OLSEN-P DISTRIBUTION IN A THIN BLACK CHERNOZEM AS INFLUENCED BY FERTILIZERS AND CROP ROTATIONS

C.A. Campbell[1], G.P. Lafond[2] and V.O. Biederbeck[1]

[1]Research Station, Research Branch, Agriculture Canada, Swift Current, Saskatchewan, S9H 3X2; [2]Experimental Farm, Research Branch, Agriculture Canada, Indian Head, Saskatchewan, S0G 2K0.

ABSTRACT

Inorganic phosphorus (P) is generally believed to be relatively immobile in Chernozemic soils. However, available P (e.g., Olsen-P) has been found at depth in some soils and this has been postulated to be either the result of leaching or of transportation by plant roots. Legumes, in particular, are believed to be involved in the latter mechanism. A long-term (34-yr) crop rotation study conducted on a heavy clay, thin Black Chernozemic soil at Indian Head, Saskatchewan, was sampled to a depth of 4.5 m in May and September, 1991, to determine the influence of fertilization, cropping frequency, legume green manure and legume-grass hay crops on Olsen-P distribution in the soil profile. The results indicated that Olsen-P may indeed leach in Chernozemic soils, especially when fallow-containing cropping systems are fertilized. It also appeared that deep rooted legumes, such as sweetclover green manure and alfalfa-bromegrass hay crops do increase Olsen-P in the subsoil, possibly through root decomposition <u>in situ</u> or some other mechanism.

INTRODUCTION

Inorganic P is known to be relatively immobile in soils because it is readily fixed by Ca and Mg in neutral or alkaline soils, by Fe or Al in acid soils, and by clays (Russell 1973). Nonetheless, some workers have isolated large amounts of $NaHCO_3$-extractable-P, i.e., Olsen-P (Olsen 1954) as deep as 2 m in soils in Colorado (Trierweiler 1961). Bowman and Savory (1992) also found high amounts of organic P at 2.25 - 2.55 m in Colorado soils.

The mechanism by which available P reaches such depths, is the subject of much speculation. Plants are well known to be able to cycle P via their roots (Russell 1973); thus Read and Campbell (1981), in trying to account for the significant gradual increase in Olsen-P to 1.2 m depth in a heavily fertilized Brown Chernozemic soil in southern Saskatchewan, speculated that this mechanism was involved. But, Richards and Belanger (1989) working on an acidic soil in Eastern Canada, ascribed P increase at depth (0.45 - 0.6 m) to leaching. Phosphorus can leach in soil if the P is in the organic form, such as low molecular weight fulvic acids, which have been shown to play a key role in the genesis of Spodosols (Schnitzer and Desjardins 1969). However, only a recent study by Schoenau and Bettany (1987) have provided any evidence of a similar mechanism being possible in Chernozemic soils.

There is a common belief that biennial and perennial legumes, because of their deep roots, and intense mycorrhizal infection, have the ability to solubilize and take up P from the subsoil; then, when they are plowed under, the roots decompose and release this P, thereby increasing soil P availability for succeeding crops (Saskatchewan Agriculture, Soils and Crops Branch 1986). However, no scientific evidence supporting this concept has been provided.

A long-term crop rotation study, initiated in 1958 at the Agriculture Canada Research Station at Indian Head, Saskatchewan (Zentner et al. 1987) allowed us to assess some of the aforementioned questions.

The objective of this study was to determine the influence of (a) fertilizer, (b) cropping frequency, (c) legume green manure, and (d) legume-grass hay crops, on Olsen-P distribution at depth in the soil profile.

MATERIALS AND METHODS

General Description of Rotations

This rotation study has been described elsewhere (Zentner et al. 1987) therefore, we will only present a brief outline of the experiment here plus details pertinent to this P study.

The long-term crop rotation experiment at Indian Head involves 11 crop rotations; we discuss eight (Table 1). The experimental area is situated on Indian Head heavy clay, a thin Black Chernozemic soil. The pH of the 0 - 0.15 m depth is about 7.5 in dilute $CaCl_2$ and the organic N concentration is about 0.2%.

The plots, each 4.5 m x 33.5 m, with ample roadways, are organized in a randomized block design with four replicates. All phases of each rotation were present each year. All tillage and cultural operations were performed with field-sized equipment. Sweetclover as green manure and alfalfa-bromegrass as hay crops, were undersown with the preceeding wheat crop.

Rates of N and P fertilizer applied to rotations receiving fertilizer (neither legume-containing rotations received any fertilizer) varied over the study period (Zentner et al. 1987). During 1958-1977 fertilizer N as ammonium nitrate-phosphate (23-23-0), and P as monoammonium phosphate (11-48-0) were applied according to rotation specifications and the general recommended rates for this region. Since 1978, N as ammonium nitrate (34-0-0) and P as 11-48-0 were applied based on soil test levels of N and P determined in October. On average, wheat grown on fallow annually received 6 kg N ha^{-1} over the period 1958 to 1977, and 10.5 kg ha^{-1} from 1978 to 1991; wheat grown on stubble annually received 24 kg N ha^{-1} from 1958 to 1977 and 76 kg N ha^{-1} thereafter. Phosphorus was generally similar for wheat on fallow and wheat on stubble over the study period, averaging about 8-12 kg P ha^{-1} annually.

Soil Sampling for Deep Distribution of Olsen-P and Soil Moisture

We took soil cores to a depth of 4.5 m on May 28 and September 4, 1991, in each of the four replicates of designated rotation phases (Table 1) using a Giddings soil corer. The influence of rotation phase on Olsen-P was also assessed by sampling the fallow, wheat on fallow, and final hay phases in the 6-yr rotation. Two holes were drilled per plot and the soil divided into 0.3 m layers. Subsamples of known length were taken from each 0.3 m layer for D_b and soil moisture determination (gravimetrically). The remaining soil samples from two 0.3 m lengths were combined to give one sample per depth layer. This soil was air-dried immediately, ground and sieved to < 2 mm aggregates and stored until analyzed for Olsen-P (Hamm et al., 1970) several months later (all P analyses done at same time). The procedure involved shaking the soil with 0.5 M sodium bicarbonate at pH 8.5, in the presence of charcoal to remove bicarbonate-extractable organic P, and determining the bicarbonate-extractable inorganic P on an auto-analyzer. The moisture contents (% by wt) of the soil were converted to volumetric units (ha-cm) by multiplying by the length of the segment and its D_b.

Part of the soil was used to determine particle size distribution (Bouyoucos 1928), and part for determining soil moisture potential characteristics on pressure plate and membrane (Table 2).

Table 1. Crop rotations sampled and their previously determined† organic matter nitrogen content

Rotation‡ sequence	N and P fertilizer applied	Organic N ($t\ ha^{-1}$ in 0-0.15 m)
F-(W)	No	2.94
F-(W)	Yes	3.04
F-(W)-W	No	2.97
F-(W)-W	Yes	3.24
GM-(W)-W	No	3.37
(F)-(W) -W-H-H-(H)	No	3.48
Cont (W)	No	3.17
Cont (W)	Yes	3.46

†Organic N measured in 1987 (Campbell et al. 1991).

‡F = fallow, W = spring wheat, GM = sweet clover green manure, H = alfalfa-brome-grass cut for hay, Cont = annual cropping. Phases in parenthesis were sampled.

Table 2. Some selected characteristics of Indian Head soil

Soil layer (m)	Bulk density ($Mg\ m^{-3}$)	Particle Size Distribution: Sand (%)	Silt (%)	Clay (%)	Moisture content at: -0.03 M Pa (ha-cm)	-4.0 M Pa (ha-cm)
0.0-0.3	1.28	13.6	19.4	67.0	16.9	10.1
0.3-0.6	1.35	9.2	12.1	78.7	17.1	10.6
0.6-0.9	1.46	10.8	8.3	80.9	17.3	9.6
0.9-1.2	1.60	28.1	24.0	47.9	15.2	7.4
1.2-1.5	1.74	29.0	24.2	46.8	14.8	6.6
1.5-1.8	1.67	30.7	23.8	45.5	13.9	6.0
1.8-2.1	1.66	27.4	27.6	45.0	13.9	5.7
2.1-2.4	1.67	22.4	24.2	53.4	15.6	7.0
2.4-2.7	1.70	26.0	24.3	49.7	15.2	6.6
2.7-3.0	1.81	22.4	26.5	51.1	16.9	7.3
3.0-3.3	1.69	27.3	31.0	41.7	14.9	6.0
3.3-3.6	1.77	26.8	35.2	38.0	14.6	5.0
3.6-3.9	1.85	32.4	32.7	34.9	14.4	5.2
3.9-4.2	1.90	38.3	30.9	30.8	13.4	4.7
4.2-4.5	2.01	42.6	29.2	28.2	13.5	4.9

†Values in parentheses are (±) standard deviations.

Meteorological data were collected at a meteorological site located about 1 km from the test site. The precipitation data are presented in Table 3.

Statistical Analysis

The Olsen-P and soil moisture results were analyzed: (i) as a split plot with rotation phase as main plot and depth as subplot for samples taken on May 28, 1991; (ii) as a split-split plot with time of sampling as main plot, rotation phase for wheat on fallow and Cont W treatments as sub-plot, and depth as sub-subplots; and (iii) as a split-split plot analysis with sampling time as main plot, rotation phase as sub-plot and depth as sub-sub-plot to determine possible effects of rotation phase in the 6-yr rotation. In these analyses LSDs were calculated for comparing treatment means according to Little and Hills (1978).

RESULTS AND DISCUSSION

Effect of Fertilizer and Cropping Frequency

Analysis of results for samples taken in May 1991 showed evidence of a buildup of Olsen-P in the top 0.3 m wherever fertilizer has been applied regularly (Fig. 1). This is not surprising and reflects the fact that plants take up a very small proportion of the P applied each year (Campbell et al. 1984; Stewart et al. 1989). Olsen-P in the surface soil layers was higher under fallow-containing systems than under annually cropped systems, in spite of the much higher amount of P applied to Cont W over the years (Table 4), probably because of the much greater amount of P uptake in the latter system as well. The buildup in Olsen-P in fertilized monoculture wheat systems tended to be reflected in layers below the rooting zone of the wheat, to about 1.5 m. This was particularly true of the fallow-containing systems (Fig. 1) and might be an indication that some P is being leached with periodic movement of water into the subsoil (Fig. 2) in wet years. Continuous wheat, generally showed lowest amounts of Olsen-P in the subsoil because it keeps the soil drier for longer periods and because it probably immobilized more P due to the greater amounts of crop residues it produces. Fertilized Cont (W) exported more P in grain than the fallow-containing systems, but while exported P was exactly balanced by P fertilizer in fallow systems, applied P exceeded exported P in the Cont W (Table 4). Thus, these differences in P balance do not explain the higher Olsen-P we observed under the well fertilized fallow-containing systems.

Effect of Legumes

The effect of legumes on Olsen-P contents in the subsoil, although not always significant, showed consistent evidence of higher amounts in the subsoil under legume green manure and especially under alfalfa-brome hay crops than under unfertilized F-W-W (Fig. 1, bottom). In fact, the Olsen-P in the subsoil under the hay system was generally higher than all other systems at the 2.7 to 3.3 m depth. One contributor to this higher Olsen-P under legumes could be related to higher VA mycorrhizal activity. Legume roots are known to be heavily infected by such fungi which will solubilize calcium phosphates. The higher Olsen-P under legumes may also be related to rooting depth. In Montana, Black et al. (1982) reported that sweetclover could root to 1.8 to 2.4 m and alfalfa as deep as 4.3 m under ideal growing conditions. There was evidence from the soil moisture distribution data (Fig. 2) that hay crops withdrew moisture to at least 2.4 m in our study. We speculate that plow-down of the legumes is followed by decomposition of roots and release of their P _in situ_; some of this mineralized P is then extracted as Olsen-P. A third possibility may be that P is leached in low molecular weight, labile organic form, or as inorganic phosphate complexed to soluble organic matter (Frossard et al. 1989). These rotations, including the 6-yr forage-containing system, did show evidence of considerable NO_3 -N leaching to depth in past and recent years (Campbell et al., 1993).

Table 3. Monthly precipitation† received at Indian Head during the study period compared to the long-term average for this area

	Monthly precipitation (mm)			
Month	1990	1991	Study period (1958-1991)	Long-term (90-yr mean)
January	29	3	19	21
February	6	12	15	18
March	52	24	21	22
April	23	48	27	28
May	38	60	51	50
June	102	123	68	74
July	105	48	62	53
August	75	45	51	56
September	5	32	42	42
October	9	27	24	25
November	7	11	17	17
December	32	35	22	22
Total	483	468	419	428

†Growing season (1 May to 31 August) precipitation totalled 319, 277, 232 and 233 mm for 1990, 1991, the study period, and for the long-term, respectively.

Our results appear to support the general theory that legumes can increase P availability in soils (Saskatchewan Agriculture Soils and Crops Branch 1986), although we doubt that this increase in P availability would be sufficient to preclude the need for addition of some fertilizer P. Furthermore, much of this subsoil P is situated beyond the rooting depths of spring wheat. A deeper rooting crop such as winter wheat or safflower might be able to assimilate more of this deeper available P. However, the deep-rooted legume forage-containing rotation also depleted soil moisture in the 1.5 to 2.4 m depth and this might hinder uptake of subsoil available P.

Olsen-P Changes During the Growing Season

The analysis to determine whether any changes in Olsen-P could be detected over the growing season showed a significant interaction between crop rotation and depth ($P < 0.0001$). Further, time of sampling was significant at $P < 0.10$ and the interaction of time of sampling x depth was significant at $P < 0.20$. Because we have discussed the crop x depth interaction for samples taken in May 1991 we will not discuss this further because the conclusions reached are generally the same. However, we have presented the Olsen-P content in the 0 - 1.2 m layer

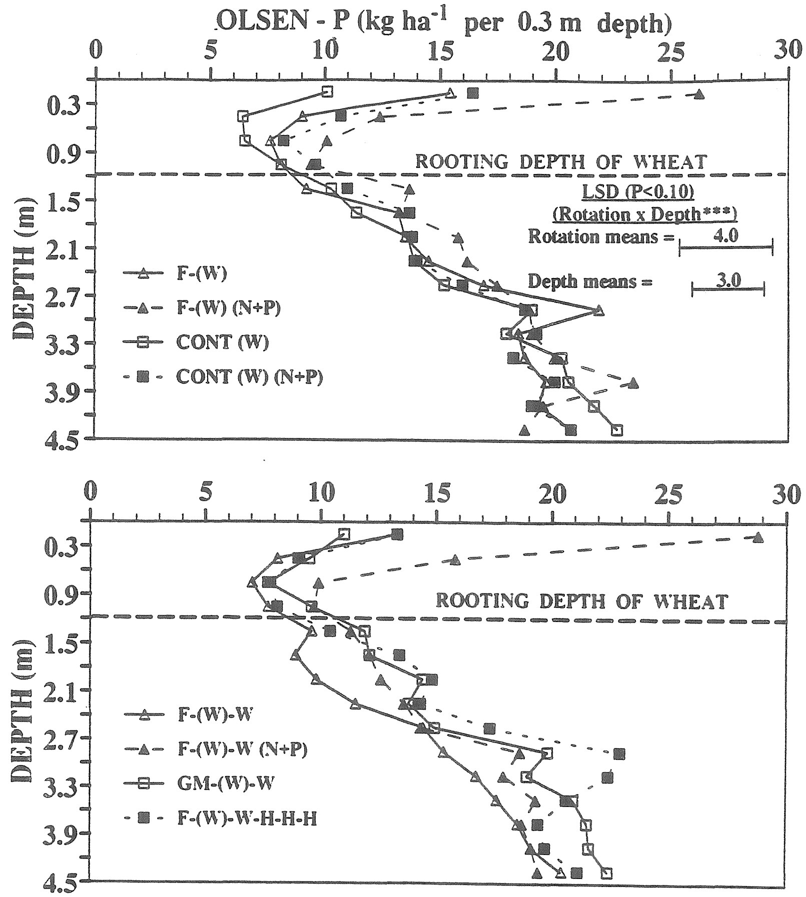

Figure 1. Olsen-P distribution in soil profile at Indian Head, Sask. (top): Effect of fertilizer and cropping frequency; (bottom): effect of sweetclover green manure and alfalfa-bromegrass hay crops in rotation with spring wheat (sampled May 28, 1991). (The LSD's shown pertain to both top and bottom).

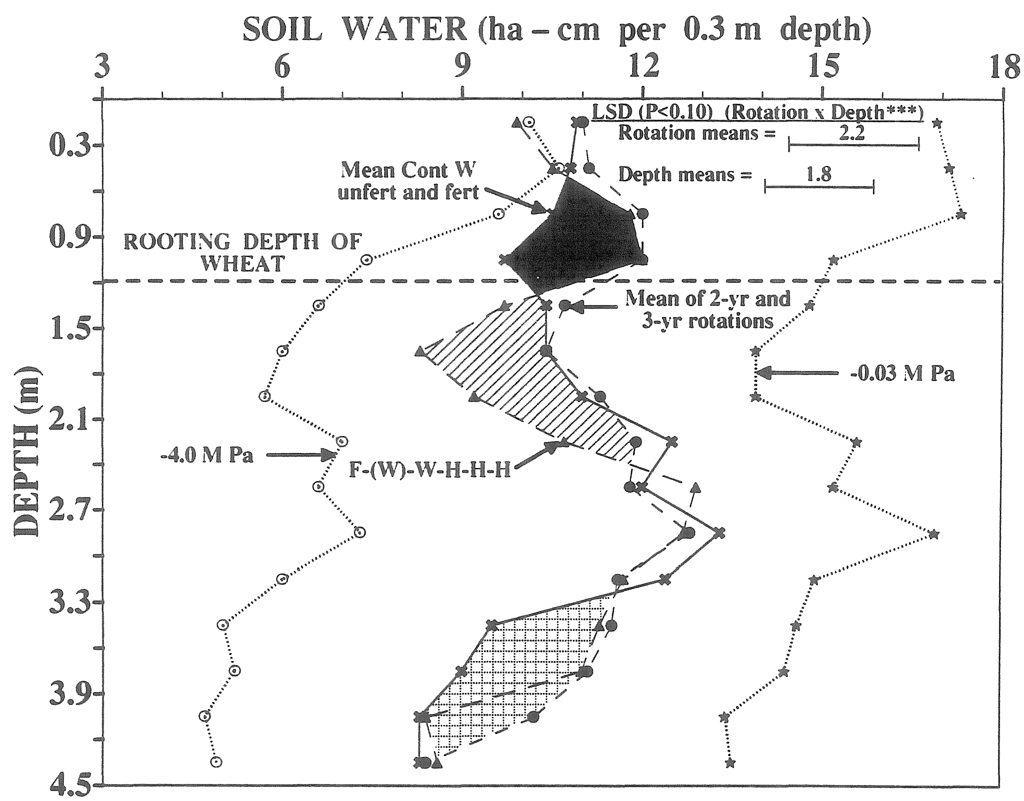

Figure 2. Effect of cropping systems on water distribution in soil profile. (Values are averaged over time of sampling, and also over fertilizer and fallow treatments because they were generally not significantly different in most soil layers).

Table 4. Estimated amount of P exported in grain from rotations during 34-yr period (1958-1991) and amount of P applied as fertilizer

Yields and P exported† from system	Rotation Phase														
	F-(W)	F-(W) (N+P)	F-(W)-W	F-W-(W)	F-(W)-W (N+P)	F-W-(W) (N+P)	GM-(W)-W	GM-W-(W)	F-(W)-W -H-H-H	F-W-(W) -H-H-H	F-W-W- (H)-H-H	F-W-W- H-(H)-H	F-W-W- H-H-(H)	Cont (W)	Cont (W) (N+P)
Mean annual yield (kg ha^{-1})	2176	2479	2302	1097	2604	2013	2509	1437	2701	1845	1189	2641	2827	1029	1960
Mean annual P exported (kg ha^{-1})	9.1	10.4	9.7	4.6	10.9	8.5	10.5	6.0	11.3	7.8	3.1	6.9	7.4	4.3	8.2
P exported from rotation‡ in 34 yr (kg ha^{-1})	155	177	157		213		182				200			147	280
P applied as fertilizer in 34 yr (kg ha^{-1})	0	176	0		216		0				0			0	306

†Assumed %P in wheat grain = 0.42; in alfalfa = 0.28; in grass = 0.22. Assumed hay = 50% alfalfa and 50% grass.

‡For the 2-yr rotation this was the amount of P in grain for wheat on fallow x 17; for the 3-yr rotations this was sum of P in grain for the two crop years x 11; for Cont W it was the amount for annual wheat x 34; and for the 6-yr rotation it was the sum of P in wheat grain and hay in 5 crop years x 5.5.

(rooting depth of wheat) to demonstrate that this is where most of the growing season change in Olsen-P occurred (Fig. 3). The decrease in P due to plant uptake was mainly apparent in the fertilized systems and in the legume-containing systems, perhaps because these were the systems providing the greatest plant biomass (and thus P uptake). Although we were able to find evidence that P uptake influences Olsen-P at Indian Head where it is humid and yields are large, Campbell et al. (1984) were not able to demonstrate this relationship effectively in the much drier, lower yielding conditions at Swift Current.

Effect of Rotation Phase

The analysis of the rotation phase data in the 6-yr rotation showed that time of sampling x rotation phase was significant ($P < 0.05$). The results showed some evidence of P mineralization during the growing season coupled with possible leaching of Olsen-P (Fig. 4, top). Conversely, cropping the system to wheat depleted Olsen-P in the top 1.2 m as expected (Fig.4, middle and bottom). There was no evidence of the deep depletion of Olsen-P following the third year hay crop (Fig. 4, bottom) and we could not explain the apparent lower levels of Olsen-P between 3.3 and 4.5 m under this system.

CONCLUSIONS

This long-term (34-yr) crop rotation study at Indian Head provided evidence indicating that P may not be as immobile in soil as we are lead to believe. Although it is not nearly as mobile as nitrate, it appears that Olsen-P can, over time, be leached beyond the root zone of wheat in fertilized fallow-containing cropping systems even on chernozemic soils. As well, there was evidence supporting the common belief that deep rooted crops, such as legumes, may solubilize and use P at depth; thus, upon decomposition of the roots, the mineralized P becomes available in situ and can be extracted as Olsen-P. However, the amount of Olsen-P made available in this way does not appear to be substantial enough to preclude the requirement for additional fertilizer P, if acceptable levels of crop production are to be achieved.

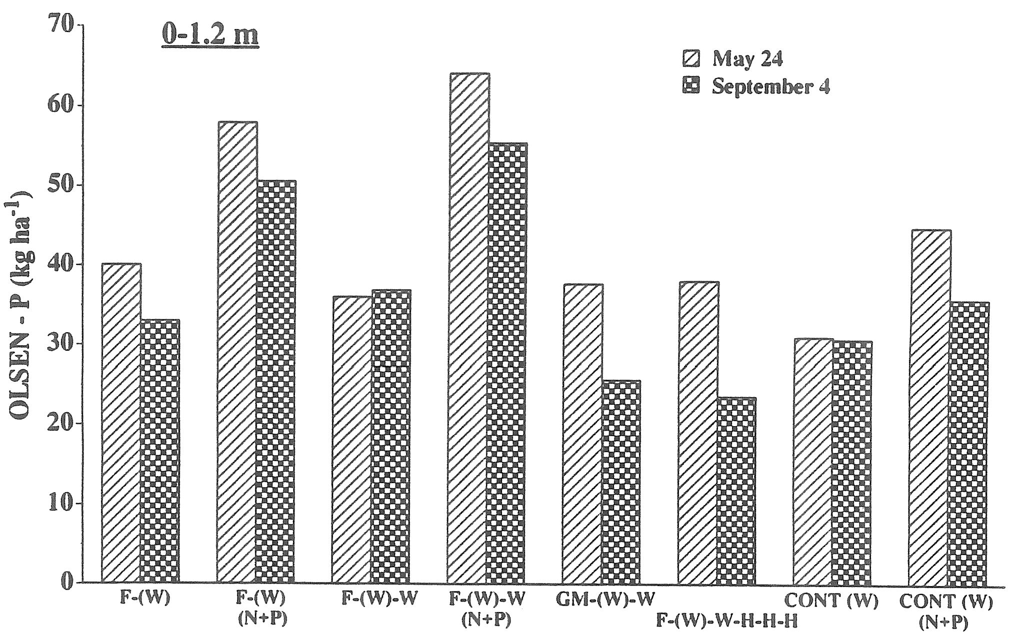

Figure 3. Changes in Olsen-P in the cereal root zone (0-1.2 m) between May 28 and September 4, 1991 for the 8 rotation treatments sampled.

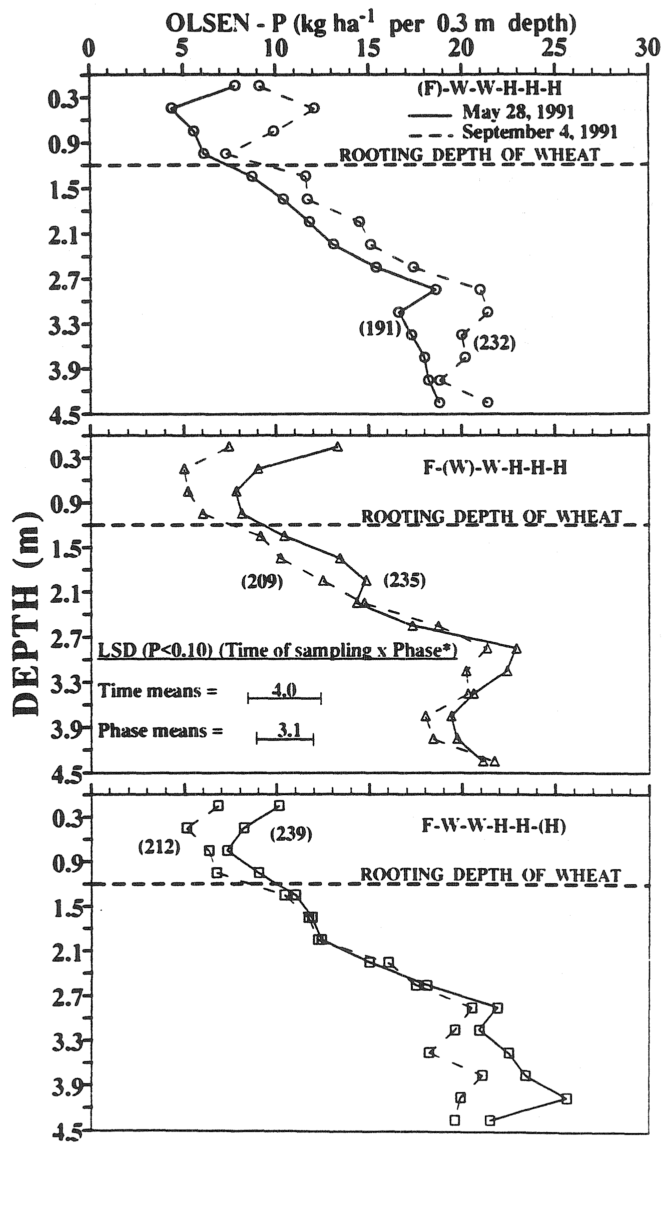

Figure 4. Effect of rotation phase in F-W-W-H-H-H rotation on deep distribution of Olsen-P measured on May 28 and September 4, 1991. (The phase in parentheses was the one sampled and the numbers in parentheses denote total Olsen-P in 0-4.5 m). (The LSD's shown pertain to all three phases).

ACKNOWLEDGEMENT

We wish to acknowledge technical assistance of D. Hahn, R. Ljunggren, P. Taylor, K. Kattler and B. Blomert. This project was partly funded by a grant from the National Soil Conservation Program of Canada.

REFERENCES

Black, A. L., Siddoway, F. H. and Aase, J. K. 1982. Soil moisture use and crop management (dryland) pp. 215-231. In Soil Salinity, Proc. First Ann. Western Prov. Conf., Rationalization of Water and Soil Research and Management. Alta. Nov. 29 - Dec. 2, 1982.

Bouyoucos, G. J. 1928. The hydrometer method for making a very detailed mechanical analysis of soils. Soil Sci. 26:232-238.

Bowman, R. A. and Savory, D. J. 1992. Phosphorus distribution in calcareous soil profiles of the Central Plains. Soil Sci. Soc. Am. J. 56:423-426.

Campbell, C. A., Lafond, G. P., Leyshon, A. J., Zentner, R. P. and Janzen, H. H. 1991. Effect of cropping practices on the initial potential rate of N mineralization in a thin Black Chernozem. Can. J. Soil Sci. 71:43-53.

Campbell, C.A., Lafond, G.P. and Zentner, R.P. 1993. Nitrate leaching in a Udic Haploboroll as influenced by fertilization and legumes. J. Envir. Quality (Submitted).

Campbell, C. A., Read, D. W. L., Winkleman, G.E. and McAndrew, D. W. 1984. First 12 years of a long-term crop rotation in southwestern Saskatchewan. Bicarbonate-P distribution in soil and P uptake by the plant. Can. J. Soil Sci. 64:125-137.

Frossard, E., Stewart, J.W.B. and St. Arnaud, R.J. 1989. Distribution and mobility of phosphorus in grassland and forest soils of Saskatchewan. Can. J. Soil Sci. 69: 401-416.

Hamm, J. W., Radford, F. G. and Halstead, E. H. 1970. The simultaneous determination of nitrogen, phosphorus and potassium in sodium bicarbonate extracts of soils. pp. 65-69. In Technicon International Congress, Advances in Automatic Analysis, Industrial Analysis 2. Futura Publ. Co., Mt. Kisco, NY.

Little, T. M. and Hills, F.J. 1978. Agricultural experimentation - design and analysis. John Wiley and Sons.

Olsen, S. R., Cole, C. V., Watanabe, F. S. and Dean, L. A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA, Circ. 939. U.S. Gov't Print. Office, Washington, D. C.

Read, D. W. L. and Campbell, C. A. 1981. Bio-cycling of phosphorus in soil by plant roots. Can. J. Soil Sci. 61:587-589.

Richards, J. E. and Bélanger, G. 1989. Movement to the sub-soil of P applied to an acidic soil cropped to timothy-grass for twenty six years. Can. J. Soil Sci. 69:875-878.

Russell, E. W. 1973. Soil conditions and plant growth. 10th ed. Longman Group Ltd., London, England.

Saskatchewan Agriculture, Soils and Crops Branch. 1986. Soil Improvement with Legumes. Bulletin M10-86-02. Regina, SK.

Schnitzer, M. and Desjardins, T. G. 1969. Chemical characteristics of a natural soil leachate from a humic podzol. Can. J. Soil Sci. 49:151-158.

Schoenau, J. J. and Bettany, J. R. 1987. Organic matter leaching as a component of carbon, nitrogen, phosphorus and sulfur cycles in a forest, grassland, and gleyed soil. Soil Sci. Soc. Am. J. 51:646-651.

Stewart, J. W. B., McKenzie, R. H., Moir, J. O. and Dormaar, J. F. 1989. Management effects on phosphorus transformation and implications for soil test recommendations. Pages 526-543. In Soils and Crops Workshop. Sask. Advisory Council on Soils and Agron., Univ. of Sask. Feb. 16 and 17, 1989.

Trierweiler, J. F. 1961. Vertical distribution of available phosphorus in the Fort Collins Series. Masters Thesis. Colorado State Univ., Fort Collins, CO.

Zentner, R. P., Spratt, E. D., Reisdorf, H. and Campbell, C. A. 1987. Effect of crop rotation and N and P fertilizer on yields of spring wheat grown on a Black Chernozemic clay. Can. J. Plant Sci. 67:965-982.