DO PHOSPHORUS TMDLs INTERFERE WITH CROP NUTRIENT RECOMMENDATIONS?

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Background

Historically, phosphorus (P) fertilizer recommendations for crops have been based on the crop grown, soil P test levels, locally correlated and calibrated yield responses, efficient use of P fertilizer, and fertilizer and crop price ratios. With the implementation of TMDLs and the need for reduced P loading in surface waters, P fertilizer applications must also safeguard water quality.

In order to understand the challenges that this presents and the possible changes in P fertilizer recommendations and practices that may be necessary, one first needs to understand the transport mechanisms for P, the effects that runoff, soil erosion, and excessive levels of soil test P and stratification of P in the soil profile has on P losses, and how P fertilizer and manure additions and crop management practices interact with these factors.

The purpose of this paper is to review the P loss mechanisms and the location in the soil profile from which P is being lost, and relate how current tillage and P fertilizer application practices are contributing to P losses.

Mechanisms of P Loss

The primary method by which agricultural P is contaminating surface waters is through surface water runoff, although losses also can occur by wind and by leaching. Losses of P in surface water runoff (Fig. 1) occur primarily by three processes (1) as direct loss of soluble P from P fertilizer and manure before these materials are totally adsorbed by the soil, (2) as dissolution of P in runoff resulting from the intermixing of the runoff water with solute and soil P in the near surface soil zone, and (3) as transport of sediment and organic particulate P materials in runoff as a result of soil erosion (Sharpley, 1985; Daniel, et al. 1994; Lory, 1999).

The application of P fertilizer or manure on the surface of the soil will immediately place the soluble P in these P materials at risk. Nearly all P fertilizers and most manure contain significant quantities of soluble P (Table 1). If the P in these P fertilizer materials intermixes with runoff water before completely being adsorbed by the soil, a significant amount of soluble P can be transported off the field. Conditions that favor direct losses of P are the application of P fertilizer or manure to already wet soil which can then quickly generate runoff, applying P fertilizer or manure on frozen or compacted soil, or applying P fertilizer or manure to any soil that restricts infiltration and favors runoff. Various researchers (Gascho et al. 1999; Daverede et al. 2000) have reported incidences of direct losses of soluble P in runoff. At the Integrated Agricultural Management System (IAMS) site in east-central Kansas, we (Janssen and Pierzynski, 2001) also found this to be a significant source of soluble P loss (Fig. 2). During this three-year study we surface broadcast and deep-banded P on no-till and incorporated P with tillage two out of three years. No P fertilizer was applied the second year. Soluble P concentrations in the runoff, on the average, were 4 to 5 times greater both years following P fertilizer application compared to the year with no P fertilizer applied. Concentrations of soluble P in runoff were highest the first couple of runoff events after P fertilizer application and then declined quickly with repeated runoff events. Deep-banded, and P incorporated by tillage did not cause elevated levels of soluble P. Some agronomists have referred to this short-term, direct loss of soluble P from surface applied P fertilizers and manure as flash soluble P losses (Lory, 1999).

Soluble P in runoff can also be lost as the result of dissolution of P by rainwater intermixing with solute and soil P in the near surface soil zone (top 5 cm of soil). Loss of P by this process is considered to be on going with losses occurring each time there is a runoff event. The amount of P loss by this process is controlled by the chemical properties of the soil, the amount of P accumulation in the near surface soil zone, and the intensity of intermixing of the rainwater and surface soil. Pote et al. (1996) reported that there is a strong linear relationship between soil P test level in the top one inch of soil and losses of soluble P in runoff. Others (Sharpley et al., 1986 and Romkens and Nelson, 1974;) have found similar relationships. The best strategy for preventing this kind of on going, slow leak soluble P loss is to not allow P to accumulate in the near surface soil zone.

Losses of P in runoff water can also occur in the form of particulate or sediment-bound P. This kind of P loss is primarily the result of soil erosion. Factors that influence soil erosion also affect particulate P losses. These factors include soil type, field slope, rainfall intensity and amount, percent crop residue cover, tillage, and all factors that either help protect or dislodge soil or speed up or slow the flow of runoff water. Use of no-till has been one of the most effective means to reduce soil and particulate forms of P losses.

The proportions of dissolved and particulate P in runoff will vary widely depending on the crop grown and the field surface soil conditions. In highly erosive or tilled fields with P fertilizer or manure incorporated, most P losses will occur as particulate P. In pastures or fields with permanent grass cover and with surface broadcast P, the predominant form of P in runoff will generally be soluble P.

Soluble P is the form of P in runoff that is most readily useable by algal and aquatic plants. Particulate P consists mostly of relatively insoluble inorganic P compounds with P absorbed to Fe, Al, and Ca along with smaller amounts of various forms of organic P. Particulate P must undergo desorption, dissolution or mineralization before it affects water quality. Both forms of P losses can cause eutrophication of surface waters. Therefore, both forms of P losses must be controlled.

So From Where Are Most of The P Losses Occurring?

The soil zone from which most of the soluble and particulate P losses are occurring is from a thin layer of surface soil less than 5 cm (two inches) deep (Sharpley 1985). The exception would be if deep-rill soil erosion were occurring. The greater the amount of P fertilizer or manure applied to the surface of this soil zone, or the greater the accumulation of P within this near surface soil zone, the greater will be the potential for P losses in runoff.

Consequently, a simple strategy for minimizing the source component of P loss in surface water runoff would be to keep the concentration of P in this near surface soil zone as low as possible. This has not generally been a high priority in the past. Furthermore, changes in tillage practices have resulted in the increased accumulation of P in this critical surface soil zone. With tillage systems changing from moldboard plow to chisel-plow and field cultivation, and now to no-till, the stratification and accumulation of P in the near surface soil layer has increased (Shear and Moschler, 1969, Griffith et al., 1977). Long-term application of P fertilizer and manure at rates exceeding crop uptake has also contributed to elevated levels of surface soil P.

How Might Future P Fertilizer Recommendations Reverse This Trend?

Soil Test

Soil testing and applying P fertilizer only where P fertilizer is needed will be an important first step. The depth of soil sampling will need to reflect both crop needs and environmental risk. Traditionally, the depth of soil sampling for determining crop needs has been 6 to 8 inches. Some have recommended that a shallower (0-4 inch) sample depth be used for no-till (Whitney, 1982). For environmental purposes the sample depth will need to reflect the very shallow runoff water, soil loss zone. Consequently, a split-depth core sample with separate analysis and interpretations for the shallow depth and the composite depth would have significant advantages over a single depth sample.

P Rate and Threshold P levels

The rate of P recommended and the cutoff-level for which no additional P is recommended will need to be based on soil P test correlation and yield calibration data that is based on today's genetics and tillage practices. Where needed, the rate of P recommended should reflect profitable yield increases or product quality benefits. When soil P test levels exceed crop response levels, no fertilizer should be recommended except possibly for starter P. There is no justification to continually apply P fertilizer beyond the level where there is no longer a crop response. Continued applications will only increase the potential for environmental P problems.

Method of P Application

The recommended method for applying P fertilizer and manure could very well be the most important and necessary change in future P fertilizer recommendations. More importantly the location in the soil profile where the P fertilizer accumulates may be the key to long-term protection of surface water quality. Historically, P fertilizer recommendations for crops have not specified how the P fertilizer was to be applied. That decision was left to producers, except for cases where soil P test levels were low and banding of P was recommended to improve P fertilizer use efficiency, or starter P fertilizer was recommended to improve early season uptake and growth under cool wet field conditions. In most cases, crop producers, out of convenience, cost, or lack of application equipment, have chosen to surface broadcast P. This worked reasonably well during the moldboard plow era, as it was an inversion type tillage operation. As tillage practices changed to chisel-plow and field cultivators, the depth of P incorporation decreased and stratification of P increased. The incorporation depth of P decreased even further with the adoption of no-till. The effects that reduced tillage and broadcast P fertilizer applications can have on the stratification of P in soil is illustrated by profile samples collected after just four years of P fertilizer application in east central Kansas (Janssen, et al., (1998) (Fig. 4). The distribution of P in the no-till system with P broadcast (Fig. 4A) shows the characteristic shallow vertical stratification of P that results from surface-applied P without incorporation. The distribution of P in the chisel-disk, field-cultivate tillage system with the same rate of P broadcast (Fig. 4B) also shows vertical stratification, but with slightly more depth of incorporation than no-till. The distribution of P in the no-till tillage system with deep-banded P (Fig. 4C) has a distinctive deeper pattern of placement centered roughly on the knife outlet depth. Although there is a smearing effect of P above the knife outlet from the tillage action of the applicator knife with deep-banded P, nearly all of the P is concentrated below the critical 5 cm depth, surface soil, runoff water zone. This is not the case with P broadcast on the soil surface.

Various researchers (Mueller et al., 1984; Daverede et al., 2000; Romkens et al, 1973) have studied the effects that tillage and P fertilizer placement can have on losses of P in runoff. In Kansas, we (Janssen, et al, 2000) also have conducted research evaluating the effects of tillage and P fertilizer placement on P runoff losses (Figs. 4 and 5). In a three-year study at the East Central Experiment Field near Ottawa, KS, we found that losses of soluble P varied with tillage systems and P fertilizer treatments. Averaged across three growing seasons, soluble P losses were highest with broadcast P in no-till, intermediate for ridge-till, and least for chisel-disk. The incorporation of the broadcast P in the chisel-disk system greatly reduced soluble P losses. In the ridge-till system, where the broadcast P was only partially covered by the shaving of the ridge at planting, soluble P losses were moderate compared to no P application. In the no-till system, where the broadcast P remained nearly all exposed on the surface of the soil, soluble P losses increased nearly six-fold compared to no P fertilizer applied. In contrast, deep-banded P increased soluble P losses only slightly in all tillage systems. This was because placement of the P fertilizer was below the critical surface soil, runoff loss zone.

Losses of total P in the runoff were also affected by the tillage and P fertilizer treatments. Total P losses were highest with the chisel-disk, field-cultivate system, followed by ridge-till and no-till. Generally, the conservation tillage systems (no-till and ridge-till) reduced soil losses (data not shown) and that reduced total P losses. Most total P in runoff in row-crop systems is the result of sediment P losses. Broadcast P also tended to cause higher total P losses than deep-band P. This could be a reflection of increased P enriched sediment loss with broadcast P.

These data show that conservation tillage systems can reduce total P losses in runoff, but fertilizer P must be sub-surface applied to prevent increased losses of soluble P. With the acreage of no-till increasing and the projections for more growth, P fertilizer placement will become an increasingly important part of fertilizer recommendations.

Timing May be the Only Choice

There will be situations where subsurface placement or incorporation of P is not possible. In those situations, best timing of the P application may be the next best alternative. Application of P fertilizer during periods of low runoff probability should reduce P losses. Timing will be most helpful for prevention of direct or flash soluble P losses. Timing will have less probability of reducing P losses resulting from dissolution of P by rainwater intermixing with the soil surface and losses of particulate P as these are more year-around type losses.

Not all Fields will Require Environmental Safeguards

The potential for runoff can vary widely between regions, watersheds, fields and soils. With runoff being the predominant transport mechanism for loss of P form agricultural fields, the runoff generating characteristics of the fertilizer application site becomes a critical factor in making environmentally sound P fertilizer recommendations. If the receiving site has little or no potential for generating runoff, then requirements for P placement, soil erosion control, and timing of the P fertilizer application is of limited concern, other than the effects that these might have on crop response, economics, or applicator preferences. However, where runoff is likely or conditions exist for even occasional significant runoff, then all of these factors become important. Consequently, in this era of TMDLs a more comprehensive approach for making P fertilizer recommendations is needed today than in the past. This has lead to the concept of P indexes (Lemunyon and Gilbert, 1993).

P index

A P index is designed to identify a field's vulnerability for P loss based on transport (surface runoff, erosion, leaching, and landscape position) and source (soil P and rate, method, and timing of applied P) factors. The sum of several weighted factors is used to rank fields that are at greatest risk for transporting P. Based on these rankings, P fertilizer and manure will need to be recommended differently.

Summary

Application of P fertilizer will continue to be needed to maintain current and future levels of crop production. Some of the phosphorus from these P fertilizer applications will be lost to surface water runoff. However, with the use of soil testing and P-indexing, and the use of soil erosion control measures and sub-surface P applications where needed, these P losses can be largely prevented.

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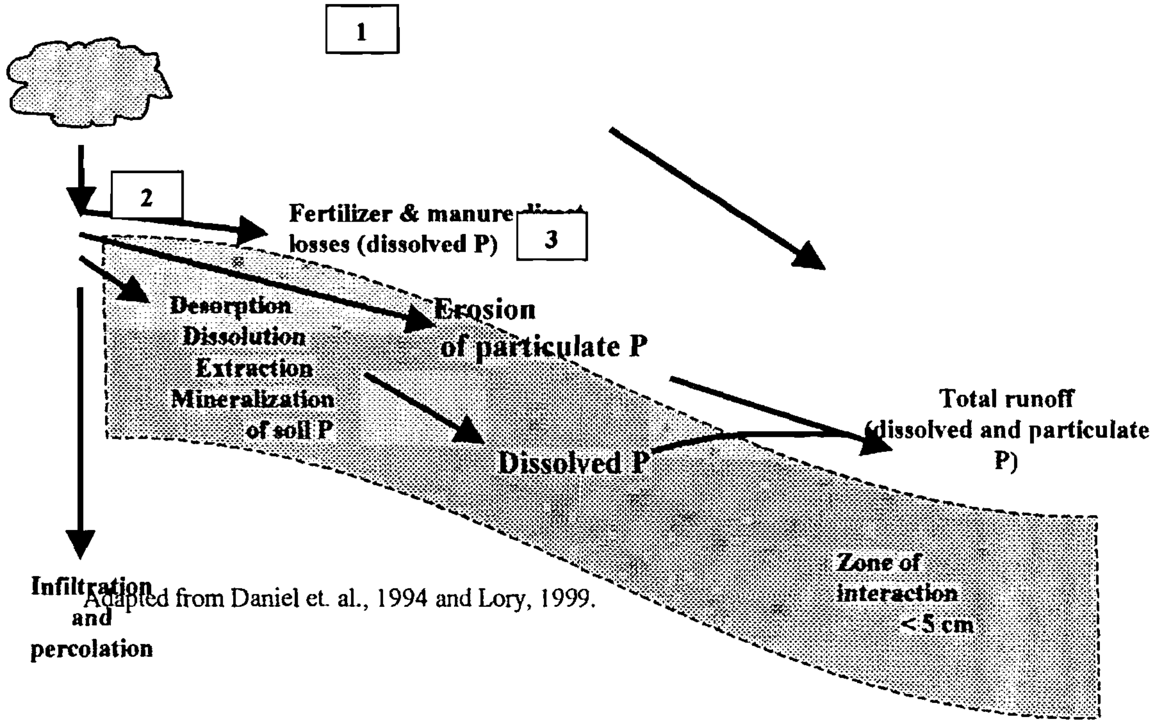

Adapted from Daniel et. al., 1994 and Lory, 1999.

Fig. 1. Processes involved in the transport of dissolved and particulate P in runoff.

Table 1. Water solubility of common phosphorus fertilizer sources.

Source	N	P_2O_5 Content Total	P_2O_5 Content Available	Percent of Available Phosphorus that is Water Soluble
	%	%	%	%
Superphosphate	0	21	20	85
Conc. Superphosphate (Triple)	0	45	45	85
Monoammonium Phosphate (MAP)	11	49	48	92
Diammonium Phosphate (DAP)	18	47	46	90
Ammonium Polyphosphate (POLY)	10	34	34	100
Phosphoric Acid	0	54	54	100
Rock Phosphate	0	34	3 to 8	0

Source: Ohio Agronomy Guide, Ohio Cooperative Extension Service, Bull. 472

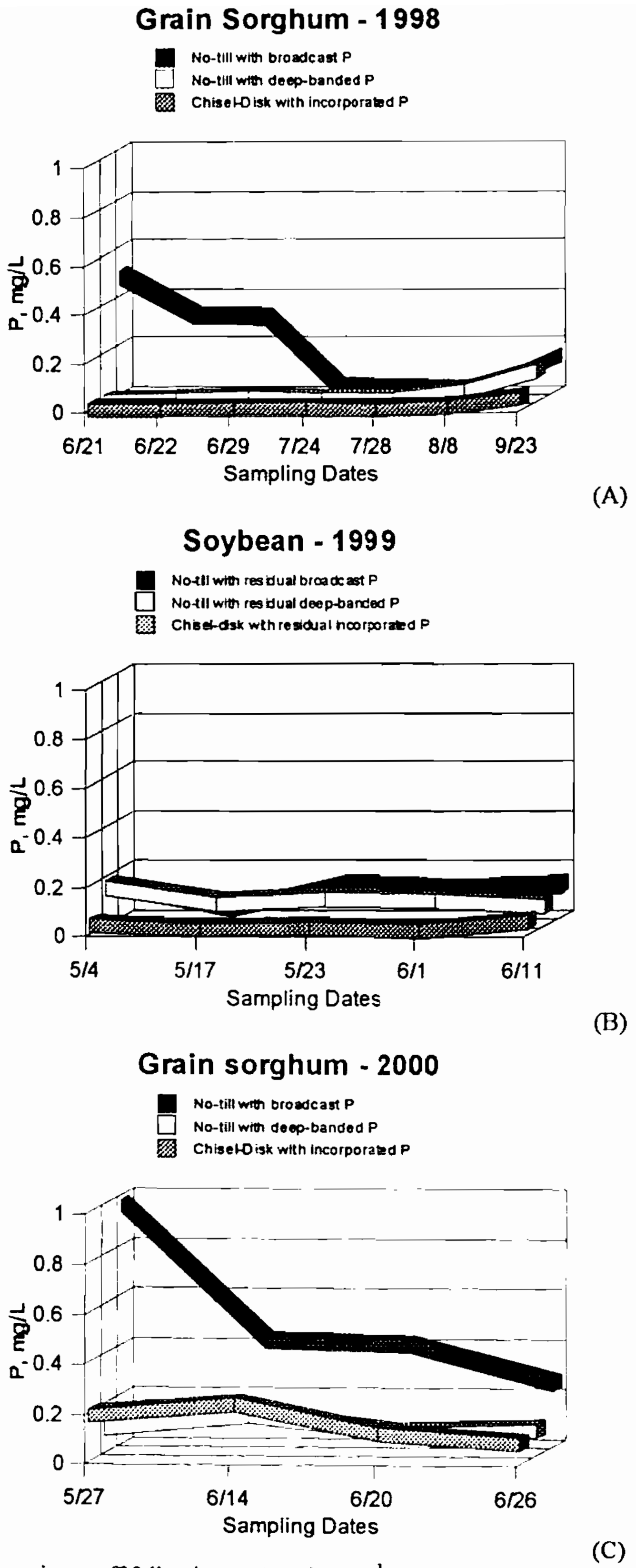

Fig. 2. Soluble P concentrations in runoff following: (A) 16 kg ha $^{-1}$ P applied to grain sorghum June 19, 1998; (B) no P applied to soybean in 1999; and (C) 16 kg ha $^{-1}$ P applied to grain sorghum May 16, 2000.

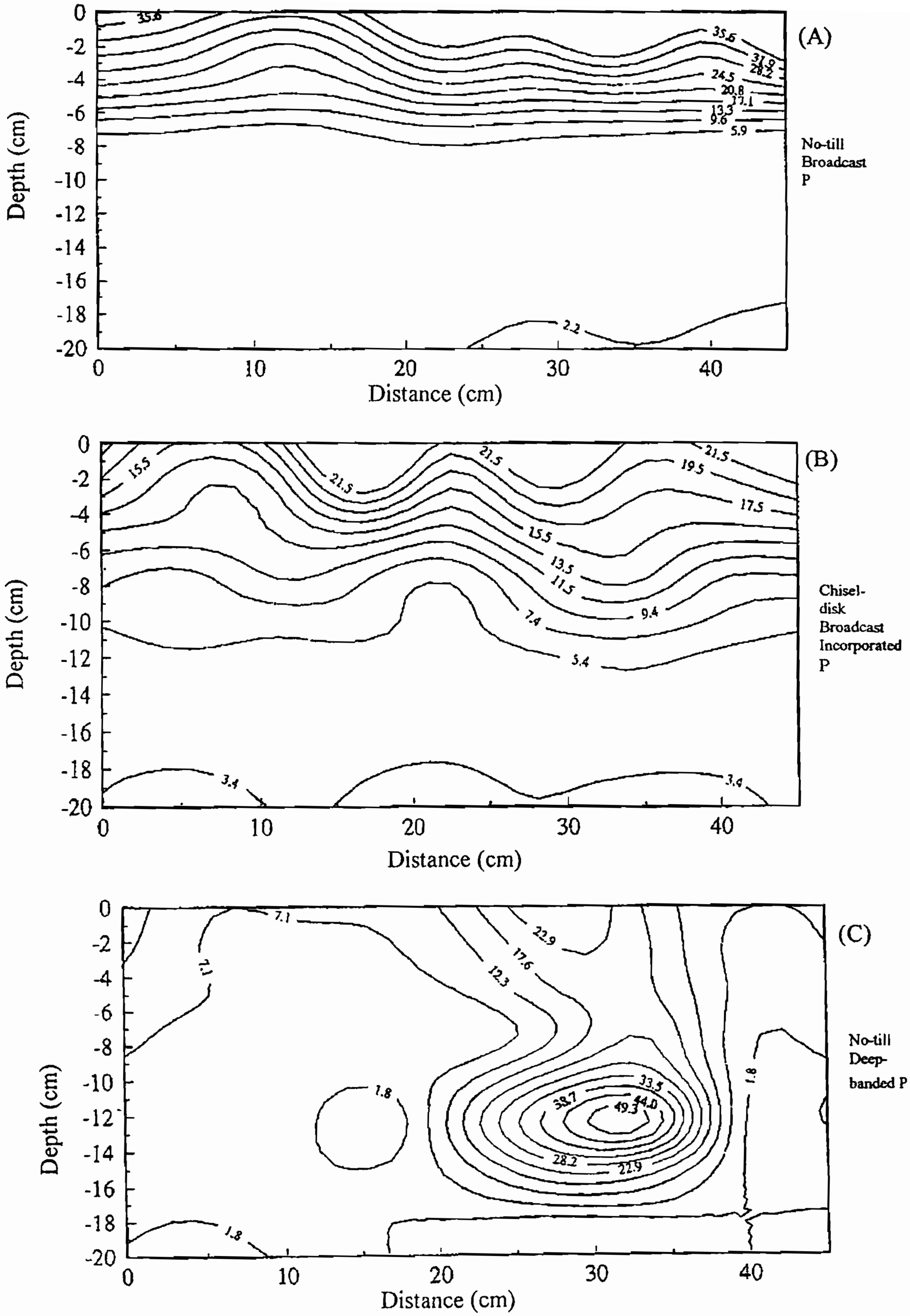

Fig.3. Distribution of residual P in milligrams per kilogram soil following tillage and 4-yr P application at 30 kg ha^{-1}yr^{-1}with (A) P broadcast and no-till; (B) P broadcast and chisel-disk-field-cultivate; and (C) deep-banded and no-till.

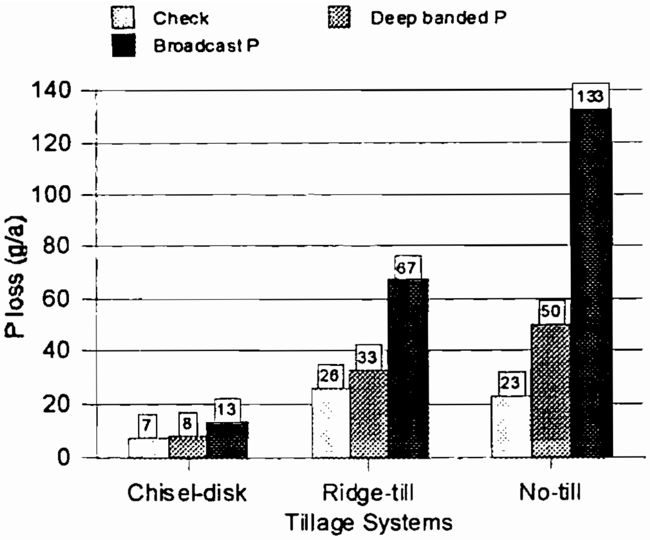

Fig. 4. Effects of tillage and P rate/placement on soluble P losses in runoff (3-yr average).

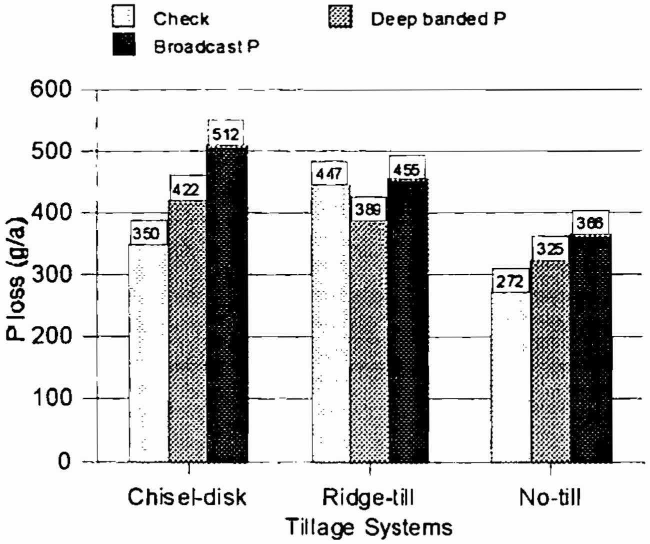

Fig. 5. Effects of tillage and P rate/placement on total P losses in runoff (3-yr average).

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