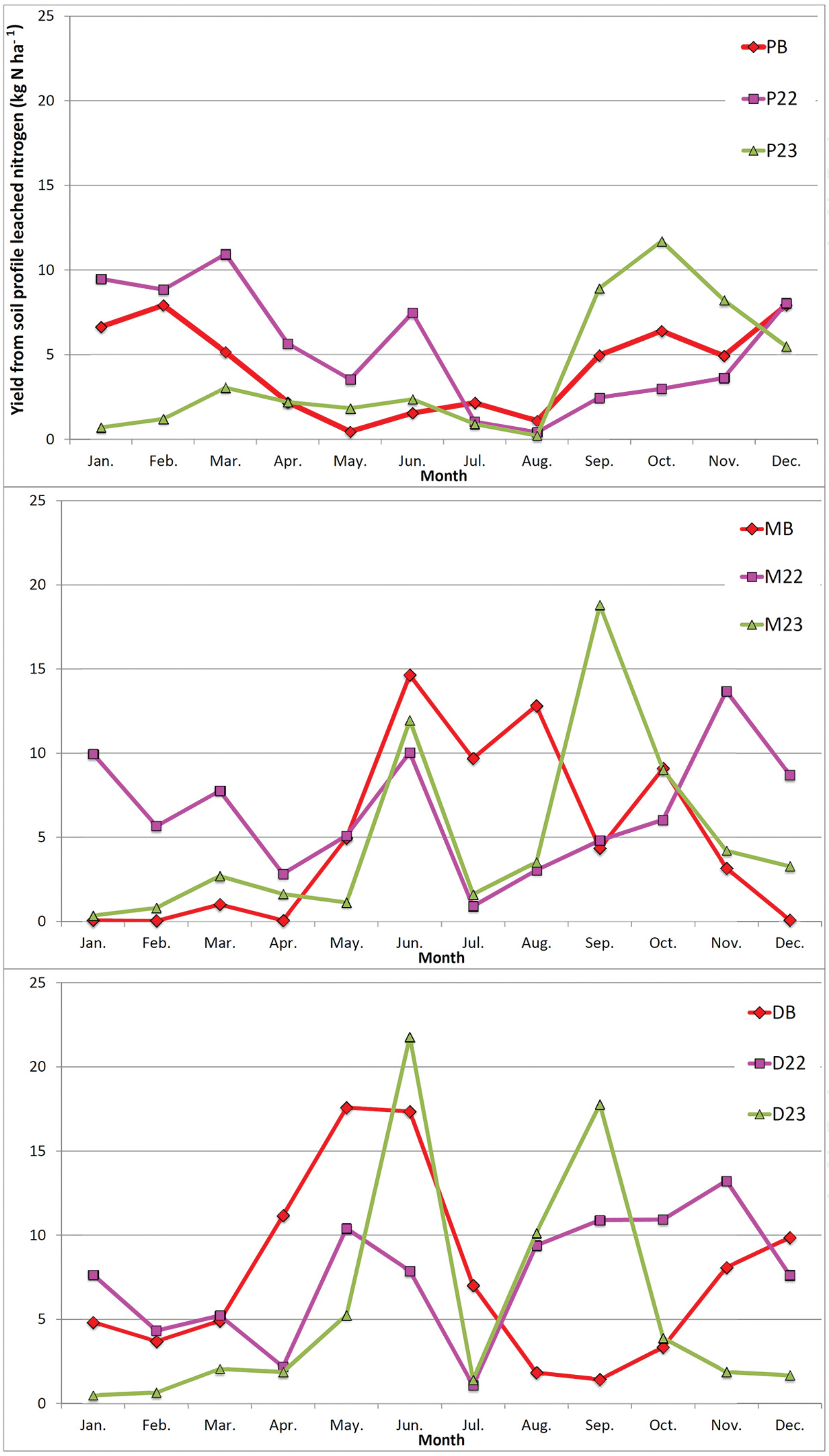

Figure 5. Comparison in simulated average monthly nitrogen leaching (kg ha^{-1}) between base and alternative organic vegetable (22) and field crops (23) agricultural management scenarios for research locations Ptuj (P), Maribor (M) and Dobrovce (D) in the period between 2003 and 2011 (Scenarios key in **Tables 2** and **5**).

One of the options for the reduction in N leaching could be expanding ban on organic fertilisers with exclusion of cattle and pig slurry from the practice also on WPZ II and III. This could lead in farmers' revolt and dramatic socio-economic changes on short term and restructuring the farm production on long term. This was investigated in Scenarios 18 (cattle farms) and 20 (pig farms) (**Table 5** and **Figure 6**). However, results did not show dramatic changes in the reduction of N leaching as organic fertilisers were substituted with mineral ones. In addition to that, a new problem would emerge as surplus N would need to be properly treated. The same was simulated when we replaced corn with soya beans (Scenarios 19 and 21) (**Table 5** and **Figure 6**). Although applied amount of fertilisers (organic and mineral) were reduced in the rotation, the nitrogen from symbiotic fixation was still released in the environmental and subject of mineralisation. On annual level, legumes fixate 150–250 kg N per hectare [20].

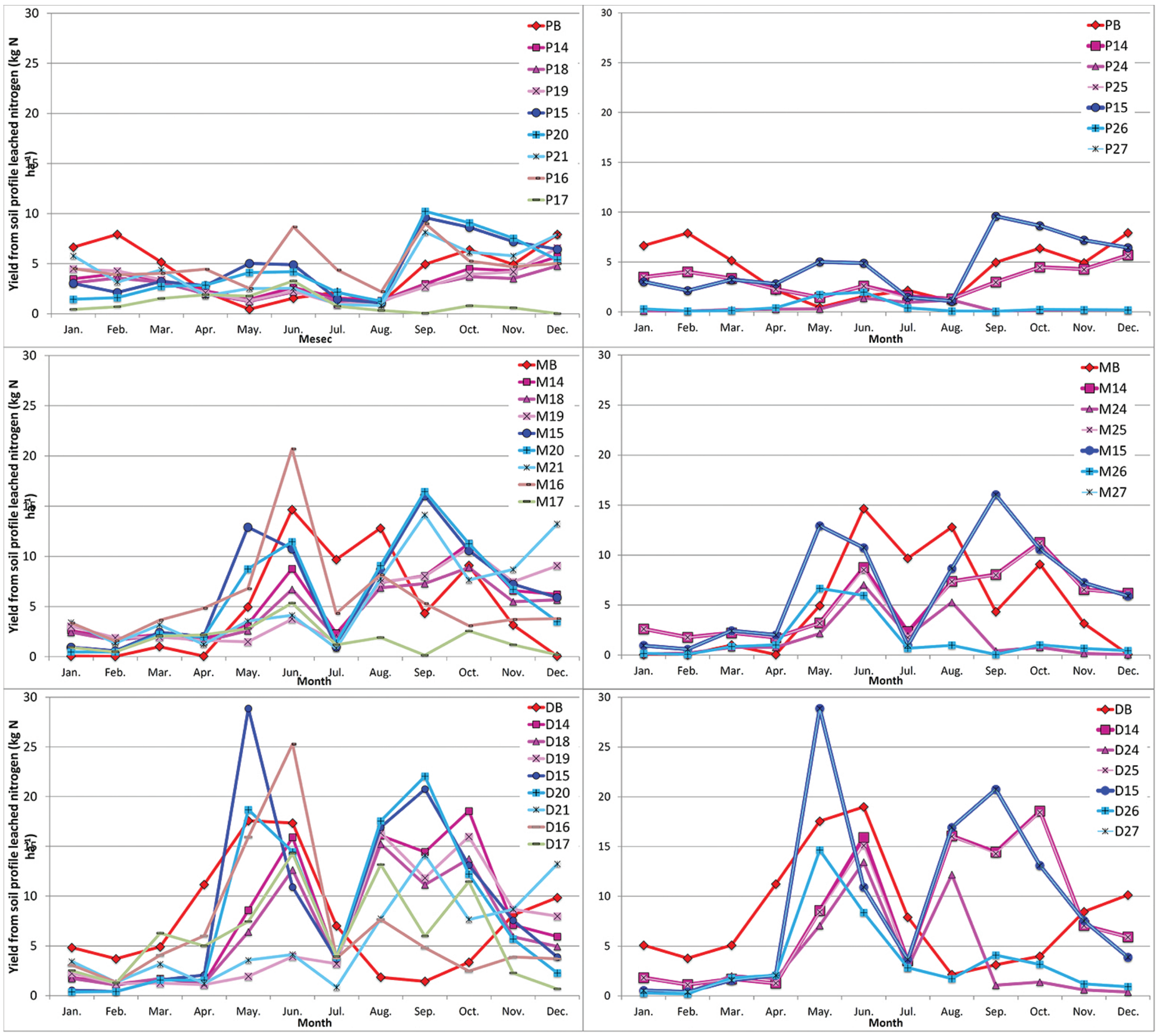

Figure 6. Comparison in simulated average monthly nitrogen leaching (kg ha^{-1}) between base and alternative agricultural management (Scenarios 14–21 and 24–27) for research locations Ptuj (P), Maribor (M) and Dobrovce (D) in the period between 2003 and 2011 (Scenarios key in **Tables 2** and **5**).

Rotations adapted to WPA zone I regime (Scenarios 24, 26, 28 and 30) reduce losses of N while the development of biomass and yield is not affected (**Table 5** and **Figure 6**). The main reason for this is the ban on the use of liquid animal manure and strictly controlled application of mineral N during the growing season. The effects of the measures are not equally effective in all areas. Efficiency is strongly related to the soil properties. This type of scenarios is a very attractive option for regulators (State), with few very relevant side effects on agriculture, for which the regulator will have to provide answers and solutions. The first effect is the surplus of livestock manure, the second is the cost for mineral fertilisers and the third, the control of measures implementation if the zone I regime would be extended over greater area.

Measures of WPA zone II and III regime have minimal effects on arable land which means that farmers can practically farm without any serious limitations (Scenarios 25, 27, 29 and 31) (**Table 5** and **Figure 6**). It is also possible that farmers adapted production technologies according to the requirements of the regulations for water bodies in the area of the Drava Plain. Results show stable N balance, which is similar to the average situation outside of WPA. Given the fact that WPA zone I regime covers only a small part of the Drava Plain (2.3%), the effect of these measures on the quality of groundwater is minimal (**Figure 2**). In addition to that in the large central part of the Drava Plain with shallow soils and under the WPA zone II and zone III regimes, a normal agricultural practice is taking place. The results of the SWAT model show that it is possible to reduce the quantity of the applied and thus also leached N, without any important effect on biomass or yield production.

4. Conclusions

The results show that the soil-type properties have the greatest impact on the nitrogen balance, with the same technology of production and weather conditions. Comparison of base- and adapted-farming practices with each other showed that the same agricultural practice is not suitable for all soil types. According to current regulation of WPA measures, restricting the intake of nitrogen fertilisers is not defined in terms of soil type. The results show that for the purpose of preventing the negative nitrogen balance, it is necessary to design WPZ regimes according to the soil types.

It is also important to increase control over the implementation of the measures prescribed by the regulation for the aquifer water bodies in the Drava Plain and the Rural Development Programme of the Republic of Slovenia, especially through cross-compliance under EU Common Agricultural Policy.

The comparison also showed that in locations Ptuj and Maribor fertilise more than is recommended for the average yield, according to national guidelines. Replacing part of organic fertilisers for the mineral and vice versa showed that organic fertilisers cause excess nitrogen that is available for leaching. For each type of soil, it is necessary to check the nutrient's holding capacity. It is necessary to ensure that we know what quantity of nutrients is required at a given soil properties to achieve optimal or even maximal yields for preventing leaching of excessive nitrogen. We recommend more efforts in introducing crops that require less inputs of nitrogen for growth (e.g. soya beans), and also in raising awareness of the need to reduce the fertilisation rates by their number and quantity.

In the organic farming, it is necessary to introduce fertilisation management based on the soil properties. Results show that outdoor vegetables production on shallow and sandy soil is not optimal agricultural practice from the drinking water protection perspective and is in certain situations even comparable to conventional production.

Grassland use is a good alternative to arable. Different methods of farming practices on grassland land use, also intensive ones, have according to national guidelines proved to be extremely beneficial from the nitrogen balance perspective. However, it is necessary, with the help of professional services, to clearly specify the amount and type of N fertiliser rate, which has to be dependent on the soil type and properties.

Agricultural practices adjusted to the stricter WPA I regime considerably reduce the loss of nitrogen from the soil and do not impact the yield which remains stable. The current state represents a good balance between the benefits for good-quality status of drinking water and economic situation of agricultural holdings.

On the other side, we have less strict WPA II and III regime minimal effects on N leaching from arable land which could mean that producers cultivate land without any serious restriction or they adjusted agricultural practices according to the requirements of the WPA regulations.

Measures of WPZ II and III regimes are virtually no different than the average conventional production practices outside the WPZ. Since these two areas occupy the vast majority of WPZ and because we have, in regard to the commitments adopted from Water Framework Directive, achieved good-quality status of groundwater throughout the aquifer, it is necessary to change the current approach of forming WPZ regimes. The current system for determining the WPZ regimes is positioned so that it fully ignores the characteristics of the soil.

Assessing the impact of the scenarios was done with the knowledge of the uncertainties of the model. Uncertainties were associated with the establishment of production technologies, rotations, dates of harvest, grass-cut dates, dates of mechanical tasks and dates of fertilisers' application. All these data are just an average estimate, as each farmer has their own time schedule and technology of production, which varies according to the type of crops, crop and livestock species, intensity of agricultural production and changing weather conditions. Additional uncertainty originates in soil maps, firstly because of spatial resolution, and secondly because the model requires information on wilting point, field capacity and hydraulic conductivity which are not part of standard soil map.

According to the results, we suggest that future measures or WPA regimes are formed according to the type and properties of the soil and not only on the groundwater flow direction and proximity of drinking water wells. Constant communication with the land owners and cultivators in the area and their regular education is vital for successful transformation of the area. We recommend more efforts of professional agricultural services in the introduction of agricultural crops that require less inputs of nitrogen for growth such as soya and in raising awareness on the need for reducing fertiliser norms by its number and quantity. Grassland is a good alternative to the arable use, but help of professional services is needed to specify the type of fertiliser N and norms depending on the soil type and properties.

The results of this study are a product of a one-computer model for catchment modelling (SWAT) and understanding of one catchment modeller. Therefore, the final assessment of the scenarios should never be regarded as definitive, but only as a possible response of the system to changes. Model results and their interpretation by the modeller must lead to constructive discussions with the aim of achieving and maintaining good water quality in the research area of the Drava Plain, which is also the aim of the Water Framework Directive.

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