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Evaluation Of BMPs Scenarios For Minimizing Phosphorus And Sediments Transport In Sprinkler Irrigation System

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Abstract. *Simulation models are useful tools to quantify the effects of best management practices (BMPs). After SWAT (Soil and Water Assessment Tool) adaptation and calibration for intensive irrigated watershed, it has been used to evaluate the impact of several (BMPs) on water yield (WYLD), total suspended sediment (TSS), organic P (ORG_P), soluble P (SOL_P), and total P (TP) at the outlet of the Del Reguero stream watershed (Spain). Economic impacts of the BMPs on crop gross margin were also evaluated. In total, 6 individual scenarios and 14 combinations of various management practices including tillage (conservation and no-tillage), fertilizer (incorporated, recommended, and zero), and irrigation (adjusted to crop needs) were been tested. Results indicate that the best individuals BMPs (adjusted irrigation water use BMP) reduced WYLD to 31.4%, TSS loads 33.5%, and TP loads to 12.8%, in comparison of the initial conditions. When individual BMPs were combined, the percentage reductions of losses were increased. The BMPs combination between optimum irrigation application, conservation tillage and reduced P fertilizer dose was the best analysed one with a TP loads reduction about 22.6%. For corn and alfalfa, the best BMP scenario was the combination between conservation tillage and reduced P fertilizer dose, reaching an increase of gross margin by 309 € ha^{-1} and 188 € ha^{-1}, respectively. While for sunflower and barley, the best scenario was the combination between irrigation adjustment, conservation tillage and reduced P fertilizer dose. The increase of gross margin under this BMP was about 171 € ha^{-1} and 307 € ha^{-1}, respectively.*

Keywords. Best management practices, hydrological model, intensive irrigation, sprinkler irrigation, SWAT, total phosphorus, water quality.

Introduction

Intensive agricultural practices are identified to release significant amounts of nutrients, especially phosphorus (P) and sediment, to receiving water bodies (Monaghan et al., 2005). Excessive use of poultry litter and inorganic fertilizers is associated to higher P concentration in runoff (USEPA, 2000). Moreover, sediment loss from top soil containing relatively large amounts of nutrients can threaten water quality and decrease the productive capacity of the land (USEPA 2003). In the Ebro basin (north-east Spain), irrigated agriculture is a major component of the hydrologic balance and, therefore, may have a significant impact on the rivers quality in this basin. In a recent survey on water quality performed in several agricultural watersheds in the Ebro Valley (Spain), Skhiri and Dechmi (2011a) concluded that diffuse P pollution is of major significance and that trend will continue in the absence of corrective action.

To reduce nutrient losses from agricultural lands, many practices have been proposed, including on-farm nutrient management (rate added and method of application), tillage operations (conservation and no-tillage), and proper irrigation management (Sharpley et al., 2001). Therefore, simulation models are necessary to evaluate best management practices (BMPs) performance in reducing non-point source pollutants from agricultural watersheds and for making watershed management recommendations (Chaubey et al., 2010). A number of simulation models have been designed to evaluate best management practices. Among all these models, SWAT (Arnold et al., 1998) offers the greatest number of management alternatives for modelling agricultural watersheds (Arabi et al., 2007). SWAT has been used extensively in U.S. Department of Agriculture (USDA) sponsored research for assessment of best management practice (BMP) impacts on water quality including within the Conservation Effects Assessment Project (CEAP) as described by Duriancik et al. (2008) and Richardson et al. (2008). The model may also be used by the European Community to achieve the objectives of the Water Framework Directive.

The SWAT model was modified (named SWAT-IRRIG) to improve it performance in intensive irrigation systems, and evaluate it’s predictions in modeling water flow, sediments and phosphorus loads. The model validation was performed for a sprinkler irrigated watershed that represents a typical setup of the main irrigated area in the middle Ebro River Basin. The objectives of this study were: (i) to identify and test the effectiveness of several BMPs scenarios using SWAT-IRRIG; (ii) to evaluate their effects on water quality in terms of total water yield, sediments losses and phosphorus loads; and (iii) to evaluate the economic impact of BMPs on crops gross margin.

Material and methods

The study area includes the Del Reguero watershed (DRW) situated in the Alto Aragon Irrigation District, which represents the largest irrigated area in the Middle Ebro River Valley (Spain). The total watershed area is 18.65 km^2 and the main irrigated crops were corn, alfalfa, sunflower, and barley. The average phosphorus application rates were 50, 98, 23 and 50 kg ha^{-1} for alfalfa, corn, sunflower and barley, respectively. The fertilizers were applied with no limitation rates. Moreover, the majority of farmers do not incorporate fertilizers into the soil (below the top 10 mm of soil). The average water irrigation depth applied was 830, 898, 474 and 215 mm for respectively alfalfa, corn, sunflower and barley. A more detailed study area characterisation can be found in Skhiri and Dechmi (2011b and c).

The irrigation and fertilizer management data obtained for the famer’s operations provided the ability to accurately simulate the actual on-farm management practices (baseline conditions).

The BMPs considered in this study were grouped into three categories: (i) nutrient management (incorporated, recommended and reduced fertilizer); (ii) irrigation management; and (iii) tillage operations (conservation tillage and the no tillage).

Nutriments management scenarios

1. Phosphorus fertilizer incorporation (P_INC): The SWAT model assumes that surface runoff interacts with the 10 mm of the top soil (Neitsch et al., 2005). This means that before the BMP application, 7% of P fertilizer was applied into the top 10 mm. This percentage was replaced by 0% in the BMP applied. In SWAT, the incorporation of fertilizer is possible by means of the parameter FRT_SURFACE (fraction of fertilizer applied to top 10 mm of soil) in the "mgt." file (Neitsch et al., 2005).
2. Recommended P fertilizer dose (P_REC): For this BMP and each crop, P_REC was estimated considering the P harvested in crops (CFI, 1998; Fixen and Garcia, 2006, MAPA, 2007) and the average local crop yields gathered from field surveys. The P fertilizer recommended rates calculated are 50, 45, 25 and 20 kg P ha^{-1} for alfalfa, corn, sunflower and barley, respectively (Table 1).
3. Reduced P fertilizer dose (P_RED): This scenario was based on the result of soil surveys performed in DRW. Considering the agronomic interpretation of soil P-Olsen concentrations proposed by López Ritas (1975), all surveyed fields, occupied by corn, alfalfa, sunflower, and barley, presented high P-Olsen concentrations in the layer 0 – 30 cm (25 < P-Olsen > 34 mg kg^{-1}). So, P fertilizer dose reduction to 0 kg P ha^{-1} was considered for corn, alfalfa, sunflower, and barley.

Irrigation management scenario

The scenario consists in using an optimum irrigation scheduling by adjusting irrigation water use (I_ADJ) to crop net irrigation requirement (NIR). Daily NIR were calculated as the difference between daily crop evapotranspiration (ETc) and daily precipitation (Pr) adjusted to the effective one (Pr_{ef}). Daily ETc was calculated from the reference evapotranspiration (ET_0) and the respective crop coefficients (Kc). Duration of the crop development phases and Kc values were obtained from Martinez-Cob et al. (1998). Reference evapotranspiration was calculated using the FAO Penman-Monteith method described by Allen et al. (1998). Meteorological data used to calculate ET_0 was taken at the Huerto meteorological station (41º56'59"N and 00º08'09"W). Daily values of Pr_{ef} were estimated in function of the ETc, the total available water (TAW) and the soil available water (AW) of each type of soil as show equation 1 (Causapé, 2009). For practical reason and as farmers are required to increase the volumes of crops NIR by 10% in order to take into account possible losses, the daily net irrigation requirements for corn, alfalfa, sunflower and barley were calculated using equation 2.

$Pr_{ef} = Pr$ if $Pr < TAW + ETc – AW$; otherwise $Pr_{ef} = TAW + ETc – AW$ (1)

$$NIR\ (mm) = [(K_c \times ET_0) - Pr_{ef}] \times 1.1 \quad (2)$$

Once the daily NIR were calculated, their values were summed until getting a total volume of almost 20 mm. than, the corresponding date and water volume were applied in SWAT as an irrigation event. The annual average depths of water applied as the I_ADJ for corn, alfalfa, sunflower and barley are summarized in Table 1.

Table 1. Farmer's phosphorus application rates baseline (kg P ha^{-1}), recommended P fertilizer dose BMP (P_REC) (kg P ha^{-1}), water irrigation depth baseline (mm) and irrigation management scenario BMP (I_ADJ) values considered for alfalfa, corn, sunflower, and barley.

	P application rates (kg P ha^{-1})				Water irrigation depth (mm)			
	Baseline			BMP	Baseline			BMP
	2008	2009	Mean	P_REC	2008	2009	Mean	I_ADJ
Alfalfa	32	68	50	50	796	864	830	699
Corn	100	95	98	45	898	898	898	787
Sunflower	25	20	23	25	474	473	474	620
Barley	41	59	50	20	241	189	215	421

Tillage operations scenarios

The conservation tillage (CST) and the no tillage (NOT) scenarios were tested and compared with the conventional tillage (CVT), which represents the actual farmers' practices. CST and NOT practices are practically absent in the study area. In SWAT, the CST and NOT operations differ in terms of mixing efficiencies (EFFMIX) which specifies the fraction of materials (residue, nutrient, and pesticides) on the soil surface that are mixed uniformly throughout the soil depth specified by DEPTIL (depth of mixing caused by the tillage operation). The DEPTIL and EFFMIX values for CVT, CST and NOT operations are presented in Table 2.

Table 2. Conventional tillage (CVT), conservation tillage (CST) and no tillage (NOT) scenarios parameters and their depth of till (DEPTILL) and mixing efficiencies (EFFMIX) values considered in SWAT-IRRIG simulations.

Scenario	**Tillage operation**	**DEPTILL (mm)**	**EFFMIX**
CVT (baseline)	Moldboard plow	150	0.95
	Cultivator	100	0.25
	Roller packer	40	0.05
CST	Cultivator	100	0.25
NOT	Generic no tillage mixing	25	0.05

BMP analysis

In total, 20 BMP scenarios were tested. Six of the scenarios correspond to those previously described while the other 14 scenarios consist of combinations of the first six BMPs. The impact of BMPs scenarios on water quality are presented as percent reductions in average annual losses of water yield (WYLD, mm), total suspended sediments (TSS, tons), organic P (ORG_P, kg), soluble P (SOL_P, kg) and total P (TP, kg) from the actual farmers' practices in the DRW. The calibrated SWAT-IRRIG model, considering the actual farmer practices, was run for 2 years period from 2008 to 2009 to calculate WYLD, TSS, ORG_P, SOL_P and TP actual values. For each previously described BMP above cited, SWAT-IRRIG model was run for the same period (2008-2009) and the percent reduction was calculated as:

$$\text{Reduction (\%)} = \frac{\text{preBMP} - \text{postBMP}}{\text{preBMP}} \times 100 \qquad (3)$$

where pre-BMP and post-BMP are SWAT-IRRIG outputs before and after implementation of the BMP, respectively. A paired *t* test (α = 0.05 and 0.10) (Walpole et al., 2002) was performed on the simulated monthly values of WYLD, TSS, ORG_P, SOL_P, and TP losses at DRW outlet to test the significance change in the BMPs application. STATGRAPHIC version 5 was used.

Economic impacts of implemented BMPs

The implementation of such BMPs could increase or decrease the total incomes and costs at farmer scale. Therefore, for the irrigated agriculture economic sustainability, it is important to consider the impact of BMP scenarios on farmer revenue in the election of the beneficial ones. For this reason, pre-BMP and the 20 considered post-BMP gross margins were estimated and analysed in this work. The best economic scenario should produce the highest positive increase on crop gross margin and at the same time the highest reduction on TP losses compared to the initial conditions.

Gross margins were computed for corn, alfalfa, sunflower, and barley taking into account total incomes and total costs obtained from farmer interviews and public databases. For the determination of total costs, several concepts were used: water fees, fertilizers, tillage, phytosanitary, seeds, machinery, grain drying, and irrigation water. Total income was calculated as the sum of crop yield income and subsidies of the respective crop.

The average crop yields used in the calculation of pre-BMP and post-BMP gross margins were obtained from the SWAT-IRRIG outputs corresponding to the 2008 and 2009 years. Crop prices were obtained from the Barbastro agricultural cooperative located in Peralta de Alcofea. European Union subsidies resulting from the application of the Common Agricultural Policy were obtained from public databases (MARM, 2009). Gross margin for each crop was determined subtracting total cost from total income of the evaluated crop. The price of P (set to 1.25 € kg^{-1} of P_2O_5) was calculated by multiple regression considering 15 prices of fertilizer products and percentage of active nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) that contain. Prices of fertilizer products were obtained from public databases (MARM, 2010). The price of the fertilizer product is the dependent variable and the percentages of N, P_2O_5, and K_2O are the independent variables. The fitted model equation is:

$$\text{Price}\,(€) = 0.88 \times \text{N} + 1.25 \times \text{P}_2\text{O}_5 + 0.37 \times \text{K}_2\text{O}, \quad r^2 = 0.986 \text{ and adjusted } r^2 = 0.983 \qquad (4)$$

The reduction in conservation and no tillage costs were calculated according to Pérez and Martínez (2007) and are presented in Table 3. For the practice of no tillage, farmers have to apply more herbicides for the treatment of weeds. Therefore, the cost of machinery used in the practice of no tillage is a little bit higher than that used in the case of conservation tillage. The irrigation management BMP scenario does not imply a reduction in water price (0.024 € m^{-3}) or water fees (66 € per irrigated hectare).

Table 3.Total cost of machinery (€ ha^{-1}) used for conventional tillage (CVT), conservation tillage (CST), and no tillage (NOT) for corn, alfalfa, sunflower, and barley.

Scenario	Corn	Alfalfa	Sunflower	Barley
Conventional tillage (CVT)	158.6	223.9	148.5	138.4
Conservation tillage (CST)	101.2	167.0	84.6	81.8
No tillage (NOT)	103.5	169.0	87.4	84.2

Result and discussion

Average water yield losses (2008-2009), total suspended sediments, organic P, soluble P and total P simulated by SWAT-IRRIG considering initial conditions (baseline) are 119.6 mm, 25.4 tons, 30.6 kg, 197.0 kg, and 227.6 kg, respectively. Monthly stream discharges ranged from 2.40 mm in January 2008 to 23.55 mm in April 2009. The maximum discharge took place during the irrigation season, mostly late spring and summer. On a monthly basis, TSS loads varied from 0.21 Mg in January 2008 to 8.85 Mg in August 2009. Higher TSS loads occurred in spring and summer 2009 under rainfall and irrigation conditions (e.g. 8.62 Mg in April 2009; 8.85 Mg in August 2009) whereas lower loads corresponded with low base flow. On a monthly basis, TP loads ranged from 5.85 kg in January 2008 to 47.08 kg in April 2009. The highest TP loads occurred mainly during spring and summer months (months of fertilization) and occasionally during autumn. The daily TP concentrations varied from 0.022 mg L^{-1} to 0.475 mg L^{-1} (CV = 211%). The highest TP concentrations were registered during the irrigation season of both considered years.

The corresponding results when the individual BMPs scenarios were considered are presented in Figure 1. Results indicate that the lowest losses of water yield, total suspended sediments, and total P were been achieved with the scenario I_ADJ.

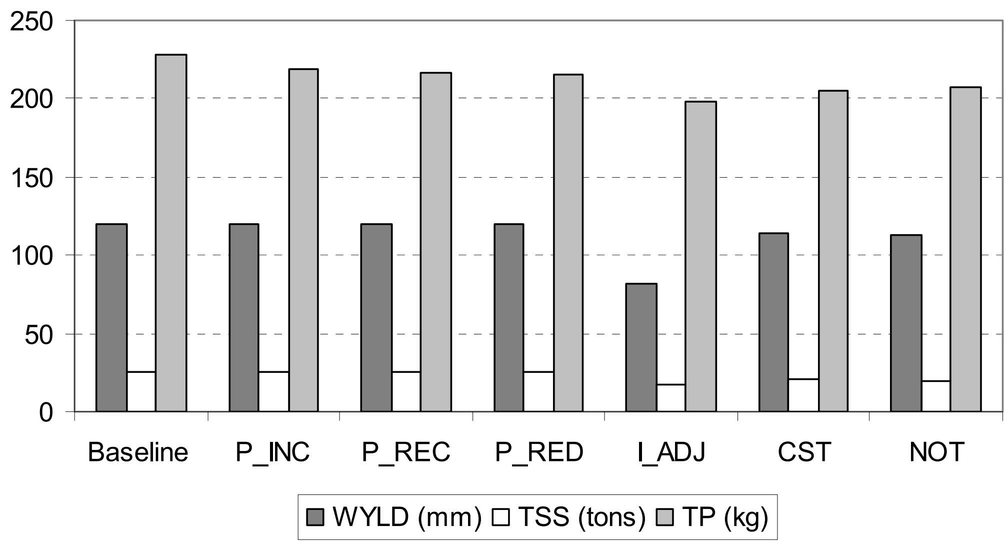

Figure 1. The simulated water yield (WYLD, mm), total suspended sediments (TSS, tons), and total phosphorus (TP, kg) average values regarding the application of baseline, phosphorus fertilizer incorporation (P_INC), recommended phosphorus fertilizer dose (P_REC), reduced phosphorus fertilizer dose (P_RED), adjusted irrigation water (I_ADJ), conservation tillage (CST) and the no tillage (NOT) scenarios.

Nutrients BMP scenarios

The results indicate that P fertilizer incorporation (scenario 1 in Table 4) leads to reduction of losses for all P forms. The impact of P incorporation is most significant ($P < 0.10$) for SOL_P (4.7%) and TP 4.0%. While the lowest impact of P_INC scenario was found for ORG_ P with a percentage reduction of 0.1% (not significant). The resulted reduction of TP losses was similar to those found by Osei et al. (2003) for the Upper North Bosque River Watershed (UNBRW). One of the major land uses in this watershed is forage fields (23%) and in general the UNBRW has a warm-temperate, subhumid climate with hot summers such as the DRW. The application of the recommended P fertilizer dose (scenario 2 in Table 4) and no P fertilization (scenario 3 in Table 4) BMPs presented similar reduction of ORG_P, SOL_P, and TP losses, compared to the initial conditions. On average, the implementation of P_REC and P_RED BMPs scenarios reduced ORG_P, SOL_P and TP losses by 0.1, 5.8, and 5.1%, respectively. However, only losses of SOL_P and TP under P_REC and P_RED scenarios were significantly different ($P < 0.10$) from the initial conditions.

The nutrients BMP scenarios did not impact significantly the ORG_P losses for the fact that almost of the P fertilizers applied in the DRW were in mineral form. Also, the application of those scenarios did not have any impact on the average amount of crop P uptake (28.64 kg ha^{-1}). In the other hand, the application of the P_INC scenario increased the final amount of mineral P in the soil by 1.94%. This highlights that the amount of P fertilizer applied by farmers was high, leading to an accumulation of P in the soil profile. However, the application of P_REC and P_RED scenarios decreased the final amount of P in the soil by 0.02 and 0.10%, respectively.

Irrigation BMP scenario

The results indicate that the adjustment of the irrigation water dose to the crop water requirements reduced WYLD, TSS, and all P forms losses at the DRW outlet (scenario 4 in Table 4). Using this BMP, farmers could save 1950 and 1830 m^3 ha^{-1} of water for corn and alfalfa, respectively. This water saving is very important given the high extent of corn and alfalfa in the DRW. The annual average losses of WYLD, TSS, ORG_P, SOL_P and TP under I_ADJ scenario were 82.0 mm, 16.9 tons, 28.6 kg, 170.1 kg, and 198.5 kg and were significantly lower ($P < 0.05$) than those obtained under the initial conditions. The estimated percentage reductions in SOL_P (13.7%) were twice times greater than the corresponding reductions in ORG_P (6.7%). This is probably due to the magnitude of SOL_P levels contained in the DRW soils with respect to ORG_P fraction. The average initial amount of SOL_P in the soil was more than forty-seven times higher than average initial amount of ORG_P.

Results indicate that applying less irrigation water for corn and alfalfa, compared to the initial conditions, resulted in yield decreases of about 2.5 and 7.1%, respectively. However, this yield decrease was within the range of yield variation of such crops in the DRW. While in the case of sunflower and barley, for which more irrigation water was applied to meet crop water needs, an increase of yield about 11.3 and 12.9% was observed, respectively. The average sunflower and barley yield obtained with I_ADJ scenario were 3.95 and 6.77 tons ha^{-1}, respectively.

The comparison between nutrient and irrigation BMPs impacts revealed that the management of transport factor (irrigation water) was more efficient in reducing the losses of WYLD, TSS, ORG_P, SOL_P, and TP than the management of source factor (nutrients). Therefore, impacts of I_ADJ scenario on WYLD, TSS, ORG_P, SOL_P and TP losses were, respectively, 100%, 100%, 98%, 60%, and 63% higher than average percentage reductions obtained from nutrient BMPs (scenarios 1, 2, and 3).

Table 4. The SWAT-IRRIG model initial conditions and the percentage changes resulted from each BMP application of total water yield (WYLD, mm), total suspended sediments (TSS, Mg), organic phosphorus (ORG_P, kg), soluble phosphorus (SOL_P, kg), and total phosphorus (TP, kg) average values. The considered BMPs are: phosphorus fertilizer incorporation (P_INC), recommended P fertilizer dose (P_REC), reduced phosphorus fertilizer dose (P_RED), adjusted irrigation dose (I_ADJ), conservation tillage (CST) and no tillage (NOT).

Baseline scenario	WYLD	TSS	ORG_P	SOL_P	TP
	119.6	25.4	30.6	197.0	227.6
Percentage reduction from baseline (%)					
1. P_INC	0.0	0.0	–0.1	–4.7§	–4.0§
2. P_REC	0.0	0.0	–0.1	–5.8§	–5.0§
3. P_RED	0.0	0.0	–0.1	–5.9§	–5.1§
4. I_ADJ	–31.4‡	–33.5‡	–6.7‡	–13.7‡	–12.8‡
5. CST	–5.0	–20.5§	+5.3	–12.4‡	–10.0§
6. NOT	–5.4	–21.0§	+9.1	–11.9‡	–9.1§
7. I_ADJ + CST	–36.3‡	–54.3‡	–5.9	–24.9‡	–22.3‡
8. I_ADJ + NOT	–36.7‡	–54.8‡	–3.0	–24.6‡	–21.7‡
9. I_ADJ + P_INC	–31.4‡	–33.5‡	–6.7‡	–14.1‡	–13.1‡
10. I_ADJ + P_ REC	–31.4‡	–33.5‡	–6.7‡	–13.6‡	–12.6‡
11. I_ADJ + P_RED	–31.4‡	–33.5‡	–6.8‡	–19.7‡	–17.9‡
12. P_REC + P_INC	0.0	0.0	–0.1	–5.9§	–5.1§
13. P_REC + CST	–5.0	–20.4§	+5.3	–12.7‡	–10.3§
14. P_REC + NOT	–5.4	–21.0§	+9.1	–12.1‡	–9.2§
15. P_RED + CST	–5.0	–20.4§	+5.3	–12.7‡	–10.3§
16. P_RED + NOT	–5.3	–21.0§	+9.1	–12.1‡	–9.2§
17. I_ADJ + CST + P_ REC	–36.3‡	–54.3‡	–5.8	–24.9‡	–22.3‡
18. I_ADJ + NOT + P_ REC	–36.7‡	–54.8‡	–3.0	–24.7‡	–21.7‡
19. I_ADJ + CST + P_RED	–36.3‡	–54.3‡	–5.9	–25.2‡	–22.6‡
20. I_ADJ + NOT + P_RED	–36.7‡	–54.8‡	–3.0	–24.8‡	–21.9‡

‡ Significantly different from the initial conditions (α = 0.05)
§ Significantly different from the initial condition (α = 0.10)

Tillage BMPs scenarios

Results indicate that on average, both tillage BMPs considered (scenario 5 and 6 in Table 4) induced a decrease of WYLD (5.2%), TSS (20.8%), SOL_P (12.2%), and TP losses (9.6%), and an increase of ORG_P (7.2%) losses. However, the values of WYLD and ORG_P losses, under CST and NOT BMPs, were not significantly different from the initial conditions. With less intensive tillage practices the yields of SOL_P ($P < 0.05$), TSS and TP ($P < 0.10$) were significantly different from those obtained under initial conditions. The CST practice was a little bit better than NOT in terms of SOL_P and TP losses. The ORG_P yields were higher under CST and NOT practices compared to the conventional tillage (CVT). This was mainly due to the fact that conventional tillage did mix the residues properly with the soil for a greater depth, which finally decomposed. Therefore, attachment of ORG_P in sediments was poor and the resultant losses were less than with CST and NOT. The build up of easily ORG_P on the surface due to the lack of soil inversion and mixing enhanced the ORG_P loss under CST and NOT tillage practices. Similar findings were also reported by Tripathi at al. (2005) in the Nagwan watershed

(India) where the major grown crops are corn and rice. On the other hand, the decreasing tillage intensity resulted in an increase of baseflow by 2.9%, while surface runoff and total water yield were decreased by 25.4 and 4.7%, respectively (data not shown).

Combined BMPs scenarios

In general, the combined BMPs scenarios (scenarios 7 to 20 in Table 4) were more efficient in reducing water, soil and phosphorus losses than individual ones. When the I_ADJ BMP was combined with the CST and NOT BMPs (scenarios 7 and 8 in Table 5, respectively), the predicted percentage reductions were greater in comparison with the individual I_ADJ scenario. On average, the implementation of scenarios 7 and 8 resulted in percentage reductions of 36.5, 54.6, 4.5, 24.8, and 22.0%, for WYLD, TSS, ORG_P, SOL_P and TP losses from the initial conditions, respectively. Those average percentage reductions of WYLD, TSS, ORG_P, SOL_P and TP losses resulted from scenarios 7 and 8 were in average 16.2%, 62.8%, 33.6%, 80.7%, and 71.9% higher than those obtained when I_ADJ BMP was applied individually, respectively. However, when I_ADJ scenario was combined with nutrient BMPs (scenarios 9 to 11 in Table 4), percentage reductions of WYLD remained the same. The TSS, SOL_P and TP percentage reduction was decreased, while percentage reduction of P_ORG was increased. The combination of P_REC and P_INC BMPs (scenario 12) did not show a significant difference from the applied individually.

The SWAT-IRRIG model was also used to quantify the combined impact of fertilizer BMPs (P_REC and P_RED) simulated in tandem with the tillage BMPs (CST and NOT) on the tested components (scenarios 13 to 16 in Table 4). Percentage reductions obtained with those scenarios were quite similar to those obtained in the case of individual CST and NOT scenarios. The combination of tillage (CST and NOT), irrigation (I_ADJ) and fertilizer (P_REC and P_RED) BMPs (scenarios 18 to 20 in Table 4) did not have a significant added benefit compared to results obtained in scenarios 7 and 8.

BMPs scenarios economic impacts

The economic impact of BMPs scenarios on the gross margin is presented in Euros per hectare for the most representative crops in Table 5. The gross margins values resulted under initial conditions were 631.1 € ha^{-1} for corn, 970.7 € ha^{-1} for alfalfa, 99.8 € ha^{-1} for sunflower, and 421.1 € ha^{-1} for barley. A negative value showed in Table 5 indicates that the BMP reduced the gross margin of the corresponding crop, compared with the initial conditions results, whereas a positive value indicates that the BMP increased the gross margin of the evaluated crop. Results indicated that the economic impacts of BMPs varied widely from scenario to scenario and from crop to crop. The highest economic impact was showed with scenario nº 15 and corn, which occupied 41% of the irrigated area in the DRW (Table 5).

For the case of corn, the economic impact of BMPs scenarios ranged from -27.4 € ha^{-1} (scenario 9 in Table 5) to 308.6 € ha^{-1} (scenario 15 in Table 5) with a coefficient of variation of 84.3%. However, BMP scenario nº 15 did not coincide with the highest percentage reduction of TP losses from the DRW. This is mainly due to the fact that scenario nº 15 includes the reduction of P application dose to 0 kg ha^{-1}. The average total cost of fertilizers applied for corn during 2008-2009 period is about 558.2 € ha^{-1}. The reduction of P fertilizer dose to 0 kg ha^{-1} decreased the average total cost of corn fertilizer to 283.3 € ha^{-1}, which highly increased the gross margin. On the other hand, the highest percentage reduction of TP loss (-22.6%), compared to initial conditions, corresponds to an increase of corn gross margin of 296.6 € ha^{-1} (scenario nº 19 in Table 5).

In the case of alfalfa, the economic impact of BMPs scenarios ranged from -91.5 € ha^{-1} (scenario 9 in Table 5) to 188.5 € ha^{-1} (scenario 15 in Table 5) with CV value 252.0%. In this case, the lowest economic impact is due to the decrease of alfalfa yield by 7.1%, compared to initial conditions. The reduction of the amount of P fertilizer increased the gross margin of alfalfa by the means of scenario nº 15. As it has been showed for corn, scenario nº 19 coincides with the highest percentage reduction of TP losses. This scenario permits an increase of alfalfa gross margin about 112.4 € ha^{-1}.

Table 5. Average calculated gross margin (€ ha^{-1}) of implemented best management practices during the period 2008-2009, and the changes (€ ha^{-1}) from the initial condition scenario for corn, alfalfa, sunflower, and barley. The considered BMPs are: phosphorus fertilizer incorporation (P_INC), recommended P fertilizer dose (P_REC), reduced phosphorus fertilizer dose (P_RED), adjusted irrigation dose (I_ADJ), conservation tillage (CST) and no tillage (NOT).

Baseline scenario (€ ha^{-1})	Corn	Alfalfa	Sunflower	Barley
	631.1	970.7	99.8	421.1
Changes from baseline: € ha^{-1}				
1. P_INC	-15.5	-15.5	-15.5	-15.5
2. P_REC	148.0	12.8	-5.6	84.6
3. P_RED	274.9	141.0	64.8	141.0
4. I_ADJ	-11.9	-76.0	69.8	112.4
5. CST	33.7	47.5	36.6	53.8
6. NOT	14.6	38.8	17.1	49.8
7. I_ADJ + CST	21.7	-28.5	106.5	166.2
8. I_ADJ + NOT	2.6	-37.2	87.0	162.2
9. I_ADJ + P_INC	-27.4	-91.5	56.7	96.9
10. I_ADJ + P_ REC	136.1	-63.2	64.2	197.0
11. I_ADJ + P_RED	263.0	64.9	134.7	253.3
12. P_ REC + P_INC	132.5	-2.7	-21.1	69.1
13. P_ REC + CST	181.7	60.3	31.0	138.4
14. P_ REC + NOT	162.6	51.6	11.5	134.4
15. P_RED + CST	308.6	188.5	101.4	194.8
16. P_RED + NOT	289.5	179.8	81.9	190.8
17. I_ADJ + CST + P_ REC	169.7	-15.7	100.9	250.8
18. I_ADJ + NOT + P_ REC	150.6	-24.5	81.4	246.8
19. I_ADJ + CST + P_RED	296.6	112.4	171.3	307.2
20. I_ADJ + NOT + P_RED	277.5	103.7	151.9	303.2

With regard to the sunflower, the economic impact of BMPs scenarios ranged from -21.1 € ha^{-1} (scenario 12 in Table 5) to 171.3 € ha^{-1} (scenario 19 in Table 5) with CV value of 81.2%. In this case, the highest percentage reduction of TP losses coincides with the best sunflower gross margin. Because of gross margin of sunflower was very low (99.8 € ha^{-1}), this crop was not important in the study area during 2008-2009 periods (only 9% of irrigated are). However, during the 2010 year, sunflower price was 0.39 € kg^{-1} instead of 0.20 € kg^{-1}. If the 2010 sunflower price was considered in this analysis and the 2008-2009 average data were used, the resulted gross margin will increase to 754.0 € ha^{-1}. For barley, the scenario with highest percentage reduction of TP losses coincides with the best barley gross margin.

Conclusion

The environmental impact variability between the considered 20 BMPs was observed. When the BMPs only targeting the source factor (P in the soil or P in fertilizers), the resulting percentage of reduction of TP will be low (on average 4.7% reduction, compared to initial conditions). In terms of phosphorus losses, the conservation tillage practice seems to be better than no tillage and the optimum irrigation management, according to crop net irrigation requirement, is most appropriate because decreased significantly the losses of WYLD, TSS, ORG_P, SOL_P, and TP. However, the most relevant conclusion is related to the use of several BMPs at the same time. The combination between adjusted irrigation dose, reduced P fertilizer dose and conservation tillage BMPs showed the highest percentage reduction of TP losses from DRW (22.6%). In the case of sunflower and barley this scenario resulted in the highest increase of their gross margin (171.3 and 307.2 € ha^{-1}, respectively). While for corn and alfalfa, this scenario did not imply the highest increase of their gross margin (some yield reduction). For those crops, the highest increase in gross margin was reached by the combination of reduced P fertilizer dose and conservation tillage BMPs (308.6 and 188.5 € ha^{-1}, for respectively corn and alfalfa). The optimum irrigation water applied in this case should be revised. The new knowledge acquired from this work should help scientists, policy makers and farmers to take optimal decisions for a sustainable management of agricultural irrigated watersheds under similar environmental conditions.

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