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Spatial variation of crop rotations and their impacts on provisioning ecosystem services on the river Drava alluvial plain

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ABSTRACT

Fertile river plains, like the study area of the river Drava alluvial plain in Slovenia, have ideal conditions for agricultural production. At the same time the question arises of how farming practices (food provisioning) on shallow alluvial soils affect the quality status of water bodies and clean fresh water provisioning. In the presented study, we used extensive monitoring and the Soil and Water Assessment Tool (SWAT) to investigate the influence of different combinations of soil types and crop management on environmental processes (nitrogen (N) leaching and plant growth) at three study sites (Ptuj, Maribor and Dobrovce). The results show that 2/3 of leached N load from the Ptuj, Maribor and Dobrovce study sites can be expected in intervals of 51.3 ± 43.4 kg N ha^{-1}, 59.9 ± 27.5 kg N ha^{-1} and 97.5 ± 51.8 kg N ha^{-1} $year^{-1}$, respectively. The average maximum leached N load from the Ptuj, Maribor and Dobrovce fields can reach 109.1 kg TN ha^{-1}, 103.9 kg N ha^{-1} and 194.4 kg N ha^{-1} $year^{-1}$, respectively. The results indicate that it would be, for the purpose of balancing the effects of current practices on ecosystem services, necessary to arrange and design water protection zones (WPZ) according to individual soil type properties, and assign appropriate agricultural production technologies to them to minimise N leaching.

1. Introduction

The impacts of agriculture on the ecosystem depend to a large degree on natural conditions such as soil or climate. Fertile river plains, like the study area of the river Drava alluvial plain in Slovenia, have ideal conditions for agricultural production. If reliable water sources is available for irrigation, namely large amounts of rainfall and melting snow stock in the mountains, major problems with food provisioning in such areas should be eliminated (Li et al., 2011; Jensen et al., 2014). At the same time the question arises of how farming practices (food provisioning) on shallow alluvial soils affect the quality status of water bodies (rivers, groundwater aquifer) and fresh water provisioning.

Natural resources provide many ecosystem services which humans, over thousands of years, learned how to use, exploit and often also misuse. The United Nations Environmental Programme (UNEP) defines ecosystem services as the benefits

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people obtain from the ecosystem. It classifies ecosystem services into (1) provisioning services, i.e., the products obtained from ecosystems (e.g. fresh water and food), (2) regulating services, i.e., the benefits obtained from the regulation of ecosystem processes (e.g. climate and flood/drought regulation, water purification), (3) cultural services, i.e., non-material benefits obtained from ecosystems (e.g. aesthetic, educational, recreational), and into (4) supporting services necessary for the production of all other ecosystem services (e.g. soil formation, nutrient cycling, water cycling) (UNEP, 2005). The interventions of humans through agricultural technological development has increased food provisioning services, but impairs other services such as fresh water provisioning or water regulation and purification (Beringer et al., 2011; Curmi et al., 2013; Rulli et al., 2013).

Agriculture as a continuum of the ecosystem is crucial for food security, given the current rate of population growth (9 billion by 2050). Therefore, better collaboration between the water, food and land planning sectors are required. Provisioning an adequate amount of food requires stable production, better policies and optimal use of natural resources. Agriculture management can also be the source of potential 'disservices' like negative nutrient balance, loss of habitat biodiversity, erosion, pesticide poisoning (Power, 2010). These are usually more connected to the market policy and distribution of food, rather than the capability of growing or producing enough food. The negative impacts of agriculture can be largely ameliorated with appropriate management. In this manner, countries with higher environmental awareness and environmental problems recognise that various efforts are required in managing agroecosystems, like crop rotation changes, production technique changes, fertiliser use and agri-environmental measures, which not only improve the state of the water and its provisioning, but also positively influence other ecosystem services and the ecosystem as a whole. The Water Framework Directive (2000/60/EC) and its daughter directives such as the Nitrate Directive (91/676/EEC) are good examples that countries can work together to reach a win–win situation between food production and water quality. However, further efforts are required to meet the full potential of those directives. Small but gradual attempts in balancing food production with the needs of ecosystems are also seen in the European Union Common Agricultural Policy (CAP), which is adapting different agri-environmental measures as cross-compliance in subsidy payment schemes. This is mostly seen in nitrogen balances at the field level, which are gradually in decline while crop production rises. While currently the majority of on-farm management practices and measures are concentrated on regulating the supply and quality of blue water (surface water and groundwater), green water (soil moisture) availability measures (modified tillage regime, mulching, rain-harvesting) and quality measures (cover cropping, legume N fixation, modified fertilisation rates, diversifying rotations) gain their importance. They play crucial roles in reducing evaporation, storage and distribution of water in soils and consequently nutrient leaching to water bodies (Glavan et al., 2013a; Power, 2010; Drinkwater and Snapp, 2007). As approximately 20% of nitrogen fertilisers in agriculture are lost to aquatic ecosystems, increased nitrate levels in drinking water bodies are of serious concern to water managers, policy makers and the research community (Galloway et al., 2004; Bouwman et al., 2009). It is also estimated that agriculture contributes around 55% of the nitrogen entering European Seas (Bouraoui and Grizzetti, 2014).

Researchers all over the world are investigating the importance of soil properties and land use interactions in nutrient management, and the effectiveness of the measures to address diffuse pollution of water bodies from agriculture (Nangia et al., 2008; Snapp et al., 2010; Zupanc et al., 2011; Jégo et al., 2012; Mueller-Warrant et al., 2012; Glendell et al., 2014). They use different methods like on-site experiments, sampling and monitoring, or computer modelling (Glavan et al., 2013b). A successful example of such models is the Soil and Water Assessment Tool (SWAT) which is capable of predicting the impacts of alternative management practices on water quality (Gassman et al., 2007; Ullrich and Volk, 2010). Eco-hydrological models are regularly used in the research community for assessing the impacts of management practices and soil properties on water quality and plant growth. The impact of soil properties and their proper representation due to high spatial heterogeneity is gaining the importance, which is caused by the improvement of soil sampling and laboratory analysis procedures, use of pedotransfer functions and upgrading model algorithms (Deliberty and Legates, 2003; Mapfumo et al., 2004; Bossa et al., 2012; Williams et al., 2012; Boluwade and Madramootoo, 2013). Usually models like SWAT are reconceptualised and improved to achieve better representation at the HRU level (Post et al., 2007; Easton et al., 2008; White and Arnold, 2009; Arnold et al., 2010; Fu et al., 2014; Rathjens et al., 2014).

Despite growing efforts and interest in integrated catchment management, induced by environmental regulations like the EU Water Framework Directive; data/information on the spatial variability of crucial soil profile parameters and characteristics for controlling N leaching are still scarce and incomplete. The main reason for data scarcity originates from, financial, labour and time constraints. Thus, this can lead to uncertainties in data representation and model output results influencing decision making (Volk, 2013). A quantitative review of ecosystem services studies by Seppelt et al. (2011) showed that more that 60% of all studies did not derive their presented results using observations and measurements, and that only one-third based their results on validated data. Due to Volk (2013), research needs of sound ecosystem services modelling are the provision of new knowledge on trade-offs, scenario analysis, transparency in the modelling approach, modularity and re-usability of existing model systems, and the incorporation of learning and model building in cooperation with stakeholders.

The main objective of this paper is to investigate the impact of different combinations of agricultural practices (crop rotation, fertilisers) and soil type characteristics on nitrogen leaching and plant growth, as they importantly impact provisioning ecosystem services like a clean fresh water supply and food supply. This will be demonstrated with the comparison of water balance, nitrogen balance and plant growth variables for three different crop rotations and soil types.