TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

PROCESSES INVOLVED IN MOBILIZATION OF PHOSPHORUS IN DIFFERENT FARMING SYSTEMS IN SOUTHWESTERN ONTARIO: NUTRIENT LEVELS IN PLANT TISSUES AND SOILS

FINAL REPORT

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PREFACE

This report contains partial results of a broader research project which constitutes the first author's Ph.D. thesis. Most of the research presented herein was financed by the TED-SWEEP Program. We included some supplementary information obtained from the broader study, which was supported by the Natural Sciences and Engineering Research Council of Canada and by Conselho Nacional de Desenvolvimento Cientifico e Tecnológico (CNPq), Brazil, who provided financial support to the first author.

The complete version of this research will be released upon completion of the project, which is anticipated to October 1, 1991.

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EXECUTIVE SUMMARY

The effects of the application of different types of phosphorus-containing fertilizers (rock P, super phosphate and compost) were examined on six different farms in order to identify some of the critical parameters for the mobilization of phosphate. The farms (three organic and three conventional) provided a gradient of conditions ranging from long-term organic to moderately intensive conventional. Three other experiments examined how crop, soil, and residue management practices on a long-standing organic farm affect mobilization of native and applied phosphate. The main findings of these four experiments are summarized below:

(1) RESPONSES TO DIFFERENT PHOSPHORUS FERTILIZERS IN ORGANIC AND CONVENTIONAL FARMING SYSTEMS

Two methods of extracting soil P were compared: anionic resin and sodium bicarbonate. A significant positive correlation between the two extraction methods was found. However, only the resin extraction method was sensitive enough to detect statistically significant differences between the fertilizer treatments.

Applications of super phosphate and compost each resulted in significant higher ($p< 0.05$) soil P (resin) than in controls in 3 out of 9 comparisons. On all farms, the values for soil P (resin) in compost and super phosphate treatments were numerically higher than those in controls. There was no statistically significant response to rock P.

Percent of P in one month old barley plants was significantly correlated with soil P (resin). There was no correlation of percent the percent of P in barley leaves at the heading stage with soil P. Over all farms, barley grain yields were significantly correlated to the percent of P in one month old plants. However when farms were considered individually this correlation was not always significant.

Percent of P in barley plants was not significantly affected by the fertilizer treatments except in one organic farm. Grain yields were significantly affected by the treatments only in one (conventional) farm.

Mycorrhizal infection tended to be lower on the super phosphate treatment on all farms. There was no indication that the percent of mycorrhizal infection was highest on the organic compared to the conventional farms. Similarly, there was no indication of either root or soil phosphatase activities being higher in one of the two types of farms.

(2) EFFECT OF THREE TILLAGE/STRAW TREATMENTS ON SOIL P AND CROP NUTRITION.

Three tillage treatments were imposed on a field after barley was harvested: mouldboard ploughing, discing, both with barley straw removed and discing with barley straw retained. In the second year, three P containing fertilizers (as in experiment 1) were superimposed on the main tillage treatments. Soil fertility and nutrient contents of two different crops that followed these treatments were examined.

The disk + straw treatment increased soil P (resin) one year after the tillage treatments were imposed. As in experiment 1, no significant differences were found when soil P was extracted with sodium bicarbonate. Grain yields of maize, soil phosphatase activity and P concentration in maize grains were also higher under the disc + straw treatment. Compost and super phosphate increased soil P but no effect of rock phosphate was observed.

Our data indicates that the tillage/straw regime by itself can improve P nutrition.

(3) EFFECTS OF GREEN MANURING AND ROCK PHOSPHATE ON P NUTRITION OF DIFFERENT CROPS

Different green manures (faba beans, oil seed radish, buckwheat and weeds) were established in plots that had received 0 or 180 kg P_20_5/ha as rock phosphate.

Rock phosphate increased soil P(resin) levels in 1988 and 1989. Green manures had no effect on increasing the levels of soil P when rock P was applied. Oat plants accumulated more Ca when buckwheat was the previous crop.

(4) EFFECTS OF CARBON ADDITIONS ON NITROGEN FIXATION AND P NUTRITION OF HAIRY VETCH AND FOLLOWING CROPS.

Three levels of oat hulls (0, 5, 10 t/ha) were incorporated into the soil with two levels of rock phosphate (0 and 180 kg P_20_5/ha) and hairy vetch planted in the summer of 1989. In 1990, maize was planted and the residual effects of 1989 treatments monitored.

Both levels of oat hulls significantly decreased levels of soil nitrate in June 1989, improved nitrogen fixation (acetylene reduction) and vetch biomass production as well as decreased weeds. Total uptake of N, P, K, Ca was improved by the addition of oat hulls. The amount of nutrients carried into the system by the oat hulls were smaller than the surplus of nutrient accumulated in vetch biomass under the effect of 5 t oat hulls/ha. This indicate that oat hulls stimulated growth by a mechanism other than addition of nutrients.

CONTENTS

INTRODUCTION

Interest in organic farming and low-input farming systems has grown over the last decade. Because such systems are often managed with low or no addition of soluble fertilizers, crops often have to rely on poorly soluble native sources of nutrients, using biological mechanisms to make them available.

Among the five macronutrients, N and P are generally the ones commonly limiting crop growth, either because of the large amount required for plant growth, or because of limited availability, respectively. N and P nutrition are related. N uptake can influence P uptake by changing the pH of the root-soil interface and hence, P availability (Riley & Barber, 1971; Soon & Miller, 1978; Bekele et al, 1983; Aguilar & Van Diest, 1981). Soil and root phosphatases are also involved in cycling and absorption of P (Bieleski & Ferguson, 1983; Sharpley, 1985; Tarafdar & Jungk, 1987) as well as the symbiosis with vesicular-arbuscular mycorrhizal fungi (Abbot &Robson, 1984; Smith & Gianninazzi-Pearson, 1988).

In systems where P or N are added as soluble fertilizers, many of these processes may be inhibited and the system becomes dependent on a continued supply of soluble nutrients from external sources to function; e.g. N fertilizers inhibit biological nitrogen fixation (Marschner, 1986), P fertilizers inhibit mycorrhizal infection (Smith & Gianninazzi-Pearson, 1988) and soil and root phosphatase activity (Spiers & McGill, 1979; Bieleski & Ferguson, 1983) that catalyzes the breakdown of organic fractions of soil P into inorganic phosphate. Thus in organic farming, the strategy is to provide net inputs of nutrients to the farm in relatively insoluble form and to rely on biological processes to make them available. P is usually imported as rock-P; processes such as composting, green manuring and simply high biological activity in the soil are relied upon to make it available. Rock-P is often put in gutters to absorb odours and activate it (Lampkin, 1990).

The processes affecting mobilization and uptake of P can be expected to vary considerably between different farming systems because of variation in management practices, types and rates application of inorganic and organic fertilizers, and in cropping sequences. In order to identify some of the critical parameters for the mobilization of phosphate in different farming systems, we examined the effects of applying different types of P fertilizer on crops and on selected biological processes on each of 3 organic and 3 conventional farms. The farms varied respectively in regard to the length of time under organic management and in intensity of chemical use. Overall they provided a gradient of conditions ranging from long term organic to moderately intensive conventional. Three other experiments dealt more specifically with how crop, soil and residue management practices on a long-standing organic farm affect mobilization of native and applied phosphate.

This report details results of chemical analyses of tissues and soils which were supported by a grant from the SWEEP Program. Some supplementary information obtained from the larger study, which was supported by the Natural Sciences and Engineering Research Council of Canada, is summarized.

DESCRIPTION OF THE FARMS

The farms are located in a traditional cereal growing area in southern Ontario. Farms in this region are mostly mixed cereal and livestock farms where spring grain (barley and oats), maize and alfalfa are the main crops. Organic residues from the animals are used on most of the farms as fertilizers, in addition to synthetic fertilizers (on the conventional farms).

ORGANIC FARMS

01 (Reibling's, Tavistock)

The Reibling farm - Oak Manor - is the oldest organic farm in the area. It was converted to organic practices 19 years ago. Cereals and maize, legumes like faba beans, peas, hairy vetch and clover as well as minor crops as buckwheat and oilseed radish are used in a rotation on its 150 acres. Livestock comprise about 50 beef cattle in a semi-confined system. All feed is produced on the farm or comes from by-products of a mill on the farm that processes grains from other organic farms.

Compost and green manuring are the only fertilizers currently being used. Compost is used on non-legumes. Legumes and non-legumes are alternated whenever possible. Weeds are controlled by cultivation.

02 (Pfenning's, New Hamburg)

Unlike most organic farms, this farm does not have any livestock nor is manure imported. Vegetables, the main crop, are rotated with soybeans and cereals such as winter wheat and barley. Nitrogen fixed by soybeans, and incidental inputs from rain seem to be the only nutrient inputs to this farm. It has been managed that way for 8 years.

03 (Bender's, Tavistock)

This is the most recently converted farm. Organic management started 5 years ago. It is similar to 01 but there are more animals such as pigs, cows, fowl and sheep. Part of the feed is imported from other farms. Compost is used but not on as regular a basis as at 01. Legumes such as alfalfa and clover are used. Oilseed radish and buckwheat are also grown as green manures.

CONVENTIONAL FARMS

C1 (Gingerich's, New Hamburg)

This is a mixed dairy farm. The main crops are maize, spring grains and alfalfa. Crops are often repeated in the same field although rotation is done to some extent. Fertilizers such as urea, and potash have been used as well as atrazine, other herbicides and fungicides. Raw manure is applied in a regular basis.

C2 (Stock's, Tavistock)

This is also a dairy farm with the same features as C1 but there is more fertilizer use than at C1.

C3 (Cressman's farm, Tavistock)

This is a mixed farm with beef as the main product. Fertilizers and pesticides are used and the main crops are mixed grains and maize. The raw manure is spread on a regular basis.

Table 1 shows some soil fertility parameters obtained from the fields where the experiments were set up, on the 6 farms in the fall of 1989:

Table 1 - Soil fertility parameters for the 6 farms.

FARMS	**Soil nutrients[1] (mg/kg)**			
	P	K	Ca	pH
01	10	148	137	7.5
02	18	222	261	7.9
03	20	74	156	6.9
C1	18	185	63	7.4
C2	13	106	218	6.5
C3	40	169	171	7.9

[1] P was extracted with sodium bicarbonate (Olsen et al., 1954);
K, Ca and Mg were extracted with in ammonium acetate solution

OUTLINE OF THE EXPERIMENTS

(1) RESPONSES TO DIFFERENT P FERTILIZERS IN ORGANIC AND CONVENTIONAL FARMING SYSTEMS

(I) 1988

FARMS: 2 organic (01 and 02) and 1 conventional[1] (C1)

TREATMENTS:
No fertilizer
Triple superphosphate (60 kg P_20_5/ha)
Rock phosphate (180 kg P_20_5/ha)
Compost (10 ton/ha)

The commercial designation and composition of the rock phosphate according to the manufacturer is:
Zorafos - Soft phosphate with colloidal clay
Available phosphoric acid - 2%
Total phosphoric acid - 18%
The compost used was produced at farm 01.
Analysis:
N% - 1.12
P% - 0.90
K% - 1.11
Ca% - 3.43
Mg% - 0.60

PLOT SIZE: 2 X 2m

CROP: Barley cv. Leger

EXPERIMENTAL DESIGN: Randomized complete blocks with 6 replicates on each farm

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[1] The farm designations were assigned based on:
(a) Organic farms - years under organic management.
01 - 20 years
02 - 9 years
03 - 6 years
(b) Conventional farms - intensity of inputs
C1 - least intensive to C3 most intensive

OBSERVATIONS[1]: **<u>Soil P, sodium bicarbonate (Olsen et al., 1954)</u>** and anionic resin extraction (Sibbesen, 1977)
<u>Soil[2] K, Ca, Mg, pH</u>
<u>Percent of N, P, K, Ca, Mg in barley grain and straw[3]</u>
Yield (Grain and straw)
Weed biomass
Mycorrhizal infection (Brundrett et al, 1984 McGonigle et al, 1990)
Root and soil phosphatase activity measured through the reduction of p-nitrophenyl phosphate (Tabatabai & Bremner, 1965)

(ii) 1989
FARMS: 3 organic (01, 02, 03) and 3 conventional (C1, C2, C3)

TREATMENTS: as above

PLOT SIZE: as above

CROP: as above

EXPERIMENTAL DESIGN: Randomized complete blocks, 4 replicates per farm

OBSERVATIONS[1] Soil P (anionic resin)
<u>Soil P, K, Ca, Mg, pH</u>
<u>Percent of nutrients (N, P, K, Ca, Mg) in one month old plants and at heading stage</u>
Yields (grain and straw)
Weeds biomass
Mycorrhizal infection (Brundrett et al, 1984; McGonigle et al, 1990)
Root and soil phosphatase activity (Tabatabai & Bremner, 1965)
Root length (Tennant, 1975)

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1 The variables in **<u>underlined</u>** characters are those performed with the SWEEP contract
2 Soil K, Ca and Mg were extracted with in neutral ammonium acetate solution
3 All plant tissue analysis were performed according to the methodology of Thomas et al. (1967).

(2) EFFECTS OF THREE TILLAGE/STRAW TREATMENTS ON SOIL P AN CROP NUTRITION

LOCATION: Oak Manor Farm

YEARS: 1987 to 1989

TREATMENTS: After harvesting barley, the field was divided into 9 strips which were mouldboard ploughed (no straw), disced (no straw) and disced (with barley straw); in 1988 four treatments (no fertilizers, superphosphate, rock phosphate and compost as described on the previous experiment) were superimposed to the main treatments.

CROPS: The field was divided into 2 strips, perpendicular to the tillage treatments, strip A - 270 X 15 m and strip B - 270 X 58 m in which 2 different cropping sequences were followed.

SEQUENCE OF CROPS:

PERIOD	STRIP A	STRIP B
FALL 88	OILSEED RADISH	FABA BEANS
SPRING 88	PEAS	Maize
FALL 88	WINTER WHEAT+CLOVER	Maize
SPRING 89	CLOVER	OATS
FALL 89	CLOVER	CLOVER

PLOT SIZE: Strip A - 30 X 15m
Strip B - 30 X 58m
Superimposed plots in 1988 - 2 X 2m

EXPERIMENTAL DESIGN: Randomized complete blocks, 3 replicates
In 1988: split plot, with the tillage treatments in the main plots and P fertilizers in the sub-plots, randomized complete blocks, 3 replicates

OBSERVATIONS:

1987. Crop yields and weeds biomass
ARA (acetylene reduction activity) of faba beans
<u>Soil P, K, Ca, Mg, pH</u>

1988. Pea yields and weed population
Maize roots phosphatase activity
Maize roots mycorrhizal infection
<u>Nutrients in Maize grain (N, P, K, Ca, Mg)</u>
<u>Soil P, K, Ca, Mg, pH.</u>

1989. **<u>Nutrients in wheat grain (N, P, K, Ca, Mg)</u>**
<u>Nutrients in Clover leaf tissues (N, P, K, Ca, Mg)</u>

Oats yields
Soil P, K, Ca, Ma, pH

(3) EFFECTS OF GREEN MANURING AND ROCK PHOSPHATE ON P NUTRITION OF DIFFERENT CROPS

LOCATION: Oak manor Farm

YEAR: 1987 to 1989

TREATMENTS: Rock phosphate (180 kg P_20_5/ha) and no rock phosphate
Green manures: oilseed radish, buckwheat, faba beans and weeds

PLOT SIZE: 5 X 9 m (subplots)

EXPERIMENTAL DESIGN: split plot with rock phosphate treatments in the main plots and green manures in the subplots, randomized complete blocks, 4 replicates

CROPS: Fall 87 - Green manures
Spring - 88 Oats
Summer - 89 Green manures

OBSERVATIONS:

1987. Green manures and weeds biomass
Percent of P in green manures
Soil P, K, Ca, Mg, pH Mycorrhizal spore counts

1988. Oat yields
Mycorrhizal infection in oat roots
Root and soil phosphatase activity
Soil P, K, Ca, Mg, pH
Nutrients in oat plants and grain (N, P, K, Ca and Mg)

1989. Green manure biomass
nutrients in green manures (N, P, K, Ca, Mg)
Soil P, K, Ca, Mg, pH

(4) EFFECTS OF ADDITIONS OF CARBON ON NITROGEN FIXATION AND P NUTRITION OF DIFFERENT CROPS

LOCATION: Oak Manor Farm

YEAR: 1989

TREATMENTS: Oat hulls incorporation: 5 and 10 ton/ha and no oat hulls
Rock phosphate: 180 kg P_20_5/ha and no rock phosphate

PLOT SIZE: 15 X 9m

EXPERIMENTAL DESIGN: Split plot, with oat hull treatments in the main plots and rock phosphate levels in the subplots, randomized complete blocks, 4 replicates

OBSERVATIONS: ARA (acetylene reduction activity) of hairy vetch
Weed biomass
Mycorrhizal infection
Soil Nitrates, P, K, Ca, Mg, pH
Nutrients in vetch and weed biomass (N, P, K, Ca, Mg)

STATISTICAL ANALYSIS

For the statistical treatment of the data, an ANOVA was first performed. Then a Tukey test was used for mean separation in the cases where the ANOVA resulted in significant F values ($P < 0.05$). Significant F values at the 10% levels ($P < 0.10$) were also considered as trends in the discussion.

RESULTS

(1) Response to different P fertilizers in organic and conventional farming systems

In this set of experiments, there were three primary questions or hypotheses that we wished to test:

1- Are rock phosphate and compost more effective sources of P under organic than under conventional management?

2- Do the different fertilizers affect the balance of major nutrients?

3- Are biological phenomena related to P nutrition enhanced in organic compared to conventional systems?

Three P-containing fertilizers - superphosphate, compost and rock P were applied to plots on which barley was grown, on each of 3 farms in 1988 and 6 farms in 1989. The rates of application were based both on the farmers' current use and the rates recommended by the Field Crops Recommendations Guide (Ontario Ministry of Agriculture, 1989).

There were three criteria for effectiveness of P fertilizers:soil P levels, plant tissue P and crop yields. Two methods of measuring soil available P were used: bicarbonate extraction which is the standard for Ontario and the anionic resin method (Amer et al. 1965 modified by Sibbessen, 1977). In several studies the resin method shows a good correlation with plant P uptake (Cooke & Hislop, 1963; Olsen & Khasawneh, 1980; Sibbessen, 1983; Bowman et al., 1986). The two methods are correlated (Nesse et al., 1988 and Soon, 1990). However, when rock phosphates are used, acid extractants can overestimate P values (Chien, 1978) whereas water extraction and sodium bicarbonate will underestimate it (Menon et al., 1989).

In this study there was a good correlation between the two methods of measuring soil available P in 1988 r = 0.94, Figure 1).

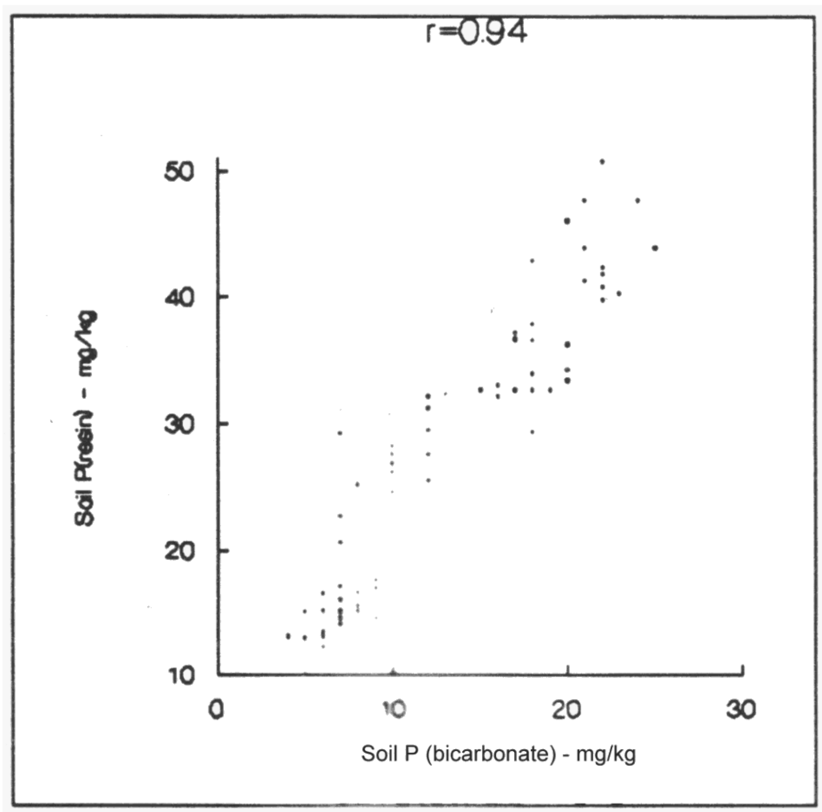
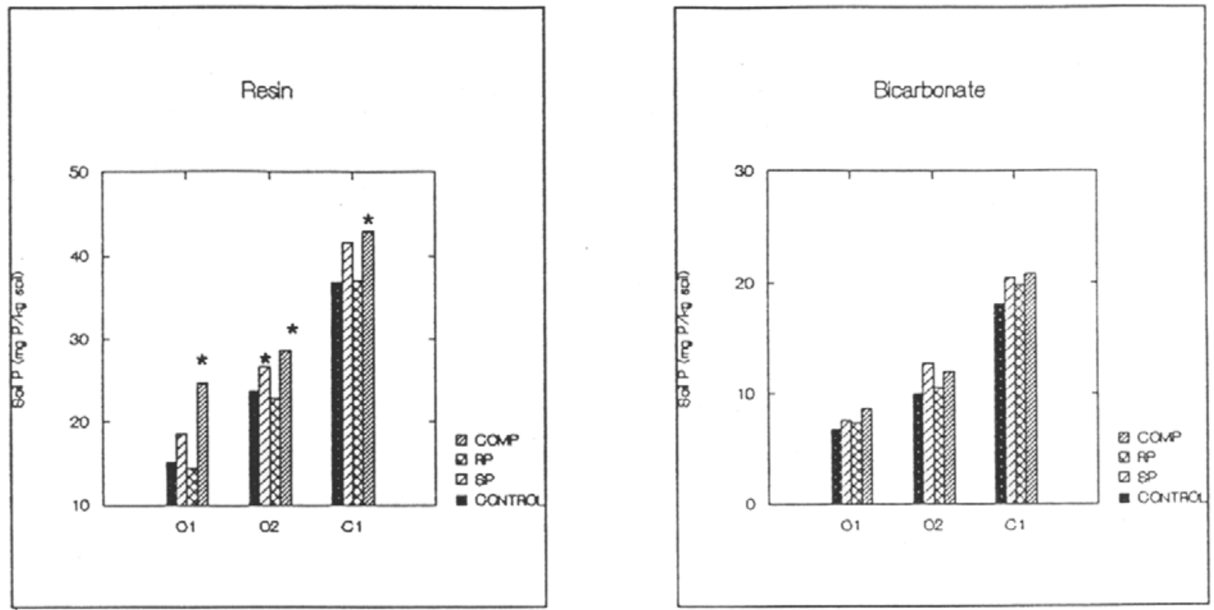


Figure 1. Relation between soil P measured by two extractants: anionic resin and sodium bicarbonate.

Differences between treatments were more pronounced for the resin method in 1988. Only that method resulted in statistically significant differences (Figure 2). Hence this method was used routinely.



* Different from control (Tukey test, p < 0.05)

No significant differences among treatments.

Figure 2. Effects of P Fertilizers on Soil P measured by two extraction methods in 1988.

Applications of super phosphate and compost each resulted in significantly higher ($P < 0.05$) soil available P than in controls in 3 out of 9 comparisons (Table 2 and Figure 2) ; on all farms the values for both compost and super phosphate were numerically higher than the control values. There were no statistically significant responses to rock phosphate, nor any trends of increases.

Thus, there did not appear to be pronounced differences between farming systems in response to the different types of P fertilizers. Overall, lowest soil P values were found on the oldest organic farms (01 and 02).

Table 2 - Effects of P fertilizers on available P (anionic resin extraction) levels in different farming systems over two years.

TREATMENTS	1988 FARMS		
	C1	C2	C3
CONTROL	15.2b	23.7b	36.8b
SUPER P	18.6b	26.7a	41.5ab
ROCK P	14.4b	22.8b	36.9b
COMPOST	24.6a	28.7a	42.8a
F VALUE	9.8***	7.91^{**}	4.03*`
CV%	19.9	9.2	9.5

TREATMENTS	1989 FARMS					
	01	02	03	C1	C2	C3
CONTROL	20.5	22.0 a	37.7b	40.2b	37.1	50.3
SUPER P	22.2	30.5a	58.0 a	46.1a	44.6	52.3
ROCK P	18.6	21.0 a	47.6 ab	42.5 ab	35.0	44.7
COMPOST	24.7	31.4a	48.9 ab	43.6 ab	41.0	53.8
F VALUE	1.16	4.38*	7.8*	9.74*	2.83^{+}	0.5
CV%	21.7	19.9	10.7	3.6	12.8	21.7

+,* significant at 0.1 and 0.05 probability levels, respectively.
Values followed by the same letter on each column are not significantly different (Tukey test P <0.05).

There were no statistically significant effects of P fertilizer type on total P in the crop at harvest in 1988 (Tables 3a, 3b and 3c in Appendix). In 1989, a significant correlation $r = 0.68^{**}$) was observed between the soil available (resin) phosphorus and the percent of P in one month old barley plants (Figure 3). This correlation indicates that both the soil P method (resin) and the sampling time were adequate to study P nutrition of the plants. According to the literature, P supply is more important in the early phases of development for different crops (Avnimelech & Scherzer, 1970; Romer & Schilling, 1986; Barry & Miller, 1989).

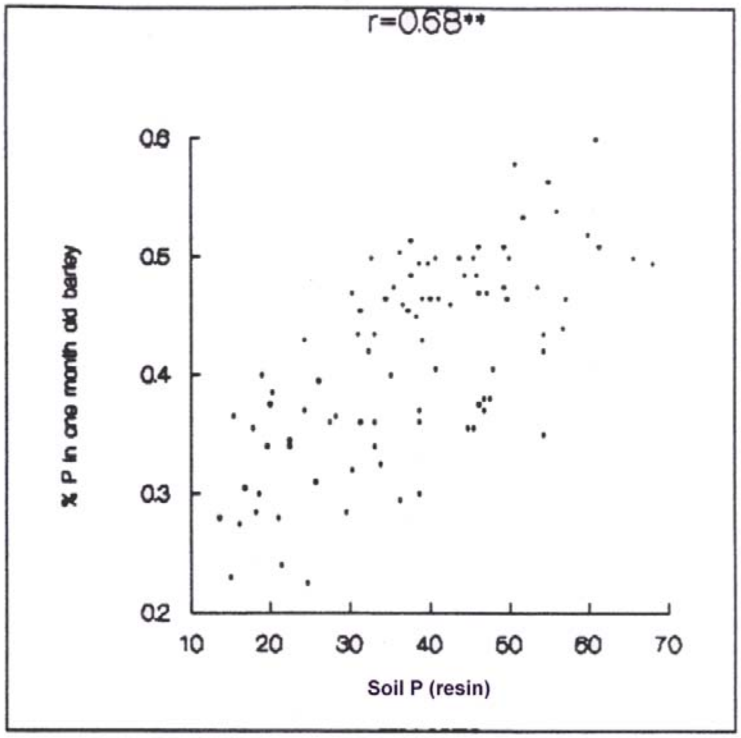


Figure 3. Correlation between the percent of P in one month old barley plants and soil P (resin).

The correlation coefficients of percent of P in 2 stages of development (Table 3), confirm that the 1 month old stage associates better with soil P and grain yield than the heading stage.

Table 3 - Correlation coefficients between percent of P in barley plants at 1 month old stage and heading stage.

	Soil P	Yield
P 1 month	0.716**	0.628**
P heading	0.310 ns	0.012 ns

The overall correlation between soil available (resin) P and grain yield was not significant (Figure 4). However, when each farm is considered individually (Table 4), significant correlations between these variables are observed. There was a significant positive correlations in 02, as well as negative ones in C1 and C2.

Table 4 - Correlation coefficients of soil P (resin) and % of P in one month old barley plants with barley yields.

FARM	#observations	correlation coefficients®)	
		P(resin)x yield	% P x Yield
01	16	0.27 ns	0.50**
02	16	0.59**	0.62**
03	12	0.19 ns	0.26 ns
C1	16	-0.87***	-0.42+
C2	16	-0.60**	-0.07 ns
C3	15	0.49+	0.75***

+, *, **, *** significant at 0.1, 0.05, 0.01 and 0.001 probability levels, respectively.

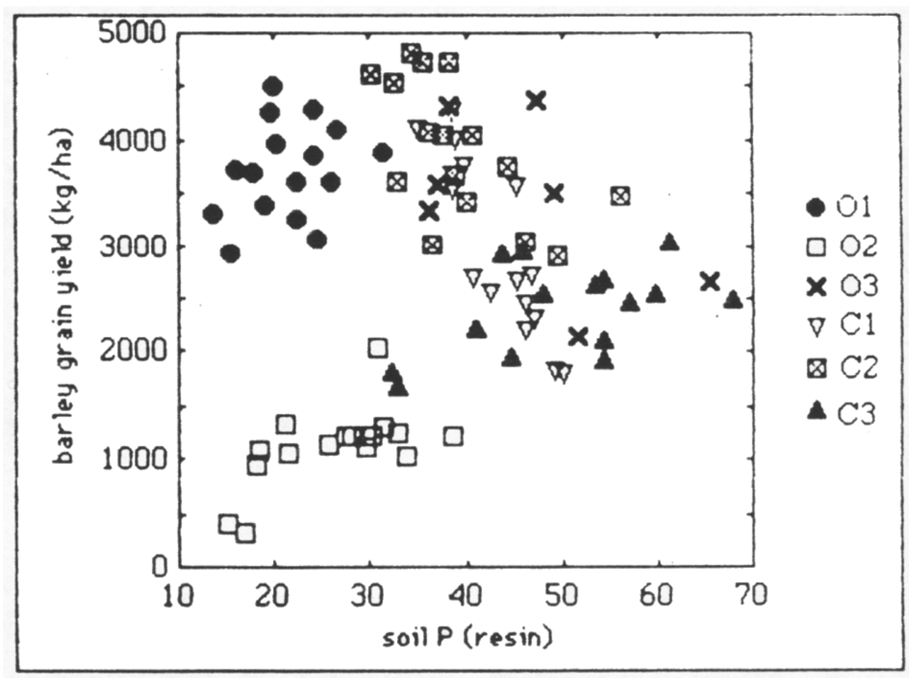


Figure 4. Correlation between Barley grain yield and soil P (resin).

The correlation between the percent of P in 1 month old plants and grain yields was significant r = 0.38**, data not shown). Again when the farms were considered individually, only three had positive significant correlation coefficients (Table 4). This is possibly an indication that other factors were limiting plant nutrition on those three farms (03, C1, C2). The grain yields (Table 5) were only affected by the treatments in 01.

Table 5. Barley grain yields (kg/ha) in 1989.

TREATMENTS	FARMS					
	01	02	03	C1	C2	C3
CONTROL	3388b	913	3561	3317	4128	2488
SUPER P	3981a	1138	3437	2503	3982	2488
ROCK P	3650ab	985	2479	3449	3667	2469
COMPOST	3850ab	1457	3215	2741	3486	2396
NITROGEN[1]	3273	2045	3416	2228	4302	2997
F VALUE	4.93*	2.97	2.12	3.92	0.79	0.04
CV%	6.3	24.9	18.2	15.2	11.3	21.1

Values followed by the same letter on each column are not significantly different (Tukey test P <0.05).
+, *, **, *** significant at 0.1, 0.05, 0.01 and 0.001 probability levels, respectively.
[1] Side plots with 50 kg N/ha. These results were not included in the ANOVA.

The P fertilizer treatments did not have significant effects on the percent of P in the plants, except at farm C1 where compost and superphosphate increased plant P levels (Table 6).

Table 6- Effects of P fertilizers on the percent of P in one month old barley plants.

TREATMENTS	FARMS					
	01	02	03	C1	C2	C3
CONTROL	0.33	0.31	0.43	0.38b	0.49	0.44
SUPER P	0.37	0.30	0.46	0.50a	0.48	0.47
ROCK P	0.34	0.27	0.44	0.38b	0.46	0.42
COMPOST	0.38	0.39	0.44	0.47a	0.50	0.43
F VALUE	1.64	3.23^{+}	0.35	53.78^{***}	1.65	0.30
CV%	10.4	16.6	11.4	3.8	5.7	14.8

Values followed by the same letter on each column are not significantly different (Tukey test P <0.05).
+, *, **, *** significant at 0.1, 0.05, 0.01 and 0.001 probability levels, respectively.

The percent of mycorrhizal infection in 1989 (Table 7) was lowest on the organic farm 01 and the conventional C3. Overall, the percent of infection was numerically lower in the superphosphate treatment on all farms. Significant differences were observed on farm 03 only. No relationship between mycorrhizal infection and soil P or percent of P in one month old plants was observed. Our data do not support the assumption that organic farming stimulate mycorrhizal infection.

Table 7. Effects of P fertilizers on the percent of mycorrhizal infection (% arbuscules) in roots of one month old barley plants.

TREATMENTS	FARMS					
	01	**02**	**03**	**C1**	**C2**	**C3**
	% Arbuscules					
CONTROL	10.5	29.9	24.2a	22.6	26.2	18.0
SUPER P	5.7	23.8	15.1bc	12.8	27.2	20.3
ROCK P	13.3	23.5	10.3c	21.7	21.1	16.87
COMPOST	9.1	24.1	19.1ab	18.9	29.9	13.05
F VALUE	2.4	0.31	8.77 **	3.47^{+}	0.76	0.32
CV%	3.7	8.9	3.4	3.6	7.2	8.6

Values followed by the same letter on each column are not significantly different- (Tukey test p< 0.05).
Numbers were transformed (arcsin x+1) prior to performing the ANOVA.
+, *, **, *** significant at 0.1, 0.05, 0.01 and 0.001 probability levels, respectively.

The root phosphatase activity, a variable that is normally interpreted as an indicator of P stress (Bieleski & Ferguson, 1983), did not behave consistently in relation to soil P levels, percent of P in the plants or organic versus conventional farming system (Table 8). Soil treatments did not affect the enzyme activity.

Table 8 - Effects of P fertilizers *on* root phosphatase activity *in* one month old barley plants.

TREATMENTS	FARMS					
	01	02	03	C1	C2	C3
	μg p-nitrophenol phosphate.g $root^{-1}.h^{-1}$					
CONTROL	2542	3168	1370	1928	2363	2561
SUPER P	2519	3068	1880	1233	2683	3182
ROCK P	2225	2979	1634	1841	2670	3214
COMPOST	1986	2440	1584	1657	2461	2743
F VALUE	1.18	0.93	2.38	1.62	0.27	2.48
CV%	20.9	23.1	17.0	29.1	24.0	14.0

Values followed by the same letter on each column are not significantly different (Tukey test p< 0.05).
+, *, **, *** significant at 0.1, 0.05, 0.01 and 0.001 probability levels, respectively.

The values for soil phosphatase activity (Table 9), also show that there is not a higher activity on the organic, compared to the non-organic farms, as previously hypothesised.

Significant effects of soil treatments on soil phosphatase were found only on the conventional farm C2, where compost decreased the enzyme activity.

Table 9 - Effects of P fertilizers on soil phosphatase activity

TREATMENTS	FARMS					
	01	02	03	C1	C2	C3
	μg p-nitrophenol phosphate.g $root^{-1}.h^{-1}$					
CONTROL	298.1	289.3	278.2	336.9	325.7a	182.8
SUPER P	304.9	297.8	319.2	384.9	318.1a	163.7
ROCK P	325.5	323.4	248.28	446.0	287.4ab	190.5
COMPOST	322.1	314.9	248.3	371.8	233.7b	209.6
F VALUE	0.3	0.23	0.53	1.51	6.51 *	0.51
CV%	15.5	21.07	33.8	19.21	11.24	28.4

Values followed by the same letter on each column are not significantly different (Tukey test p< 0.05).
+, *, **, *** significant at 0.1, 0.05, 0.01 and 0.001 probability levels, respectively.

The assumption that P fertilizers additions decrease soil phosphatase activity (Spiers & McGill, 1979) activity, could not be confirmed in this study, either in relation to P fertilizer additions to the plots or in relation to routine P fertilization at the conventional farms. The uptake of other major nutrients did not seem to be affected by the treatments. No interaction among nutrients were found and the assumption that the treatments affected the balance of nutrients could not be supported (Tables 3a, 3b, 3c and 4 in appendix).

(2) Effects of three tillage/straw treatments on soil P and crop nutrition

The questions we wished to examine in this experiment were:

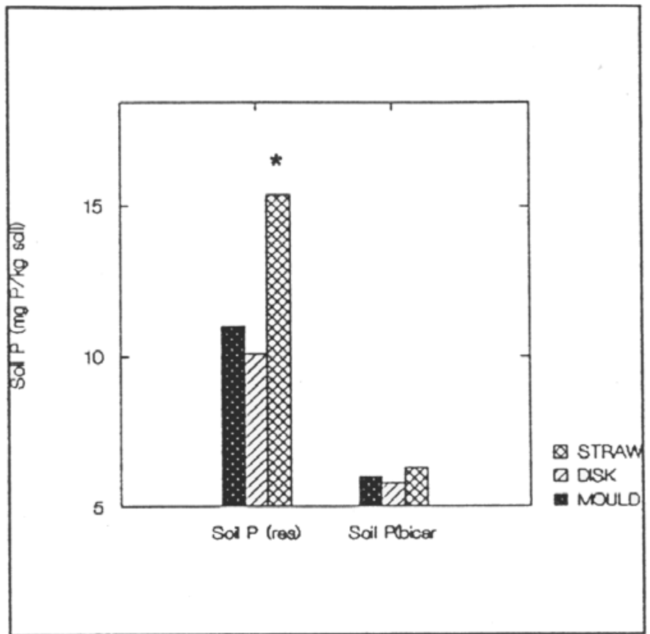
1- How do different tillage/straw conservation methods affect P nutrition over several successional crops?

2- How do different P fertilizers interact with these tillage methods?

This trial was set up in the August of 1987. Barley was harvested from the field in early August. Then the field was cultivated in three different ways: straw removed and mouldboard ploughed, straw removed and disced, straw retained and disced. The field was then split in two sections perpendicular to tillage treatments and two different crop sequences established (see outline of experiment, page 6).

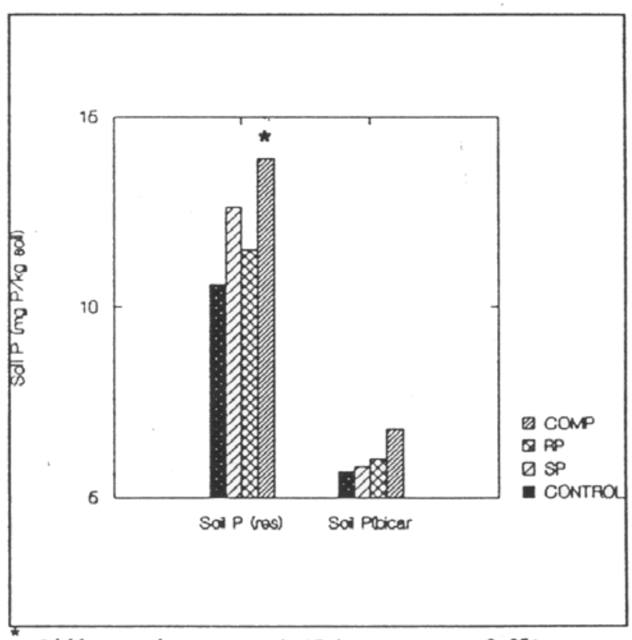
In 1988, four P fertilizer treatments were superimposed on the strips of different tillage/straw regimes: (a) control; (b) rock phosphate; c) super phosphate; (d) compost. Maize and peas were each planted on one of the strips. In 1989, oats and winter wheat were planted.

The disk+straw treatment increased soil P (resin) in 1988. Compost and superphosphate also increased soil P (resin) (Figures 5 and 6). As occurred in experiment 1, no significant effect of treatments were detected when soil P was extracted by sodium bicarbonate (Table 5 in appendix). No interaction between tillage methods and P fertilizer treatments occurred (Figures 5 and 6 and table 5 in appendix). Both treatments, compost and disk+straw, increased the percent of P in maize grains (Table 5 in appendix) and grain yields (data not shown) compared to the control.



* Different from control (Tukey test, p < 0.05)

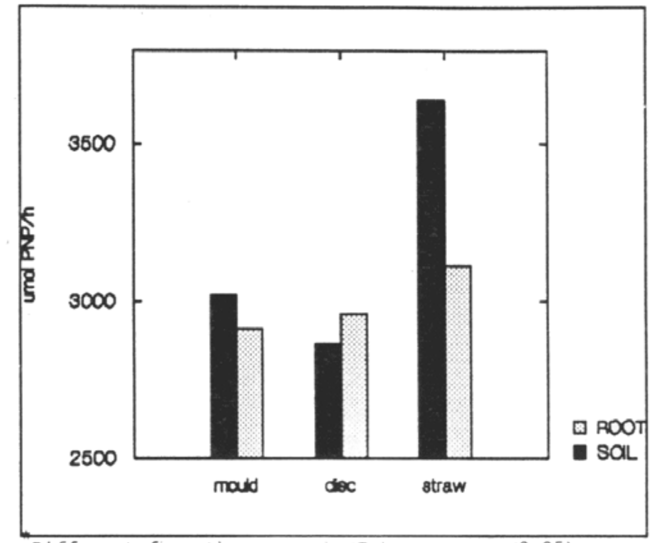
Figure 5. Effects of tillage methods on soil P measured in 1988 by two methods.



* Different from control (Tukey test, p <0.05).

Figure 6. Effects of P soil treatments on soil P measured in 1988 by resin and sodium bicarbonate extraction.

The disk + straw treatment significantly increased the soil phosphatase activity (Figure 7). The same results were obtained by Perucci et al. (1988) with additions of maize residues. Root phosphatase activities were not affected.



Different from the control (Tukey test, $p<0.05$).
Root= Root phosphatase activity
Soil= Soil phosphatase activity

Figure 7. Effects of tillage methods on soil phosphatase activity.

No effects of the treatments were observed on nutrient uptake by oats in 1989 (Table 6 in appendix). Soil P levels were still numerically higher on the disk +straw treatment, but the differences were non-significant.

The results obtained so far indicate that the tillage/straw regime by itself increased soil P and improved plant nutrition.

(3) Effects of green manuring and rock phosphate on P nutrition of different crops

In this experiment there were three main questions we wished to examine:

1- Are rock phosphates reactive in a long term cropping sequence?
2- Do different green manures affect the solubility of the rock phosphate?
3- How do different crops respond to both rock phosphate and green manures?

This trial was set up in 1987 at Reibling's farm. It was a split plot design with two levels of rock phosphate assigned to the main plots: no rock phosphate and one rate of rock phosphate equivalent to 180 kg $P_2 0_5$/ha. Three green manure crops, i.e. oilseed radish, buckwheat and faba beans, and control (weeds) were assigned to the subplots.

Plots were established in early August and the green manures were cut down in mid-October. In the spring of 1988, the green manures were worked into the soil and oats planted.

In the fall of 1988, the same green manures were again planted. Because of the drought, the green manures did not establish well and it was decided to leave the area fallow until 1989. In mid-summer of 1989, the green manures were replanted again. In the spring 1990 maize was planted.

Soil available phosphorus measured by anionic resin and bicarbonate extraction were significantly correlated r = 0.92) (Figure 7). As observed in experiment 1, the effect of rock phosphate application on soil P levels was only detected when the anionic resin was the extractant. In this case, rock phosphate increased soil P levels one year after its application (Figure 8).There was no effect of the green manures on the soil variables examined, i.e. P, K, Ca, Mg and pH (Table 8a in appendix).

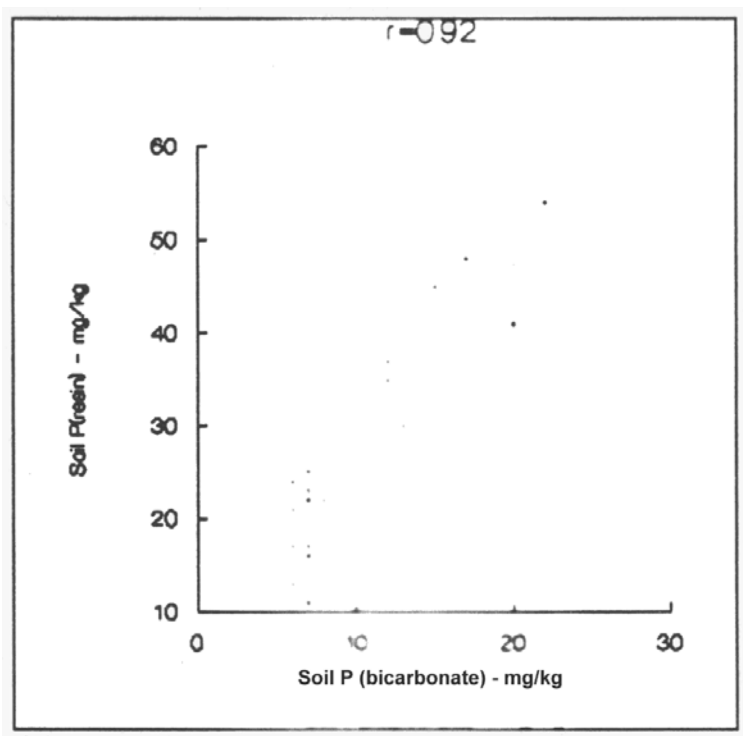


Figure 8. Correlation between soil P extraction with anionic resin and sodium bicarbonate.

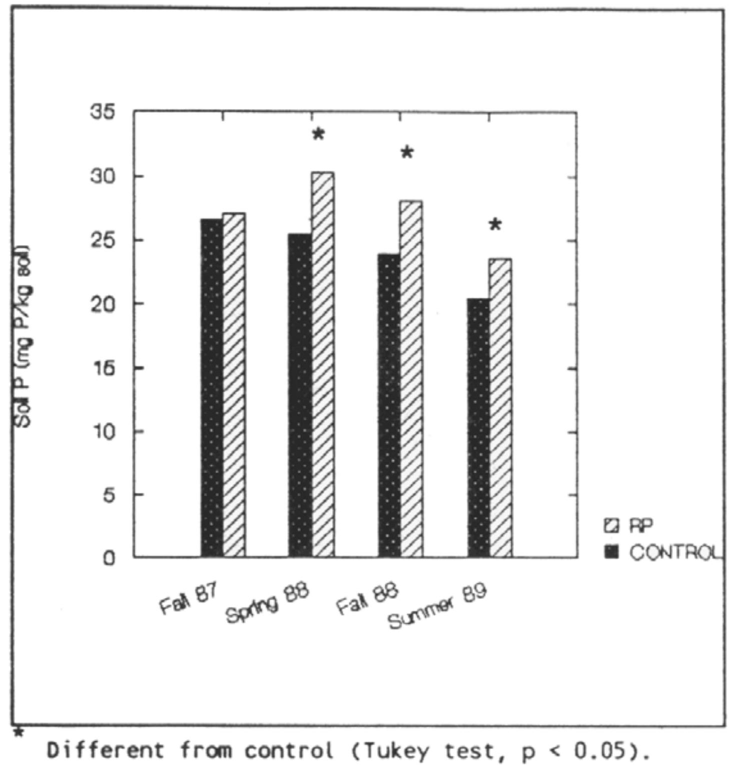
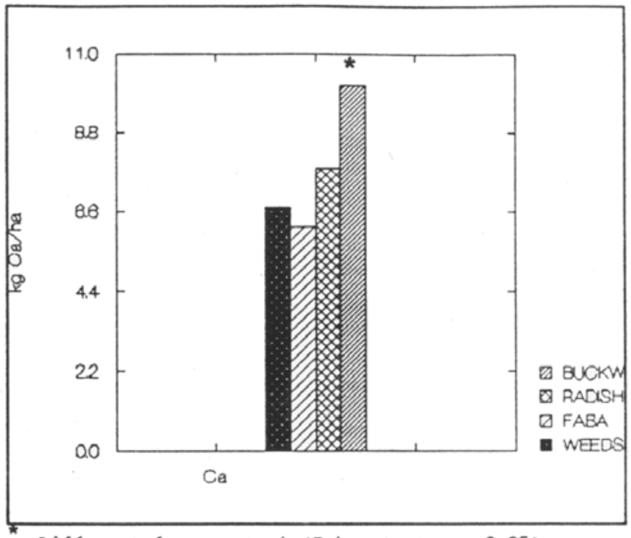


Figure 9. Effect of rock phosphate on soil P (resin).

ANOVA showed no response of oats to the increase of P levels following the application of rock phosphate. However, there was a response of oats to the previous green manure species. An increase in N and P in oat grains occurred when faba beans had been the previous crop. Also an increase in Ca in oats straw was found where buckwheat had been the previous crop (Figure 10 and Table 8b in appendix). Buckwheat is reported to be a good Ca feeder plant (Bauer, 1921; Truog, 1922; Bekele et al., 1983) and it may have contributed to the Ca absorption by oats.

The data showed that rock phosphate could increase the levels of soil P for two consecutive years.



* Different from control (Tukey test, $p < 0.05$).

Figure 10. Effect of the previous green manure on the amount of calcium in oats straw.

(4) Effects of carbon addition on nitrogen fixation and P nutrition of hairy vetch and following crops.

The questions we wished to examine in this experiment were:

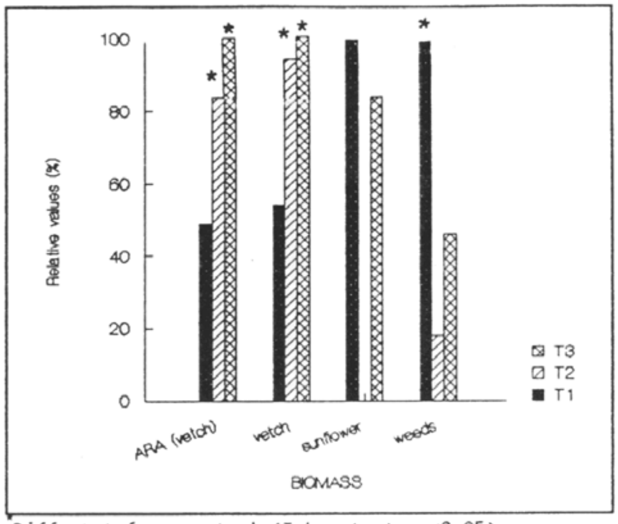
1- Can carbon additions (oat hulls) increase nitrogen fixation of a legume crop?
2- Does this legume crop have a better P nutrition when fixing more nitrogen?
3- Does this legume affect P nutrition of a following crop?

This experiment was set up in 1989. Three levels of oat hulls (0, 5 and 10 t/ha) were incorporated into the field with two levels (0 and 180 kg P_20_5) of rock phosphate. Treatments were arranged in a split-plot design with 4 replicates. Rock phosphate levels were assigned to the main plots and oat hulls levels were assigned to the subplots (see page 7 for details). Hairy vetch was planted early in the summer. A non nitrogen-fixing control crop (sunflower)was planted in small plots in the vetch field so that we compare growth responses of a non-nitrogen fixing with a nitrogen fixing plant.

In the spring of 1990, maize was planted and the residual effects of the treatments were monitored.

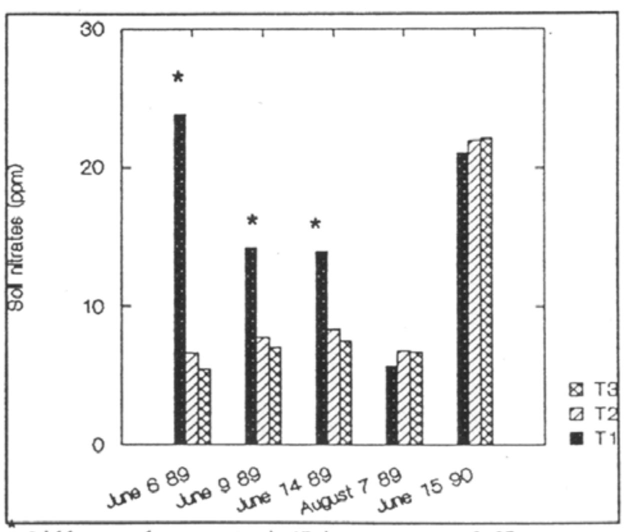
Incorporation of oat hulls resulted in lower soil nitrate levels, higher nitrogen fixation rates and biomass production and fewer weeds (Figures 11 and 12).

No effects of the treatments on other soil nutrients were obtained. Although the percent of nutrients in vetch tissue was not affected by the treatments, the total nutrients accumulated by the vetch biomass were highest under the effect of oat hulls (Table 10).



* Different from control (Tukey test, $p<0.05$).
T1=control, T2=5 t oat hulls/ha, T3=10 t oat hulls/ha.
ARA was originally expressed as umol $C_2H_4 . g\ root^{-1} . h^{-1}$;

Figure 11. Effects of oat hulls on nitrogenase activity (acetylene reduction), and vetch, sunflower and weed biomass production.



* Different from control (Tukey test, $p< 0.05$).
T1= control, T2= 5 t oat hulls/ha, T2= 10 t oat hulls/ha

Figure 12. Effect of oat hulls incorporation on soil nitrate levels.

Table 10- Nutrients in vetch biomass.

	TOTAL NUTRIENTS IN VETCH BIOMASS - kg/ha				
	N	**P**	**K**	**Ca**	**Mg**
+ Rock P	117.5	10.1	74.8	41.7	7.1 b
- Rock P	122.7	10.1	76.8	44.4	8.4a
F values	0.32	0.00	0.06	2	9.01**
Oat hulls (t/ha)					
0	74.7b	6.1 b	47.9b	27.9b	6.2
5	134.8a	11.4a	88.5a	52.9a	8.6
10	150.8a	12.9a	90.9a	45.6a	8.4
F value	8.12*	9.34**	4.14+	6.28*	2.63
C.V.(%)	18.7	23.2	26.8	13.3	13.2

+, *, **, *** significant at 0.1, 0.05, 0.01 and 0.001 probability levels, respectively.

Averages are significantly different (Tukey test - $p < 0.05$) when followed by different letters.

The amount of nutrients carried into the system by the oat hulls (Table 11) were smaller than the surplus of nutrients accumulated in the vetch biomass under the effect of the 10 t/ha treatment.

Table 11 - Total nutrients in oat hulls (kg/ha).

Treatment (t/ha)	N	P	K	Ca	Mg
5	22.50	3.46	24.75	6.52	2.925
10	45.00	6.93	49.50	13.05	5.85

This indicates that the oat hulls stimulated plant growth by a mechanism other than the addition of nutrients. In the case of nitrogen, biological fixation was probably involved. Rock phosphate addition did not affect the nutrition of vetch except for decreasing the amount of Mg absorbed by vetch (Table 10).

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APPENDIX

(1) Response to different P fertilizers in organic and conventional farming systems.

Table 1. Effects of soil treatments on available P and K at two organic (01 and 02) and one conventional (C1) farm in 1988. (values are averages of six replicates)

FARMS	SOIL P (mg/kg soil)					
	(bicarbonate)			(Resin)		
	01	02	C1	01	02	C1
TREATMENTS						
Control	6.8	10.0	18.1	15.2b	23.7b	36.8b
Super P	7.5	12.8	20.5	18.6b	26.7a	41.5ab
Rock P	7.3	10.5	19.8	14.4b	22.8b	36.9b
Compost	8.6	12.0	20.8	24.6a	28.7a	42.8a
F value	1.71	1.68	2.36	9.8***	7.91**	4.03*
C.V.(%)	19.2	21.9	9.5	19.9	9.2	9.5

TREATMENTS	SOIL K(mg/kg soil)		
	01	02	C1
Control	132.3ab	83.5	206.0
Super P	119.6b	75.5	204.7
Rock P	143.8ab	70.8	204.3
Compost	150.0a	81.3	220.7
F value	3.94*	1.31	0.71
C.V.(%)	12.11	5.8	10.9

+, *, **, *** significant at 0.1, 0.05, 0.01 and 0.001 probability levels, respectively.

Averages are significantly different (Tukey test - $p < 0.05$) when followed by different letters.

Table 2. Effects of soil treatments on available Ca, Mg and soil pH at two organic (01 and 02) and one conventional (C1) farm in 1988.(values are averages of six replicates).

Farm	01	02	C1
TREATMENTS		**Soil Ca (mg/kg soil)**	
Control	3340	3333	1375
Super P	3226	3295	1400
Rock P	3208	3343	1436
Compost	3300	3348	1366
F value*	2.22	0.61	0.65
C.V(%)	3.1	2.3	6.7
		Soil Mg (mg/kg soil)	
Control	300	172	178
Super P	304	148	181
Rock P	323	180	176
Compost	325	180	184
F value *	0.56	2.19	0.48
C.V.(%)	13.4	14.3	6.7
		Soil pH	
Control	7.2	7.5	5.8
Super P	7.2	7.6	5.7
Rock P	7.3	7.6	5.8
Compost	7.3	7.6	5.9
F value *	0.21	0.16	0.34
C.V.(%)	2.5	1.4	

* All the F values are non-significant ($p > 0.10$).

Table 3a. Effects of soil treatments on nutrient uptake by barley at the organic farm 01 in 1988 (values are averages of six replicates).

FARM 01					
	Nutrients in barley straw (kg/ha)				
	N	**P**	**K**	**Ca**	**Mg**
TREATMENTS					
Control	22.2	2.4	29.2	13.5	5.0
Super P	21.7	2.6	29.3	13.7	4.8
Rock P	18.3	1.9	26.6	11.2	4.3
Compost	24.2	2.6	27.3	15.2	5.8
F value	1.55	0.79	0.13	2.36	1.88
C.V.(%)	22.4	35.4	32.1	19.7	
	Nutrients in barley grain (kg/ha)				
Control	40.5	7.2	11.9	1.3	2.6
Super P	35.1	6.2	10.5	1.7	2.3
Rock P	37.2	6.5	12.3	1.3	2.5
Compost	41.1	7.3	12.2	1.3	2.8
F value	0.56	0.80	0.43	0.18	0.55
C.V.(%)	23.8	22.1	27.1	27.8	25.2
	Total nutrients(straw + grain) (kg/ha)				
Control	62.6	9.6	41.1	14.8	7.7
Super P	56.8	8.8	39.7	14.9	7.1
Rock P	55.5	8.4	38.9	12.5	6.8
Compost	65.2	6.9	39.5	16.5	8.5
F value	2.12	2.10	0.04	2.34	2.48+
C.V.(%)	13.0	12.9	27.0	18.0	15.6

+ : significant at 0.1 probability levels.
Averages are significantly different (Tukey test - $p < 0.05$) when followed by different letters.

Table 3b. **Effects of soil treatments on nutrient uptake by barley at the organic farm 02 in 1988 (values are averages of six replicates).**

FARM 02					
	Nutrients in barley straw (kg/ha)				
	N	**P**	**K**	**Ca**	**Mg**
TREATMENTS					
Control	19.5	2.6	46.3	13.7	4.7
Super P	15.8	1.3	35.2	10.5	3.8
Rock P	20.5	2.1	43.3	15.8	5.0
Compost	18.3	1.91	41.8	13.5	4.3
F value	0.77	2.12	1.04	2.54+	1.34
C.V.(%)	28.5	41.5	25.4	23.6	24.0
	Nutrients in barley grain (kg/ha)				
Control	44.4	7.9	14.1	1.6a	3.3
Super P	31.9	5.2	9.0	1.0a	2.1
Rock P	39.0	7.2	12.6	1.5a	2.8
Compost	38.4	6.8	12.5	1.4a	2.7
F value	2.79+	1.84	2.74+	3.29*	1.88
C.V.(%)	19.4	30.2	26.2	26.3	22.04
	Total nutrients (straw+ grain) (kg/ha)				
Control	63.9a	10.5	60.4	12.3ab	7.8a
Super P	47.9b	6.6	44.3	11.4b	5.9a
Rock P	59.5ab	9.3	55.9	17.3a	7.8a
Compost	56.7ab	8.7	54.5	15.0ab	7.1a
F value	4.48*	2.69+	1.71	2.92+	3.24*
C.V.(%)	12.8	25.5	22.0	22.2	16.03

+, *: significant at 0.1 and 0.05, probability levels, respectively. Averages are significantly different (Tukey test - $p < 0.05$) when followed by different letters.

Table 3c. **Effects of soil treatments on nutrient uptake by barley at the conventional farm C1 in 1988 (values are averages of six replicates).**

	FARM C1				
	Nutrients in barley straw(kg/ha)				
	N	**P**	**K**	**Ca**	**Mg**
TREATMENTS					
Control	19.7	2.0	43.7	10.3	4.1
Super P	18.8	1.8	40.3	10.6	3.9
Rock P	21.3	2.2	49.2	11.3	4.2
Compost	19.5	2.2	40.9	9.6	3.8
F value	0.37	0.40	0.93	1.81	0.62
C.V.(%)	17.0	29.6	17.6	12.9	12.7
	Nutrients in barley grain (kg/ha)				
TREATMENTS					
Control	28.3	4.9	7.7	0.9	1.5
Super P	25.6	4.2	6.7	0.8	1.6
Rock P	32.0	5.6	8.6	1.1	2.0
Compost	31.0	5.0	8.2	1.1	1.9
F value	1.41	2.39	1.26	2.5+	1.21
C.V.(%)	29.2	19.2	22.9	21.0	30.0
	Total nutrients(straw + grain)(kg/ha)				
Control	48.0	6.9ab	51.4	11.3	5.6
Super P	44.4	6.0b	47.0	11.4	5.5
Rock P	53.3	7.8a	57.8	12.5	6.2
Compost	50.5	7.3ab	49.1	10.6	5.8
F value	2.11	3.50*	1.63	1.66	0.98
C.V.(%)	13.0	14.2	17.4	12.5	13.5

+, *: significant at 0.1 and 0.05, probability levels, respectively. Averages are significantly different (Tukey test - p< 0.05) when followed by different letters.

Table 4. Effect of soil treatments on % nutrients in one month old barley plants at three organic (03, 01 and 02) and three conventional (C1, C2, C3) farms, 1989. (Values are averages of four replicates)

			FARM 01		
TREATMENTS	**%N**	**%P**	**%K**	**%Ca**	**%Mg**
Control	3.44	0.33	3.86	0.79	0.17
Super P	3.36	0.37	3.64	0.83	0.19
Rock P	3.57	0.34	4.03	0.81	0.18
Compost	3.42	0.38	4.31	0.75	0.16
F value	0.18	1.64	1.86	1.67	1.73
C.V.(%)	12.3	10.4	10.3	6.3	10.6
			FARM 02		
	%N	**%P**	**%K**	**%Ca**	**%Mg**
Control	3.46	0.31	4.62	0.68	0.22
Super P	3.30	0.30	4.34	0.63	0.20
Rock P	3.65	0.27	4.40	0.71	0.24
compost	3.14	0.39	4.23	0.66	0.17
F value	1.15	3.23+	0.32	1.57	2.03
C.V.(%)	12.1	16.6	13.6	8.6	20.3
			FARM 03		
	%N	**%P**	**%K**	**%Ca**	**%Mg**
Control	3.41	0.43	4.63	0.74	0.16
Super P	3.57	0.46	4.70	0.73	0.16
Rock P	3.67	0.44	4.70	0.74	0.16
Compost	3.16	0.44	4.63	0.71	0.15
F value	1.09	0.35	0.02	0.73	1.06
C.V.(%)	12.4	11.4	10.6	4.4	8.2

Table 4. Cont'd

	FARM C1				
	% N	**%P**	**%K**	**%Ca**	**%Mg**
Control	4.26a	0.38b	6.51	0.76	0.210ab
Super P	3.96b	0.50a	6.27	0.70	0.187b
Rock P	4.46a	0.38b	6.28	0.81	0.212a
Compost	4.46a	0.47a	6.66	0.73	0.200ab
F value	4.66*	53.78***	0.78	1.52	4.65*
C.V.(%)	5.1	3.8	6.5	10.1	5.2
	FARM C2				
	%N	**%P**	**%K**	**%Ca**	**%Mg**
Control	4.88	0.49	5.46	1.22a	0.17
Super P	5.09	0.48	5.44	1.35ab	0.19
Rock P	4.97	0.46	5.27	1.30b	0.18
Compost	4.95	0.50	5.37	1.48a	0.16
F value	1.65	1.65	0.27	9.4**	0.24
C.V.(%)	2.6	5.7	6.1	5.3	6.9
	FARM C3				
	%N	**%P**	**%K**	**%Ca**	**%Mg**
Control	4.10	0.44	5.29	0.82	0.22
Super P	4.33	0.47	5.37	0.94	0.23
Rock P	4.22	0.42	5.14	0.89	0.22
Compost	4.27	0.43	5.41	0.90	0.21
F values	0.19	0.30	0.09	2.73	0.54
C.V.(%)	10.7	14.8	14.4	8.6	10.5

+, *, **, *** significant at 0.1, 0.05, 0.01 and 0.001 probability levels, respectively. Averages are significantly different (Tukey test - $p < 0.05$) when followed by different letters.

(2) Effects of three tillage/straw treatments on soil P and crop nutrition.

Table 5. Effects of soil and tillage treatments on soil nutrients and nutrient uptake by maize in 1988. (Values are averages of three replicates

	SOIL NUTRIENTS(mg/kg soil)				
	P(bicarb)	**P(resin)**	**K**	**Mg**	**Ca**
Soil treatments					
Control	5.66	10.62b	77.22	229.2	3356.7
Super P	5.77	12.65ab	74.55	220.4	3382.2
Rock P	6.00	11.52b	78.89	217.3	3421.1
Compost	6.77	13.95a	76.44	230.22	3234.4
F values	3.01+	3.92*	0.43	0.12	1.04
Tillage treatments					
Mouldboard	6.00	10.99b	82.6	193.5	3242.0
Disk	5.83	10.14b	74.58	195.5	3395.0
Disk + straw	6.33	15.42a	73.08	28.39	3408.0
F values	1.75	103***	0.47	2.52	1.24
C.V.(%)	17.9	14.3	10.7	25.2	7.1

Table 5. Contd.

	% NUTRIENTS IN MAIZE GRAIN				
	N	**P**	**K**	**Ca**	**Mg**
Soil treatments					
Control	1.37	0.22b	0.33ab	0.004ab	0.092
Super P	1.37	0.23ab	0.33ab	0.002b	0.101
Rock P	1.41	0.22b	0.32b	0.005ab	0.092
Compost	1.44	0.25a	0.35a	0.009a	0.094
F values	0.77	4.39*	2.88+	3.00*	2.24
Tillage treatments					
Mouldboard	1.39	0.22b	0.32b	0.006	0.10
Disk	1.38	0.22b	0.33ab	0.004	0.09
Disk + straw	1.42	0.24a	0.34a	0.005	0.09
F values	0.42	6.28+	2.71	0.48	0.90
C.V.(%)	8.6	7.3	5.9	91.2	14.0

+, *, **, *** significant at 0.1, 0.05, 0.01 and 0.001 probability levels, respectively.

Averages are significantly different (Tukey test - $p < 0.05$) when followed by different letters.

Table 6. Effects of soil and tillage treatments on nutrient uptake by oats. (Values are averages of three replicates)

	% NUTRIENTS IN OAT LEAVES (HEADING)				
	N	P	K	Ca	Mg
Tillage treatments					
Mouldboard	0.96	0.27	2.59	0.29	0.11
Disk	0.98	0.24	2.35	0.30	0.11
Disk + straw	0.98	0.28	2.49	0.29	0.11
F values	0.03	2.84	0.50	0.04	0.00
C.V. (%)	9.7	7.4	11.7	15.0	5.4
	% NUTRIENTS IN OAT GRAINS				
	N	**P**	**K**	**Ca**	**Mg**
Tillage treatments					
Mouldboard	1.55	0.40	0.58	0.08	0.10
Disk	1.51	0.41	0.58	0.08	0.11
Disk + straw	1.53	0.39	0.55	0.08	0.10
F values	0.50	4.24+	1.88	0.40	0.40
C.V. (%)	2.6	2.1	3.4	6.4	5.0
	TOTAL NUTRIENTS IN OAT GRAINS - kg/ha				
	N	**P**	**K**	**Ca**	**Mg**
Tillage treatments					
Mouldboard	31.51	8.20	11.72	1.70	2.11
Disk	32.06	8.74	12.27	1.69	2.25
Disk + straw	34.25	8.78	12.36	1.86	2.30
F values	0.39	0.31	0.18	0.67	0.71
C.V. (%)	12.3	11.7	11.6	11.3	9.3

+, *, **, *** significant at 0.1, 0.05, 0.01 and 0.001 probability levels, respectively.

Averages are significantly different (Tukey test - $p < 0.05$) when followed by different letters.

Table 7. Effects of tillage treatments and rock phosphate on nutrient uptake by winter wheat and clover. (Values are averages of three replicates)

	% NUTRIENTS IN WINTER WHEAT LEAVES (HEADING STAGE)				
	N	**P**	**K**	**Ca**	**Mg**
Tillage treatments					
Mouldboard	2.68	0.34	1.75	0.77	0.21
Disk	2.86	0.39	1.71	0.80	0.21
Disk + straw	2.73	0.38	1.71	0.78	0.21
F values	1.92	1.57	0.87	0.56	1.00
C.V. (%)	4.3	10.9	2.6	40.3	2.7

	% NUTRIENTS IN WINTER WHEAT GRAIN				
	N	**P**	**K**	**Ca**	**Mg**
Tillage treatments					
Mouldboard	1.46	0.34	0.42	0.086	0.102
Disk	1.38	0.33	0.40	0.098	0.096
Disk + straw	1.37	0.33	0.40	0.093	0.098
F values	0.54	0.11	1.06	1.86	0.76
+ Rock P	1.39	0.33	0.41	0.09	0.095b
- Rock P	1.42	0.34	0.39	0.89	0.102a
F values	2.08	1.04	3.43	0.08	18.00**
C.V.(%)	3.1	7.3	5.6	9.7	3.6

Table 7. Contd.

	% NUTRIENTS IN CLOVER LEAVES				
	N	P	K	Ca	Mg
Tillage treatments					
Mouldboard	3.57	0.28	2.08	1.81	0.49
Disk	3.67	0.27	1.91	2.12	0.51
Disk + straw	3.76	0.29	1.81	1.82	0.49
F values	1.27	1.16	1.02	3.5	1.89
+ Rock P	3.67	0.28	1.89b	1.92	0.52
- Rock P	3.66	0.28	1.98a	1.89	0.49
F values	0.01	0.52	9.13*	0.13	4.67+
C.V.(%)	8.6	6.3	3.4	8.7	6.0

+, *, **, *** significant at 0.1, 0.05, 0.01 and 0.001 probability levels, respectively.
Averages are significantly different (Tukey test - $p < 0.05$) when followed by different letters.

(3) Effects of green manuring and rock phosphate on P nutrition of different crops.

Table 8a. Effect of rock phosphate applied in 1987 and green manures on soil nutrients in 1988. (Values are averages of four replicates).

	SOIL NUTRIENTS(mg/kg soil)				soil
	P	**K**	**Ca**	**Mg**	**pH**
+ Rock P	10.8	226.4	3257.2	261.3a	7.2
- Rock P	9.6	179.2	3306.5	272.1a	7.3
F value	1.22	2.96	0.2	9.75*	0.7
Green manure species					
Weeds	9.5	195.5	3261	297.2	7.3
Faba beans	10.1	217.1	3302	263.9	7.3
Oilseed radish	10.5	219.0	3277	256.7	7.2
Buckwheat	10.6	179.7	3286	249.0	7.3
F values	0.81	0.98	0.21	2.45+	0.14
C.V.(%)	15.5	26.3	3.2	14.3	2.09

+, *, **, *** significant at 0.1, 0.05, 0.01 and 0.001 probability levels, respectively.

Averages are significantly different (Tukey test - $p < 0.05$) when followed by different letters.

Table 8b. **Effect of rock phosphate and green manures on nutrient uptake by oats. (Values are averages of four replicates)**

	% NUTRIENTS IN OATS STRAW				
	N	**P**	**K**	**Ca**	**Mg**
+ Rock P	1.21	0.19	2.68	0.91	0.27
- Rock P	1.20	0.19	2.52	0.91	0.27
F value	0.03	0.02	1.28	0.00	0.06
Green manure species					
Weeds	1.19ab	0.18	2.69	0.89ab	0.26b
Faba beans	1.27a	0.20	2.43	0.74b	0.24b
Oilseed radish	1.10b	0.18	2.64	0.89ab	0.26b
Buckwheat	1.27a	0.18	2.65	1.11a	0.32a
F values	4.98**	0.88	0.59	3.49*	5.87**
C.V.(%)	8.5	15.0	16.4	25.2	15.2
	TOTAL NUTRIENTS IN OATS STRAW - kg/ha				
	N	**P**	**K**	**Ca**	**Mg**
+ Rock P	9.89a	1.52a	22.19	7.54	2.26
- Rock P	8.85a	1.38a	18.69	6.85	2.05
F value	12.5*	32.5*	2.44	0.92	0.6
Green manure species					
Weeds	8.35	1.28	18.61	6.18b	1.89b
Faba beans	9.23	1.46	18.13	5.40b	1.81b
Oilseed radish	9.13	1.50	22.62	7.55ab	2.82a
Buckwheat	10.78	1.56	22.40	9.67a	2.19ab
F values	1.18	0.7	0.82	4.85**	4.32*
C.V.(%)	28.3	28.1	36.6	33.3	30.0

Table 8b. Contd.

% NUTRIENTS IN OATS GRAINS	N	P	K	Ca	Mg
+ Rock P	2.35	0.4	0.56	0.14	0.12
- Rock P	2.36	0.41	0.56	0.13	0.12
F value	0.03	0.37	0.41	0.7	0.02
Green manure species					
Weeds	2.35a	0.41ab	0.56	0.13	0.12
Faba beans	2.38a	0.44a	0.58	0.13	0.12
Oilseed radish	2.33a	0.40b	0.56	0.13	0.12
Buckwheat	2.37a	0.38b	0.56	0.15	0.12
F values	3.62*	6.54***	0.23	0.66	0.86
C.V.(%)	1.4	5.9	8.9	28.6	5.3

TOTAL NUTRIENTS IN OATS GRAINS - kg/ha	N	P	K	Ca	Mg
+ Rock P	10.40	1.80	2.51	0.61	0.54
- Rock P	9.43	1.65	2.25	0.52	0.49
F values	0.29	0.26	0.4	1.34	0.34
Green manure species					
Weeds	9.85	1.73ab	2.35	0.54	0.52
Faba beans	12.43	2.30a	3.01	0.70	0.64
Oilseed radish	11.15	1.91ab	2.72	0.63	0.56
Buckwheat	7.21	1.17b	1.69	0.46	0.37
F values	1.02	3.16*	2.24	1.24	2.08
C.V.(%)	39.1	40.5	42.7	44.2	39.4

Table 8b. Contd.

	TOTAL NUTRIENTS IN OATS (STRAW + GRAINS) - kg/ha				
	N	P	K	Ca	Mg
+ Rock P	20.30	3.33	24.71	8.16	2.80
- Rock P	18.31	3.03	20.95	7.58	2.60
F value	0.84	0.82	1.63	0.31	0.30
Green manure species					
Weeds	18.20	3.01	20.96	6.72a	2.34
Faba beans	22.25	3.90	21.34	6.19a	2.49
Oilseed radish	19.60	3.32	24.03	7.79a	2.66
Buckwheat	17.99	2.72	24.09	10.12a	3.20
F values	1.01	2.30	0.32	3.50*	1.97
C.V.(%)	26.1	26.5	35.8	31.0	26.8

+, *, **, *** significant at 0.1, 0.05, 0.01 and 0.001 probability levels, respectively.
Averages are significantly different (Tukey test - $p < 0.05$) when followed by different letters.

(4) Effects of carbon additions on nitrogen fixation and P nutrition of hairy vetch and following crops.

Table 9. Effects of oat hulls and rock phosphate on soil nutrients and nutrient uptake by hairy vetch. (Values are averages of four replicates).

	SOIL NUTRIENTS (mg/kg soil)				
	P	**K**	**Ca**	**Mg**	**pH**
+ Rock P	6.16	117.75	2946	247.83	7.32
- Rock P	6.33	122.25	2553	239.33	7.31
F values	0.07	0.13	1.55	0.68	0.02
Oat hulls (t/ha)					
0	6.50	116.75	2619	245.00	7.32
5	6.12	114.75	2501	234.13	7.38
10	6.12	128.50	2453	251.63	7.25
F value	0.57	0.51	2.59	0.31	0.61
C.V.(%)	24.3	25.6	4.5	10.33	2.2
			% NUTRIENTS IN VETCH BIOMASS		
	N	**P**	**K**	**Ca**	**Mg**
+ Rock P	4.65	0.40	2.92	1.70	0.30
- Rock P	4.47	0.37	2.90	1.65	0.32
F values	3.09	1.07	0.01	0.14	1.36
Oat hulls (t/ha)					
0	4.33b	0.36	2.89	1.71	0.36a
5	4.54ab	0.38	2.89	1.84	0.29b
10	4.83a	0.41	2.94	1.48	0.27b
F value	4.68+	2.48	0.01	4.7+	19.57**
C.V.(%)	5.6	15.6	19.7	18.3	12.4

Table 10. Effects of oat hulls and rock phosphate on nutrient uptake by sunflower. (values are averages of four replicates).

	N	P	K	Ca	Mg
	% NUTRIENTS IN SUNFLOWER PLANTS				
	N	**P**	**K**	**Ca**	**Mg**
+ Rock P	1.84	0.32	3.70	2.13	0.55
- Rock P	1.89	0.31	3.84	2.28	0.60
F values	0.50	0.01	0.10	0.73	0.54
Oat hulls (t/ha)					
0	1.94	0.29a	3.31a	2.12	0.60
10	1.80	0.34a	4.24a	2.30	0.55
F value	1.12	19.5*	30.43*	2.32	6.88+
C.V.(%)	7.6	14.7	22.3	15.7	21.5
	TOTAL NUTRIENTS IN SUNFLOWER - mg/pl				
	N	**P**	**K**	**Ca**	**Mg**
+ Rock P	101.9	17.0	197.0	116.3	31.2
- Rock P	107.3	17.5	211.6	126.9	34.4
F values	0.15	0.03	0.36	2.16	0.16
Oat hulls (t/ha)					
0	120.2	18.0	202.4	132.5	38.48
10	89.0	16.5	206.2	110.6	27.1
F values	5.43+	0.37	0.01	0.23	3.95
C.V.(%)	26.9	27.7	23.7	35.7	48.3

* Sunflower was only cultivated on two rates of oat hulls.

+, *, **, *** significant at 0.1, 0.05, 0.01 and 0.001 probability levels, respectively.

Averages are significantly different (Tukey test - $p < 0.05$) when followed by different letters.

Table 11. Effects of oat hulls and rock phosphate on the % of nutrients in weeds.

		% NUTRIENTS IN WEEDS				
Hulls (t/ha)	Rock P	**N**	**P**	**K**	**Ca**	**Mg**
0	+	2.05	0.25	3.33	2.03	0.53
	-	2.05	0.26	3.70	1.84	0.51
5	+	2.00	0.23	3.41	2.28	0.59
	-	1.75	0.24	3.11	1.48	0.50
10	+	2.60	0.31	3.83	2.13	0.48
	-	2.22	0.26	3.82	2.06	0.57