



Phosphorus losses in two agricultural systems from South Spain

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Vidal Barrón², and Isabel Díaz²**

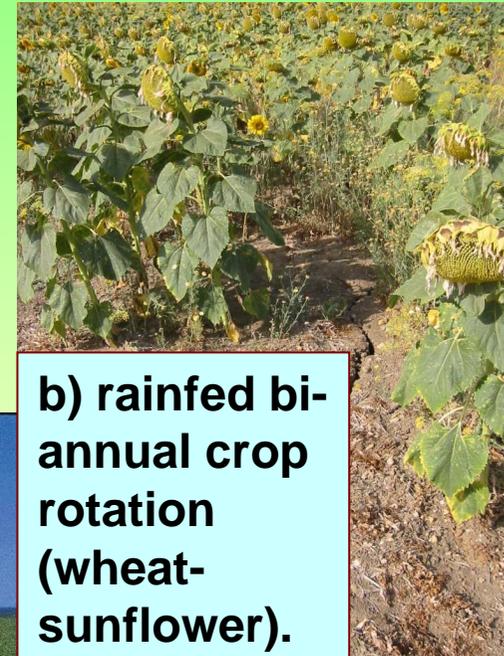
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INTRODUCTION

Little information is available about P losses in agricultural soils from South Europe, in particular in Mediterranean areas from Spain. This work describes P losses in two representative agricultural systems:

a) bi-annual crop rotation (sugar beet-cotton) under irrigation in reclaimed marsh soils



b) rainfed bi-annual crop rotation (wheat-sunflower).





Marsh soils,
close to
"Doñana area"

EXPERIMENTAL

Marsh soil in the Marisma of Lebrija, SW Spain

Tile-drained soil in the estuarine region of the river Guadalquivir (total drained area 40000 ha)

Drain flow and P content in water was monitored during four years (from 1999 to 2000 and from 2003 to 2004).

Main soil properties were:

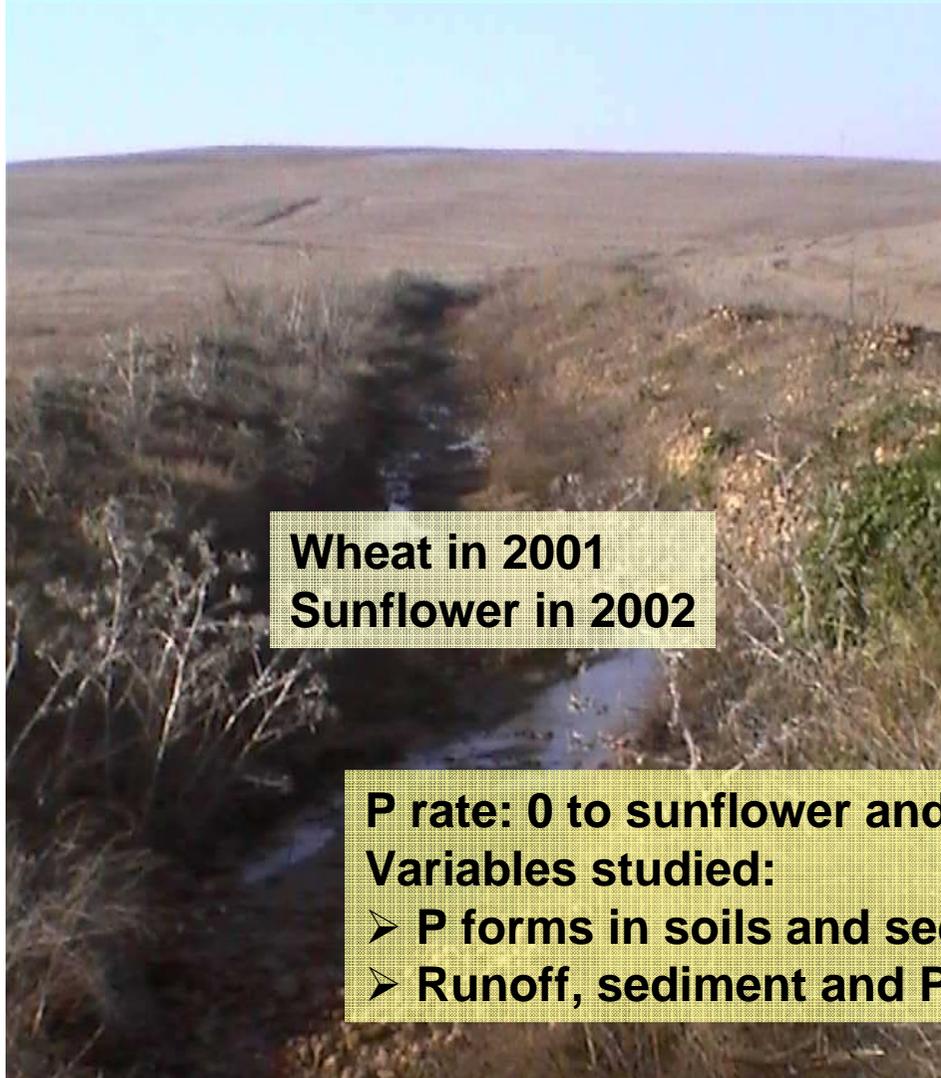
- from 0 to 30 cm depth, 70 % clay content; 24 % carbonate content; 19 mg kg⁻¹ Olsen P.
- from 30 to 90 cm depth, 47 % clay content; 35 % carbonate content; 12 mg kg⁻¹ Olsen P.

Catchment 1

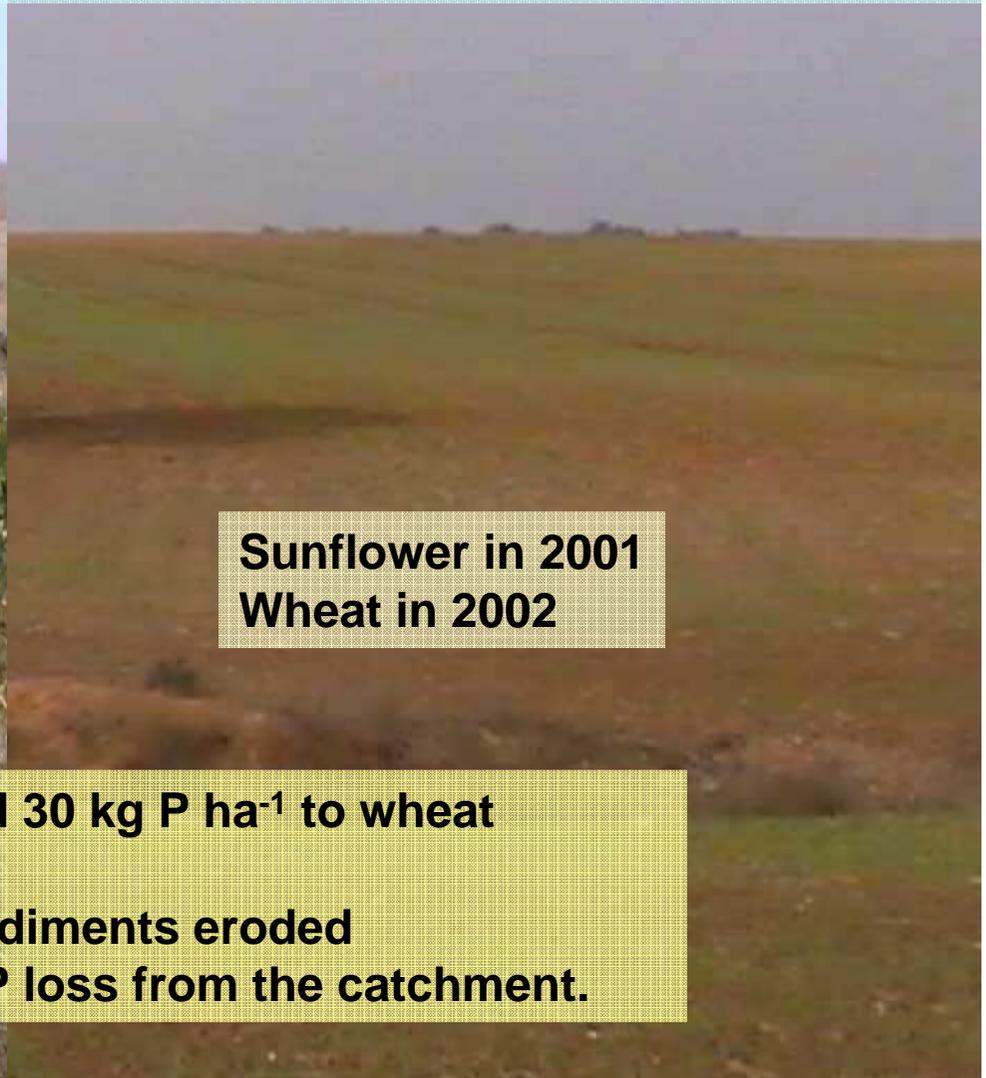
61.5 ha; soils were mainly Vertisols; 44-50 % clay content in upper horizon; pH 7.4-7.9; Olsen P: ranging from 10 to 85 mg kg⁻¹; 80 % of the catchment surface ranging from 10 to 30 mg kg⁻¹

Catchment 2

24.5 ha; soils were mainly Alfisols; 6 - 33 % clay content in upper horizon; pH 7.4 - 8; Olsen P: ranging from 5 to 70 mg kg⁻¹; 80 % of the catchment surface ranging from 20 to 30 mg kg⁻¹



Wheat in 2001
Sunflower in 2002



Sunflower in 2001
Wheat in 2002

P rate: 0 to sunflower and 30 kg P ha⁻¹ to wheat

Variables studied:

- **P forms in soils and sediments eroded**
- **Runoff, sediment and P loss from the catchment.**



**Hand made
flow meter
used in
marsh soils**



**Isco flow meter and
sampler in
catchments**

RESULTS AND DISCUSSION

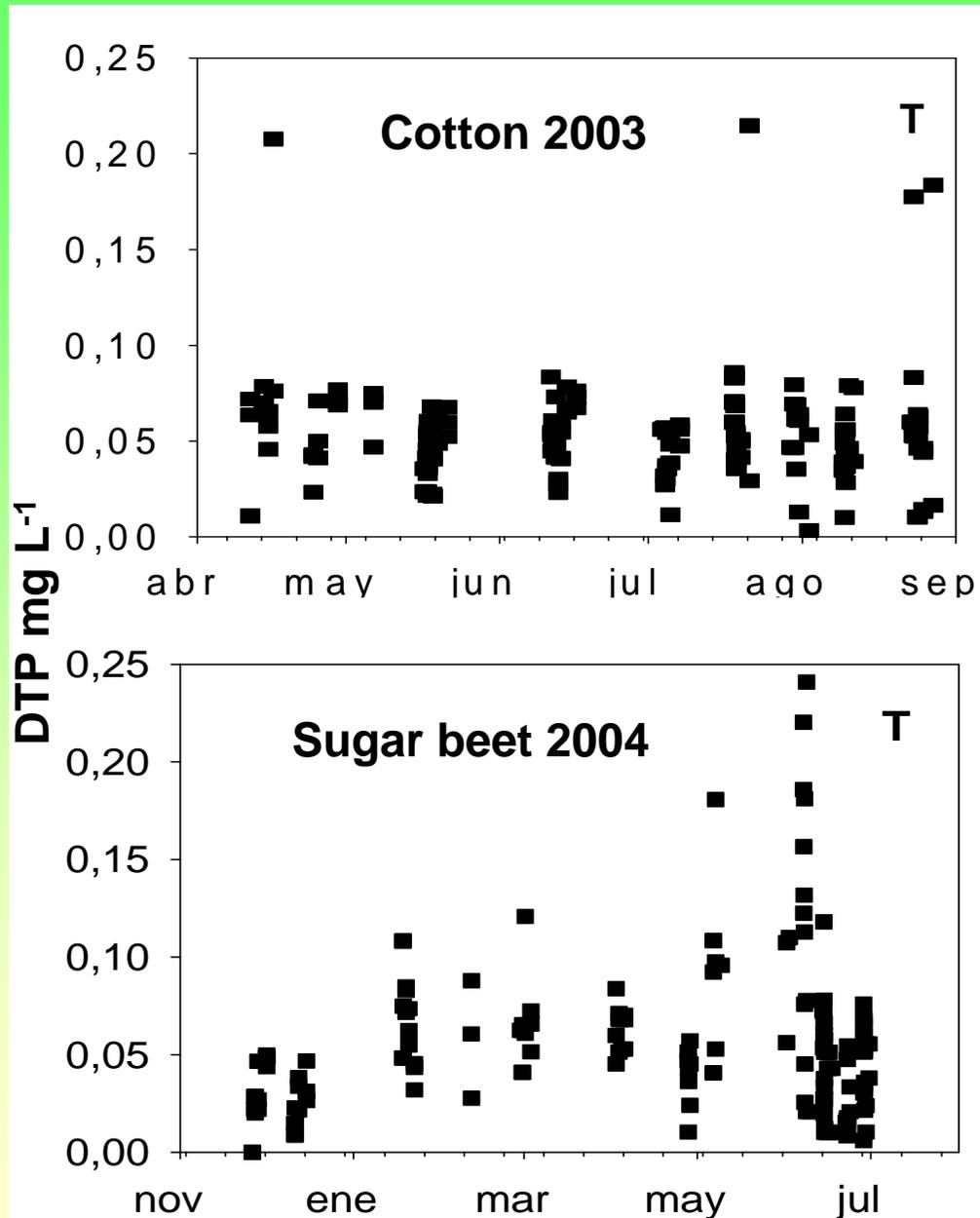
Table 1. Concentration of different P forms in drainage water and P losses in drainage water in a tile-drained marsh soils from the Guadalquivir Valley (SW Spain) in three different growing seasons with different irrigation water management †

Crop	Drainage fraction	Concentration			Losses		
		DRP	DTP	TP	DRP	DTP	TP
		----- mg L ⁻¹ -----			----- g ha ⁻¹ -----		
Sugar beet 1999	0.03	0.068 ± 0.008	0.116 ± 0.026	0.123 ± 0.066	16	19	20
Cotton 2000	0.35	0.039 ± 0.024	0.053 ± 0.024	0.077 ± 0.048	113	154	211
Cotton 2003	0.07	0,046 ± 0,026	0,054 ± 0,027	0,080 ± 0,070	34	37	51
Sugar beet 2004	0.02	0,041 ± 0,029	0,054 ± 0,038	0,109 ± 0,180	5	7	10

† DRP, dissolved molybdate reactive P; DTP, dissolved total P; TP, total P; drainage fraction, fraction of applied water lost through drainage during the growing season; rain + irrigation was 1003 mm in 1999, 900 mm in 2000, 1116 in 2003, and 890 in 2004.

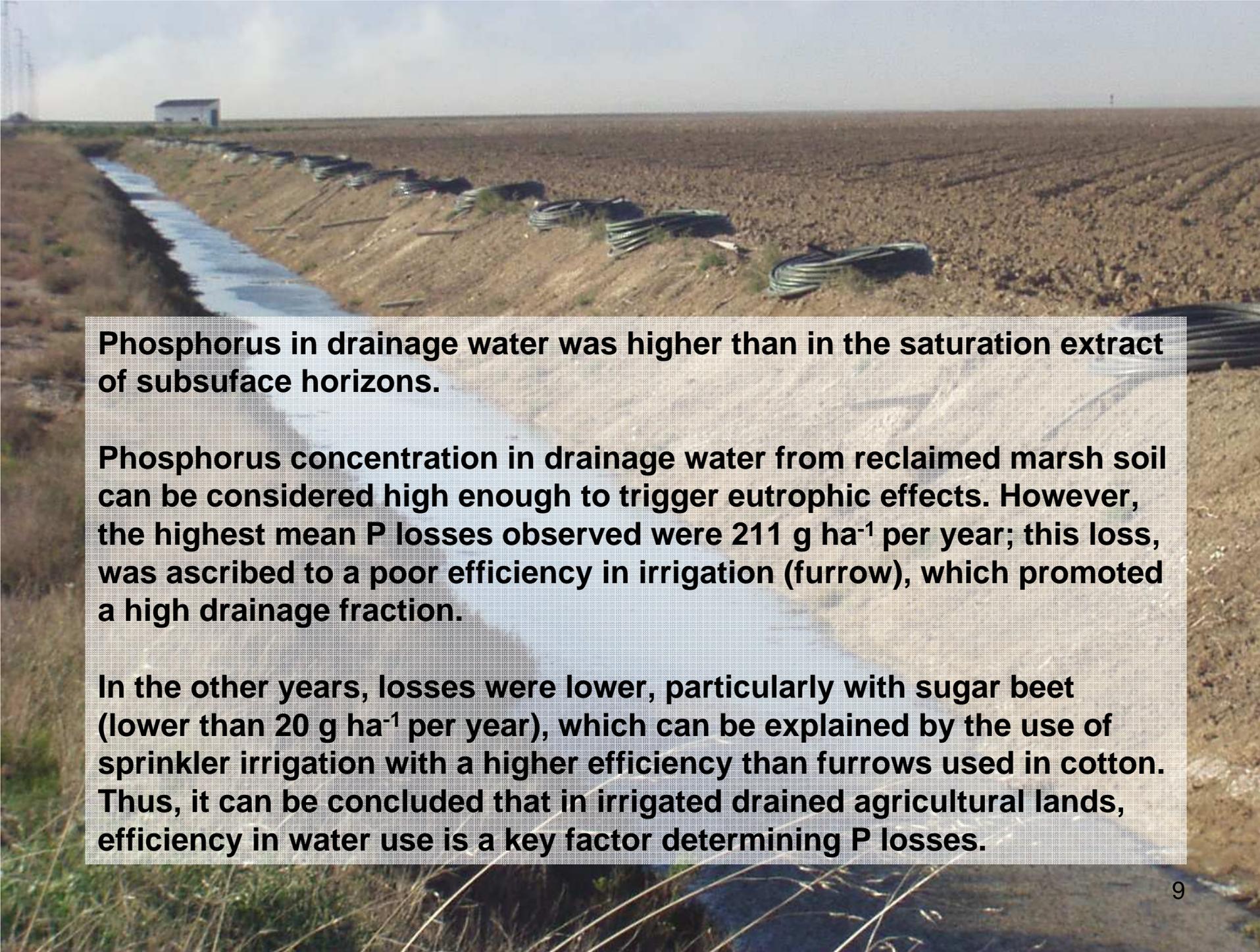
Applied P fertilizer to each crop 70 kg P ha⁻¹

Means and standard deviations



No effect of fertilization on P concentrations

Higher concentrations at the end of the cycle, probably due to crack opening



Phosphorus in drainage water was higher than in the saturation extract of subsurface horizons.

Phosphorus concentration in drainage water from reclaimed marsh soil can be considered high enough to trigger eutrophic effects. However, the highest mean P losses observed were 211 g ha⁻¹ per year; this loss, was ascribed to a poor efficiency in irrigation (furrow), which promoted a high drainage fraction.

In the other years, losses were lower, particularly with sugar beet (lower than 20 g ha⁻¹ per year), which can be explained by the use of sprinkler irrigation with a higher efficiency than furrows used in cotton. Thus, it can be concluded that in irrigated drained agricultural lands, efficiency in water use is a key factor determining P losses.

Table 2. Overland flow, sediment and phosphorus losses during different rain events in a Vertisol catchment in S Spain[†]

Date	Rain	Runoff	Sediment loss	Total P loss in runoff	DTP loss in runoff
	----- mm -----	-----	-----	kg ha ⁻¹ -----	
11/01/2002	24	3.3	292	0.18	0.001
21/03/2002	55	50	14514	9.66	0.022
17/04/2002	31	13	634	0.46	0.009

[†]DTP, dissolved total P

← Sunflower

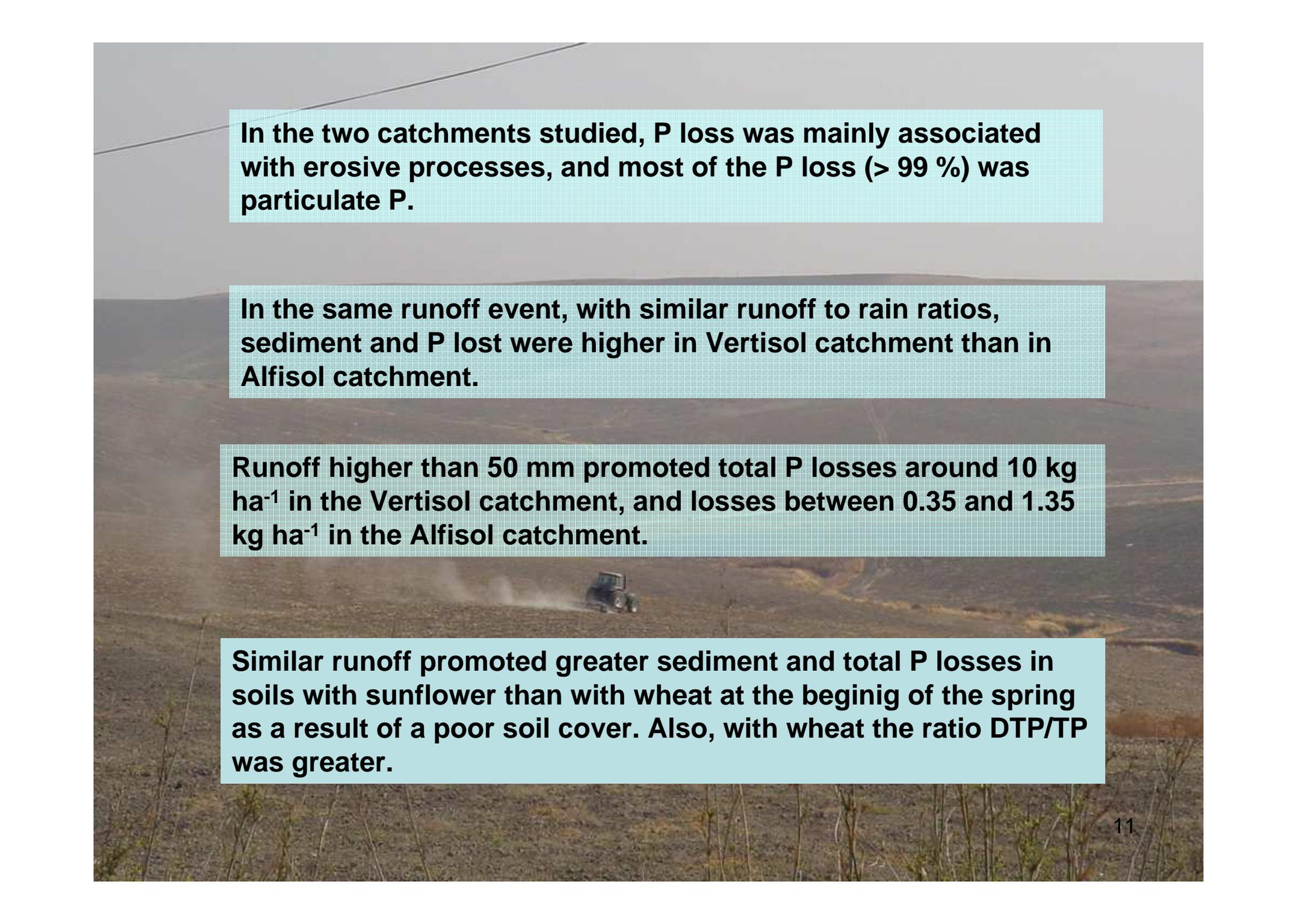
Table 3. Overland flow, sediment and phosphorus losses during different rain events in an Alfisol catchment in S Spain[†]

Date	Rain	Runoff	Sediment loss	Total P loss in runoff	DTP loss in runoff
	----- mm -----	-----	-----	kg ha ⁻¹ -----	
16/01/2001	59	27	131	0.24	0.055
22/01/2001	23	2	12	0.02	0.004
13/03/2001	162	47	1816	1.35	0.132
30/01/2002	11	0.6	32	0.02	0.001
21/03/2002	55	54	395	0.35	0.097

[†]DTP, dissolved total P

← Sunflower

← Wheat

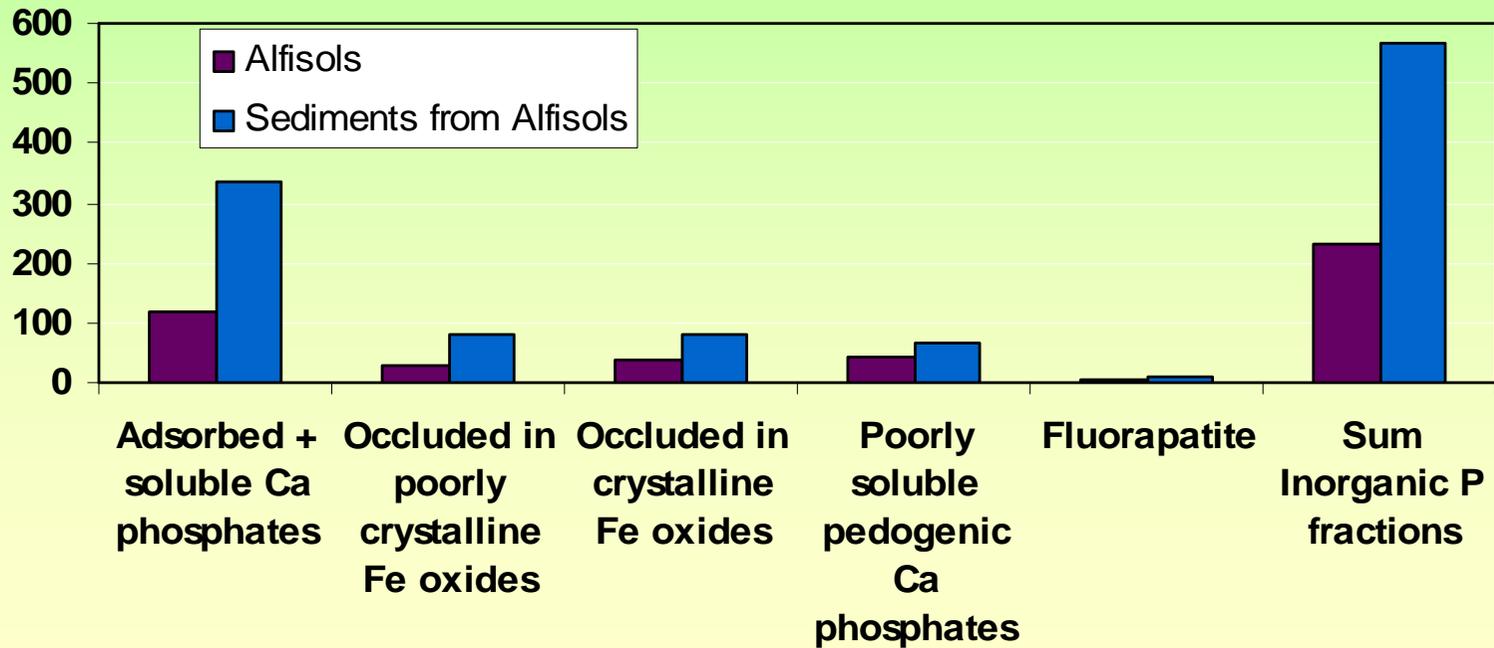
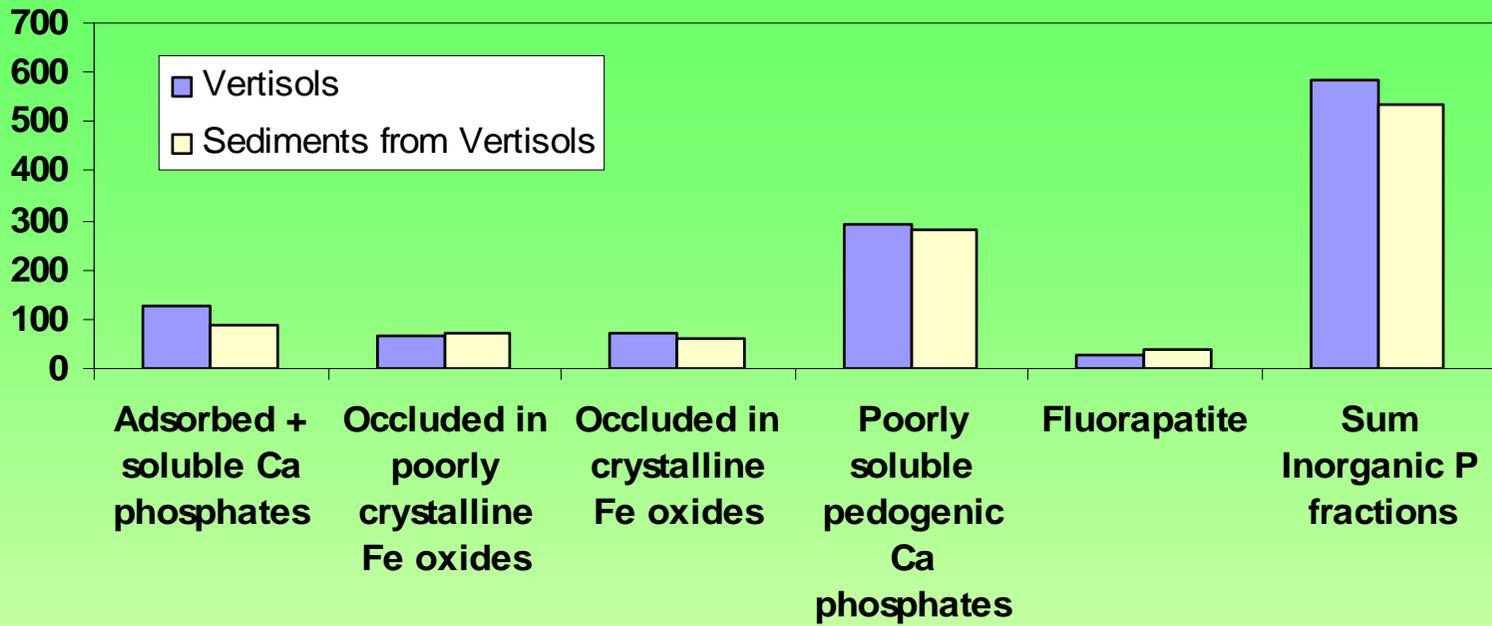


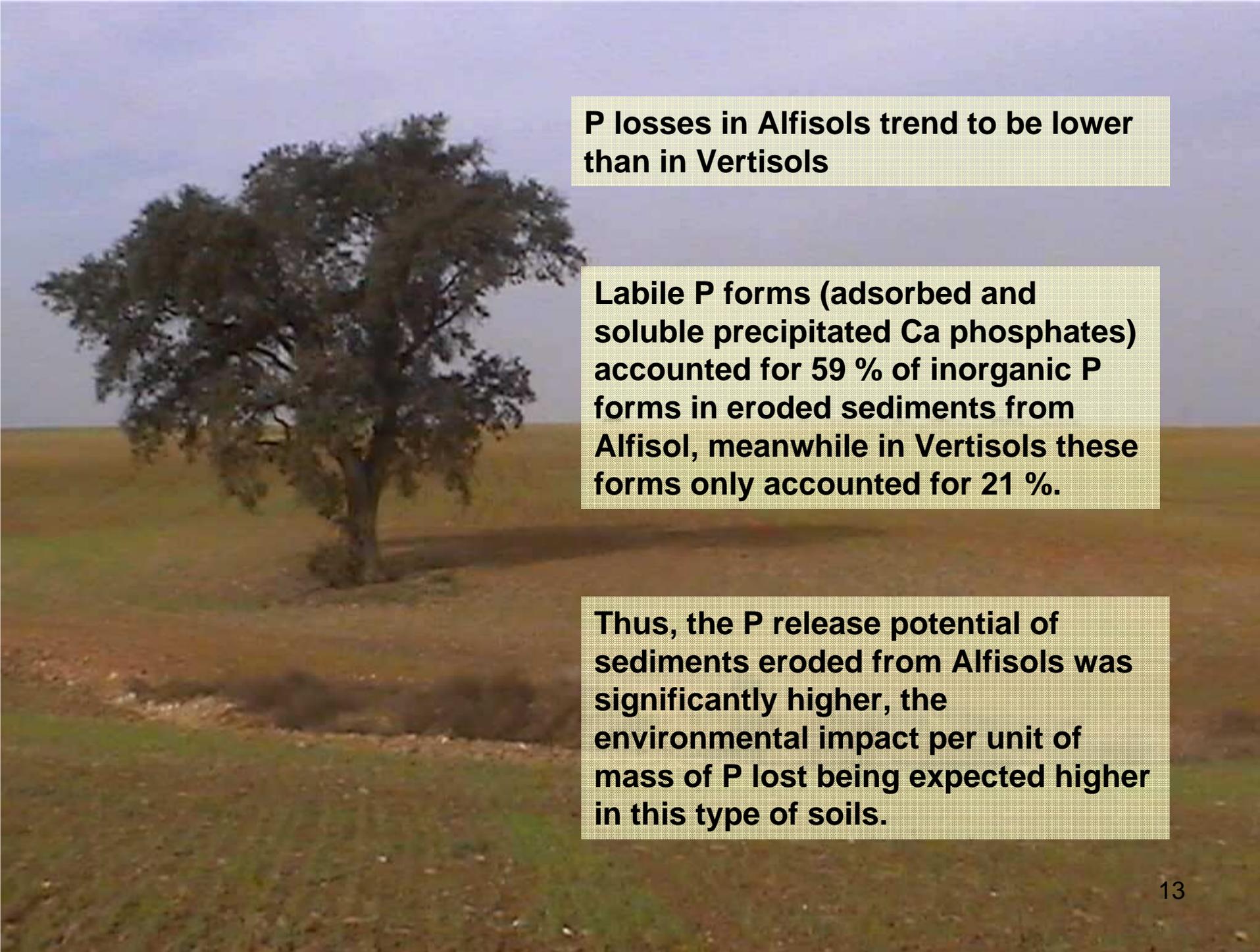
In the two catchments studied, P loss was mainly associated with erosive processes, and most of the P loss (> 99 %) was particulate P.

In the same runoff event, with similar runoff to rain ratios, sediment and P lost were higher in Vertisol catchment than in Alfisol catchment.

Runoff higher than 50 mm promoted total P losses around 10 kg ha⁻¹ in the Vertisol catchment, and losses between 0.35 and 1.35 kg ha⁻¹ in the Alfisol catchment.

Similar runoff promoted greater sediment and total P losses in soils with sunflower than with wheat at the beginig of the spring as a result of a poor soil cover. Also, with wheat the ratio DTP/TP was greater.





P losses in Alfisols trend to be lower than in Vertisols

Labile P forms (adsorbed and soluble precipitated Ca phosphates) accounted for 59 % of inorganic P forms in eroded sediments from Alfisol, meanwhile in Vertisols these forms only accounted for 21 %.

Thus, the P release potential of sediments eroded from Alfisols was significantly higher, the environmental impact per unit of mass of P lost being expected higher in this type of soils.

SOME INFORMATION PUBLISHED ABOUT SOILS FROM SOUTH SPAIN

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Effect of Soil Properties and Reclamation Practices on Phosphorus Dynamics in Reclaimed Calcareous Marsh Soils from the Guadalquivir Valley, SW Spain

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*Saline and sodic soils pose major agronomic problems in arid and semiarid regions. Marsh soils in the Guadalquivir Valley are representative of saline and sodic soils in estuarine environments, and are frequently reclaimed for agricultural use. Flooding affects the nature of P sorbent surfaces in soils; it increases the proportion of poorly crystalline Fe oxides relative to highly crystalline ones, which predominate in the calcareous soils typical of the region. Poorly crystalline Fe oxides and silicate clays appear to be the main P sorbent surfaces in these soils. Carbonates seemingly have adverse effects on short-term P sorption, probably as a result of Fe oxides being partly occluded in them. Salinity, sodicity, and soil amendments can affect P forms and P dynamics in soil. Olsen P is negatively correlated ($r = -0.81^{**}$) with the Na/Ca mole ratio, and positively correlated with sulfate concentration in the 1:1 extract ($r = 0.75^{**}$), indicating that soils that receive large amounts of Ca amendment (e.g., phosphogypsum) exhibit increased contents in available P. The increased Ca saturation as a result of the amendment raises the short-term sorption capacity of sorbent surfaces and results in a major contribution of Ca phosphate precipitation to long-term P sorption, as suggests the relationship between d (exponent of time in the modified Freundlich equation) and the Na/Ca mole ratio in the 1:1 extract*

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Phosphorus loss in tile drains from a reclaimed marsh soil amended with manure and phosphogypsum

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Key words: Artificial drainage, Furrow irrigation, Soil amendment, Sprinkler irrigation, Subsurface flow

Abstract

Reclamation of Guadalquivir river marshes (SW Spain) constitutes a representative example of wetland reclamation in Southern Europe. Nowadays, this is an important area of tile-drained soils (40,000 ha) with an intensive irrigated agricultural production where high fertilizer rates are usually applied. In tile-drained soils, flow through macropores or cracks, which connect the nutrient rich topsoil with drain lines, can be an important pathway for nutrient transfer from soil. In order to study P loss in these soils and how it is affected by soil amendment usually applied in the zone (phosphogypsum and manure) an experiment was performed during two consecutive growing seasons on a reclaimed marsh soil from the Guadalquivir Valley. In the first season (1998–1999), sugar beet (*Beta vulgaris* L.) was grown under sprinkler irrigation at a rate of 2.5 mm h⁻¹; in the second (2000), cotton (*Gossypium hirsutum* L.) was grown under furrow irrigation at 8–10 mm h⁻¹. The amendments applied included manure (30 Mg ha⁻¹), and phosphogypsum (13 and 26 Mg ha⁻¹). Drainage events were recorded, and water samples collected and analyzed for total P (TP), dissolved total P (DTP), and dissolved reactive P (DRP). Total P in drainflow ranged from 0 to 0.818 mg l⁻¹ in the 1998–1999 season and from 0 to 0.565 mg l⁻¹ in the 2000 season. The major P form in drainflow was DRP, which accounted for about 50% of TP in the two growing seasons (the mean DRP concentration was 0.068 mg l⁻¹ in 1998–1999 and 0.043 mg l⁻¹ in 2000). Dissolved organic P accounted for a higher portion of DTP in the first season (37%) than in the second (13%). A larger load of phosphorus was observed on plots receiving manure. This treatment significantly increased ($P < 0.05$) the cumulative drainflow during the 1998–1999 growing season (sprinkler irrigation, low drainflow rates). This is consistent with the increased losses of TP, DTP, DAHP, and DRP resulting from this treatment in this growing season. In the following season, DTP loading were significantly increased by manure ($P < 0.05$). This seems to be related mainly to significantly increased DOP losses ($P < 0.01$), particularly during the first drainage event. The higher fraction of applied water was lost by drainage under furrow irrigation (high drainflow rates) is consistent with the high TP load during the 2000 growing season (199–285 g ha⁻¹) relative to the 1998–1999 season (20–59 g ha⁻¹). This difference in P losses was much greater than those resulting from amendment of the soil.

Abbreviations: DAHP – dissolved acid hydrolyzable P; DOP – dissolved organic P; DRP – dissolved reactive P; DTP – dissolved total P; PG – phosphogypsum; PP – particulate P; TP – total P



Iron-related phosphorus in eroded sediments from agricultural soils of Mediterranean areas

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Abstract

A fraction of P in eroded sediments is attached to Fe oxides (Fe-related P). Reduction of Fe oxides in the bottom of water reservoirs is considered to mobilize P bound by poorly crystalline Fe oxides, which is supposed to be the main Fe(III) form available for microbial reduction in anoxic environments. The main objective of this work was to compare Fe and P extracted from suspended sediments of representative agricultural soils of the Guadalquivir Valley (SW Spain) with those in their source soils in order to predict the proportion of Fe-related P in eroded sediments that can be released under anoxic environments. A sequential extraction involving NaOH (P_{OH}), citrate bicarbonate (P_{CB} and Fe_{CB}), citrate (P_{C} and Fe_{C}), citrate ascorbate (P_{CA} and Fe_{CA}), citrate bicarbonate dithionite (P_{CBD} and Fe_{CBD}), acetate (P_{OAc}), and HCl (P_{HCl}) was used for this purpose.

The P content in suspended sediments was four times higher than in the source soils. This is the result, in part, of the increased Fe concentration in sediment compared to total soil. The sum of P_{OH} and P_{CB} accounted for 38% of the combined P fractions in sediments, while 24% was released by reductants ($P_{\text{CA}}+P_{\text{CBD}}$). Overall, the $P_{\text{CB}}/P_{\text{CB}}$ ratio in sediments was higher than in soils (0.75 ± 0.38 vs. 0.25 ± 0.1). This can be ascribed to the higher ratio of Fe related to poorly crystalline Fe oxides to that related to crystalline oxides in sediments ($Fe_{\text{CB}}/Fe_{\text{CB}}=0.19 \pm 0.07$) than in soils ($Fe_{\text{CB}}/Fe_{\text{CB}}=0.05 \pm 0.02$).

The ratio of Fe_{CB} to Fe_{CB} was higher at low sediment charge in runoff. The mean P/Fe mole ratio in citrate ascorbate extracts (essentially dissolves poorly crystalline Fe oxides) was higher in soils (0.068 ± 0.056) than in sediments (0.022 ± 0.009); in citrate bicarbonate dithionite extracts (dissolves oxides not reduced by citrate ascorbate), it was the same for soils and sediments (0.01). This indicates that poorly crystalline oxides with low P contents are preferentially eroded. The concentration of P fractions associated to Fe oxides in sediments decreased at increased sediment concentration in runoff, due to a decrease in Fe (ca and cbd extractable) with increasing sediment concentration in runoff.
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Keywords: Phosphorus; Fe oxides; Runoff; Sediments; P fractionation

Abbreviations: TP, total P; OP, organic P; cb, citrate bicarbonate; c, citrate; ca, citrate ascorbate; cbd, citrate bicarbonate dithionite; OAc, acetate buffer; PP, particulate P.

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1. Introduction

Phosphorus release from eroded sediments to water constitutes a significant process from an environ-

Phosphorus Fractions and Release Patterns in Typical Mediterranean Soils

Concepción Saavedra and Antonio Delgado*

ABSTRACT

Phosphorus forms dictate the P release potential of soils in agricultural and environmental terms. The main purpose of this work was to study P forms by sequential chemical fractionation in soils typical of Mediterranean areas, establishing correlations between P fractions and soil properties, and identify the relationships of specific P fractions to P release potential as determined using P sinks (anion-exchange resins). To this end, three different fractionation methods were used. A comparison of the results obtained with the three sequential fractionation schemes provides useful information about P forms in representative Mediterranean soils, allowing the distinction of P fractions which include: (i) the more labile P forms (essentially adsorbed P), (ii) most of pedogenic Ca phosphates, (iii) most of low soluble pedogenic Ca phosphates, (iv) lithogenic Ca phosphates, (v) P occluded in poorly crystalline Fe oxides, and (vi) P occluded in crystalline Fe oxides. The ratio of the P fraction, which includes the more labile P forms (essentially adsorbed) to combined non-organic P fractions was negatively correlated with soil pH ($r = -0.83$, $P < 0.001$) and positively correlated with the portion of combined Fe fractions related to poorly crystalline oxides ($r = 0.84$, $P < 0.001$). The greatest of P desorbable from resins (Q_{max} in the Jolimon-Muller equation) was related mainly to the combined P fractions including adsorbed P and precipitated Ca phosphates in the studied soils. The amount of P desorbed at 1 h (Q_{1h}) accounted for a sizeable fraction of Q_{max} (between 29 and 59%), the $Q_{\text{1h}}/Q_{\text{max}}$ ratio being positively correlated with the portion of combined non-organic P fractions related to adsorbed P ($r = 0.66$, $P < 0.01$), and negatively correlated with the portion of combined P fractions related to low soluble pedogenic Ca phosphates ($r = -0.67$, $P < 0.01$).

PHOSPHORUS FERTILIZER reactions determine the dominant potentially labile P forms in soils and hence the proportion of soil P that can be released to the soil solution or water reservoirs. This accounts for the agronomic or environmental significance of P in agricultural soils. In broad terms, P binding to soil particles results from surface adsorption or precipitation. The relative contribution of these two processes is related to soil properties and fertilizer management practices (Afif et al., 1993), precipitation of Ca phosphates is widely assumed to be the dominant reaction in calcareous soils at P concentrations above $10^{-4.2}$ M (Castro and Torrent, 1998; Tunesi et al., 1999).

Because of its low content in soil, the precipitated phase in soil resulting from P fertilizer addition has traditionally been determined with indirect methods based on phase diagrams (Fixen et al., 1983; Havlin and Westfall, 1984). Only ^{31}P NMR spectroscopy has proved an effective

direct method for studying P speciation in acid (Al and Ca related P, Lookman et al., 1996) and calcareous soils (Ca related P, Delgado et al., 2000; Delgado et al., 2002). Iron related P (Fe phosphates or P bound by Fe oxides), however, cannot be examined by this technique. Sequential chemical extraction methods have often been used to study the nature of P forms in soils and sediments. These methods are based on the selective extraction of operationally defined P fractions by using single extractants in a sequential manner. The discrimination of Ca related P (Ca phosphates) from Fe related P has been achieved in some cases (Olsen and Sommers, 1982; Golterman and Bonman, 1988). However, this information may be inadequate with a view to predicting the potential release of P from soils (e.g., no distinction is usually made between soluble and low soluble Ca phosphates or between adsorbed and occluded P in oxides). In calcareous soils, part of extracted P using NaOH (mostly adsorbed P, Olsen and Sommers, 1982) is re-adsorbed by calcite and then released in the following step (citrate bicarbonate), making it difficult to discriminate adsorbed P from P precipitated in soluble Ca phosphates (Williams et al., 1971). Although this shortcoming is shared by the sequential method of Ruiz et al. (1997), this method does distinguish low soluble pedogenic Ca phosphates from lithogenic fluorapatite, and P occluded in poorly crystalline Fe oxides from that occluded in crystalline Fe oxides.

In general, fractionation methods do not quantify the organic fraction by means of a specific extractant; rather, the fraction remaining after inorganic constituents have been removed is taken to be OP (Barbanti et al., 1994). To avoid underestimating OP as result of hydrolysis during removal of inorganic forms in sediments, Golterman (1976) proposed the use of chelating agents at the same pH as the sediment to characterize inorganic P forms (Fe bound P and Ca bound P).

The purposes of this work were to study: (i) P forms in typical Mediterranean soils using three different sequential fractionation methods, (ii) the differences in dominant P fractions between soil types and how these fractions are determined by soil properties, and (iii) the relationships between the P release potential, estimated by means of P sinks (resins), and P fractions in these soils.

MATERIALS AND METHODS

Soils

Seventeen soils from the Guadalquivir Valley, South Spain (Palma del Río, 37°43' N Lat., 5°13' W Long.), were selected

Abbreviations: Cit, citrate; CA, citrate ascorbate; CB, citrate bicarbonate; CBD, citrate bicarbonate dithionite; EDTA, ethylenediamine tetraacetic acid salt; Golterman fractionation method as modified by Díaz-Expósito et al. (1999); OAc, acetate; OP, organic P; OS, Olsen and Sommers (1982) sequential fractionation method; R, Ruiz et al. (1997) fractionation method; TP, total P; WP, water-extractable P.

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Phosphorus Forms in Overland Flow from Agricultural Soils Representative of Mediterranean Areas

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Abstract: Phosphorus (P) losses through overland flow (surface runoff) may contribute to eutrophication of water bodies. The main purpose of this work was to study P forms in overland flow (dissolved and particulate) to identify which can be potentially used by algae. To this end, rainfall on 17 representative soils from Mediterranean areas was simulated, and P forms in overland flow studied by chemical and sink (resin, iron oxide-impregnated paper strip) extraction; sequential chemical fractionation of the suspended sediments was also used to establish "operational pools" with a differential capacity of P release. Total P (TP) in runoff ranged from 0.089 to 0.765 mg L⁻¹ and was mainly related to suspended sediment (particulate P, 86% of TP on average). Iron oxide strip P, which is taken to be an estimate of algal-available P, accounted for 34% of TP on average in runoff samples; most of the P extracted by this sink was particulate P (68%). In most cases, FeO strip P was equivalent to dissolved reactive P (DRP) plus P extracted by NaOH and citrate-bicarbonate in suspended sediment (the more labile P fractions) ($F = X$, $R^2 = 0.82$; $P < 0.001$; $n = 15$). One can thus assume that Fe oxide extracts DRP, adsorbed P on sediments, and P related to highly soluble precipitated Ca phosphates, but it does not extract releasable P through reduction of sorbent surfaces or the organic P that can be mineralized in the bottom of water reservoirs, which must be taken in account to estimate the long-term algal-available P in runoff.

Keywords: Algal-available P, dissolved phosphorus, Fe oxide paper strip, particulate phosphorus, phosphorus fractionation

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Effects of Tillage on Phosphorus Release Potential in a Spanish Vertisol

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No-till (NT) practices usually increase the P content in soil surface. The main purpose of this work was to study the long-term effects of the soil tillage system on the P release potential in the surface layer of a Vertisol from southwest Spain and to correlate it with changes in P content and forms. The three tillage treatments investigated were: (i) conventional tillage (CT) with a moldboard plow and field cultivator; (ii) minimum tillage (MT) with a field cultivator; and (iii) NT, which involved direct sowing into crop residues from the previous year. After 21 yr, NT resulted in enhanced organic matter, Olsen P, organic P, and total P contents relative to CT and MT in the top 5 cm of soil. The ratio of labile inorganic P fractions to P related to sparingly soluble pedogenic Ca phosphates in the surface soil layer was much greater under NT (0.8) than under CT (0.57) or MT (0.55). This was ascribed to a decreased precipitation of sparingly soluble Ca phosphates because of the enrichment in organic matter under NT, and accounted in part for the higher portion of inorganic P related to labile fractions in NT (0.19 vs. 0.09 in CT and 0.10 in MT). The increased P release potential of surface soil as estimated by using P sinks indicated that an increased dissolved P concentration in runoff and a greater amount of potentially releasable P per unit mass of surface soil lost through erosive processes can be expected with NT than with MT or CT.

Abbreviations: CT, conventional tillage; EDTA, ethylenediaminetetraacetic acid; MT, minimum tillage; NT, no-till; WP, water-extractable phosphorus.

Many agricultural soils in Europe have an available P content that clearly exceeds the critical values for P fertilizer response (Behrendt and Boekhold, 1993; Barberis et al., 1996). In this situation, soil P has become more of an environmental concern than an agronomic one in areas of intensive cropping and livestock production, where P loads from soil can promote eutrophication (Shapley et al., 1994; Shapley, 1995).

Overland flow is believed to be the primary origin of P losses from agricultural soils (Shapley and Menzel, 1987; Shapley et al., 1994; Stevens et al., 1999). As readily desorbable P accumulates in topsoil, its concentration decreases with increasing depth (Stamm et al., 1998) and P is transported in solution or associated with eroded particles (Kroonung, 1992). In general, P associated with eroded particles (mainly adsorbed or precipitated P) accounts for most P in overland flow from cultivated agricultural lands (Shapley et al., 1992; Bundy et al., 2001; Saavedra and Delgado, 2006). Thus, an immediate way of decreasing P movement is by minimizing particulate erosion and transport (Uusitalo et al., 2000; Andraski et al., 2003).

The benefits of long-term NT over CT include higher infiltration rates and reduced soil erosion (Dick et al., 1989; Shipitalo and Edwards, 1998), which help to reduce P loss from soils (Chambers et al., 2000; Kinnell et al., 2001). Cultivation methods using no tillage and leaving an undisturbed soil surface during winter exhibit highly reduced P loads (Puustinen et al., 2005); however, NT increases the stratification of soil organic C and nutrient availability in soil (Franzenhebers and Hox, 1996; Crozier et al., 1999;

Duiker and Beegle, 2006). Specifically, enrichment of the soil surface in Bray P-1 (top 5 cm of soil, Hussain et al., 1999), and bicarbonate- and resin-extractable P (top 8 cm of soil, Zibilske et al., 2002) have been reported. This surface enrichment may affect the pattern of P loss from soil; although total P losses are unrelated to soil test P levels, dissolved P concentrations are highly dependent on soil test P levels (Hooda et al., 2000; Andraski and Bundy, 2003; Andraski et al., 2003). Thus, although NT can reduce soil erosion and loss of P associated with eroded particles, this practice can increase dissolved P in runoff (Puustinen et al., 2005). This is of environmental significance because dissolved P is readily available for algae growth (Dik and Heathwaite, 1998; Elholm and Krogerus, 2003), and may increase the bioavailable/total P ratio in overland flow under NT.

Phosphorus forms dictate the P release potential of soils in agronomic and environmental terms (Sartell and Morris, 1992; Saavedra and Delgado, 2005a). The use of sequential fractionation methods to study P forms allows the definition of operational P fractions that differ in the ease with which they can be released from soil to water (Ruiz et al., 1997; Delgado and Torrex, 2000; Maguire et al., 2000). Phosphorus fractionation techniques can thus provide useful information about the P release potential of soils (Saavedra and Delgado, 2005b). The increased P concentration in soil surfaces under NT to which P fertilizer is broadcast, and the increase in organic matter content under this tillage system, may significantly affect the relative ratios between different P fractions in soil (Delgado et al., 2002) and may account for changes in P loss patterns in untilled soils.

The objectives of this work were to determine: (i) how the soil tillage system affects P content and forms in the surface of a Vertisol typical of European Mediterranean areas, (ii) how tillage methods affect the P release potential of soil surfaces as estimated by chemical extraction and the use of P sinks, and (iii) how changes in P fractions can explain changes in estimated P release potential.

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Phosphorus losses in two agricultural systems from South Spain

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