Mobilization of phosphorus in organic and conventional farming systems in Southwestern Ontario

by

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Submitted in partial fulfilment of the requirements
for the degree of Doctor of Philosophy

at

Dalhousie University
Halifax, Nova Scotia
August, 1992

ISBN 0-315-80083-6

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ABSTRACT

Organic farms are often characterized by no addition of soluble fertilizers. Crops have to rely on poorly soluble sources of nutrients, using biological mechanisms to make them available. The effects of 3 P-containing fertilizers (Rock phosphate (RP), superphosphate (super-P) and compost) were examined on 3 organic and 3 conventional farms to identify some of the critical parameters for the mobilization of P in fields cultivated with barley. The farms provided a gradient of conditions ranging from long-term organic to moderately intensive conventional. Soil P, plant P and yields were used to judge the effectiveness of P fertilizers. The biological variables examined were root mycorrhizal (VAM) infection, root acid phosphatase (P-ase), root length and soil acid P-ase.

There was no indication that RP and compost were more effective on organic than on conventional farms. Compost was, in most cases, as efficient as super-P in raising soil P levels, plant P and yields. Super-P tended to decrease VAM infection, while compost had no effects, compared to control. Root P-ase did not, in general, respond to the treatments, but it was correlated with a parameter of the internal plant P demand. Soil P-ase was in most cases unaffected by the treatments. There were not consistent differences in treatment effects between organic and conventional farms when variables were examined individually, but nutrient uptake occurred in a slower fashion in the organic than in the conventional farms. A multivariate analysis showed that the 2 longest-standing organic and the most intensive conventional farm were each clustered separately, whereas the other 3 farms were clustered together.

Three other experiments examined how crop, soil and residue management practices on a long-standing organic farm affect mobilization of native and applied P. In the 1st experiment, discing with straw retained from the previous crop and discing alone were tested in comparison to mouldboard ploughing (straw not retained). Mouldboard ploughing increased yields of green manure crops in the first year. Discing with straw had the most residual effect, increasing soil P levels and maize yields in the 2nd year, oats biomass in the 3rd year and % Mg in clover in the 4th year, compared to the other treatments.

In the 2nd experiment, RP was used with 4 green manures (GM): oilseed radish, buckwheat, faba beans and weeds. In the plots that received RP, higher levels of soil P_{res} were found over the ensuing 3 years. Effects of the GM were observed in the 1st year. Faba beans increased the % N and % P in oat grains in the 2nd year. In the 3rd year, buckwheat decreased maize yields as a result of competition from volunteer buckwheat. The VAM infection tended to be lower in maize roots on plots on which the GM were non-mycorrhizal type.

In the 3rd experiment, oat hulls were applied to the soil with RP, and hairy vetch grown. Oat hulls reduced soil NO_3^- levels, increased N_2 fixation and stimulated uptake of other nutrients by vetch. A possible boost of P accumulation by vetch under the higher levels of oat hulls occurred. No residual effect of the treatments was evident on a 2nd crop.

ACKNOWLEDGMENTS

I would like to thank CNPq - Conselho Nacional de Desenvolvimento Científico e Tecnológico (Brazil) for the financial support during most of my PhD.

I would like to thank my supervisor, David Patriquin, for his guidance, and for his confidence on my research skills, during my field work in Ontario.

I am grateful to the farmers and their respective families for their indispensable cooperation: David Reibling, Whilhelm Pfenning, Larry Bender, Stanley Gingerich, Howard Cressman and George Stock.

The assistance and support of Dr. M.H. Miller, Dr. T.P. McGonigle, Mr. W. Mitchell, Mr. Earl Gagnon and other members of the staff from the Department of Land Resource Science, University of Guelph are greatly appreciated.

Financial support for the research was provided by an operating grant from the Natural Sciences and Engineering Research Council; costs for some analyses of plants and soils were covered by a contract from the Soil and Water Environmental Enhancement Program (S.W.E.E.P.) in Ontario.

Many thanks also to:

Rupert Jannasch for the company, help and fun in the first year of my field work;

Roger Samsom and Chantal Foulds for their friendship, support and for the good time during all those years;

Allison Reibling for her company and for making my life easier during the long and tedious sections of laboratory work;

June Tasker and Margaret Hope-Simpson for proof reading this thesis;

Very special thanks to:
all the Reibling family for their invaluable support and always friendly treatment;

and to Micheal S. Warren for his friendship and for making my life enjoyable even in the most difficult times.

GENERAL INTRODUCTION

Farming practices have undergone intensive change and evolution over the last 150 years (Warkentin, 1992). Beginning with the work of Liebig on plant nutrition, there was an intensification of use of synthetic fertilizers in agriculture. Use of fertilizers rose very rapidly after WW2 and was followed by a rapid rise in the use of pesticides. These practices resulted in a highly productive agriculture in terms of food production, but by the 60's and 70's it was recognized that they were causing serious problems of pollution of soil and water and degradation of the soil resource. That led to the introduction of legal restrictions on the types and levels of various agrochemicals that could be used. Since the early 80's the concept of sustainable agriculture has gained widespread acceptance as an approach which is minimally polluting but which is also highly productive and sustainable.

During the period of intensification of the use of synthetic chemicals, some farmers and researchers have eschewed the use of synthetic fertilizers and pesticides and promoted an alternative "organic" agriculture which relies as much as possible on natural processes to maintain fertility and control pests (Merrill, 1983).

Certification programs for organic farms were introduced in the mid 1980's in North America in order to assure consumers that "organic" food is indeed grown without use of synthetic fertilizers and pesticides. The organizations and the certification processes helped to define organic farming as a specific type of farming system and to identify some of the limitations to production when farming has to rely on natural processes for maintenance of soil fertility and pest control. There are 20 different Canadian certification agencies (MacRae et al., 1989). There were 95 OCIA certified producers in Ontario in 1990 (Canadian Organic Growers, 1991).

Many organic farming practices have always been a part of many conventional farming systems and the sustainable agriculture movement is encouraging greater use of natural processes as alternatives to fertilizers and pesticides. Thus today there exists a continuum of farming systems ranging from strictly organic to farms making intensive use of synthetic fertilizers and pesticides. These different farming systems provide an opportunity to examine how whole farming systems - which are not replicable on small plots - influence the nature and dynamics of nutrient cycling.

Conducting research directly on farms is also appropriate, and to a certain extent, necessary, to understand organic farming because of the nature and intensity of the biological processes in which organic farmers rely for provision of fertility, for example, N_2 fixation and N mineralization are determined to a large extent by conditions peculiar to each farm. This is much less true when synthetic fertilizers are used because they have a very consistent composition and because they do not have to be altered by biological processes in order to be taken up by crops.

In order to identify the critical parameters of soil fertility on a long-standing organic farm in southwestern Ontario, Oak Manor Farm, a broad spectrum of observations and some experiments were conducted in the summer of 1987 (Appendix A). These studies revealed a high soil pH and low levels of available soil P, but high levels of reserve soil P. Thus it appeared pertinent to examine further, processes affecting mobilization of P on that farm, and how such processes might vary between different types of farms. In the first experiment, Oak Manor and five other farms were involved. Three of the farms were organic and three conventional. They varied in regard to the length of time under organic management and on the intensity of chemical use, respectively. Overall the six farms provided a gradient of conditions ranging from long term organic to moderately intensively conventional. In this experiment, repeated at each farm, rock P, compost and super-P were incorporated into the soil and barley was grown as a test crop. The questions I wished to answer were:

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

2. Does use of these fertilizers affect the uptake of other nutrients?

3. How do the different fertilizers affect selected biological processes involved in the mobilization of P (VAM infection, root and soil P-ase, root length)?

4. How do levels of soil organic P, inorganic P and intensity of biological processes related to P nutrition in organic systems compare to those in conventional systems?

Three other experiments dealt more specifically with how crop, soil and residue management practices on Oak Manor farm affect mobilization of native and applied phosphate. The experiments involved the long term effect of different tillage/straw regimes, different green manures and addition of a carbon containing residue (oat hulls), on soil P, P uptake, crop yields and other variables related to soil fertility and plant nutrition. The questions examined for each of the three experiments were:

1. How do different tillage/straw management methods affect P nutrition over several successive years?

2. Is rock phosphate reactive in a long term cropping sequence?

   Do different green manures affect the solubility of the rock phosphate?

   How do different crops respond to both rock phosphate and green manures?

3. Can carbon additions (oat hulls) increase N_2 fixation of a legume crop?

   Does this legume crop have a better P nutrition when fixing more N_2?

   Does this legume affect P nutrition of a following crop?

As background for these experiments, the practices of organic agriculture and scientific literature comparing organic and conventional agriculture are reviewed briefly below.

ORGANIC FARMING PRACTICES

There are various words used to refer to alternative farming systems: biological, biodynamic, natural, integrated, etc. Definition and discussion of the terminology can be found in Hodges (1981) and in MacRae et al. (1989). The term organic is used in this thesis.

The majority of organic farmers in North America were at one time, conventional farmers (Lockeretz et al., 1981). The reasons for the conversion range from the recognition of the harmful effects of chemicals to economic reasons (Lockeretz et al., 1981; Brusco et al., 1985).

In a survey conducted in Australia (Conacher & Conacher, 1983), among 9 reasons cited by farmers for converting to organic management, the 4 most important, in a decreasing order were: detrimental effects of synthetic chemicals, philosophical factors (e.g. desire to "work with nature"); decline of soil fertility under conventional practices and pollution of water and soils. Since that survey was conducted, the authors reported that the number of organic farmers in Australia has been increasing as well as the demand for organic products (Conacher & Conacher, 1991).

In California, most of the organic farmers rely on irrigation and most operate one or more tractors. They grow most of the crop species produced by the State of California (Altieri et al., 1983).

The U.S.D.A.'s report on organic agriculture (U.S.D.A., 1980) defines organic farming as:

> *"Organic farming is a production system which avoids or largely excludes the use of synthetically compounded fertilizers, pesticides, growth regulators and livestock food additives. To the maximum extent feasible, organic farming systems rely on crop rotations, crop residues, animal manures, legumes, green manures, off farm organic wastes, mechanic cultivation, mineral bearing rocks and aspects of biological control to maintain soil productivity and tilth, to supply nutrients and to control insects, weeds and other pests."*

Hodges (1982) defines biological agriculture (a synonym of organic agriculture which is used more in Europe) as follows:

"A system that attempts to provide a balanced environment, in which the

maintenance of soil fertility and the control of pests and diseases are achieved by the enhancement of natural processes and cycles, with only moderate inputs of energy and resources, while maintaining an optimum productivity. The introduction, into a biological system, of chemicals such as fertilizers tends to short-circuit these natural processes and thus a proper interpretation of this definition should not allow to the use of soluble fertilizers or synthetic pesticides in the system".

For the purposes of this thesis, I am defining conventional farming systems as:

Those systems in which synthetic (e.g. urea), secondarily processed fertilizers (e.g. superphosphate) or highly soluble natural fertilizers (e.g. potash) are used as needed to achieve maximum yield and in which synthetic pesticides are commonly used for the control of weeds, pests and diseases.

Although some techniques used in organic farming are the same as in conventional farms, monocropping is not practised on organic farms. Crop rotation is considered to be an indispensable practice in organic farming for maintaining soil fertility, enhancing nutrient cycles and controlling pests and diseases (U.S.D.A., 1980). By adopting crop rotation, practising mixed livestock/crop farming, and adopting various other diversification schemes, farmers achieve several crop management objectives simultaneously and sometimes require little if any external supplementation in order to obtain sufficient protection from pests or to achieve sustained soil fertility (Lockeretz et al., 1981).

Ketcheson (1980) pointed out the importance of including forage crops in rotations in order to maintain high levels of organic carbon and high soil aggregate stability. In 3 soils in Ontario, total carbon was always higher under rotations containing hay, oats and maize than under continuous maize. Lewis et al. (1987

a) calculated that the annual maintenance P requirements for grazed annual pastures in 2 locations were reduced from 165 and 95 kg/ha to 50 and 35 kg/ha respectively, when lucerne (a perennial legume) was introduced. In the same study, Lewis et al. (1987 b) found a highly significant correlation of soil organic carbon levels with pasture age.

The different approaches to fertility in conventional and organic agriculture are a product of conceptual differences in attitudes towards the soil and the ecosystem (Arden-Clarke & Hodges, 1988). The aim of fertilization in conventional farms is to deliver nutrients directly to the crops in simple forms, while in organic farming the aim is to feed the soil and enhance the natural nutrient cycles, and maintain complex biological cycles on which these cycles depend (Hodges, 1981).

Organic farmers in the U.S.A. seem to rely on intensive mechanical cultivation as do conventional farmers (Lockeretz & Wernick, 1980). However, organic farmers commonly prefer to use the chisel plough or to practice discing instead of mouldboard ploughing which is more common in conventional systems (Lockeretz et al., 1981; U.S.D.A., 1980).

COMPARISON OF ORGANIC AND CONVENTIONAL FARMING SYSTEMS

The literature on processes involved in nutrient cycling in organic farming systems is scarce. A few on-farm comparisons of such systems are available. Yields in organic farms tend to be lower than in conventional farms, while it is claimed that soil conservation status is higher under organic systems.

Wheat yields were 28% less under organic management than under conventional management in New York and Pensylvannia (Berardi, 1978). According to Lockeretz et al. (1980), maize yields tend to be higher in conventional farming than in organic farming when conditions are favourable; under adverse conditions, organic systems tended to have higher yields. According to Liebhardt et al. (1989) maize yields under organic management were 75% of the yields under conventional in the first two years but in the third year they were equal; with soybeans the yields were greater in organic or equal to conventional for 5 years. However, in a compilation of data from 205 systems, Stanhill (1990) found no evidence that organic cultivation methods had any yield-stabilizing or "weather proofing" effects or that a transition or conversion period existed after the organic treatments are initiated.

In a study comparing P losses in 67 agroecosystems (Floate, 1978), it was found that an average of 2.4 kg P/ha was lost from fields when fertilizers were not added and 16 kg P/ha when fertilizers were added. For 90% of the systems, either a steady state or evidence for an increase in the soil organic P pool were found. The author concluded that an increase of the organic pool was occurring at the expense of the available pool. Although the author was not comparing organic versus conventional farms, the study showed that under the prevailing conditions, P losses were reduced just by not using fertilizers.

Lockeretz et al. (1981) compared different farms in the corn belt of the U.S.A. and in general, a higher percentage of carbon in the soil was found for the organic farms. Soil P was higher on the conventional farms when the extractant used was

Bray I and no difference was found when Bray II was used. In a comparison of two adjacent farms (organic and conventional), Weilgart-Patten (1982) found that soil organic matter, extractable P, total soil N and extractable K tended to be higher in the top 30 cm of the organic farm. The farms studied had negative balances for P ranging from 5 to 14 kg ha^{-1} yr^{-1}. The deficits were higher for the organic farm. However, they were not reflected in low N and P levels. Negative balances for N (14 kg ha^{-1} yr^{-1}) and P (2.19 kg ha^{-1} yr^{-1}) in organic farms were also documented by Kaffka & Koepf (1989) in a farm that has been under organic management since 1929. In that study, it was also found that C/N ratio of the organic matter increased from 8.3 to 9.6 between 1929 and 1981.

In a comparison of data on yields from 205 organic and conventional farming systems, more than half of the comparisons of milk production and bean yields showed higher yields from organic than from conventional systems (Stanhill, 1990).

Lengnick & King (1986) compared the properties of soils from two adjacent organic and conventional farms. Soil total P, Ca-phosphates and organic P were higher in the soil from the organic than in that from the conventional farm. The fractions AlFe-P and occluded P were higher in the soil from the conventional farms. The increase of AlFe-P and occluded P were associated with the addition of P fertilizers. Although the soil P levels were initially similar, application of superphosphate fertilizer increased soil P levels to a larger extent in the conventional than in the organic farm.

In a similar study comparing the long term effects (1948-1985) of organic and conventional farming on selected soil properties, Reganold et al. (1987) and Reganold (1988) found that an organic farm had higher polysaccharide content, higher organic matter, darker colour, higher water content in summer, more favourable physical properties (such as consistence and structure), higher cation exchange capacity and higher pH than a conventional farm. The soils on organic farms had also a thicker top soil layer and were less susceptible to erosion. The erosion protection was attributed mostly to the crop rotations.

Most organic farming systems in North America are characterized by diversified crop production with the inclusion of livestock, recycling of crop and animal residues, the practice of some form of conservation tillage and the absence of use of soluble P fertilizers. In contrast, conventional systems are often characterized by a specialization of crops, absence of livestock, use of mouldboard ploughing as the main tillage system, and they make use of soluble fertilizers including superphosphate.

In conventional farming, soluble P fertilizers are commonly applied repeatedly (for each crop), because they become quickly insoluble (Sample et al., 1980). This practice may constitute a waste of resources. In the U.K., for instance, much more P is applied to soils in fertilizers than the crops contain, indicating P accumulation, although P fertilizers are used every year (Cooke, 1977). The excess of P in soils may contribute to pollution of water bodies (Coote et al., 1982), and suppress biological processes that mobilize P such as mycorrhizal infection (Menge et al., 1978; Amijee et al., 1989 a and b) and root phosphatase activity (Bieleski, 1973;

Goldstein et al., 1988 a).

A positive impact of organic management, compared to conventional, on the cycling of soil nutrients in the farm seems to occur through: (i) minimization of nutrient losses by keeping them circulating within the system, (ii) improvement of soil physical properties by the addition of organic matter, which reduces runoff, and (iii) reduction of soil erosion potential.

Organic farming seems to maintain the levels of soil P in balance. Oak Manor Farm, one of the longest standing organic farms included in this research, started its organic management practices in 1972. A preliminary nutrient budget (Appendix A) suggested a positive balance of P. Deficits for N were also low and K deficits were high. On a mixed organic farm in the Netherlands, annual balances of -65, -3.2 and -22 kg/ha were found for N, P and K respectively with no imports. With imports of straw and sod, the balance became 7, -2,1 and -20 kg/ha of N, P and K, respectively (Vereijken, 1986). According to Lockeretz et al. (1980), among several farms in the corn belt of the U.S., most had N positive balances but negative ones for K. Patriquin et al. (1986), studying a mixed organic farm in Nova Scotia, found a positive balance for N, approximate self-sufficiency for P and a deficit of 56 kg ha^{-1} yr^{-1} for K. Potassium deficits seem to be common in organic farms, indicating that the losses of K through either exports of farm products or as a result of leaching, are exceeding the imports. Few or no studies have been conducted to verify the effects of organic management practices on soil fertility and plant productivity over several years.

Whether the actual level of P maintained in organic farms will supply a satisfactory amount of P to crops, will be a function of the level of its mobilization. Mobilization of P can be theoretically defined in terms of two parameters: capacity and intensity. Intensity is the measure of the gradient in the electrochemical potential of the phosphate ions across the absorbing surfaces of the plant roots; quantity is the amount of solid P phase that acts as a reserve P replenishing the losses of P from solution (Olsen & Khasawneh, 1980).

At the farm level, mobilization will occur as a function of implicit or explicit strategies. Explicit strategies include, for instance, the addition of rock P to gutters (Lampkin, 1990). Implicit strategies include the action of biological mechanisms related to plants and soil microorganisms, that are probably stimulated by low levels (quantity and/or intensity) of soluble P in the system. These biological mechanisms will intensify the dynamics of soil P in the direction of increasing the amount of P intercepted by the roots.

ASSESSMENT OF SOIL P

The soil P available to plants is a decisive variable for the evaluation of soil fertility. Soil available P can be measured using different chemical extraction methods. The traditional soil-test methods have evolved by correlating crop responses to P fertilizers with the fraction of P extracted by a given procedure (Olsen & Khasawneh, 1980). Bray I and Olsen are largely used as the P extraction method in Canada. They are correlated with Al-P forms (Kamprath & Watson, 1980), hence, these methods are generally considered adequate for assessing P in Canadian soils.

P fertilizers often form low (superphosphate) or high (diammonium phosphate) pH solutions. When these fertilizers solubilize in the soil, a large number of new compounds of Al, Fe and Ca from soil constituents form in the soil solution. These compounds will change with time to form more stable forms and may persist for some time as a source of P for plants (Sample et al., 1980). This process will be largely controlled by the soil pH. According to solubility isotherms of known P compounds (Lindsay & Moreno, 1960), Al and Fe phosphates will be more soluble in pH values around 7.0, while Ca phosphates will be more soluble in pH values below 6.0.

Organic fertilizers are the only source of fertilizers on many organic farms. It is not well documented which P fractions are increased by addition of manures or compost, and whether these fractions are important to P uptake. McAuliffe et al. (1949) expressed concerns about the accuracy of chemical soil tests in soils where only organic fertilizers are used. In natural systems, recycling of P through decomposition of added organic matter is well recognized, but in cultivated areas, where fertilizers are applied, this aspect of P supply is overlooked (Dalal, 1979). It is more common to find studies of mineralization of organic fertilizers than the opposite process, immobilization. A few studies have analyzed the effect of organic management on the distribution of the various P fractions.

When studying the P status of soils managed organically and conventionally, Lengnick & King (1986) found greater total P, organic P and Ca-P under organic management and greater Al and Fe-P under conventional management. Addition of superphosphate also increased Al-P. In a comparison of a fertilized with a non fertilized soil, Sharpley (1985) found that mineralization of soil organic P in the growing season contributed amounts of P similar to those provided by P fertilizers. Chauan et al. (1979) found that 39% of the P added to soil as grass was in the soil organic P fraction 9 months after application, whereas the remainder was part of the labile pool (extracted by anionic resin). These data suggest that a build-up of the organic fraction occurs in such soils. Some studies indicate that a build-up of organic P occurs over the winter (Dormaar, 1972; Sharpley, 1985). Although this build-up was not affected by P fertilization (Sharpley, 1985), it is not known if it would be enhanced by frequent additions of organic fertilizers. Studies by Hedley et al. (1982 a) show that the major loss in soil P over 65 years of cultivation occurred in the organic P fraction.

The best soil tests are those that closely relate to the nutrient uptake of a large group of crops, and their extractants should not chemically interact with the soil properties. The resin anionic methods and the recently developed method using a strip of paper impregnated with iron oxides (Menon et al., 1990), are neither affected by soil properties nor do they interact with the products of fertilizers. Thien & Myers (1992) developed a method for the determination of available P in which not only the usual inorganic P is considered but also organic and microbial P is considered.

In addition to the soil-related factors affecting P availability, the mechanisms in plants that make phosphate ions available enable P to be absorbed by plants from the soil solution, should be considered. These processes may be more important in organic than in conventional farms as they may be inhibited under high levels of fertilizer application. Known examples of these processes are rhizosphere acidification in rape, buckwheat and N_2-fixing legumes (McLachlan, 1976; Aguilar-Santelises & Van Diest, 1981; Grinsted et al., 1982) and citric acid excretion by lupins (Gardner et al., 1982). In organic farming, the combined effects of: (i) the use of many plant species; (ii) the greater use of plant and animal residues; (iii) the absence of soluble fertilizers and (iv) the use of systematic crop rotations, could be expected to create an environment in which the processes noted above will be more important than in conventional farms.

CHAPTER 1

RESPONSE TO DIFFERENT PHOSPHORUS FERTILIZERS IN ORGANIC AND CONVENTIONAL FARMING SYSTEMS.

1.1. 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, P and K are the ones commonly limiting crop growth: N and K because of the large amount required for plant growth, and P because of limited availability. 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, 1977; Bekele et al., 1983; Aguilar-Santelises & Van Diest, 1981). Soil and root P-ases 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 & Gianinazzi-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 in order to function. For example, N fertilizers inhibit biological N_2 fixation (Marschner, 1986), P fertilizers inhibit mycorrhizal infection (Smith & Gianinazzi-Pearson, 1988) and soil and root P-ase activity (Spiers & McGill, 1979; Bieleski & Ferguson, 1983) that catalyses 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, and how those parameters relate, I examined the effects of applying different types of P fertilizer on crops, soil chemistry and on selected biological processes on each of 3 organic and 3 conventional farms in 1988 and 1989. A similar experiment using soil from the above mentioned farms was performed in a glasshouse in 1990. The farms, lying within an area with a radius of approximately 10 km, varied 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[1]. The organic farms included 2 farms with livestock, one without; the conventional farms were all mixed crop/livestock farms.

Three variables were used to judge effectiveness of P fertilizers: soil P levels, leaf tissue P and crop yields. Two methods of measuring soil available P were examined: bicarbonate extraction which is the standard for Ontario and the anionic resin method (Amer et al., 1955; Sibbesen, 1977, 1978). In several studies, the resin method shows a good correlation with plant P uptake (Cooke & Hislop, 1963; Bowman et al., 1978; Olsen & Khasawneh, 1980; Sibbesen, 1983). The two methods are usually correlated (Nesse et al., 1988; Soon, 1990). However, when rock-P is used, acid extractants can overestimate P values (Chien, 1978) whereas water extraction and sodium bicarbonate will underestimate it (Menon et al., 1989). Soil organic P fractions were also determined.

The percentage of inorganic P (Pi) in the leaf tissues was also measured. This fraction consists mostly of P stored in the vacuoles; it is P that is not needed

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[1] The farm designations were assigned based on:

(a) Organic farms - years under organic management.

O1 - 20 years
O2 - 9 years
O3 - 6 years

(b) Conventional farms - intensity of inputs
C1 - least intensive to C3 most intensive

For the purpose of this study organic farms are defined as those where no synthetic fertilizers, herbicides or pesticides are used; conventional farms are defined as those where the products above are used on a regular basis.

by the plant at the moment of the measurement (Bieleski, 1968; Chapin & Bieleski, 1982). Therefore, the higher this fraction, the better the P nutrition (Bieleski & Ferguson, 1983).

Four variables involved in biological mobilization of P were examined: vesicular arbuscular mycorrhizal (VAM) infection, root acid P-ase, soil acid P-ase activity, and root length.

The VAM infection was separated into two basic components: percentage of roots infected with arbuscules and percentage of roots with no infection. The arbuscules are known to be the active component of the symbiosis. They are the sites where the exchange of nutrients from the fungus to the host occur (Cox & Tinker, 1976). The amount of root infected with hyphae may or may not be an accurate measure of the efficiency of the symbiosis since arbuscules are the only unique feature of VAM (McGonigle et al., 1990), while hyphae are found in any fungus. Hence, the percentage of roots infected with arbuscules was used in the discussion regarding the effect of VAM on plant nutrition.

The root P-ase activity is a variable that in some cases is thought to be responsible for hydrolysing P in some soil organic P fractions, which in turn, contributes to P uptake of crops. It can also be used as an indicator of P stress of the crop, as it was used in this study. Plants respond to P shortages with an increase of root P-ase activity (Bieleski & Ferguson, 1983).

Root geometry is relevant to P acquisition (Bieleski, 1973; Schubert & Mengel, 1989). Plants respond to P stress by modifying root architecture such as lateral root length and density of root hairs (Adalsteinsson & Jensen, 1989; Fohse et al., 1991). In this study, root length and weight were determined.

There were 4 general questions that I hoped to answer with this set of experiments; those questions and the respective hypotheses that were tested are as follows:

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

2. Does use of these fertilizers affect the uptake of other nutrients?

3. How do the different fertilizers affect selected biological variables involved in the mobilization of P (VAM infection, root and soil P-ase, root length)?

4. How do levels of soil organic P, inorganic P and intensity of biological processes related to P nutrition in organic systems compare to those in conventional systems?

It was hypothesised that:

(i) under organic management, processes involved in mobilization of P (including those cited above and possibly others) are enhanced compared to conventional management and therefore,

(ii) rock-P and compost are more effective sources of P under organic management than under conventional management; and

(iii) super-P suppresses mycorrhizal infection (as indicated by many experimental studies) and possibly other processes.

(iv) use of compost has favourable effects on mycorrhizal infection.

By looking at correlations between the many variables measured it was hoped to identify which of these are more related to P nutrition. Multivariate techniques were used to examine how all variables considered together varied between farming systems.

1.2. MATERIAL AND METHODS

1.2.1. DESCRIPTION OF THE FARMS

Six farms located in a traditional cereal-growing area in Southwestern Ontario at the boundary of Oxford, Perth and Waterloo counties were selected for the study. Farms in this region are mostly mixed cereal and livestock farms where spring barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.), maize (*Zea mays* L.) and alfalfa (*Medicago sativa* L.) are the main crops grown. Organic residues from livestock are used on most of the farms as fertilizers, in addition to synthetic fertilizers (on the conventional farms). A more detailed description of the farms and fields in which the experiments were conducted can be found in Appendix E.

Data on soil nutrients, pH, organic matter and texture for the 6 sites are given in Tables 1, 2 and 3.

Table 1. Soil fertility variables of the three farms studied in 1988 (composite samples of the control plots sampled in the last week of June).

	Soil exchangeable nutrients (mg nutrient/kg soil)				
FARMS	P_{bicarb}	K	Ca	Mg	pH in water
O1	6.8 L-M*	137.3 H	3340	300	7.2
O2	10.0 M	83.5 L-M	3333	172	7.5
C1	18.1 M-H	206.0 H-VH	1375	178	5.8

*The letters are ratings for the soil analysis according to Ontario Ministry of Agriculture (1989):L - low; M - medium; H - high; VH - very high.

Table 2. Soil texture and soil fertility variables of the six barley fields studied in 1989 (composite samples of the control plots sampled in the last week of June).

FARMS	Clay	Silt	Sand	Total*	Organic matter (%)
	Percentage of dry weight				
O1	15.7	36.7	46.1	98.6	3.6
O2	16.2	30.5	54.1	100.6	3.6
O3	27.5	39.0	27.2	93.7	3.7
C1	18.0	50.3	28.6	97.0	3.6
C2	25.2	41.1	30.1	96.7	4.8
C3	23.1	38.5	32.3	93.9	4.3

	Soil exchangeable nutrients (mg nutrient/kg soil)			
	P_{bicarb}	K	Mg	pH in water
O1	10 M**	148 H	137	7.5
O2	18 M	222 VH	261	7.1
O3	20 M	74 L-M	156	6.9
C1	18 M	185 H	63	7.5
C2	13 M	106 M	218	6.5
C3	40 H	169 H	171	7.9

*TOTAL= CLAY+SILT+SAND after organic matter was eliminated with H_2O_2.
**The letters are ratings for the soil analysis according to Ontario Ministry of Agriculture (1989):L - low; M - medium; H - high; VH - very high.

Table 3. Soil fertility variables of soil from the glasshouse experiment (composite samples from the control pots§ (sampled in the first week of July).

FARMS	Soil exchangeable nutrients (mg nutrient/kg soil)				pH in water
	P_{bicarb}	K	Mg	Ca	
O1	12.0 M*	93.2 M	146.0	2100	7.9
O2	15.0 M	54.9 L	200.0	1500	7.8
O3	27.0 H	86.2 M	234.0	1650	6.9
C1	20.0 M	132.0 H	235.0	1200	6.9
C2	16.0 M	66.2 L	221.0	2900	7.8
C3	24.0 H	91.1 M	164.0	3400	7.9

*The letters are ratings for the soil analysis according to Ontario Ministry of Agriculture (1989):L - low; M - medium; H - high; VH - very high;
§ Pots not receiving any fertilizer treatments.

1.2.2. OUTLINE OF THE EXPERIMENTS

(i) On farms, 1988

FARMS: 2 organic (O1 and O2); 1 conventional (C1)

TREATMENTS: No fertilizer
Triple superphosphate (60 kg P_2O_5/ha)
Rock-P (180 kg P_2O_5/ha)
Compost (10 t/ha; 47.1 kg P_2O_5/ha)

PLOT SIZE: 2 X 2 m

CROP: Barley cv. Leger

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

OBSERVATIONS:
Soil available P (sodium bicarbonate (P_{bicarb}) and anionic resin (P_{res})) heading stage
Soil exchangeable K, Ca, Mg, and soil pH, heading stage
Percentage of N, P, K, Ca, Mg in barley grain and straw at harvest
Grain, straw and weed biomass at harvest
VAM infection, heading stage
Root and soil acid P-ase activity, heading

(ii) On farms, 1989

FARMS: 3 organic (O1, O2, O3); 3 conventional (C1, C2, C3)

TREATMENTS: As above, compost (10 t/ha; 49.5 kg P_2O_5 /ha)

PLOT SIZE: As above

CROP: As above

EXPERIMENTAL DESIGN: Randomized complete blocks with 4 replicates on each farm

OBSERVATIONS:

Soil available P (P_{bicarb} and P_{res}), early stage
Soil organic and inorganic P fractions, heading[1] stage
Soil exchangeable K, Ca, Mg, and soil pH, heading[1] stage
Percentage of N, P, K, Ca, Mg, early and heading[1] stage
Grain, straw and weed biomass at harvest
VAM infection, early stage
Root and soil acid P-ase activity, early and heading[1] stage
Root length, heading[1] stage

(iii) Greenhouse, 1990

Soil from the above 6 farms, collected in the Spring of 1990;

TREATMENTS: No fertilizer

Triple superphosphate (60 kg P_2O_5/ha)
NPK (50, 60 and 50 kg/ha of N, P_2O_5 and K_2O, respectively)
Compost (10 t/ha; 52.0 kg P_2O_5/ha)

POT SIZE: 4 kg of soil/pot

CROP: As above

EXPERIMENTAL
DESIGN: Split plot with farms as the main plots and fertilizers as the subplots, randomized complete blocks with 4 replicates

OBSERVATIONS (all plant variables were measured on the early stage):

Soil available P (sodium bicarbonate (P_{bicarb}) and anionic resin (P_{res}))
Soil exchangeable K, Ca, Mg and soil pH
Percentage of N, P, K, Ca, Mg in barley
VAM infection
Root and soil acid P-ase activity
Soil alkaline P-ase activity
Root length and root weight

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[1]The measurements at the heading stage were done only on the control plots in 1989.

1.2.3. DETAILS OF EXPERIMENTAL METHODS

Fertilizers

Three P-containing fertilizers - triple superphosphate (super-P), compost and rock-P (RP) were applied to plots on which barley (*Hordeum vulgare L.*) was grown, on selected fields of each of 3 farms in 1988 and 6 farms in 1989. The rates of application (compost: 10 t/ha, fresh weight; super-P: 60 Kg P_2O_5 /ha) were based both on the farmers' current use and the rates recommended by the Field Crops Recommendations Guide (Ontario Ministry of Agriculture and Food, 1987).

The commercial designation and composition of the RP according to the manufacturer is: Zorafos - soft phosphate with colloidal clay. Available phosphoric acid= 2%, total phosphoric acid= 18%. The composition according to analysis performed for this study was: P extracted with neutral ammonium citrate = 2.08%, total P = 15.3%. The compost used was produced at farm O1 from cattle manure and bedding, and leftovers from the mill run by the farmer. The material was piled up during the previous summer and the composting process was carried out over the fall and winter. Table 4 shows the results of the chemical analysis of the compost used in 1988 and 1989.

Table 4. Chemical composition of the compost.

	Total nutrients (%)					Moisture (%)*
	N	P	K	Ca	Mg	
1988	1.1	0.9	1.1	3.4	0.6	47.7
1989	1.6	0.9	1.1	3.5	0.9	45.0
1990	1.5	0.9	1.1	nd	nd	41.0

* Moisture is expressed as percentage of water in compost at time of application.
nd - not determined

Field experiments

The plots were laid out in fields where barley was to be seeded by the farmers in 1988. The fertility treatments were applied to the plots before farmers prepared the seedbed. Compost, super-P and RP were broadcast by hand. No further management was conducted, except on the farm C1 where the farmer applied TILT®(Ciba-Geigy), a broad spectrum fungicide, when the plants were two weeks old. In 1989, the treatments were applied in the same fields but in different plots than in 1988, except for farm O1, where an adjacent field was used.

In 1988, determinations of root VAM infection, soil and root acid P-ase activities were made when the crop reached the heading stage (last week of June), using the methods described below. Farms were sampled on consecutive days. Soil samples were collected from 4 sites per plot, from the top 20 cm. Grain yields, straw production and weed biomass were assessed at this time. The four central rows of each plot were used for the determinations: the two inner rows for yield estimation and the two outer ones for the remaining determinations. Six plants per plot were collected for determinations of VAM and P-ase activity. For yield estimation, the whole barley plants were harvested by hand from the central 1 m of the 2 inner rows and dried at 60 C. Grains were separated from the plants and hulled using a mechanical device.

The plants were dug out of the soil maintaining as much of the root system and adhering soil as possible. The shoots were separated from the roots. The roots and adhering soil were put into plastic bags and stored in a cooler containing ice. The material was immediately taken to the lab. The adhering soil was separated from the roots and the roots were washed and cut off from the stem. Soil and root samples were assayed for acid P-ase activity as described below. Sub-samples of soil samples were taken for moisture determinations: fresh weight was measured, samples were dried at 110 C and reweighed. After the P-ase assay, the roots were cut in pieces of about 3 cm length and stored in F.A.A. (900 ml 95% ethanol + 55 ml glacial acetic acid + 55 ml formalin) for subsequent examination of VAM infection. All of the plant material was dried at 60 C and weighed to determine the dry weight.

Soil analyses were performed by the University of Guelph soil laboratory, according to the standard methods for soil analysis for Ontario. P was extracted with 0.5 M sodium bicarbonate at a ratio of 2.5 cm^3 of soil to 50 ml of sodium bicarbonate for 30 min (Olsen et al., 1954). Soil K, Ca and Mg were extracted with 1 N neutral ammonium acetate solution (ratio soil:extractant = 2.5 cm^3 :25 ml) for 15 min and determined by atomic absorption spectrophotometry. Soil nitrates were extracted with 2 M KCl solution and determined by the automated method described by Keeney and Nelson (1982).

Soil P was determined on separate samples by the anionic resin method. The methodology used was that described by Amer et al. (1955) with modifications described by Sibbesen (1977, 1978). The modification included the use of polyester netting bags containing the resin for the extraction procedure. The resin used was a BIO RAD (140-1421) "Analytical Grade anionic resin AG®1-X8".

Netting bags containing anionic resin with total anionic exchange capacity of approximately 10 meq/bag were shaken at 220 rpm and at room temperature, in a circular-type shaker (G24 environmental incubator shaker, New Brunswick Scientific Co., N.J.), with 4 g of soil and 15 ml of distilled water for 16 h. After the 16 h extraction period, the resin bags were washed and transferred into flasks containing 50 ml of 0.5 N $NaHCO_3$ for 1 h. The extract was collected and P determined colorimetrically according to the methodology of Murphy and Riley (1962).

Soil P-ase activity was measured according to the methodology of Tabatabai & Bremner (1969). This method consisted of the colorimetric estimation of the p-nitrophenol released by P-ase activity, when 1 g of fresh rhizospheric soil was incubated with 5ml of a buffered (pH=6.5) solution (0.025 mmol of p-nitrophenyl phosphate, Sigma 104, phosphatase substrate, Sigma Chemicals, St Louis, MO) and toluene, at 37 C for 1 h. A blank prepared as above, with the exception that the substrate was added at the end of the reaction time, was used to correct for the background colour. Soil sub-samples were taken for determination of moisture.

Root P-ase activity was likewise determined by colorimetric estimation of the p-nitrophenol released when 0.05 mmol of p-nitrophenyl phosphate was incubated with 32 ml of a buffer solution (pH= 6.5) and 1 g of roots at 37 C for 30 min. A blank with all reagents but no roots was included.

For determinations of VAM infection, the staining procedure of Brundrett et al. (1984) was used. One modification was introduced: the entire process of clarifying, washing and staining the roots was carried on with the roots kept in plastic cages (40 x 28 x 7 mm). The infection estimation procedure used was that of McGonigle et al. (1990). This method estimates VAM infection by the inspection of intersections between the microscope eyepiece cross hair and roots at 200 X magnification. Infections with arbuscules, hyphae and vesicles, and roots with no infection, were calculated by dividing the count for each category by the total number of intersections examined.

In 1989, the plants were sampled at the stage 31 of Zadok's scale (first node of stem visible (Ontario Ministry of Agriculture and food, 1987) and referred to hereafter as "early stage") for determination of root and soil P-ase, VAM infection and tissue nutrients. Samplings were conducted in the first week of June.

At the heading stage (last week of June), roots were collected from the control plots of each farm for determination of root length by the intersection counting method (Tennant, 1975). Cylinders containing 261 cm^3 of soil were taken in duplicate from each plot. Roots were washed free of soil and stored in F.A.A. until measurement. Leaves were sampled for inorganic P (Pi) according to the methodology proposed by Daley and Vines (1977) and for total P, as well as for N, K, Ca and Mg. The top two leaves of 6 plants per plot were taken for this purpose. Root and soil P-ase were also measured at heading following the above procedure.

Determinations of soil texture were conducted by the hydrometer method according to Day (1956). Fractioning of soil organic P was conducted according to the extraction method of Bowman (1989). Organic P was also calculated from the percentage of soil total N (measured by the soil laboratory, University of Guelph) according to the regression equations developed by Sharpley et al. (1984). These regression equations were developed using 78 soils from the U.S. ranging from calcareous to highly weathered soils. Soil samples from neighbouring fields to farms O1 and O2 were collected for determinations of organic P.

Glasshouse experiment

This experiment was conducted in 1990. The soil came from fields where the previous experiments had been performed, from areas adjacent to the 1989 plots. The soil was collected from the surface 20 cm of soil, passed through a 2 cm diameter sieve and the moisture content determined. Each pot received the equivalent of 4 kg of oven dried (110 C) soil. The fertilizer treatments were applied individually to each plot and barley cv. Leger was planted. Eight seeds were planted in each pot. Seven days after germination, plants were thinned to 5 plants per pot. The plants were sampled 35 days after germination when they reached the stage 31 of the Zadok's scale. The sampling procedure lasted for 4 consecutive days (July 5-8). One of the 4 replicates was collected per day.

Procedures used for the sampling of roots and soil for determination of P-ase activity were described in the previous experiment. After the collection of roots for P-ase activity, the roots were washed and returned to the original pots; the soil in each pot was mixed and homogenized by hand and a sub-sample of 400 g of soil taken and stored in the refrigerator until the last replicate was harvested. The refrigerated soil and root samples were then washed, roots separated and stored in FAA until the root length was determined. After the length determination, the roots were stained as described previously for VAM infection.

The shoots were collected for nutrient analysis and soil samples were taken for fertility analysis.

1.2.4. STATISTICAL ANALYSIS

Analysis of variance (ANOVA)

All of the statistical analyses were performed using the SAS software (SAS Institute INC., 1985). The data sets were tested for homogeneity of variance (Bartlett's test) prior to analysis. For all experiments, an ANOVA was performed to test for the difference of the four treatments on each farm. In the cases where the ANOVA resulted in significant F values ($p<0.05$), a Tukey test was used for mean separation (HSD). In cases where the F values were significant but the HSD did not separate the means, or in cases when the F values fell in the probability level of $0.10> p >0.05$, the differences were considered as "trends".

Multivariate analysis

Data from the study of 3 farms in 1988 and of 6 farms in 1989, were examined using multivariate statistics. For 1988 data, PCA (principal component analysis) was performed using 22 variables and 72 observations.

For the 1989 data, PCA was performed using 12 variables and 96 observations. The observations came from plots located at six farms, each of which had received four fertilizer treatments in 4 replicates (6 X 4 X 4=96). PCA was performed using the procedure "PROC FACTOR" followed by a varimax rotation; the criteria for the number of factors retained was based on the minimum eigenvalue= 1 or "mineigen=1" (SAS Institute INC, 1985).

A cluster analysis was performed using the main factors retained in the PCA to try to allocate the farms to clusters. Eight different cluster techniques (average linkage, centroid hierarchical, complete linkage, equal variance maximum likelihood, flexible-beta, McQuitty's similarity, median hierarchical, single linkage, and Ward's minimum variance - SAS Institute INC, 1985) were used; only the results of the average linkage are reported, however.

1.3. RESULTS

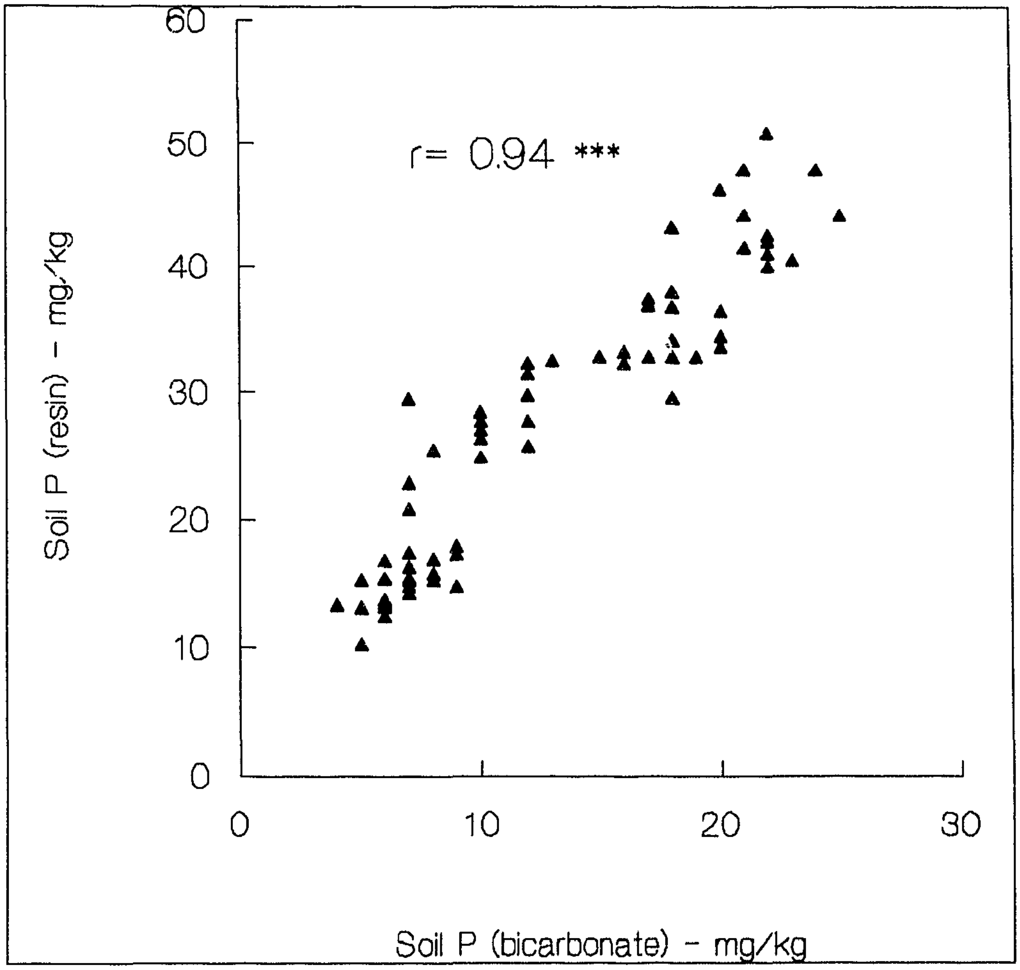
1.3.1. EFFECTS OF FERTILIZER TREATMENTS

1.3.1.1. EFFECTS OF FERTILIZER TREATMENTS ON SOIL AND PLANT NUTRIENTS AND YIELDS.

(i) Soil nutrients.

In 1988, four P treatments were applied on each of two organic farms (O1 and O2) and on one conventional farm (C1). In 1989, the treatments were applied in the same fields but on different plots and in fields on one additional organic (O3) and on two additional conventional farms (C2 and C3). Levels of soil nutrients at approximately 2 months after applying fertilizers, were examined in both years. Two methods were used to measure soil available P: the standard method for Ontario (sodium bicarbonate extraction) and the resin method (Sibbesen et al., 1977, 1978).

There was a good correlation between the results obtained by the two P extraction methods in 1988 (r= 0.94, Figure 1). The bicarbonate extracted about half of the amount of phosphate extracted by the anionic resin. Differences between treatments were more pronounced for the resin method in 1988 and only that method resulted in statistically significant differences (Table 5). Hence the anionic resin method was used routinely.



$$P_{res} = 6.0 + 1.68\ P_{bicarb}$$

Figure 1. Relation between soil P measured by two extractants: anionic resin and sodium bicarbonate. Data from 3 farms, 6 replicates and 4 treatments.

In both years applications of both super-P (60 kg P_2O_5/ha) and compost (49.5 kg P_2O_5/ha) resulted in significantly higher ($p<0.05$) soil available P than was found controls in 3 out of 9 and 4 out of 9 comparisons, respectively (Table 5). On all farms, the values for both compost and super-P were numerically higher than the control values. There were no statistically significant responses to RP (180 kg P_2O_5/ha), nor any trends of increases in soil available P.

Lowest P_{res} values were found in the oldest organic farms. There is some suggestion that more P is released on the organic than on the conventional farms: values calculated from data in Table 5 for compost (P_{res} in compost minus P_{res} in control plots), were higher in the organic than in the conventional farms, while the values for super-P (P_{res} in super-P minus P_{res} in control plots) overlap.

The fertilizer treatments had no significant effects on the levels of other nutrients examined in 1988, except at O1 where the potassium levels were lowest with super-P and highest with compost (Table 6).

Table 5. Effects of P fertilizers on soil P_{res} and P_{bicarb} levels in different farming systems over two years (averages of 6 replicates in 1988 and 4 replicates in 1989; samples taken in the last week of June for both years).

	FARMS - 1988					
TREATMENTS	O1	O2	C1	O1	O2	C1
	Soil P (mg P/kg soil)					
	P_{res}			P_{bicarb}		
Control	15.2b	23.7b	36.8b	6.8	10.0	18.1
Super-P	18.6b	26.7a	41.5ab	7.5	12.8	20.5
RP	14.4b	22.8b	36.9b	7.3	10.5	19.8
Compost	24.6a	28.7a	42.8a	8.6	12.0	20.8
F value	9.80**	7.91**	4.03*	1.71	1.68	1.36
C.V.(%)	19.9	9.2	9.5	1.92	21.9	9.5
	FARMS - 1989					
TREATMENTS	O1	O2	O3	C1	C2	C3
	Soil P_{res} (mg P/kg soil)					
Control	20.5	22.0a	37.7b	40.2b	37.1a	50.3
Super-P	22.2	30.5a	58.0a	46.1a	44.6a	52.3
RP	18.6	21.0a	47.6ab	42.5ab	34.0a	44.7
Compost	24.7	31.4a	48.9ab	43.6a	41.0a	53.8
F value	1.16	4.38*	7.80*	9.74*	2.83*	0.50
C.V.(%)	21.7	19.9	10.7	3.6	12.8	21.7

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

Table 6. Effects of P fertilizers on exchangeable K, Ca, Mg and soil pH in 1988 (averages of 6 replicates; samples taken in the last week of June).

TREATMENTS	FARMS O1	O2	C1
	Soil K (mg/kg soil)		
Control	132.3ab	83.5	206.0
Super-P	119.6b	75.5	204.7
RP	143.8ab	70.8	204.3
Compost	150.0a	81.3	220.7
F value	3.94*	1.31	0.71
C.V.(%)	12.1	5.8	10.9
	Soil Ca (mg/kg soil)		
Control	3340	3333	1375
Super-P	3226	3295	1400
RP	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
RP	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
RP	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	3.9

* significant at the 0.05 probability levels, respectively. Values followed by the same letter in each column are not significantly different (Tukey test $p<0.05$).

(ii) Biomass and plant nutrients

In 1988 the total amounts of nutrients in grain and straw were measured. In 1989, the percentages of nutrients at the early stage was measured for all treatments. Additionally, the percentage of nutrients and concentration of Pi in the leaf tissue were measured at the heading stage in the control plots.

There were no significant effects of P fertilizer type on yield of grain, straw or weeds in 1988 (Table 7) or on total P in the crop at harvest (Appendix D). Yields in 1988 were low on all farms because of drought (Appendix B).

In 1989 the grain yields were affected by the treatments on farm O1 (Table 8). Only super-P increased grain yields significantly as compared to the control. The fresh and dry weight of plants in the early stage was not significantly affected by the treatments on each farm (Table 9). The grain yields at O2 were extremely low, possibly because of N deficiency which is suggested by the response to the 50 kg N/ha in side plots (Table 8).

A highly significant effect of the fertilizers on the percentage of P in barley at the early stage was observed for farm C1 in 1989 (Table 10). Regarding the other nutrients, it was mostly at farm C1 that the effects of the treatments were noticed (Table 11). The super-P treatment had a negative effect on the percentage of N and Mg. The percentage of K values at farm C1 were the highest for all farms.

Table 7. Effects of P fertilizers on yield of barley grain, straw and weeds in 1988 (averages of 6 replicates).

TREATMENTS	FARMS O1	O2	C1
		Grain (kg/ha)	
	O1	O2	C1
Control	2076	2410	1412
Super-P	1839	1825	1302
RP	2014	2227	1623
Compost	2076	2113	1540
F value	0.34	1.86	1.29
C.V (%).	23.6	21.0	20.6
		Straw (kg/ha)	
Control	2443	3130	2680
Super-P	2485	2718	2677
RP	2149	3389	2795
Compost	2879	3135	2403
F value	2.18	1.20	1.12
C.V.(%)	20.0	20.1	14.6
		Weeds (kg/ha)	
Control	304	461	169
Super-P	238	347	106
RP	250	333	133
Compost	293	430	108
F value	1.81	0.85	0.95
C.V.(%)	21.6	42.1	57.3

All F values are non-significant.

Table 8. Effects of P fertilizers on yield of barley grain and straw in 1989 (averages of 4 replicates).

	FARMS					
TREATMENTS	O1	O2	O3[1]	C1	C2	C3
			Grain (kg/ha)			
Control	3388b	913	3561	3317a	4128	2488
Super-P	3681a	1138	3437	2503a	3982	2488
RP	3650ab	985	2479	3449a	3667	2469
Compost	3850ab	1457	3215	2741a	3486	2396
Nitrogen[2]	3273	2045	3416	3228a	4302	2997
F value	4.93*	2.97	2.12	3.92*	0.79	0.04
C.V.(%)	6.3	24.9	18.2	15.2	11.3	21.1
			Straw (kg/ha)			
Control	4226	2680	3032	4532	5186	4047
Super-P	3808	2633	3343	3695	5017	3940
RP	3806	2198	3298	5202	4895	3825
Compost	3664	2137	3096	3695	4666	3460
F value	0.70	2.20	0.16	3.34+	1.36	0.95
C.V.(%)	15.0	15.3	20.7	15.5	7.6	13.7
			Weeds (kg/ha)			
Control	932.8	925.8	96.0	679.9	0.0	0.0

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

[1] At this farm only 3 replicates were used to assess yield because of damage to the plants in one replicate.

[2] Extra plots with 50 kg N/ha (ammonium nitrate) applied on the surface on May 31. These results are not included in the ANOVA.

Table 9. Effects of fertilizers on fresh and dry weight of barley plants in the early stage in 1989 (averages of 4 replicates).

	FARMS§				
TREATMENTS	O1	O2	O3	C1	C3
			Fresh weight (g/plant)		
Control	2.74	1.29	2.09	1.79	1.67
Super-P	2.64	1.46	2.55	2.71	1.86
RP	2.47	1.91	2.63	2.16	2.12
Compost	3.05	1.64	1.96	2.8	1.74
F value	0.88	1.91	2.59	2.78+	1.37
C.V.(%)	20.2	20.4	17.9	24.1	18.6
			Dry weight (g/plant)		
Control	0.34	0.16	0.25	0.18	0.48
Super-P	0.35	0.18	0.29	0.34	0.53
RP	0.32	0.16	0.31	0.23	0.61
Compost	0.40	0.22	0.23	0.28	0.50
F value	0.89	1.58	3.71^{+}	2.71	1.37
C.V.(%)	20.2	24.0	14.0	31.2	18.6

+ significant at 0.1 probability level.

§ No samples for Farm C2.

Table 10. Effects of P fertilizers on the percentage of P in barley plants in the early stage in 1989 (averages of 4 replicates).

	FARMS					
TREATMENTS	O1	O2	O3	C1	C2	C3
			P %			
Control	0.33	0.31	0.43	0.39b	0.49	0.44
Super-P	0.37	0.30	0.46	0.50a	0.48	0.47
RP	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	53.8**	1.65	0.30
C.V.(%)	10.4	16.6	11.4	3.8	5.7	14.8

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

Table 11. Effect of P fertilizers on the percentage of major nutrients other than P in barley plants in the early stage in 1989 (averages of 4 replicates).

		FARM O1		
TREATMENTS	N %	K%	Ca%	Mg%
Control	3.44	3.86	0.79	0.17
Super-P	3.36	3.64	0.83	0.19
RP	3.57	4.03	0.81	0.18
Compost	3.42	4.31	0.75	0.16
F value	0.18	1.86	1.67	1.73
C.V.(%)	12.3	10.3	6.3	10.6
		FARM O2		
	N%	K%	Ca%	Mg%
Control	3.46	4.62	0.68	0.22
Super-P	3.30	4.34	0.63	0.20
RP	3.65	4.4	0.71	0.24
Compost	3.14	4.23	0.66	0.17
F value	1.15	0.32	1.57	2.03
C.V.(%)	12.1	13.6	8.6	20.3
		FARM O3		
	N%	K%	Ca%	Mg%
Control	3.41	4.63	0.74	0.16
Super-P	3.57	4.70	0.73	0.16
RP	3.67	4.70	0.74	0.16
Compost	3.16	4.63	0.71	0.15
F value	1.09	0.02	0.73	1.06
C.V.(%)	12.4	10.6	4.4	8.2

(continued)

Table 11. (continued).

TREATMENTS	N %	K%	Ca%	Mg%
		FARM C1		
Control	4.26a	6.51	0.76	0.21ab
Super-P	3.96b	6.27	0.70	0.187b
RP	4.46a	6.28	0.81	0.212a
Compost	4.46a	6.66	0.73	0.200a
F value	4.66*	0.78	1.52	4.65**
C.V.(%)	5.1	6.5	10.1	5.2
		FARM C2		
	N%	K%	Ca%	Mg%
Control	4.88	5.46	1.22b	0.28
Super-P	5.09	5.44	1.35ab	0.27
RP	4.97	5.27	1.30b	0.27
Compost	4.95	5.37	1.78a	0.28
F value	1.65	0.27	9.42*	0.24
C.V.(%)	2.6	6.1	5.3	6.9
		FARM C3		
	N%	K%	Ca%	Mg%
Control	4.1	5.29	0.82	0.22
Super-P	4.33	5.37	0.94	0.23
RP	4.22	5.14	0.89	0.22
Compost	4.27	5.41	0.90	0.21
F value	0.19	0.09	1.64	0.54
C.V.(%)	10.7	14.4	8.6	10.5

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

1.3.1.2. EFFECTS OF FERTILIZER TREATMENTS ON VAM INFECTION IN BARLEY ROOTS

VAM infection was assessed at the heading stage in 1988 and at the early stage in 1989. The infection was separated into two components: percentage of roots infected with arbuscules and percentage of roots with no infection. Because the percentage of vesicles was consistently lower than 1% of the root length, this fraction was disregarded.

In 1988, the percentage of the root length infected with VAM (arbuscules) was very low at farms O1 (around 3%) and at farm C1 (less than 1%) (Table 12). Overall, there was no significant effect of the fertilizer treatments on the percentage of arbuscules at the three sites (Table 12). At O2, where the percentage of roots infected with arbuscules was highest, the absolute values show a trend of decline in this variable under the effect of super-P and compost, as was expected.

In 1989, significant effects of the fertilizer treatments on the percentage of arbuscules were found only in farm O3 (Table 13). Super-P and RP significantly reduced the percentage of arbuscules compared to the control at that farm. In C1, the same trend ($p<0.10$) was observed for super-P; in two other farms, O1 and O2, arbuscules were also numerically lower under super-P. At C2, the values for super-P were slightly higher than values for the control. Farm O2 maintained high arbuscule infection, as was found in 1988. There is no evidence that one type of farming system favours the development of VAM.

Table 12. Effects of P fertilizers on the percentage of VAM infection in barley roots at the heading stage in 1988 (averages of 6 replicates).

	FARMS		
TREATMENTS	O1	O2	C1
	Arbuscules (%)		
Control	3.0	17.7	0.6
Super-P	3.8	10.2	0.6
RP	2.7	17.7	0.5
Compost	3.6	12.5	0.4
F value	0.40	1.42	0.13
C.V.(%)	22.5	27.0	29.8
	Vesicles (%)		
Control	1.0	0.4	0.8
Super-P	1.2	0.3	0.5
RP	1.3	0.4	0.4
Compost	1.0	0.3	0.6
F value	0.17	0.19	0.87
C.V.(%)	72.2	97.1	75.5
	No infection (%)		
Control	41.3	46.8	46.4
Super-P	34.5	48.0	50.7
RP	39.9	37.8	50.4
Compost	37.5	42.0	55.0
F value	0.78	2.55+	1.99
C.V.(%)	21.4	16.9	12.1

+ significant at the 0.1 probability level.

Table 13. Effects of P fertilizers on the percentage of VAM infection in roots of barley plants in 1989 (averages of 4 replicates).

	FARMS					
TREATMENTS	O1	O2	O3	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
RP	13.3	23.5	10.3c	21.7	21.1	16.9
Compost	9.1	24.1	19.1ab	18.9	29.9	13.0
F value	2.42	0.31	8.77**	3.47+	0.76	0.32
C.V.(%)	3.7	8.9	3.4	3.6	7.2	8.6
			No infection (%)			
Control	60.7	54.5	51.2b	51.8b	57.7	67.6
Super-P	61.4	66.8	63.4a	72.0a	56.9	62.9
RP	58.9	54.5	68.6a	58.4a	49.0	68.8
Compost	65.2	58.0	60.1ab	59.8b	55.9	73.5
F value	0.57	1.26	6.36*	4.50*	0.43	0.50
C.V. (%)	11.5	17.7	9.5	12.1	22.0	16.8

Values followed by the same letter in each column are not significantly different (Tukey test $p<0.05$).
Numbers were transformed (arcsin x+1) prior to performing ANOVA, according to the criteria of Gomez & Gomez (1984).
+, *, ** significant at 0.1, 0.05 and 0.01 probability levels, respectively.

1.3.1.3. EFFECTS OF FERTILIZER TREATMENTS ON ROOT AND SOIL ACID P-ASE ACTIVITIES

Soil and root P-ase activities were measured on all plots at the heading stage in 1988 and at the early stage in 1989. Additionally, soil and root P-ases were measured in 1989 the control plots at the heading stage.

In 1988 the lowest root P-ase and the highest soil P-ase occurred in farm C1 and only at that farm were there significant (negative) effects of the fertilizer treatments on P-ase activities (Table 14). Soil P-ase was 2 to 3 times higher at C1 compared to the other farms.

In 1989 the root P-ase activity was not affected by the treatments (Table 15). In 1989 soil P-ase was less variable between farms but farm C1 still had the highest value. Significant effects of soil treatments on soil P-ase activity were found only on the conventional farm C2, where compost decreased soil P-ase activity compared to the control (Table 16). Farm C1 had the highest numeric values for soil P-ase, as occurred in 1988.

The values for soil and root P-ase activity also show that there is not a higher activity on the organic compared to the conventional farms.

Table 14. Effects of P fertilizers on root and soil acid P-ase activity in barley plants at heading in 1988 (averages of 4 replicates).

TREATMENTS	O1	O2	C1
	FARMS		
	Root P-ase activity (μg p-nitrophenol phosphate g root^{-1} h^{-1})		
Control	590.5	768.8	473.2b
Super-P	578.5	674.2	342.7a
RP	567.0	757.7	422.7b
Compost	631.7	621.0	437.9b
F value	0.31	1.05	8.2**
C.V.(%)	21.0	23.9	11.2
	Soil P-ase activity (μg p-nitrophenol phosphate g soil^{-1} h^{-1})		
Control	456.2	302.2	922.5a
Super-P	426.5	302.3	823.8b
RP	413.8	302.3	854.6b
Compost	457.5	301.3	743.8b
F value	0.69	0.00	8.52**
C.V.(%)	14.6	18.2	7.4

Values followed by the same letter in each column are not significantly different (Tukey test $p<0.05$).
Numbers were transformed (arcsin x+1) prior to performing the ANOVA.
** significant at the 0.01 probability level.

Table 15. Effects of P fertilizers on root P-ase activity in barley plants at the early stage in 1989 (averages of 4 replicates).

	FARMS					
TREATMENTS	O1	O2	O3	C1	C2	C3
	Root P-ase activity (μg p-nitrophenol phosphate g root^{-1} h^{-1})					
Control	2542	3168	1370	1928	2363	2561
Super-P	2519	3068	1880	1233	2683	3182
RP	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
C.V.(%)	20.9	23.1	17.0	29.1	24.0	14.0

Values followed by the same letter in each column are not significantly different (Tukey test $p<0.05$).
All F values are non-significant

Table 16. Effects of P fertilizers on soil P-ase activity at the early stage in 1989 (averages of 4 replicates).

TREATMENTS	FARMS O1	O2	O3	C1	C2	C3
	Soil P-ase activity (μg p-nitrophenol phosphate g soil^{-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
RP	325.5	323.4	248.3	446.0	287.4ab	190.5
Compost	322.1	314.9	248.3	371.8	233.7b	209.6
F value	0.30	0.23	0.53	1.51	6.51*	0.51
C.V.(%)	15.5	21.1	33.8	19.2	11.2	28.4

Values followed by the same letter in each column are not significantly different (Tukey test $p<0.05$).
* significant at the 0.05 probability level.

1.3.2. ORGANIC AND INORGANIC SOIL FRACTIONS, ROOT LENGTH AND LEAF INORGANIC P (Pi) IN DIFFERENT FARMS

The variables described in this section were measured only at the heading stage and only on the control plots.

1.3.2.1. ORGANIC AND INORGANIC SOIL FRACTIONS

Soil samples from control plots were analyzed for organic P using the methodology of Bowman (1989). Soil organic P was also estimated from the percentage of N in soil as suggested by Sharpley et al. (1984). Organic P in soil samples from fields in neighbouring conventional farms at O1 and O2 were also examined.

The levels of soil organic P have been found to be linearly related to the percentage of N in soil (Sharpley et al., 1984). In this study, the organic P calculated from the percentage of N in soil gave values similar to those obtained by the extraction method in 4 out of the 6 farms. For soil samples from O3 and C3, the extraction method gave higher values. The standard deviations were much higher for the extraction method than for the values calculated from the percentage of N (Table 17). This could be a result of analytical errors at various steps in the fractioning method. However, the fractioning method is advantageous since it separates organic P in two different fractions instead of only one. There is no indication that total organic P obtained by both methods is higher in organic than in conventional farms (Table 17). There is no indication that any of the organic and inorganic fractions obtained are higher or lower on the organic compared to the conventional farms (Table 18). The levels of organic P in the soil of the immediate (conventional) neighbours to O1 and O2 do not indicate any increase in soil organic P in the organic compared to the conventional farms (Table 19).

Table 17. Soil total organic P from the 6 farms studied (averages of 4 replicates).

FARMS	Soil N (%)	Soil organic P (mg/kg soil)		
		Sharpley et al. (1984)		Bowman (1989)[§§]
		a[§]	b[§]	
O1	0.358	448.9 (41.8)[♠]	411.5 (32.6)	488.9 (102.0)
O2	0.375	468.1 (84.2)	422.5 (65.5)	489.7 (140.3)
O3	0.302	385.6 (39.7)	356.2 (30.9)	658.1 (104.5)
C1	0.255	332.5 (39.5)	320.9 (30.8)	373.0 (93.4)
C2	0.380	473.8 (24.4)	420.9 (19.01)	471.0 (92.4)
C3	0.324	410.5 (50.3)	385.6 (39.2)	567.9 (59.9)

[§] a and b: calculated using two regression equations developed by Sharpley et al. (1984): (a) Organic P = 44.4 + 1130 x %N; (b) Organic P =21.8 + 880 x %N + 9.96 soil pH.

[§§] Calculated using the fractioning method of Bowman (1989).

[♠] Numbers in parentheses are standard deviations.

Table 18. Soil organic P fractions (Bowman, 1989) of soils from the control plots of the six farms studied (averages of 4 replicates).

FARMS	Soil P fractions § (mg/kg soil)				
	Acid extraction		Alkaline extraction§	Total P	Soil P_{res}
	Inorganic	organic	organic		
O1	577.6 (72.7)§§	364.1 (78.0)	124.8 (27.4)	1066.5 (144.2)	20.5
O2	707.6 (24.1)	330.6 (146.5)	159.1 (63.6)	1197.3 (144.0)	22.0
O3	541.2 (14.8)	573.2 (136.0)	85.0 (64.5)	1199.4 (113.9)	37.7
C1	646.3 (58.7)	255.0 (88.4)	117.9 (22.9)	1019.2 (141.3)	40.2
C2	767.7 (12.5)	373.7 (47.5)	97.3 (17.5)	1238.7 (50.6)	37.1
C3	665.7 (113.0)	475.2 (67.3)	92.7 (28.6)	1233.6 (142.7)	50.3

§ The alkaline extract contained only traces of inorganic P.

§§ The numbers in parentheses are standard deviations.

Table 19. Soil organic P fractions on farms O1, O2 and immediate neighbours in 1989 (neighbour samples are composite samples no replicates; O1 and O2 samples are averages from 4 control plots).

FARMS	Soil P fractions				
	ACPO	ACPI	ALPO*	TP	P(res)
	(mg/kg soil)				
O1	364.1	577.6	124.8	1066.5	20.5
NEIG/O1	389.8	374.7	106.5	871.0	20.7
O2	330.6	707.6	159.1	1196.3	22.0
NEIG/O2 [1]	275.0	443.8	106.5	825.3	9.7
NEIG/O2 [1]	301.7	417.2	106.5	1650.7	10.8
NEIG/O2 [2]	384.7	656.5	124.7	1165.9	24.9
NEIG/O2 [2]	441.1	551.5	244.4	1237.0	33.7
NEIG/O2 [3]	304.0	643.0	106.5	1053.5	54.9

ACPO: organic P from acid extraction; ACPI: inorganic P from acid extraction; ALPO: organic P from alkaline extraction; TP: total P.
*The alkaline extract contained only traces of inorganic P.
[1]The field was under soybeans;
[2]The field was under field beans;
[3]The field was under grain undersown with alfalfa;

1.3.2.2. ROOT LENGTH AND LEAF INORGANIC P (Pi)

Root geometry variables are considered to be important to P acquisition (Silberbush & Barber, 1983). Pi is an important fraction of plant P because it is related to plant P metabolism (Bieleski, 1973). These two variables were measured in the control plots at the heading stage on all farms (Table 20). There was no distinct trend of differences between conventional and organic farms. Relationships of these variables with other plant and soil variables will be discussed in section 1.3.4.

Table 20. Root length and leaf inorganic P (Pi) of barley plants at heading in the control plots of the six farms studied (averages of 4 replicates).

FARMS	Root length (m/cylinder)	Pi (nmol P/3 leaf disks)
O1	10.9 (3.7)§	0.8 (0.1)
O2	17.7 (6.4)	1.1 (0.8)
O3	7.3 (1.7)	1.3 (0.1)
C1	10.6 (3.1)	0.9 (0.1)
C2	8.2 (1.1)	1.2 (0.1)
C3	6.0 (2.2)	1.3 (0.1)

§ The numbers in parentheses are standard deviations.

1.3.3. COMPARISONS OF PLANT BIOMASS, PLANT NUTRIENTS, ROOT AND SOIL P-ASE ACTIVITIES IN THE EARLY STAGE AND AT THE HEADING STAGE ON DIFFERENT FARMS.

The variables in this section were measured in both the early and the heading stage. The results for the early stage have been presented in section 1.3.1. This section will deal with the results of the heading stage which were measured on the control plots only. The trends of change between the early stage and the heading stage of each variable will be discussed.

1.3.3.1. PLANT BIOMASS

The plant biomass at the heading stage had its highest values at farms C2 and C3 (Table 21). The dry weight at the heading stage follows the same trends as the biomass at the early stage on 5 farms (plant biomass for farm C2 is not available at the early stage).

Table 21. Fresh and dry weight of barley plants at the heading stage in the control plots of the six farms studied (averages of 4 replicates).

FARMS	Fresh weight (g/plant)	Dry weight (g/plant)
O1	10.1 (3.0)§	1.8 (0.5)
O2	5.2 (1.5)	0.9 (0.3)
O3	9.1 (2.9)	1.4 (0.4)
C1	7.7 (2.1)	1.1 (0.3)
C2	16.5 (3.5)	3.0 (0.6)
C3	10.4 (2.3)	2.6 (0.6)

§ Numbers in parentheses are standard deviations

1.3.3.2. PLANT NUTRIENTS

The percentages of nutrients in barley plants at the heading stage are presented in Table 22. A comparison between the percentages of N, K, Ca and Mg at the early stage with those at the heading stage in the control plots (Figures 2 and 3), shows that in general, concentrations of nutrients were higher in the early stage. It also shows that the amounts of nutrients in plants from the organic farms at the early stage were lower than those from the conventional farms.

A different situation is presented for P (Figure 4). For the two oldest organic farms O1 and O2, percentage of P are lower in the early stage than in the heading stage (although differences are significant only for O2); for the other 4 farms (O3, C1, C2 and C3) percentages in the early stage are similar or higher (in C1) than those on the heading stage.

Table 22. Percentages of nutrients in barley plants at heading in the control plots of the six farms studied (averages of 4 replicates).

FARMS	N%	P%	K%	Ca%	Mg%
O1	2.16 (0.16)§	0.39 (0.03)	3.17 (0.25)	0.52 (0.07)	0.16 (0.01)
O2	2.10 (0.35)	0.44 (0 02)	3.79 (0.78)	0.39 (0.16)	0.20 (0.03)
O3	1.87 (0.42)	0.42 (0.51)	3.16 (0.21)	0.38 (0.02)	0.16 (0.00)
C1	1.95 (0.31)	0.36 (0.03)	3.77 (0.29)	0.35 (0.01)	0.15 (0.01)
C2	2.25 (0.06)	0.48 (0.05)	3.73 (0.42)	0.53 (0.09)	0.18 (0.00)
C3	2.21 (0.34)	0.47 (0.08)	3.92 (0.63)	0.59 (0.06)	0.18 (0.00)

§ The numbers in parentheses are standard deviations.

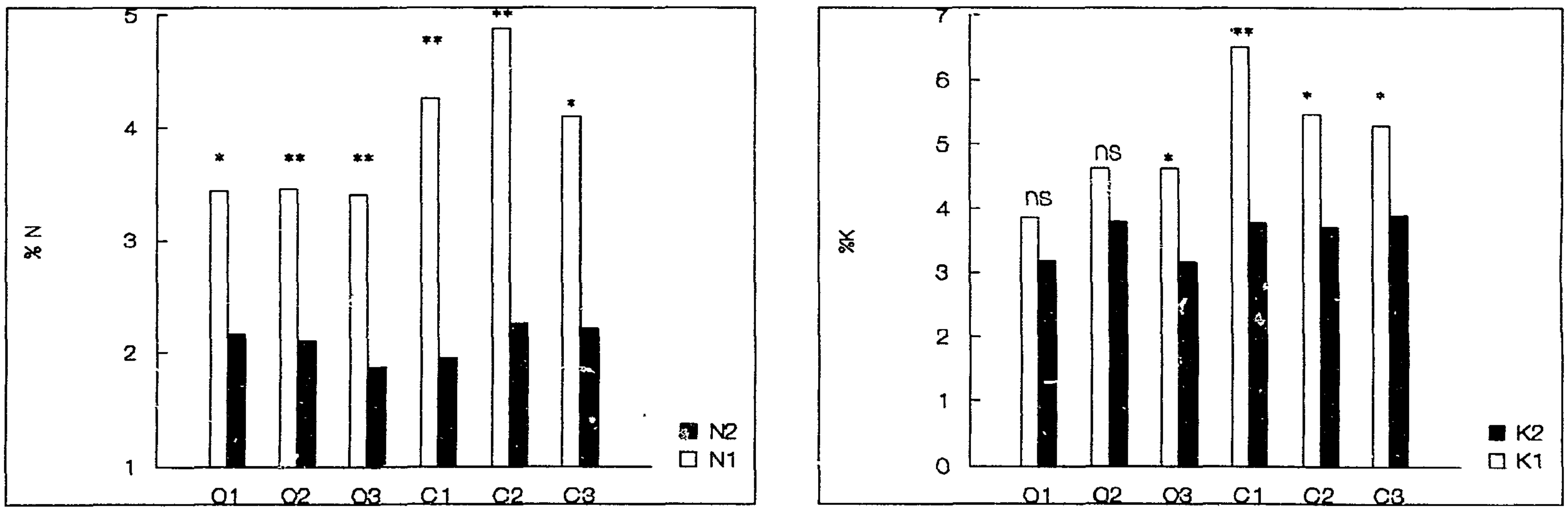


Figure 2. Percentages of N and K in barley plants in 6 farms at two sampling times in 1989: N1 and K1 - % N and % K in the early stage; N2 and K2 - % N and % K in the heading stage. Values are averages of 4 replicates (control plots).

**, *: significant at the 1% and 5% probability levels respectively; ns: non-significant (paired T-tests between early stage and heading stage).

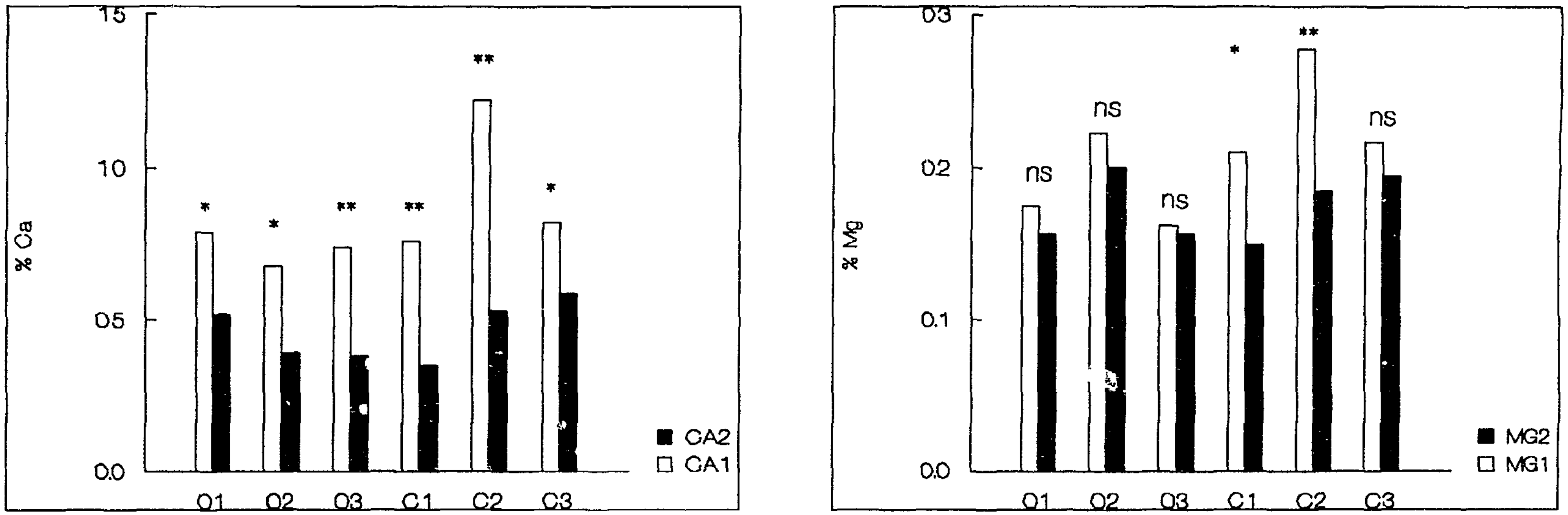


Figure 3. Percentages of Ca and Mg in barley plants in 6 farms at two sampling times in 1989: Ca1 and Mg1 - % Ca and % Mg in the early stage; Ca2 and Mg2 - % Ca and % Mg in the heading stage. Values are averages of 4 replicates (control plots).

**, *: significant at the 1% and 5% probability levels respectively; ns: non-significant (paired T-tests between early stage and heading stage).

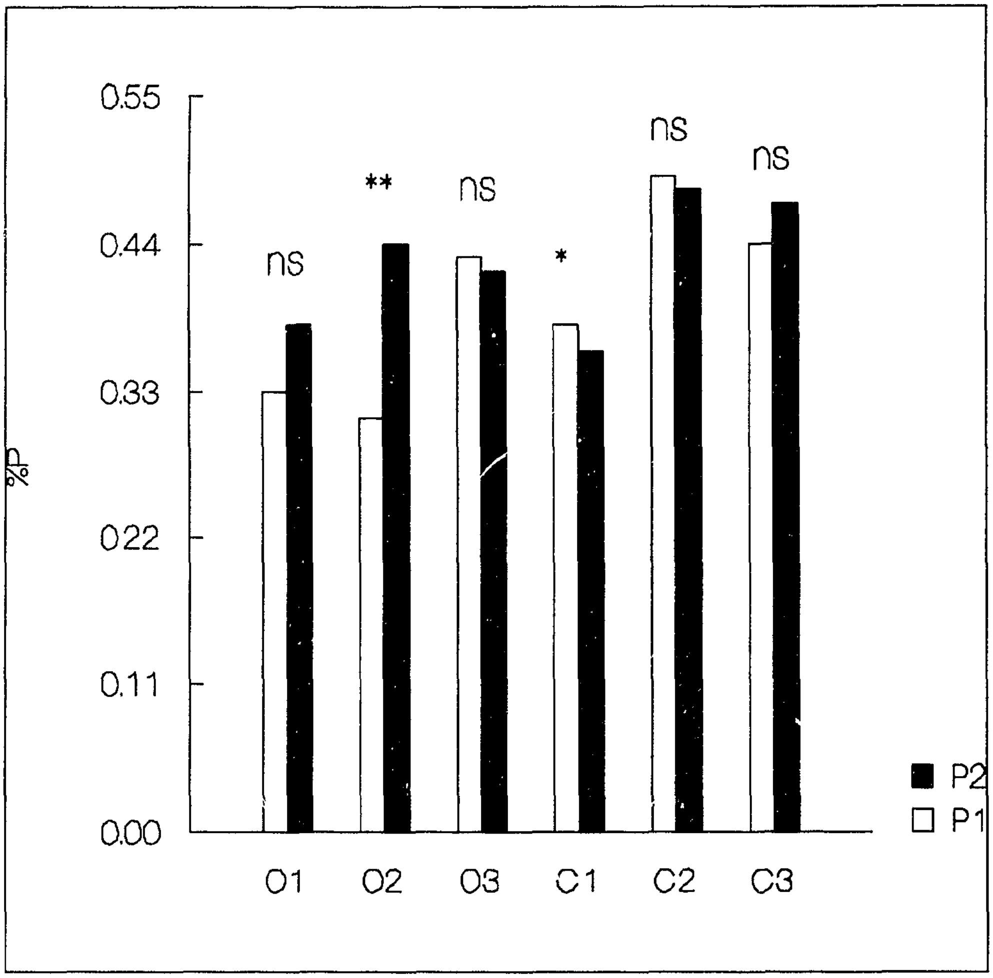


Figure 4. Percentages of P in barley plants in 6 farms at two sampling times in 1989: P1 - P% in the early stage; P2- P% in the heading stage. Values are averages of 4 replicates (control plots).

**, *: significant at the 1% and 5% probability levels respectively (paired T-tests).

1.3.3.3. ROOT AND SOIL P-ASE

Root and soil P-ase activities at the heading stage are presented in Table 23. As was found in the early stage (section 1.3 1.3.), neither soil nor root P-ase was consistently higher or lower in the organic than in the conventional farms.

Root P-ase activity was significantly lower at the heading stage than at the early stage in 4 out of 6 farms (Figure 5). The variation between farms tended to be lower at the heading than at the early stage, suggesting that at the early stage, root P-ase was more active.

Soil P-ase activity did not vary between sampling times as did root P-ase. Differences between stages were non-significant for 3 farms and significant at the 10% probability level for the other 3 farms (Figure 6). Farm C1 had the highest value for soil P-ase at both sampling times and farm C3 the lowest.

Table 23. Root and soil P-ase activity at heading in the control plots of the six farms studied (averages of 4 replicates).

FARMS	Root P-ase (μg p-nitrophenol phosphate g root^{-1} h^{-1})	Soil P-ase (μg p-nitrophenol phosphate g soil^{-1} h^{-1})
O1	1020 (199.6)§	196.4 (11.1)
O2	1240 (390.8)	234.9 (64.7)
O3	781 (109.3)	256.0 (37.1)
C1	1455 (356.3)	375.2 (51.6)
C2	919 (197.0)	270.0 (39.2)
C3	798 (235.3)	171.0 (30.1)

§ Numbers in parentheses are standard deviations.

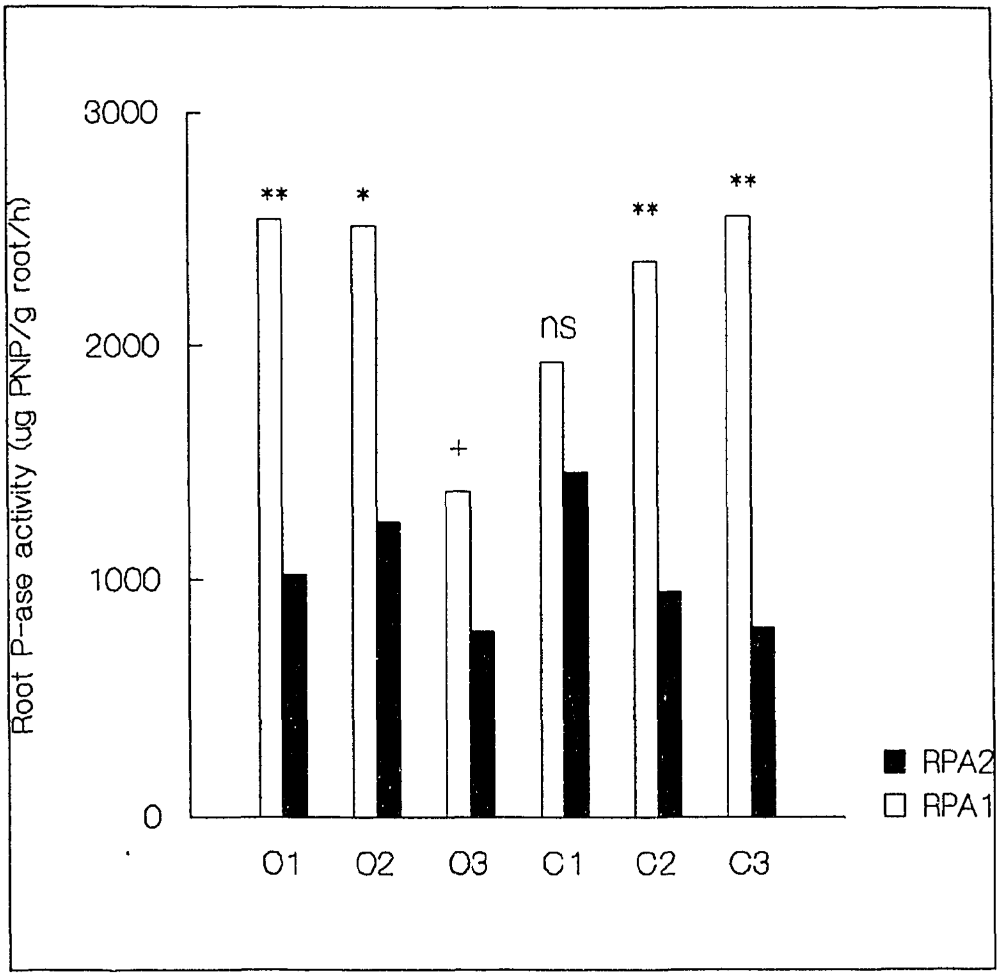


Figure 5. Root P-ase activities at two sampling times. RPA1: root P-ase at the early stage; RPA2: root P-ase at the heading stage. Values are averages of 4 replicates (control plots).

ns, +, *, **: non-significant and significant at the 10%, 5% and 1% probability levels respectively (paired T-tests).

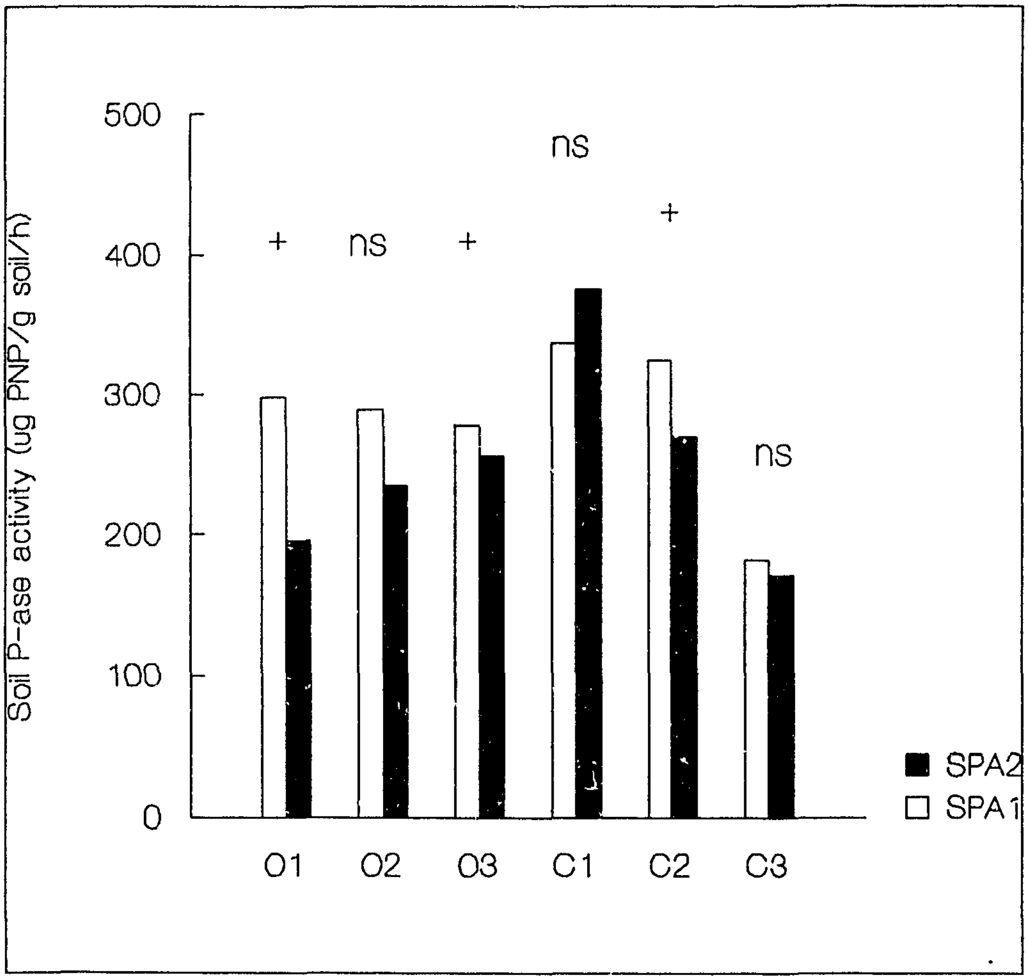


Figure 6. Soil P-ase activities at two sampling times. SPA1: soil P-ase at the early stage; SPA2: soil P-ase at the heading stage. Values are averages of 4 replicates (control plots).

ns, +: non-significant and significant at the 10% probability level respectively (paired T-tests).

1.3.4. UNIVARIATE CORRELATIONS

1.3.4.1. RELATIONSHIPS BETWEEN SOIL P_{res}, PLANT P AND YIELD.

Traditionally plant P status has been assessed at the heading stage (Ontario Ministry of Agriculture and Food, 1987). Recent work however, indicates that sampling at the earlier stages would more appropriate (Avnimelech & Scherzer, 1970; Romer & Schilling, 1986; Barry & Miller, 1989). Hence, the early stage was used in this study. Plant P was also assessed at the heading stage in control plots. As was expected, the relationships between plant P, soil P_{res} and yield were better for the early stage than for the heading stage (Table 24).

For all farms and treatments, there was a significant correlation of soil P_{res} and plant P in the early stage (Figure 7). This indicates that soil P_{res} is a good predictor of P uptake by the crop.

There is a significant but not as strong a correlation between plant P and barley grain yield (Figure 8). This suggests that between farms, soil P status is a factor contributing to differences in yield.

The relationship between yield and soil P_{res} was non-significant. Farm O1 is slightly anomalous in regard to the relationship between soil P_{res} and plant P, with higher plant P per unit of soil P_{res}. It is more anomalous in regard to the relationship between plant P and grain yield, with higher grain yield per unit of plant P. These two effects together contribute to farm O1 having high grain yields at low soil P and to the non-significant overall relationship.

Table 24. Correlation coefficients between percentage of P in barley plants in the early stage and heading stage with soil P_{res} and yield in 1989.

	Number of observations	Soil P_{res}	Grain yield
		Correlation coefficients (R)	
P early stage	24	0.716**	0.628**
P heading	24	0.310^{ns} (0.17)	0.012^{ns} (0.95)

ns, ** non significant and significant at the 0.01 probability level, respectively.
Numbers in parentheses are probability levels.

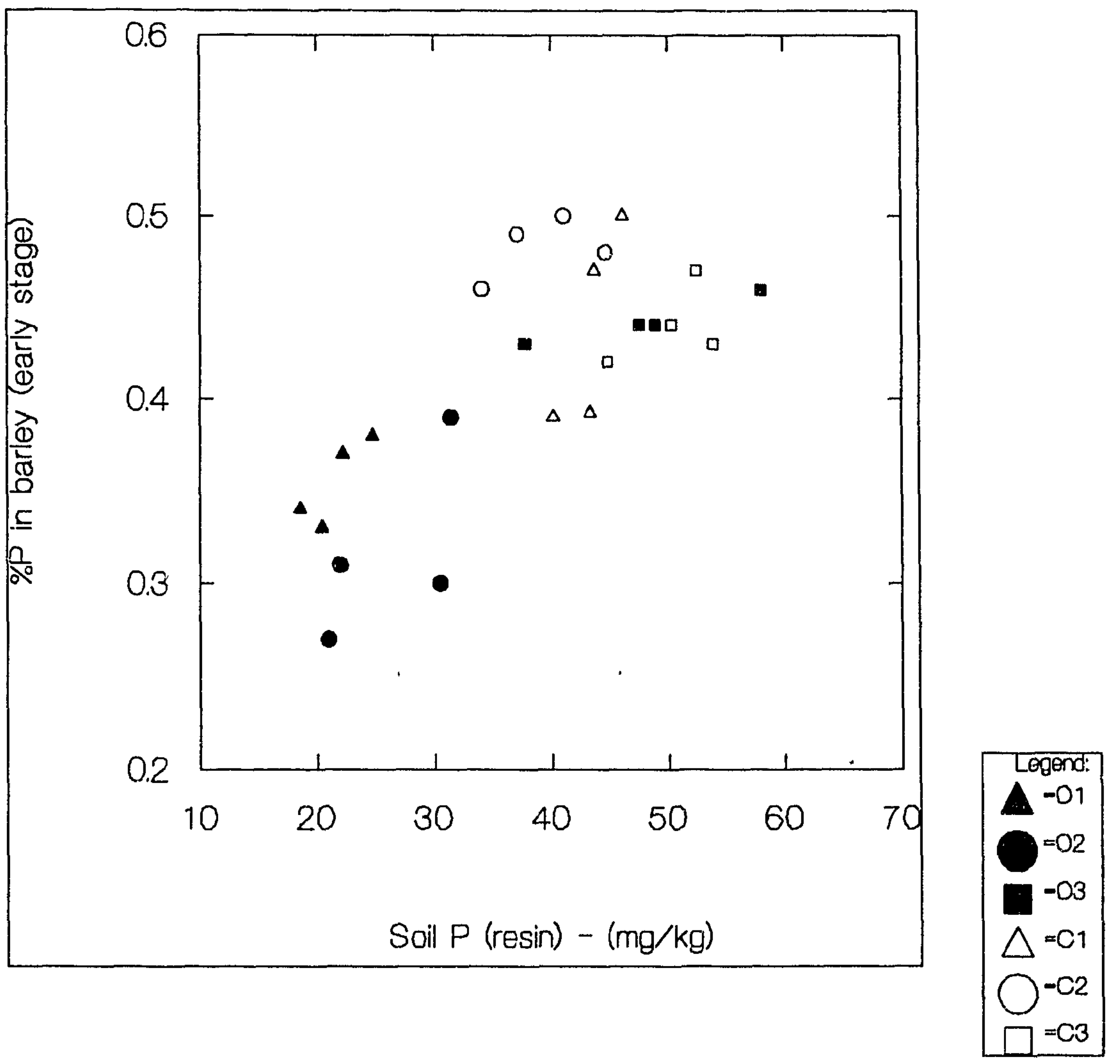
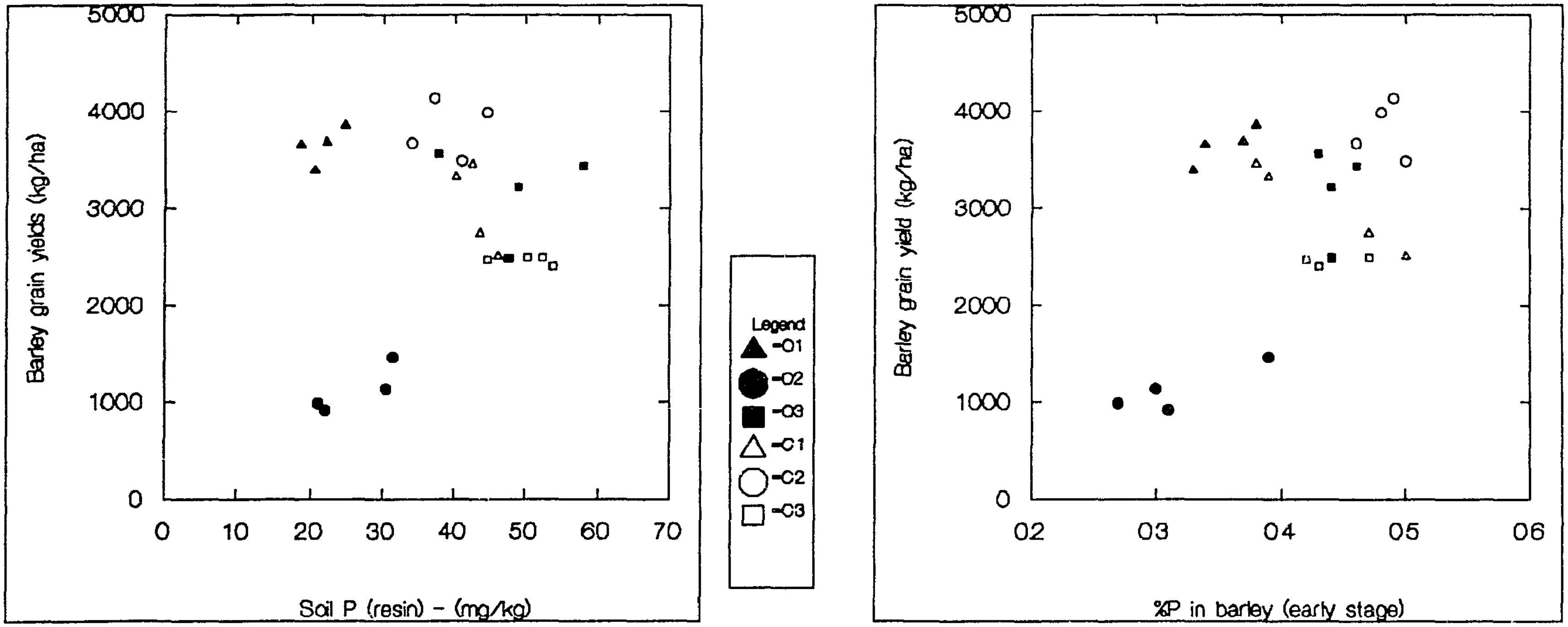


Figure 7. Relation between the percentage of P in barley plants in the early stage and soil P_{res} in 1989. Data from 6 farms and 4 treatments (averages of 4 replicates). R=0.74**



(A) (B)

Figure 8. (A) Relation between barley grain yield and soil P_{res} in 1989 ($R=0.12^{ns}$). (B) Relation between barley grain yield and percentage of P in barley plants in the early stage ($R=0.49^{*}$). Data from 6 farms and 4 treatments (averages of 4 replicates.)

When the data for each farm are examined separately, correlations between P_{res} and plant P are all positive, as was the correlation for all farms and all treatments combined (Table 25). However, correlations of plant P with yield are very low on two farms and strongly negative for farm C1. High positive correlations are observed for farms O1 and O2.

Table 25. Correlation coefficients of soil P_{res} and %P in barley plants in the early stage with barley yields (n=4).

FARMS	P_{res} X Yield	% P X Yield	P_{res} X %P
		Correlation coefficients (R)	
O1	0.62 (0.38)§	0.88 (0.12)	0.86 (0.14)
O2	0.85 (0.15)	0.87 (0.13)	0.68 (0.31)
O3	-0.08 (0.92)	0.08 (0.92)	0.96 (0.03)
C1	-0.84 (0.16)	-0.99 (0.001)	0.86 (0.13)
C2	0.10 (0.89)	-0.03 (0.96)	0.50 (0.49)
C3	-0.42 (0.58)	0.46 (0.54)	0.53 (0.46)

§ Numbers in parentheses are probability levels

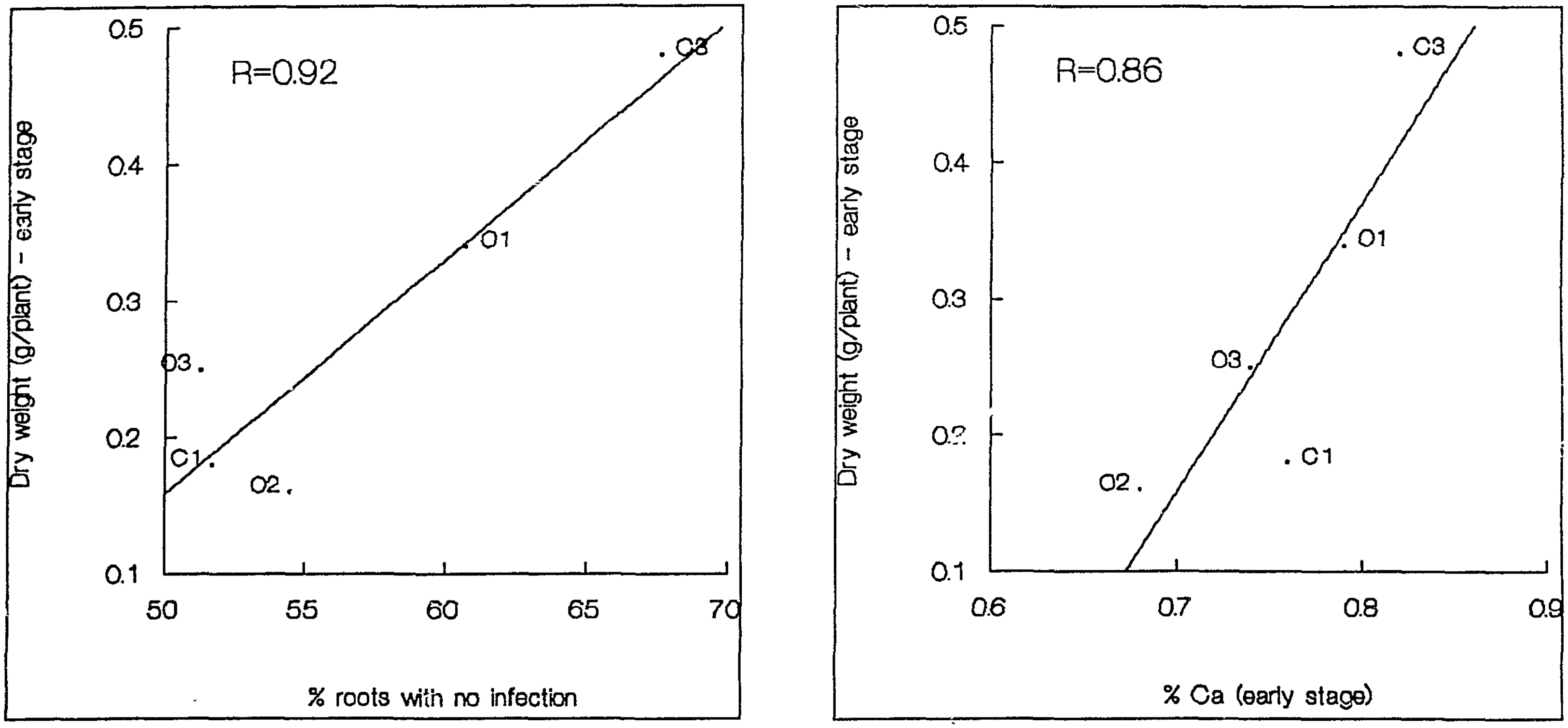
1.3.4.2. RELATIONSHIPS BETWEEN BIOLOGICAL VARIABLES AND OTHER VARIABLES

In order to examine relationships between the biological variables (VAM, soil and root P-ase activity, and root length) and between the biological variables with other variables under the natural P levels on the 6 farms, a correlation matrix containing the data of the control plots was generated (Appendix C). All relationships with correlation coefficients over 0.917 ($p<0.01$) were considered significant. A high correlation coefficient was selected in order to minimize spurious correlations, which were expected to be numerous because of a high family-wise error rate. In addition, I examined relationships that have lower correlation coefficients where there was some *a priori* reason to suspect a relationship. In many of these cases, when one of the variates was removed, a high correlation was observed.

(i) VAM

The only significant correlation between arbuscules, or no infection with other variables, is that of no-infection with early stage plant weight (Figure 9). Relationships between plant nutrients and plant weight were examined and there was a high correlation with calcium ($R=0.86$) but not with other nutrients (R equal to or less than 0.917). No-infection and arbuscules had poor correlations with Ca in the early stage ($R=0.21$ or $R=0.108$) however, there were higher correlations for no-infection and arbuscules with calcium at the heading stage ($R=0.93$ and -0.51).

The relationships between VAM infection and soil and plant P were examined to verify the expected negative relationships between these variables (Smith & Gianinazzi-Pearson, 1988). Excluding farm O1, the percentage of arbuscules showed a strong negative correlation with soil P_{res} (Figure 10). At farm O1, the percentage of arbuscules was unusually low for the level of soil P_{res} found.



(A) (B)

Figure 9. **(A)** Relation between the dry weight of barley plants in the early stage and the percentage of the root length containing no VAM infection. **(B)** Relation of percentage of Ca in barley at the early stage and plant dry weight. Data from control plots on 6 farms in 1989 (averages of 4 replicates). Data of plant weight from farm C2 are missing.

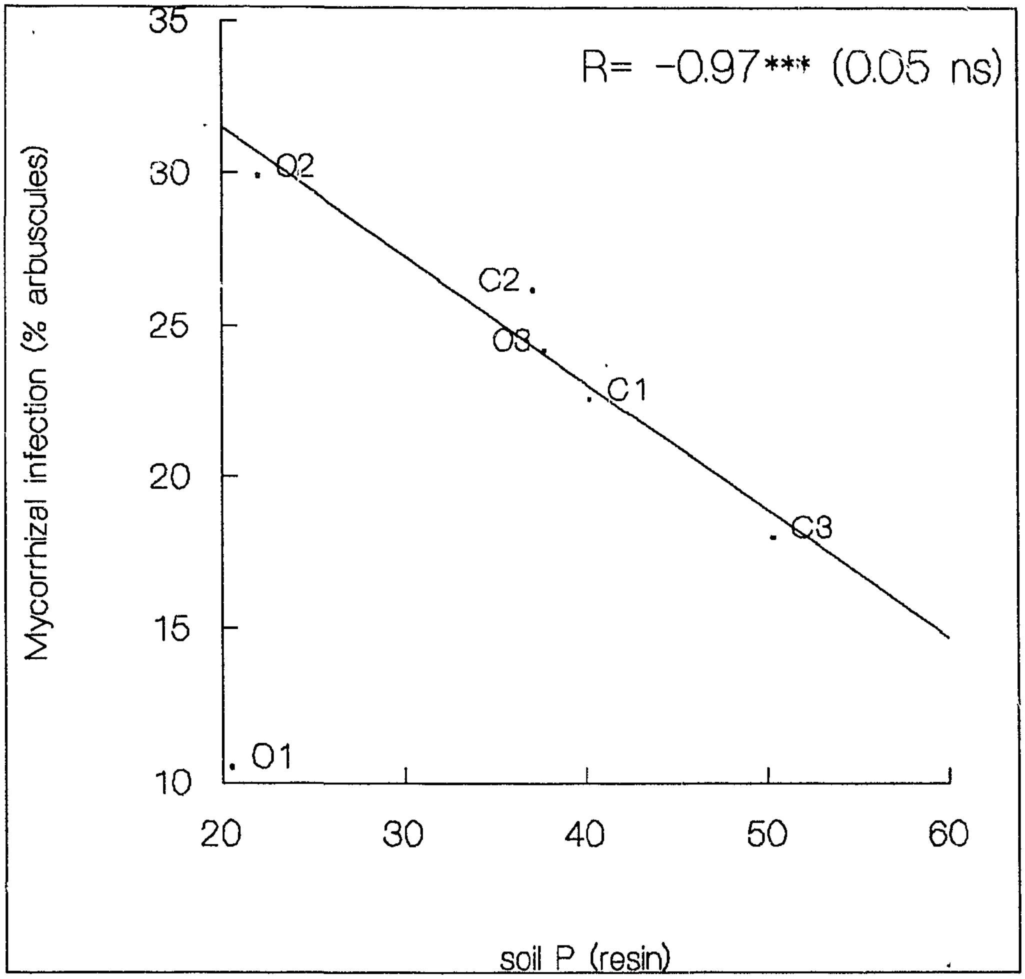


Figure 10. Relation between VAM (arbuscules) infection and soil P_{res}. Data from control plots on 6 farms in 1989 (averages of 4 replicates). The line represents the linear correlation when O1 was omitted. The first R value refers to this correlation. The R value in parentheses refers to all 6 points.

(ii) SOIL P-ASE ACTIVITIES

No significant relationships (r >0.917) were found between soil P-ase and other variables, nor were any trends suggested when plots of soil P-ase versus soil P_{res}, soil organic P and soil inorganic P fractions were examined. Sharpley (1985) demonstrated that the ratio of available (Bray)P/organic P was positively correlated with soil P-ase in unfertilized but not in fertilized soils. A similar trend was found in this study with the ratio of soil P_{res} to soil organic P (Figure 11). It appears that the relationship is better for the organic than for the conventional farms. When farm C3 is excluded, there is a high correlation for the remaining farms. It is not evident, however, why farm C3 should be excluded.

When C1 is excluded, soil P-ase was strongly negatively correlated with soil pH (Figure 12). Soil P-ase at farm C1 was anomalously high, probably because of the short term crop history (see section 1.4. Discussion). For the other 5 farms, the highest activity is found at pH=6.5 (Figure 12), the pH used for the determination of the enzyme activity in the lab. According to Skujins et al. (1962), this is the pH at which P-ases reach their maximum activity. Perhaps the P-ase assay should be performed at the actual soil pH if realistic measurements of activities are to be obtained. Trasar-Cepeda & Carballas (1991) measured P-ase activity of soil with varying pH (5.0 to 6.5) and found that the optimal pH for P-ase assay was close to the soil pH.

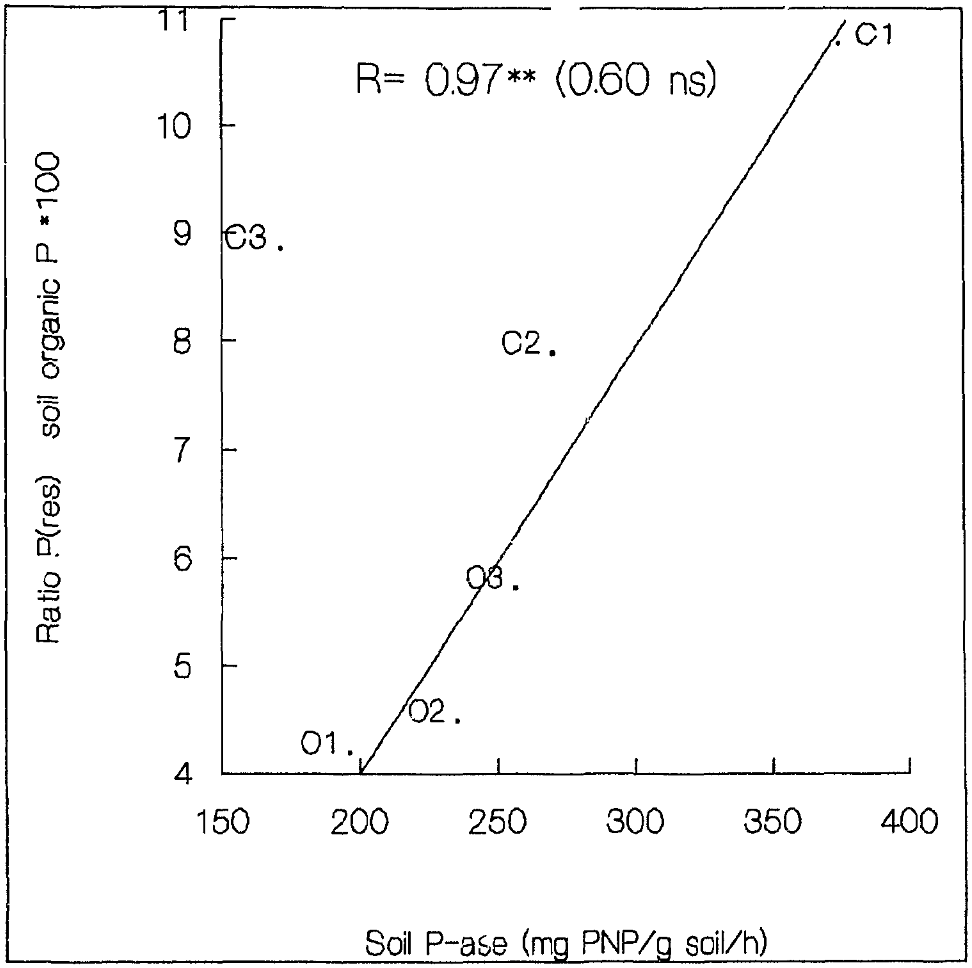


Figure 11. Relation between the ratio soil P_{res} : soil organic P and soil P-ase activity. Data from 1989 control plots on 6 farms (averages of 4 replicates). The line represents the linear correlation when C3 was omitted. The first R value refers to this correlation. The R value in parentheses refers to all 6 farms.

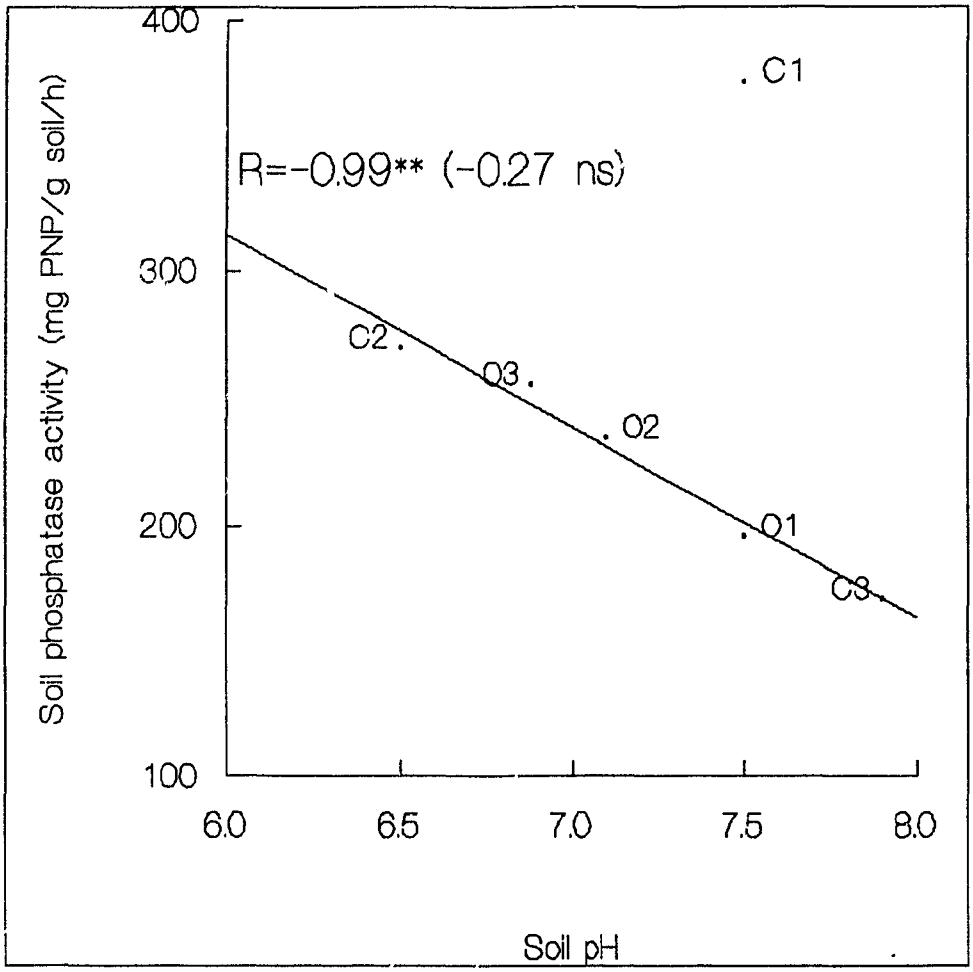


Figure 12. Relation between soil pH and soil P-ase activity. Data 1989 from control plots on 6 farms (averages of 4 replicates). The line represents the linear correlation when C1 was omitted. The first R value refers to this correlation. The R value in parentheses refers to all 6 points.

(iii) ROOT P-ASE ACTIVITIES

There were no significant relationships between root P-ase and other variables (r>0.917). Negative relationships between root P-ase activity and plant P were expected. The levels of plant P at heading were above the critical level of 0.1% (Ontario Ministry of Agriculture and Food, 1987) and no relationship between plant P and root P-ase is evident. When plant inorganic P was examined, however, trends were found (Figure 13). Plant Pi was more strongly (negatively) related to root P-ase than were other fractions of plant P, such as the percentage of P in the early and heading stage (Appendix C), indicating that inorganic plant P is used as a better parameter to assess instantaneous plant P status than total plant P. Inorganic P is a fraction of total P that is related to the internal distribution of P in the plants (Bieleski, 1973).

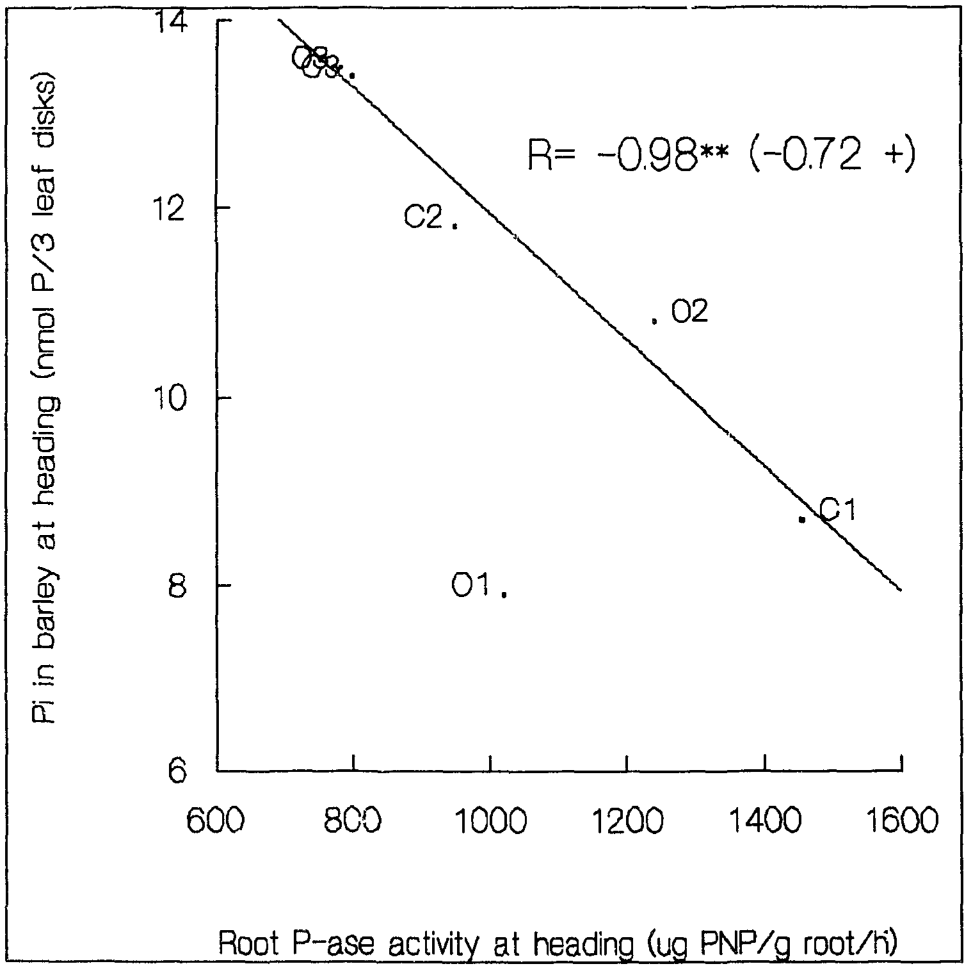


Figure 13. Relation between Pi in barley leaves (heading stage) and root P-ase activity. Data from 1989 control plots on 6 farms (averages of 4 replicates). The line represents the linear correlation when O1 was omitted. The first R value refers to this correlation. The R value in parentheses refers to all 6 points.

It could be postulated that biological variables such as root P-ase and VAM infection are simply a response to the plant internal requirement rather than to levels of P, per se. In order to test the postulate that root P-ase and VAM infection were related to P requirement, two premises were considered:

(i) by observing the data obtained for VAM infection and root P-ase activity in this and in other experiments (Chapter 2), it is clear that they are never completely absent in most situations, even in cases where P should not be limiting. This "basal" portion of the variables, may interfere with the calculations of possible causal relations between two variables, especially in conditions such as in this study, where steep gradients in soil and plant P were not found. If the "basal" value is discounted, the differences in these variables in response to plant P status may be more apparent.

(ii) the concepts of P supply, P demand and P deficit (Koide, 1991) summarized in the diagrams below:

Current P deficit = Current P demand - Current P supply

$$\frac{dP}{dt}\ (\text{deficit}) = \frac{dP}{dt}\ (\text{optimum}) - \frac{dP}{dt}\ (\text{actual})$$

Where P supply is the actual current rate of P uptake under the prevailing conditions:
P demand is a function of both the inherent growth capacity of the plant. as well as the minimum tissue P concentration necessary to sustain maximum growth.

The concept of "basal" values for P-ase activity is supported by the results of McLachlan (1980 b) who found that in P-sufficient winter wheat plants, a constant level of P-ase activity in different ages (up to 22 days) existed; in P deficient plants, P-ase activity per unit of root weight increased up to 15 days. Similar results (Goldstein et al., 1988b) were found when P-ase activity was measured in P-sufficient and P-starved tomato cells. Intercellular P-ase remained the same for both P levels, but another portion, the extracellular P-ase increased as much as 6 times over the control in the P-starved cells.

Therefore, if relationships are to be found between plant P and VAM infection or plant P and root P-ase, the variables should be treated according to items (i) and (ii). The data of percentage of P in the early stage (Table 10), was used to estimate the *P deficit*. It was assumed that the highest value for percentage of P found in each farm, is the current *P demand* (or the closest available value). By subtracting other values from these values on the same table (the current *P supplies*), an estimate of the current *P deficit* is calculated. Although the same variety was used, P demands could be different at different sites.

The data of root P-ase in the early stage (Table 15) were transformed, assuming that the lowest value on each farm was the "basal" value (a value of P-ase activity that is present in the roots but not related to P limitation). By subtracting the other values on each farm from the respective "basal" values, the result is the hypothetical extra P-ase activity in response to P limitation.

When plotted against each other, a quadratic relationship was fitted (Figure 14). The linear correlation coefficient is also significant (0.748*). Because there is a restricted number of observations, the actual nature of the relationship may not necessarily appear as shown. Theoretically, an asymptotic curve would be expected. In any case, root P-ase seems to be related to P deficit as predicted. The extent to which this P-ase will replenish the P deficit, will depend on the amounts of suitable substrate present on the root/soil interface (Tarafdar & Claassen, 1988).

When the calculated P *deficit* is plotted against the percentage of roots infected with VAM (arbuscules), VAM values are more consistently high with high P *deficits* ; when P *deficits* are lower, VAM values are highly variable. The same is true (lower values for roots with no VAM with higher P *deficits*) for the percentage of roots not infected with VAM (Figure 15).

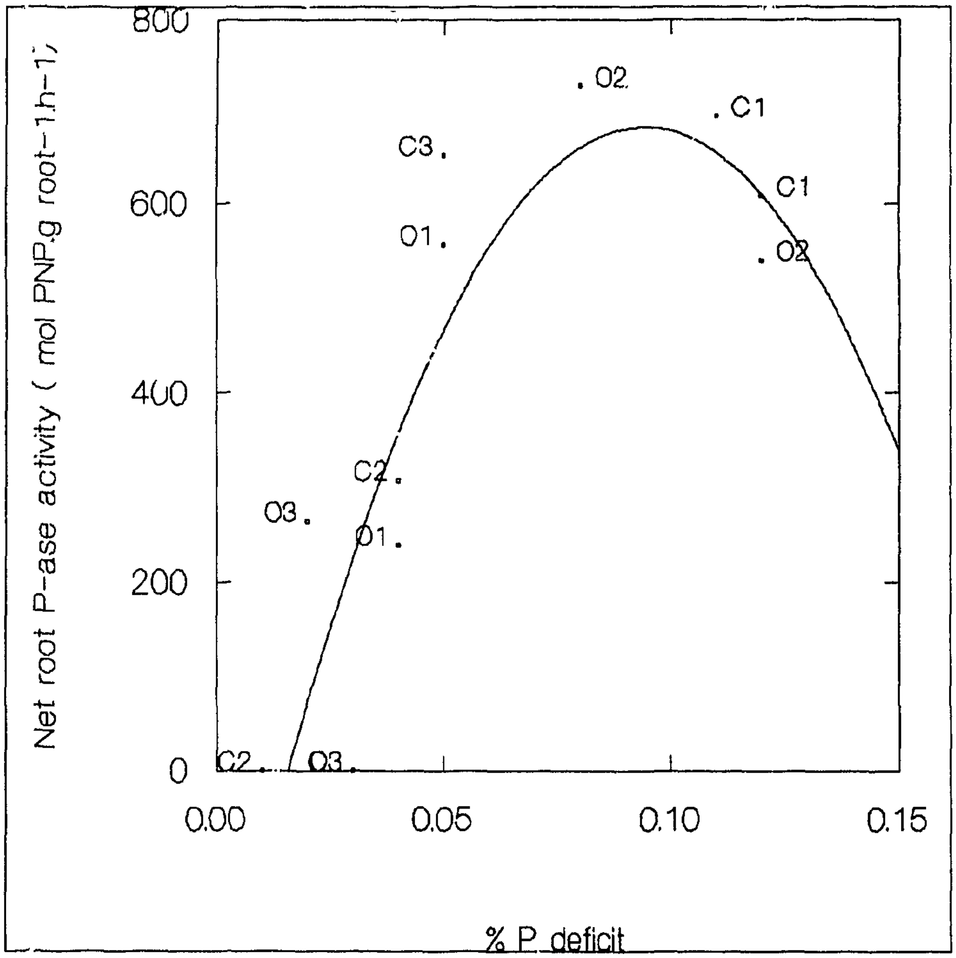


Figure 14. Relation between P deficit and net root P-ase activity. Data from 6 farms and averages of 4 replicates in 1989. Only control plots and plots treated with RP were used.

The linear correlation coefficient is 0.748*

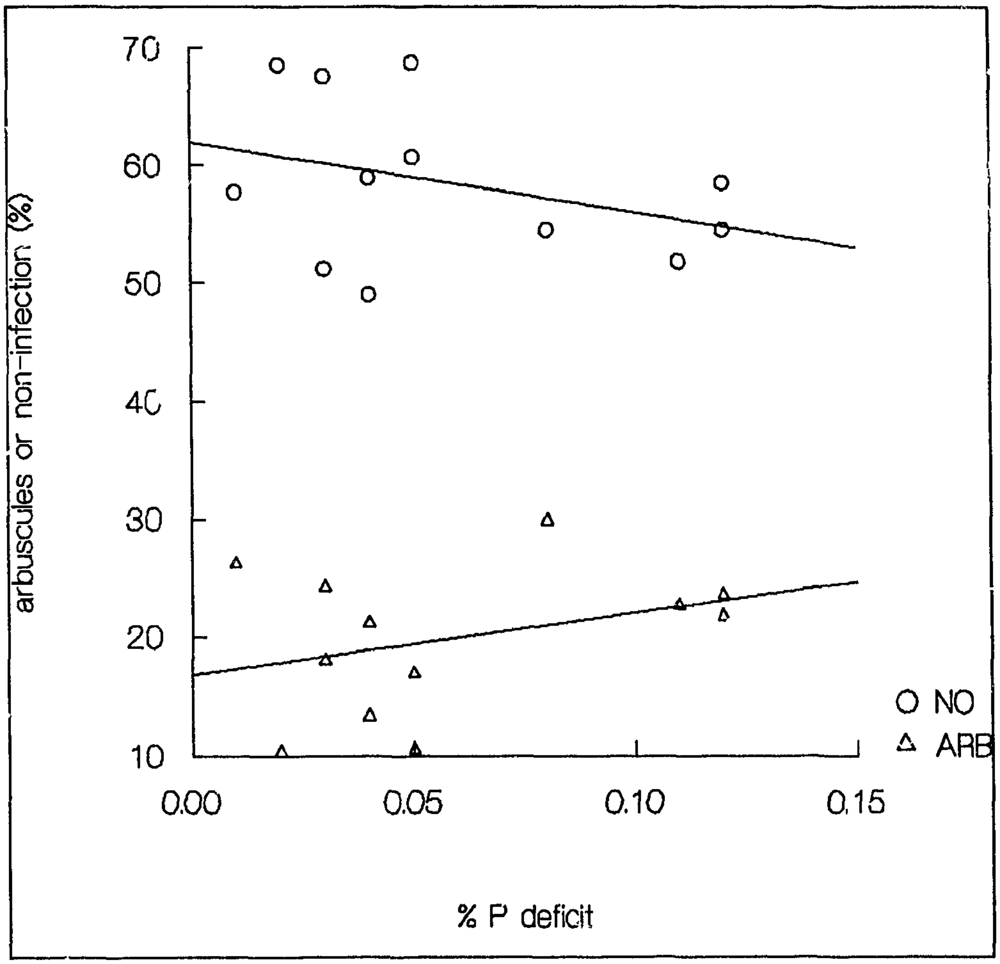


Figure 15. Relation between P deficit and VAM infection (arbuscules and no-infection). Data from 6 farms and averages of 4 replicates in 1989. Only control plots and plots treated with RP were used. The R values are 0.332 and -0.332 for arbuscules and no infection, respectively.

(iv) SOIL ORGANIC AND INORGANIC FRACTIONS

Table 26 shows correlations between soil P fractions. There are no highly significant correlations (r>0.917) between fractions. The organic alkaline fraction is negatively correlated to the organic acid fraction. Soil P_{res} showed a negative relationship with the organic alkaline fraction. Phosphorus in the alkaline extract was mostly organic (Table 18) and it was significantly positively correlated with the percentage of sand and negatively with clay fractions (Figure 16).

The various P fractions showed significant (r > 0.916) correlations with 5 other variables: soil inorganic P (acid extraction) with percentage of Mg in plants at the early stage (R=0.97); total P (acid extraction) with inorganic leaf P (0.92); total P (acid extraction) with percentage of P at heading (0.92); organic P (alkaline extraction) with root length (-0.97) and total soil P with percentage of P at heading (0.97). There is also a relatively high correlation of the calculated P deficit with soil P from the acid extractions (-0.82). This compares to the value of -0.24 for the correlation of P deficit and P_{res}. Overall, the correlations of soil total P (acid extraction) and soil total P (acid + alkaline extraction) with variables directly related to P nutrition (Table 27) are higher than for P_{res}. The R values for the organic fraction (acid extraction) are greater than those for the inorganic fractions (acid extraction), suggesting that organic fractions are quantitatively more important.

Table 26. Correlations between soil P fractions (n=6).

	ACPI	ACPO	ACPT	ALPO	PT
ACPO	-0.462	§			
ACPT	§	§	§		
ALPO	0.235	-0.670	§	§	
P_{res}	0.101	0.346	0.452	- 0.747	0.290

ACPI: inorganic P from acid extraction; ACPO: organic P from acid extraction; ACPT: total soil P from acid extraction; ALPO: organic P from alkaline extraction (the alkaline extract contained only traces of inorganic P); PT: total P .

§ Correlations which included an autocorrelation component are not given.

Table 27. Correlations between soil P fractions and plant variables related to P nutrition.

	Soil P_{res}	Plant $P_{(early)}$ %	Plant P deficit early	Plant $P_{(heading)}$ %	Plant Pi (heading)	Root P-ase (early)	Root P-ase (heading)	Soil P-ase (early)	Soil P-ase (heading)	Arbuscules (early)
P_{res}	-	0.749	-0.245	0.332	0.603	-0.43	-0.316	-0.471	0.118	0.053
PT	0.287	0.575	-0.758	0.969	0.844	0.170	-0.675	-0.455	-0.480	0.455
ACPT	0.458	0.700	-0.822	0.922	0.924	-0.033	-0.791	-0.540	-0.472	0.340
ACPO	0.350	0.447	-0.701	0.412	0.797	-0.452	-0.905	-0.596	-0.516	-0.069
ACPI	0.101	0.276	-0.08	0.606	0.084	0.574	0.229	0.127	0.102	0.521
ALPO	-0.747	-0.862	0.647	-0.274	-0.587	0.725	0.685	0.299	0.043	0.198

PT: total soil P; ACPI: inorganic P from acid extraction; ACPO: organic P from acid extraction; ACPT:total soil P from acid extraction; ALPO: organic P from alkaline extraction (the alkaline extract contained only traces of inorganic P).

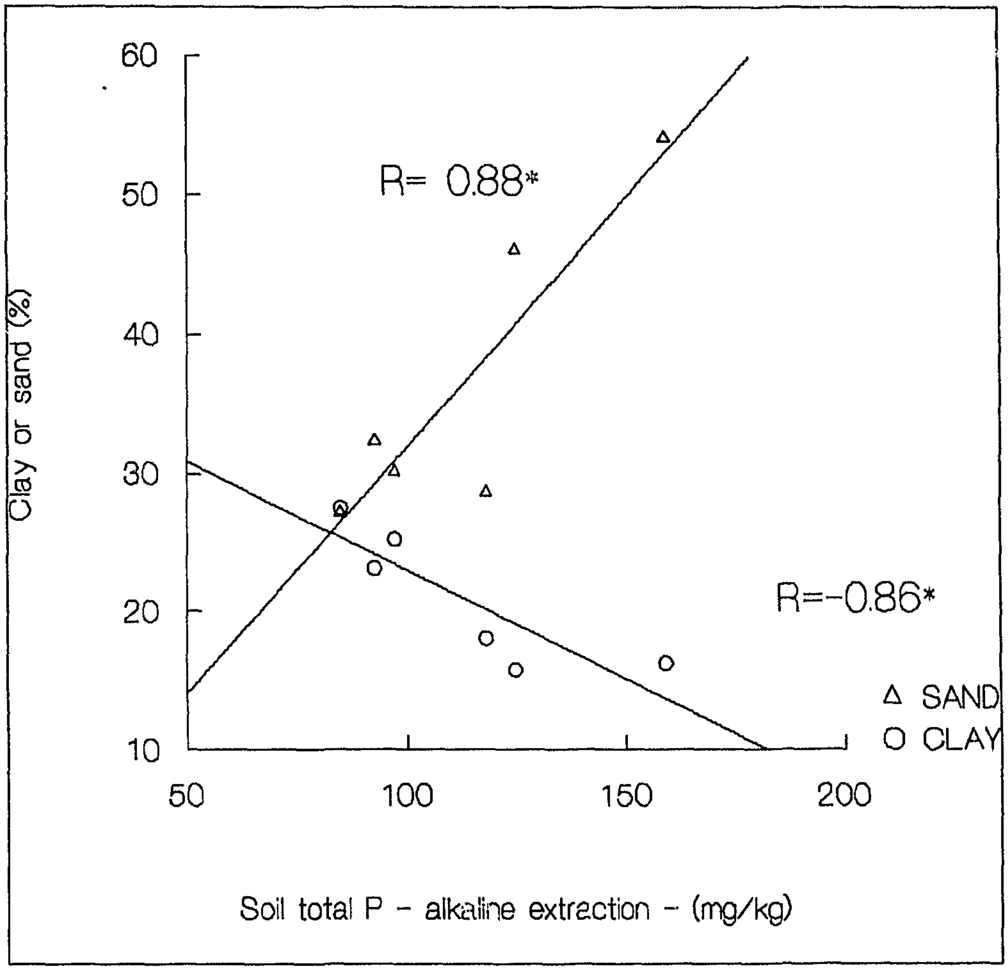


Figure 16. Relation between percentage of clay and sand, and soil P from alkaline extraction. Data from 1989 control plots on 6 farms (averages of 4 replicates).

(v) ROOT LENGTH

Root length was highly correlated with soil P from the alkaline extraction (R=0.966) (Figure 17). Other fractions of soil and plant P were negatively correlated with root length, such as P_{res} (R=-0.764) and percentage of P in plants at the early stage (R=-0.789) (Appendix C). The root length was negatively correlated with the percentage of clay and positively correlated with the percentage of sand (Figure 18). It seems likely that the correlation of root length with soil P from the alkaline extraction is not a causal one, but occurred because both root length and the fractions from the alkaline extraction are correlated with the percentage of sand.

Negative relationships were also found when root length was plotted against the percentage of P and the amount of inorganic Pi at the heading stage (Figures 19 and 20). These relationships have a low R value when all farms are included. However, when farm O2 is excluded, a negative linear trend is observed.

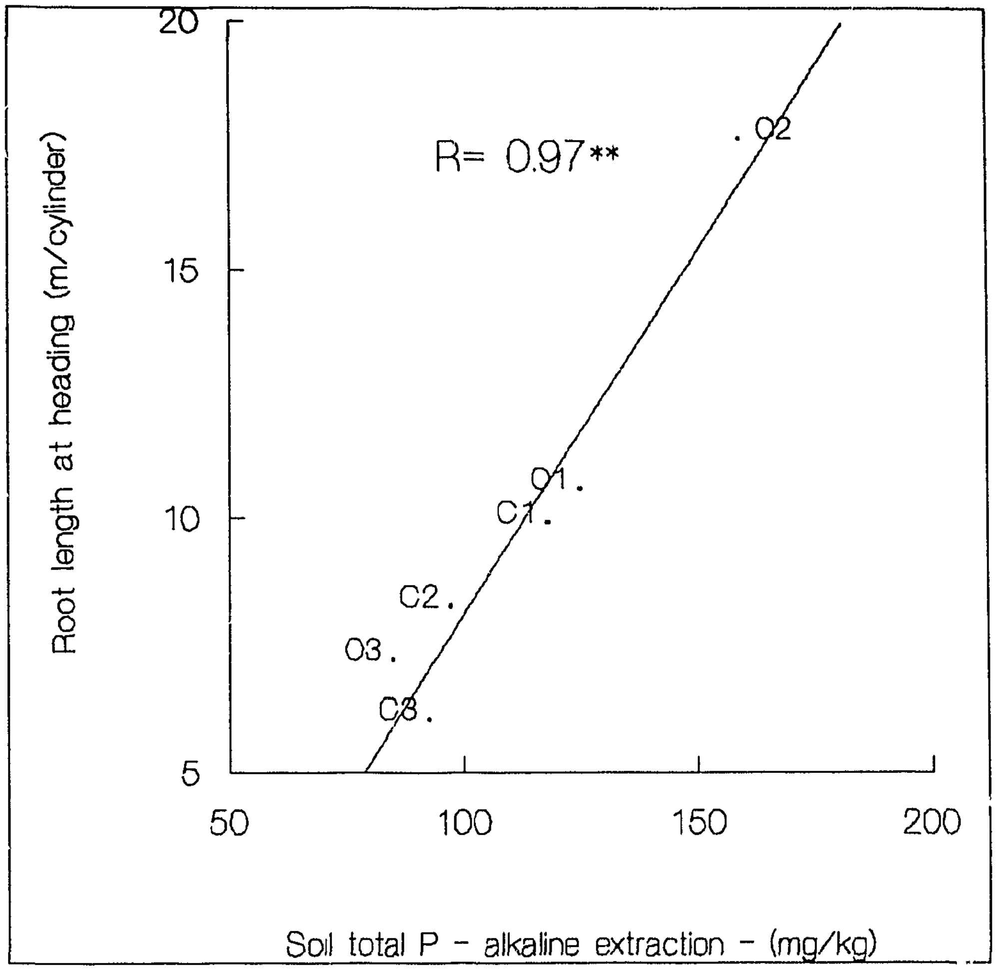


Figure 17. Relation between barley root length and soil P from alkaline extraction. Data from 1989 control plots on 6 farms (averages of 4 replicates).

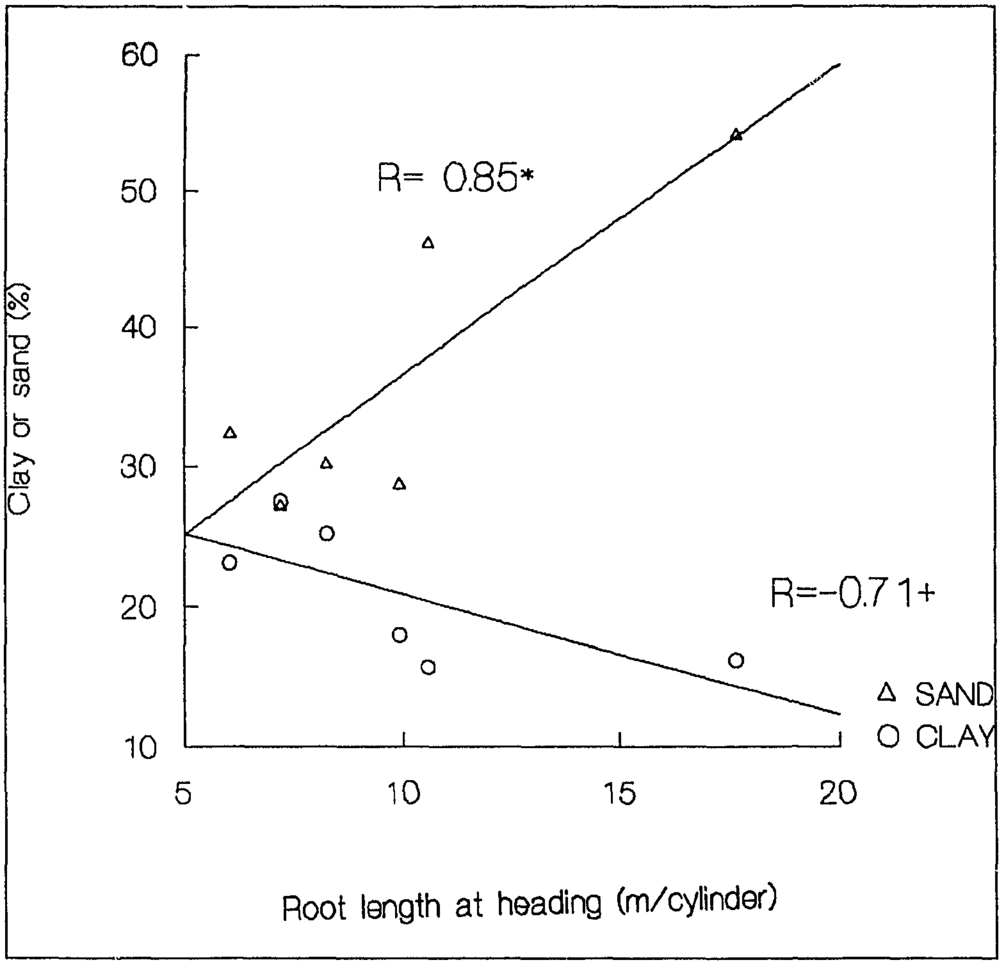


Figure 18. Relation between percentages of clay and sand, and barley root length. Data 1989 from control plots on 6 farms (averages of 4 replicates)

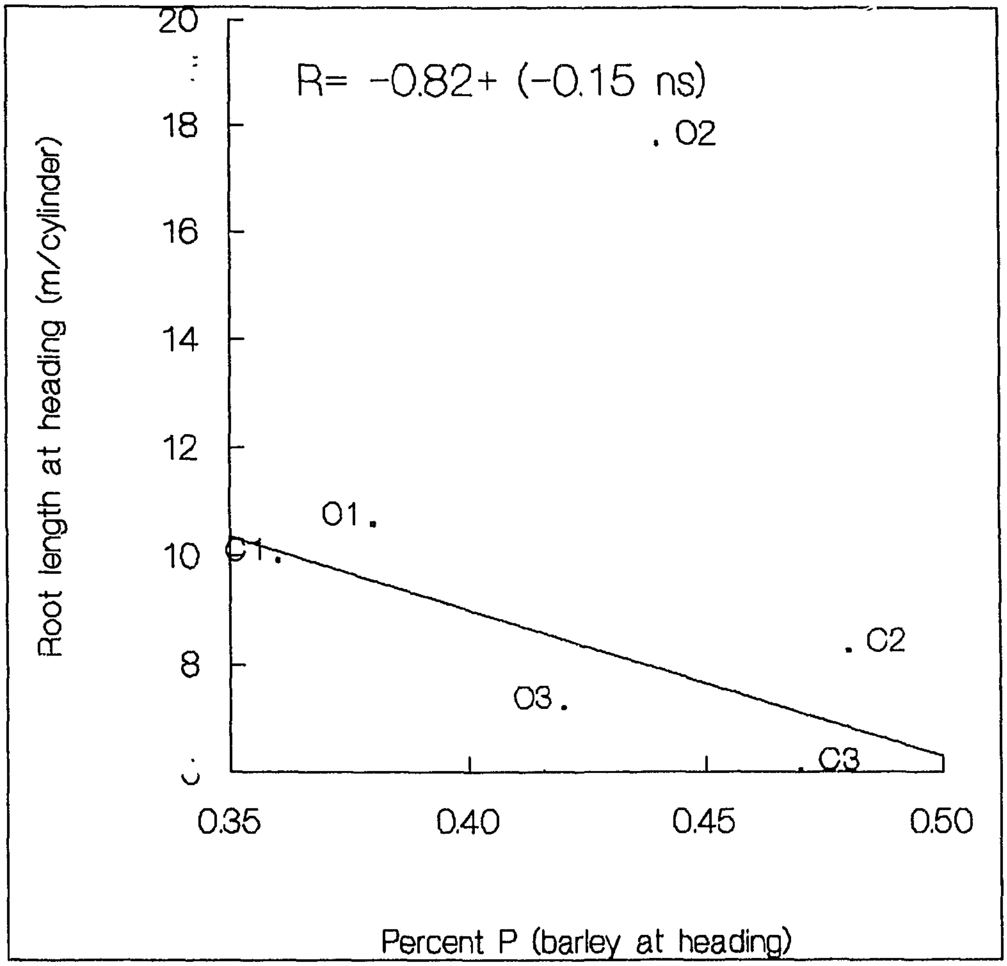


Figure 19. Relation between barley root length and the percentage of P in barley plants at heading. Data from 1989 control plots on 6 farms (averages of 4 replicates). The line represents the linear correlation when O2 was omitted. The first R value refers to this correlation. The R value in parentheses refers to all 6 points.

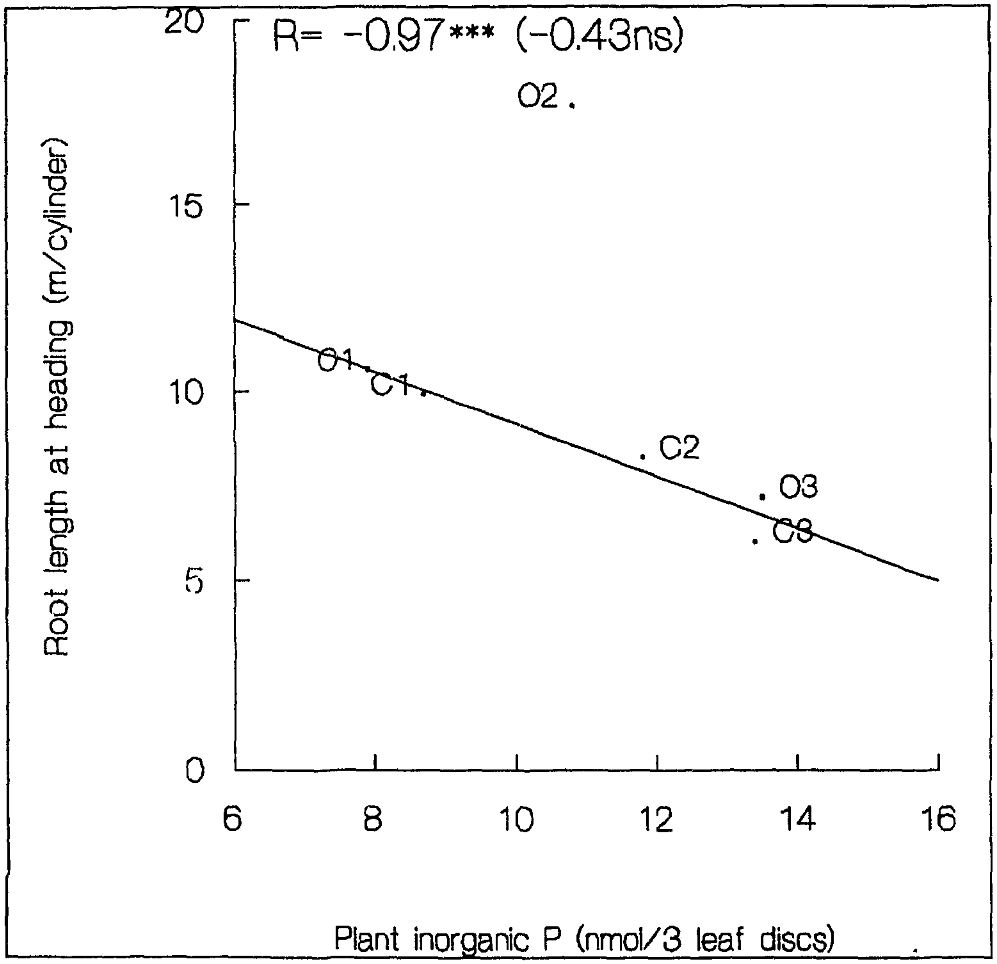


Figure 20. Relation between barley root length and the percentage of plant Pi. Data from 1989 control plots on 6 farms (averages of 4 replicates). The line represents the linear correlation when O2 was omitted. The first R value refers to this correlation. The R value in parentheses refers to all 6 points .

1.3.5. GLASSHOUSE EXPERIMENT

The glasshouse experiment was designed to: (i) compare soil and plant variables from different farming systems related to P nutrition, under a single environmental regime and (ii) evaluate whether the relationships between variables studied in the previous experiments were affected by the glasshouse environment as compared to the field. The plant and soil variables were measured at the early stage as in the 1989 field experiment. RP was not included as a treatment in the experiment because of the short term nature of the experiment, and NPK was included to determine whether N or K rather than P was limiting.

Values for the individual variables were not consistently higher or lower in one group of farms or another (Tables 28 to 32). F values for the interaction between farms and treatments were also low (Tables 33 to 35), indicating that even soil from individual farms did not respond to fertilizers uniquely under the common climatic conditions. An exception was the significant interaction between farm and fertilizer treatment for root P-ase activity (Table 33).

For all farms there was a numerical response of plant dry weight, in most cases a statistically significant response, to NPK but not to compost or super-P. This response appears to be associated with N rather than K (Table 35).

There were significant differences in soil P_{res} between farms, when all treatments were pooled together. Farms O3 and C3 had the highest levels (Table 33). All fertilizer treatments increased soil P_{res} compared to control. For most farms, values at the glasshouse were not different from the field, but the levels of soil P at farm O2 were higher in 1990 than in the previous years. Soil P-ase at O2 was also lower than in 1989.

For root P-ase activity, a significant interaction between farm and treatment effects was found (Table 33). Root P-ase activity was highest at farms O2 and C1. The interaction was significant because at farm O1, compost increased root P-ase activity compared to control and on the other farms, compost reduced it.

Root length, and root weight were highest at O2 and C1 (Table 34). There were no effects of treatments on these variables.

The percentage of P in the plant tissues was highest at farm O2 (Table 35). The NPK treatment had an effect on the percentage of N and Ca on barley plants.

The data for the VAM are compromised because the loss of a large number of samples occurred. However, they do suggest that the arbuscules were higher at farm O2 than in the field (Table 36).

Table 37 shows the results of soil nutrients other than soil P_{res}, that were measured (no statistics available).

Correlations between variables that had R values >0.8 were examined (a lower R value was selected than in the case of the field data because of the lower family-wise error rate). Of the correlations that can be compared to the field data, only pH, soil acid P-ase, root length and plant dry weight had R values > 0.8. The relationship between soil pH and soil acid P-ase was negative (R=-0.85) as in the field (R=-0.27); however the relationship of root length with plant dry weight is positive (R=0.85, Figure 21), whereas in the field it was negative (R=-0.619).

Table 28. Effects of fertilizer treatments on soil P_{res}, percentage of P in barley plants and dry weight in six farms in the glasshouse (averages of 4 replicates).

TREATMENTS	O1	O2	O3	C1	C2	C3
			Soil P_{res} (mg/kg soil)			
Control	25.3b	45.9	50.4	41.0	36.2	37.3b
Super-P	31.6ab	39.8	56.5	47.8	43.8	54.2a
NPK	32.3a	39.1	57.2	44.2	40.9	51.6a
Compost	28.9ab	46.2	53.6	48.0	40.1	45.8ab
F value	4.61*	0.42	1.21	3.12+	1.12	13.24**
C.V.(%)	9.9	27.8	10.4	8.33	14.0	8.7
			% P in barley			
Control	0.34	0.40	0.37	0.36	0.38	0.35ab
Super-P	0.32	0.40	0.37	0.38	0.38	0.37ab
NPK	0.34	0.40	0.35	0.34	0.34	0.33b
Compost	0.33	0.40	0.34	0.39	0.35	0.38a
F value	0.83	0.06	0.48	1.45	0.88	4.15*
C.V.(%)	7.1	7.4	11.8	8.6	9.3	6.1
			Dry weight (g/ 5 plants)			
Control	2.47b	2.62	2.56b	3.38	2.17b	1.46b
Super-P	2.89ab	2.97	2.29b	3.41	2.40b	2.10b
NPK	3.25a	3.30	3.58a	4.19	3.18a	3.17a
Compost	2.61ab	3.05	2.58b	3.76	2.35b	2.13b
F value	4.08*	3.37+	8.94**	2.50	8.84**	13.92**
C.V.(%)	12.1	10.3	13.7	12.9	11.9	17.1

Values followed by the same letter in each column are not significantly different (Tukey test $p<0.05$).

+, *, ** significant at 0.10, 0.05 and 0.01 probability levels, respectively.

Table 29. Effects of fertilizer treatments on the percentage of N and K in barley plants in six farms in the glasshouse (averages of 4 replicates).

	FARMS					
TREATMENTS	O1	O2	O3	C1	C2	C3
			% N in barley plants			
Control	1.67	2.1	1.41	1.73	1.91	1.61
Super-P	1.90	2.0	1.56	1.46	1.77	1.49
NPK	1.77	2.5	1.73	2.0	2.13	1.95
Compost	1.64	2.0	1.76	1.51	1.54	1.75
F value	2.18	1.21	0.44	2.80	2.59	2.93+
C.V.(%)	9.1	20.6	30.4	17.5	16.7	13.6
			% K in barley plants			
Control	2.20	3.3	1.91	2.78	2.28	2.47
Super-P	2.50	2.9	2.58	2.67	2.29	2.31
NPK	2.75	3.3	2.45	2.75	2.35	2.78
Compost	2.32	3.1	2.60	2.64	1.83	2.69
F value	3.25+	0.32	0.93	0.19	0.70	1.86
C.V.(%)	10.8	20.3	27.9	11.2	6.5	12.1

+, significant at the 0.10 probability level.

Table 30. Effects of fertilizer treatments on the percentage of Ca and Mg in barley plants in six farms in the glasshouse (averages of 4 replicates).

	FARMS					
TREATMENTS	O1	O2	O3	C1	C2	C3
			% Ca in barley plants			
Control	0.26	0.37	0.23	0.29	0.39a	0.35ab
Super-P	0.33	0.37	0.25	0.25	0.34ab	0.32b
NPK	0.34	0.43	0.34	0.33	0.41a	0.45a
Compost	0.29	0.33	0.32	0.24	0.25b	0.37ab
F value	0.99	2.55	1.21	1.41	5.49*	4.01*
C.V.(%)	25.5	14.0	34.0	25.8	17.4	14.1
			% Mg in barley plants			
Control	0.11b	0.20	0.11	0.15	0.18a	0.14
Super-P	0.12ab	0.20	0.11	0.15	0.17ab	0.13
NPK	0.15a	0.23	0.13	016	0.19a	0.16
Compost	0.11ab	0.18	0.15	0.15	0.13b	0.14
F value	4.37*	2.26	0.87	0.15	7.04**	1.53
C.V.(%)	13.8	12.9	28.3	21.6	12.2	13.0

Values followed by the same letter in each column are not significantly different (Tukey test $p<0.05$).

*, ** significant at 0.05 and 0.01 probability levels, respectively.

Table 31. Effects of fertilizer treatments on root and soil P-ase activities in six farms in the glasshouse (averages of 4 replicates).

TREATMENTS	FARMS O1	O2	O3	C1	C2	C3
	Root P-ase activity (μg p-nitrophenol phosphate g root^{-1} h^{-1})					
Control	1642c	3178	1957	2844ab	2077ab	1770
Super-P	1788bc	2399	1919	2470b	2031ab	1535
NPK	2231ab	2960	2400	3200a	2267a	2162
Compost	2488a	2141	1850	2216b	1717b	1664
F value	11.52**	3.44	1.47	7.45**	3.80*	1.62
C.V.(%)	11.3	19.4	20.3	11.7	11.6	23.8
	Soil P-ase activity (μg p-nitrophenol phosphate g soil^{-1} h^{-1})					
Control	229.9b	197.3	378.2	487.2	341.6	150.5
Super-P	240.3b	207.7	357.1	491.5	304.7	174.6
NPK	235.5b	238.2	385.4	540.9	303.9	182.1
Compost	280.5a	202.9	369.7	471.4	301.8	209.9
F value	10.70**	2.31	0.15	0.51	0.71	1.09
C.V.(%)	5.7	11.4	16.7	16.8	14.6	26.2

Values followed by the same letter in each column are not significantly different (Tukey test $p<0.05$).

*, ** significant at 0.05 and 0.01 probability levels, respectively.

Table 32. Effects of fertilizer treatments on root weight and root length in six farms in the glasshouse (averages of 4 replicates).

	FARMS					
TREATMENTS	O1	O2	O3	C1	C2	C3
			Root weight (g/400g soil)			
Control	4.29	6.13	2.70	7.81	4.49	1.27
Super-P	3.41	5.92	1.87	6.17	3.74	1.66
NPK	3.37	7.95	4.11	6.05	5.31	1.87
Compost	2.68	8.04	2.03	7.65	4.09	2.20
F value	2.98+	1.63	3.74+	1.20	0.61	3.26+
C.V.(%)	22.3	25.5	39.4	24.7	39.1	24.4
			Root lenght (m/400 g soil)			
Control	8.6	15.9	9.5	18.2	12.4	4.6
Super-P	9.3	15.6	7.2	18.5	9.9	6.0
NPK	9.3	17.3	11.8	16.6	14.5	6.9
Compost	8.5	13.1	8.4	18.8	11.3	6.0
F value	0.46	1.10	3.42+	0.78	2.06	2.16
C.V.(%)	14.8	22.4	23.0	12.4	22.2	22.0

+ significant at the 0.10 probability level.

Table 33. Effects of the site (averages of 4 replicates and 4 fertilizer treatments) and fertilizer treatments (averages of 4 replicates and 6 sites) on soil P_{res} and soil P-ase activities in the glasshouse.

FARMS	Soil P_{res} (mg P/kg soil)	Root P-ase µg p-nitrophenol phosphate g $root^{-1}$ h^{-1}	Soil acid P-ase µg p-nitrophenol phosphate g $soil^{-1}$ h^{-1}	Soil alkaline P-ase§ µg p-nitrophenol phosphate g $soil^{-1}$ h^{-1}
O1	29.5 d	2037.3b	246.6cd	23.9ab
O2	40.2 c	2669.8a	211.5d	18.9ab
O3	54.4 a	2031.6b	372.6b	18.5ab
C1	45.2 bc	2682.8a	497.7a	12.7b
C2	40.0 c	2023.5b	312.8bc	30.4a
C3	47.2 b	1782.8b	179.3d	21.1ab
F value	29.46**	15.37**	32.00**	3.98*
TREATMENTS				
Control	37 7 b	2244.8ab	297.4	na♠
Super-P	45.6 a	2023.7b	296.0	na
NPK	44.2 a	2537.0a	314.3	na
Compost	43.7 a	2012.9b	305.9	na
F value	7.87*	9.78**	0.25	na
F value (interaction)	0.84	2.13*	0.28	na
C.V.(%)	14.4	17.5	27.5	28.5

Values followed by the same letter in each column are not significantly different (Tukey test p<0.05).

*, ** significant at 0.05 and 0.01 probability levels, respectively.

♠ not available.

§ Alkaline P-ase was measured on the control plots only.

Table 34. Effects of the site (averages of 4 replicates and 4 fertilizer treatments) and fertilizer treatments (averages of 4 replicates and 6 sites) on barley root parameters and dry biomassin the glasshouse.

FARMS	Root length (m root/400 g soil)	Root weight (g root/400 g soil)	Biomass dry weight (g/5 plants)
O1	8.9c	3.4bc	2.8bc
O2	15.5a	7.0a	3.0b
O3	9.2c	2.7cd	2.7bc
C1	18.0a	6.9a	3.7a
C2	12.0b	4.4b	2.5cd
C3	5.9c	1.7d	2.2d
F value	52.19**	41.26**	23.9**
TREATMENTS			
Control	11.5	4.4	2.5b
Super-P	11.1	3.8	2.7b
NPK	12.7	4.8	3.4a
Compost	11.0	4.4	2.7b
F value	2.39+	2.18+	25.75**
F value (interaction)	1.14	0.17	1.24
C.V.(%)	21.6	31.3	14.6

Values followed by the same letter in each column are not significantly different (Tukey test $p<0.05$).
+, ** significant at 0.10 and 0.01 probability levels, respectively.

Table 35. Effects of the site (averages of 4 replicates and 4 fertilizer treatments) and fertilizer treatments (averages of 4 replicates and 6 sites) on the percentage of nutrients in barley tissue in the glasshouse.

FARMS	% N	% P	% K	% Ca	% Mg
O1	1.74b	0.33b	2.44b	0.30ab	0.12c
O2	2.16a	0.40a	3.15a	0.38a	0.20a
O3	1.61b	0.36ab	2.39b	0.29b	0.12c
C1	1.67b	0.36ab	2.71ab	0.28b	0.15bc
C2	1.84ab	0.36ab	2.18b	0.35ab	0.17bc
C3	1.70b	0.36ab	2.56b	0.37a	0.14bc
F value	4.8**	6.14**	6.13**	4.63**	17.14**
TREATMENTS					
Control	1.73b	0.37	2.48	0.32b	0.15ab
Super-P	1.70b	0.37	2.54	0.31b	0.15ab
NPK	2.02a	0.35	2.73	0.38a	0.17a
Compost	1.70b	0.37	2.54	0.30b	0.14b
F value	4.41**	1.42	0.97	5.07**	3.67*
F value (interaction)	0.75	0.64	0.65	0.83	1.12
C.V.(%)	20.0	9.72	20.8	25.2	16.8

Values followed by the same letter in each column are not significantly different (Tukey test p<0.05).

*, ** significant at 0.05 and 0.01 probability levels, respectively.

Table 36. Barley VAM infection in the glasshouse (ANOVA not presented due to missing data).

FARMS	Arbuscules (%)	Non-infection (%)	number of replicates
O1	9.6	66.1	9
O2	11.5	70.4	6
O3	5.5	76.9	11
C1	6.0	80.0	10
C2	5.6	77.9	7
C3	10.0	72.7	11
TREATMENTS			
Control	9.2	71.2	12
Super-P	9.1	74.8	16
NPK	6.1	75.2	11
Compost	6.8	75.2	15

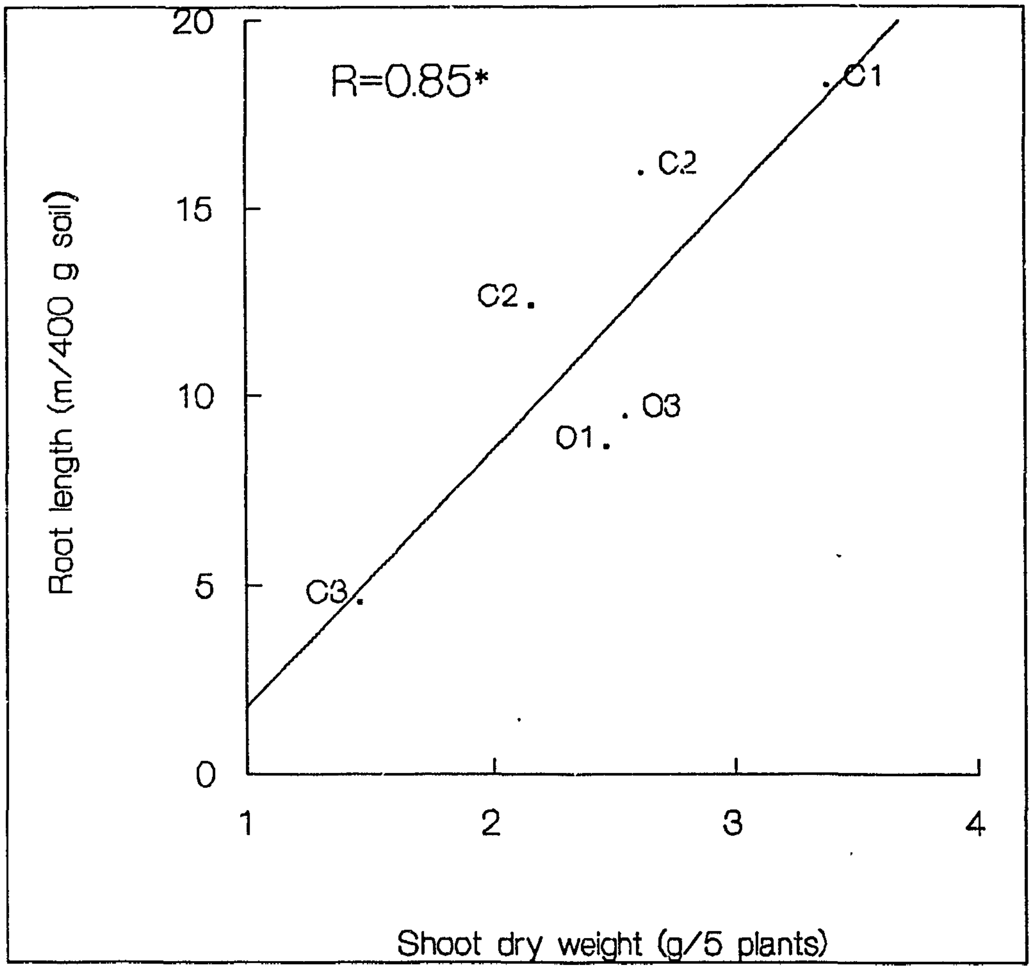


Figure 21. Relation between barley root length and shoot weight in soils from 6 farms in the glasshouse (averages of 4 replicates, control plots).

Table 37. Soil nutrients in the glasshouse experiment (results from composite samples taken at harvest).

FARMS	TREATMENTS	Soil exchangeable nutrients (mg/kg soil) P_{bicarb}	K	Mg	Ca	Soil pH
O1	Control	12	93.2	146	2100	7.9
	Super-P	14	87.2	168	2350	7.9
	NPK	13	95.7	168	2340	7.8
	Compost	17	107.0	178	2460	7.8
O2	Control	15	54.9	200	1500	7.8
	Super-P	21	55.8	207	1600	7.7
	NPK	18	58.7	213	1540	7.5
	Compost	20	63.7	188	1380	7.7
03	Control	27	86.2	234	1650	6.9
	Super-P	27	122.0	269	2030	6.8
	NPK	27	85.1	219	1600	6.8
	Compost	30	87.6	247	1830	6.9
C1	Control	20	132.0	235	1200	6.9
	Super-P	23	134.0	250	1320	6.9
	NPK	25	102.0	241	2200	7.1
	Compost	22	149.0	247	1260	7.0
C2	Control	16	66.2	221	2900	7.8
	Super-P	18	76.9	257	3300	7.8
	NPK	23	119.0	224	2550	7.6
	Compost	20	61.3	246	2800	7.8
C3	Control	24	91.1	164	3400	7.9
	Super-P	28	102.0	210	3200	7.8
	NPK	26	104.0	184	3520	7.9
	Compost	23	93.2	177	3600	7.8

1.3.6. MULTIVARIATE ANALYSES

Principal component analysis was used to examine relationships between variables and to define the factors that discriminate most between farms. Variables with high loadings on a principal component are intercorrelated; variables having high negative loadings are also intercorrelated, while variables with positive and negative loadings are negatively intercorrelated (Broschat, 1979).

Cluster analysis was used to confirm the existence of real clusters by the data, displayed by the scores of the PCA. In cluster analysis, variables which are largely the same for all data units have little discriminating power, whereas those manifesting consistent differences from one subgroup to another, can induce strong distinctions. Inclusion of strong discriminants not particularly relevant to the purpose of the analysis, can mask the search for clusters and give misleading results (Anderberg, 1973).

1.3.6.1. PRINCIPAL COMPONENT ANALYSIS (PCA) FOR DATA FROM 1988.

All soil and plant variables measured in 1988 for the three farms studied were used in the analysis (Table 38). The first 3 factors accounted for 60% of the total variation. Factor 1 had high positive loadings for soil Ca and soil pH, and high negative loadings for soil P-ase and soil P_{res}. Factor 1 is primarily related to the soil acidity. Factor 2 had high positive loadings for %N in grain, and %N, %P and %Mg in straw, and high negative loadings for grain and straw yields. This factor can be described as a yield factor. Factor 3 had high positive loading values for soil Mg and % arbuscules and a high negative loading value for % hyphae.

The location of the samples with regard to the principal components (Figures 22 and 23), show the two organic farms clustered together in one side of the plane compcsed by factor 1 versus factor 2 while farm C1 occupied the opposite side (Figure 22). These two factors together, described 45% of the total variation. The display of factor 3 versus factor 1 show a similar pattern (Figure 23). The other factors considered in the PCA (factor 4 and 5) are not shown, because they do not separate the farms in distinct groups.

A cluster analysis performed with the 3 principal components above, separated the data from farm C1 in one cluster. However, the remaining variates were not grouped by farm and different cluster procedures were not consistent on the clusters formed. The data corresponding to those farms were grouped into 2 to 5 clusters (depending on the clustering method).

There was no cluster according to fertilizer treatment, which illustrates that farm effects were greater than the fertilizer effects.

The features that most likely isolated farm C1 in a single cluster when factor 1 was considered, are lower soil pH and Ca, and higher soil K and P, when compared to the other two. Factor 1 contrasted soil P-ase with other variables such as soil pH and soil Ca. It is possible that the effect of the pH influenced the values of the other variables. When factor 3 is considered, Farm O2 polarizes towards the top of factor 3. This factor is related to the % of VAM (arbuscules) and soil Mg.

Table 38. Factor pattern for principal component analysis performed with data obtained in 1988.

VARIABLES	FACTOR 1	FACTOR 2	FACTOR 3
Weeds	0.649	-0.186	-0.059
Grain yield	0.2483	-0.835	0.236
Straw yield	-0.002	-0.783	-0.190
Soil P (res)	-0.765	-0.250	-0.407
Soil K	-0.899	0.1138	0.13
Soil Mg	0.218	0.102	0.809
Soil pH	0.939	-0.11	0.002
Soil Ca	0.942	-0.110	0.215
%N grain	-0.280	0.779	0.083
%P grain	-0.235	0.033	0.120
%K grain	0.164	-0.211	0.094
%Ca grain	-0.207	-0.016	0.003
%Mg grain	0.155	0.0344	0.035
%N straw	0.086	0.939	0.180
%P straw	0.068	0.750	0.045
%K straw	-0.665	-0.207	-0.281
%Ca straw	0.353	0.259	0.622
%Mg straw	0.301	0.731	0.454
Root P-ase	0.542	0.004	0.264
Soil P-ase	-0.829	-0.079	-0.433
%Arbuscules	0.306	0.028	0.848
%Hyphae	0.263	-0.053	-0.763
Eigenvalues	5.73	4.21	3.33
Proportion	0.26	0.19	0.15
Cumulative	0.26	0.54	0.60

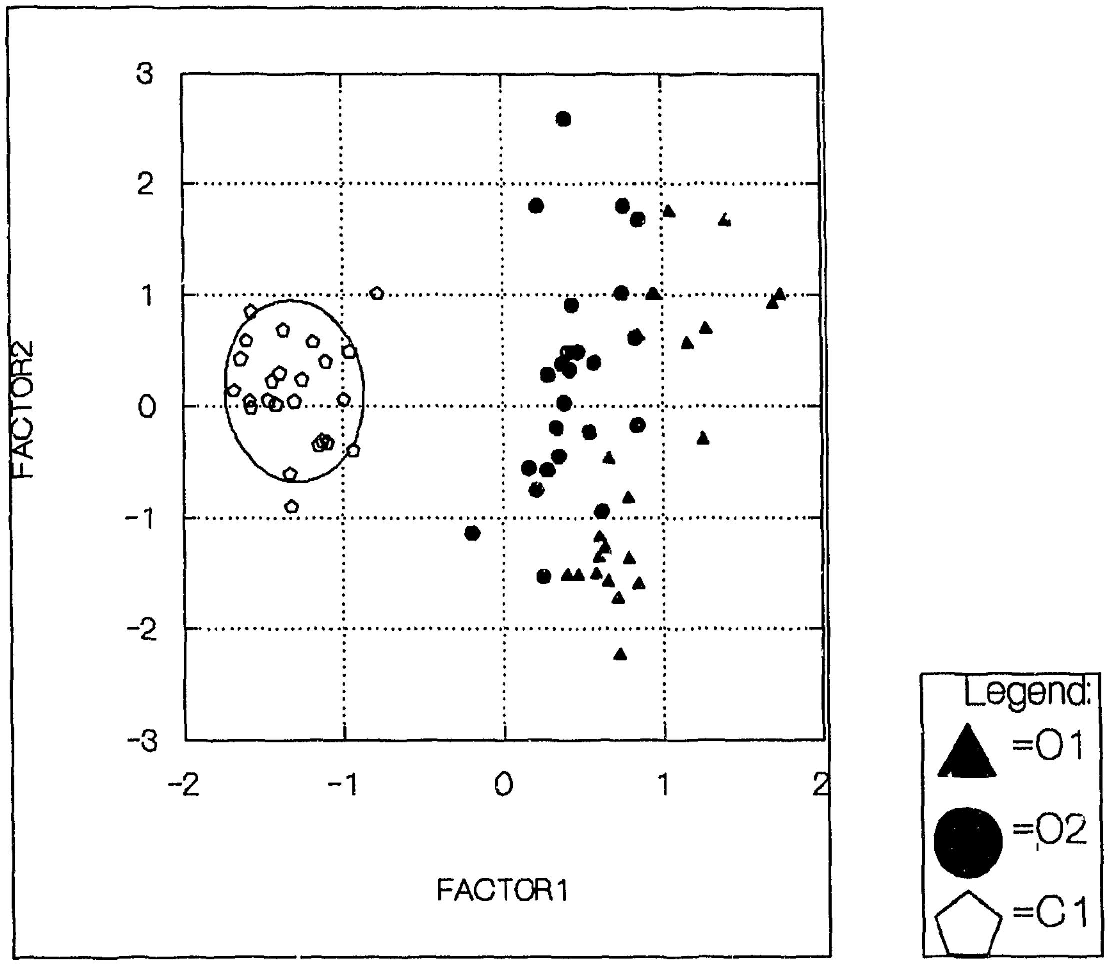


Figure 22. Position of the principal component scores for farms O1, O2 and C1, 4 treatments and 6 replicates on principal components 1 and 2. Values within the circle were determined to belong to a cluster by cluster analysis (average linkage method).

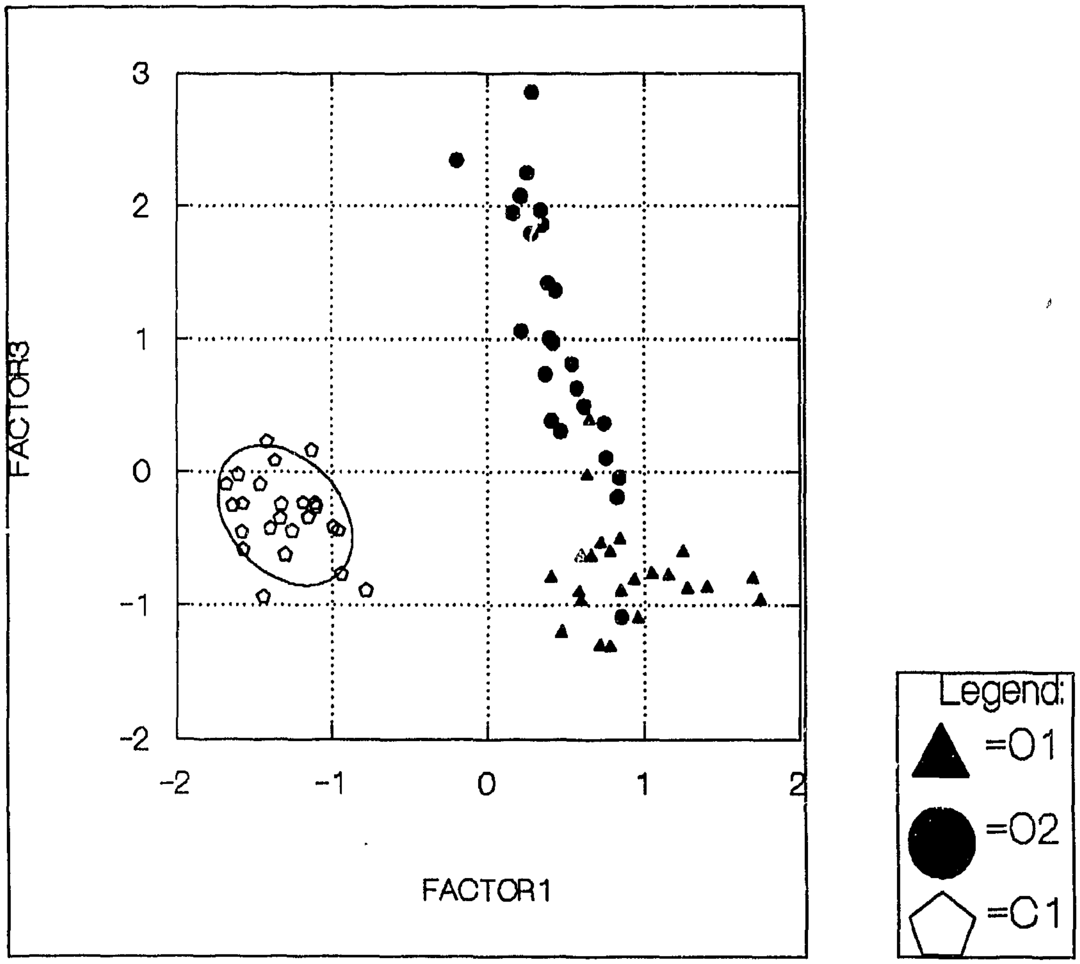


Figure 23. Position of the principal component scores for farms O1, O2 and C1, 4 treatments and 6 replicates on principal components 1 and 3. Values within the circle were determined to belong to a cluster by cluster analysis (average linkage method).

1.3.6.2. PRINCIPAL COMPONENT ANALYSIS (PCA) FOR DATA FROM 1989

In 1989, the variables from 6 farms (all fertilizer treatments) were included in the PCA (Table 39). The factor pattern for the 3 factors was retained for the analysis. The first two components account for 47% of the total variation. Most variables have high positive loading factors on both axes. Therefore, they are not negatively related to each other. Root P-ase is the only variable that has negative loadings on both factors 1 and 2. Percentage of hyphae infection in the roots has negative loadings on factor 2.

Factor 1 appears to describe a gradient from "yield component" variables (high positive loadings), such as grain yield, straw yield and % of nutrients, to a "secondary component" comprised by variables with lower loadings such as VAM infection, root and soil P-ases and soil P. Hence, factor 1 is primarily related to yield.

On factor 2, the variables with higher loadings are soil P, %P and %K in barley plants, and the lowest loadings are found on the variables % arbuscule and root P-ase activity. This second factor could be then interpreted as primarily related to nutrient supply properties in the system.

Factor 3 is strongly related to root P-ase activity and % Mg in barley plants. Plant-related factors are on the positive extreme (root P-ase) and soil-related factors on the negative extreme (soil P) of the axis. The 3 factors together explain 69% of the variation.

The location of the samples with regard to the principal factors are displayed in Figures 24 and 25. It is clear from these figures that some clumps of data exist. The cluster analysis defined 4 separate clusters, which are displayed by the figures. Two of these clusters comprise mostly data from the two oldest organic farms (O1 and O2) respectively, another cluster comprises data from conventional farm C2, and another cluster comprises two conventional (C1 and C3) and the transitional organic farm (O3). The two organic farms fell on the "biological" side of axis 2, whereas the others fell on the "chemical" side of it. The oldest organic farm (O1) and the conventional farm C2, the ones with higher yields, both fell on the same side of axis 1.

Figure 25 displays O1 and C2, in opposite sides of factor 3. O1, the oldest organic farm fell on the "biological" side of axis 2 and on the "soil" side of axis 3, whereas C2 fell on the "chemical" and "plant" sides of those axes, respectively.

Although the above observations do not have a statistical significance level, they possess a strong conceptual value. They suggest that farms receiving different intensive management practices (organic or conventional) develop in opposite directions, when a multiple set of variables containing biological information is considered.

Table 39. Factor pattern for principal component analysis performed with data obtained in 1989.

VARIABLES	FACTOR 1	FACTOR 2	FACTOR 3
Grain yield	0.89	0.00	-0.27
Straw yield	0.83	0.28	0.02
Root P-ase	-0.16	-0.28	0.69
Soil P-ase	-0.00	0.22	-0.57
Soil P(res)	0.00	0.85	-0.11
% N	0.58	0.58	0.44
% P	0.43	0.76	-0.07
% K	0.19	0.83	0.08
% Ca	0.72	0.15	0.52
% Mg	0.43	0.19	0.79
% Arbuscules	0.30	-0.45	-0.59
% Hyphae	0.03	0.14	0.55
Eigenvalues	2.9	2.8	2.67
Proportion	0.24	0.23	0.22
Cumulative	0.24	0.47	0.69

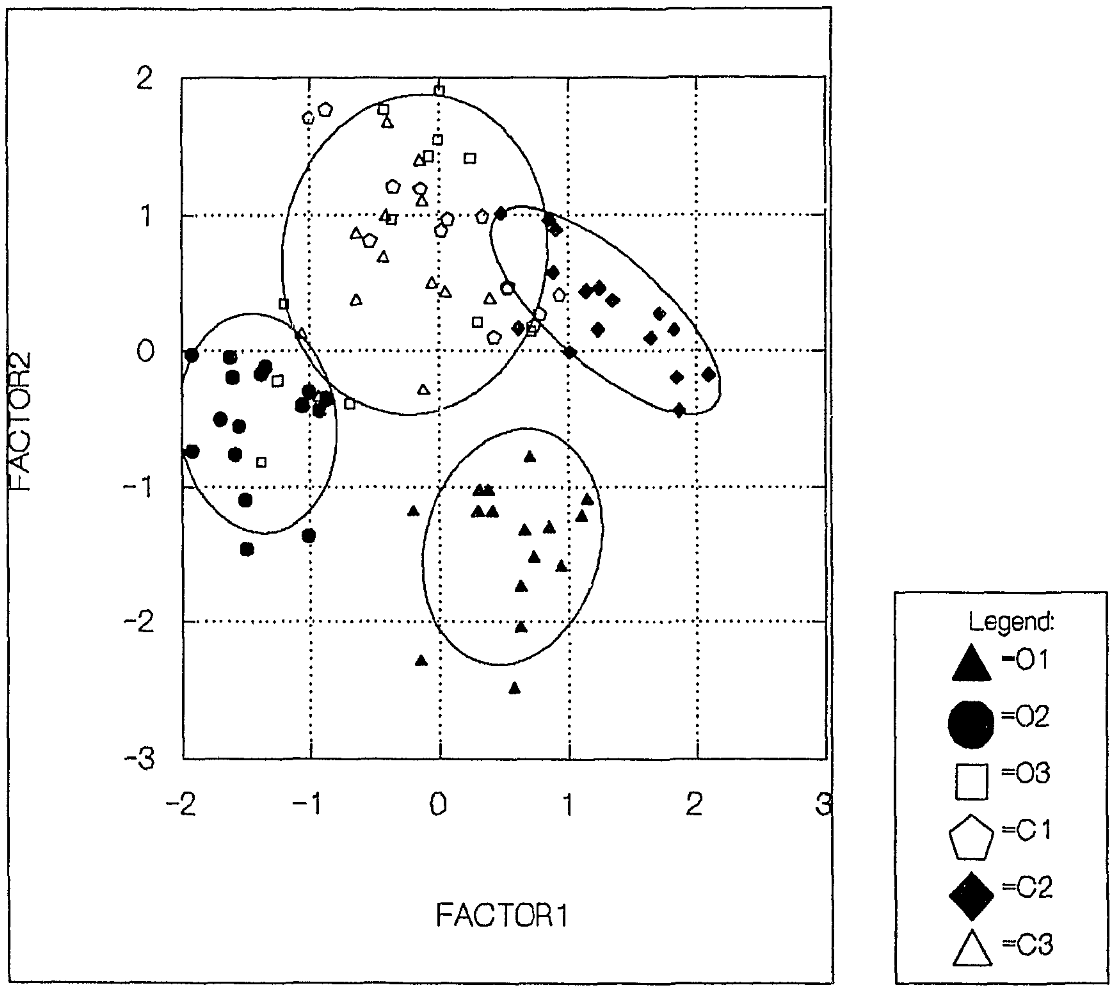


Figure 24. Position of the principal component scores for each of the 6 farms, 4 treatments and 4 replicates on principal components 1 and 2. Values within each ellipse/circle were determined to belong to distinct clusters by a cluster analysis (average linkage method).

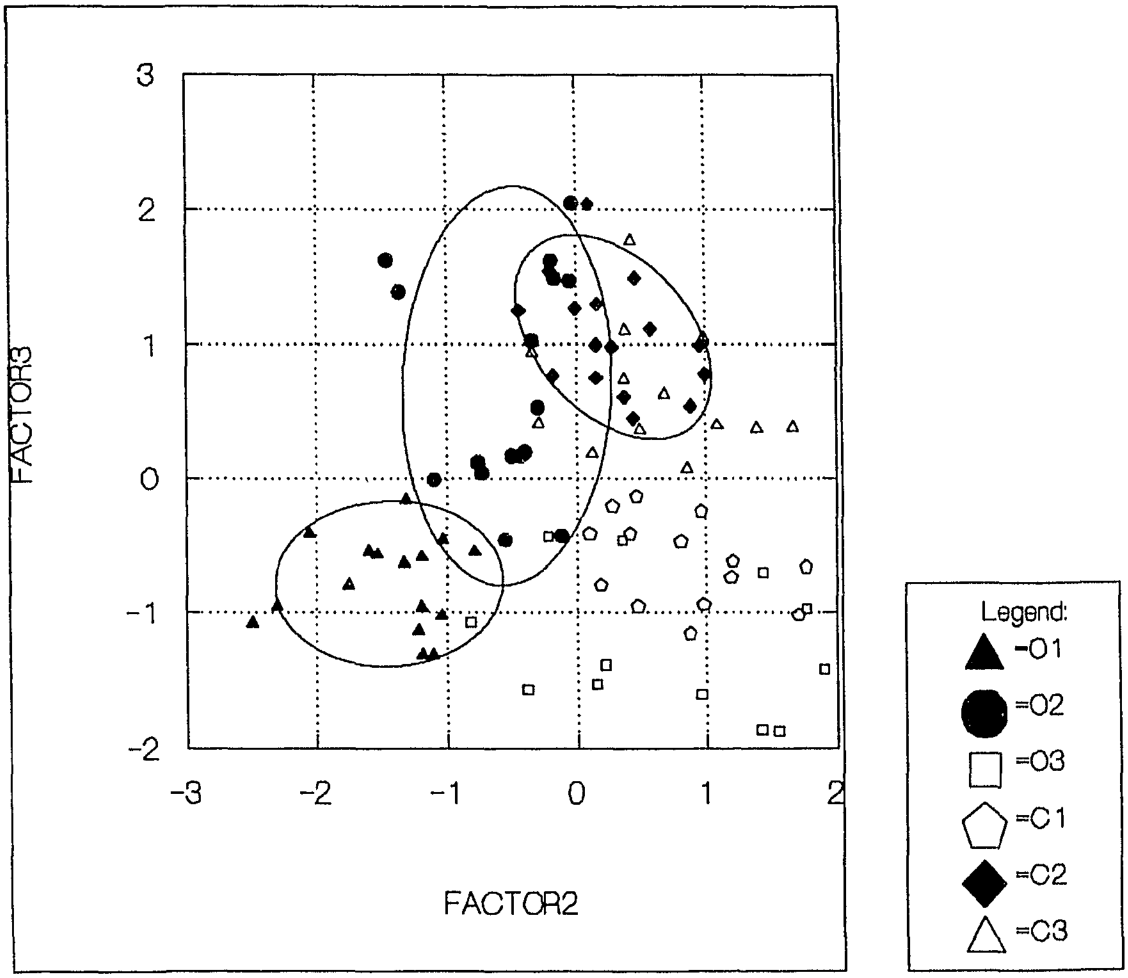


Figure 25. Position of the principal component scores for each of the 6 farms, 4 treatments and 4 replicates on principal components 2 and 3. Values within each ellipse/circle were determined to belong to distinct clusters by a cluster analysis (average linkage method).

A similar analysis was performed using subsets of the above variables. When the analysis is performed without the so-called biological variables (namely, soil and root P-ase activities and VAM (hyphae and arbuscule) infection), the result is that shown in Table 40 and Figure 26. Three factors described 85% of the variation. All of the variables have positive loadings for all 3 factors, indicating that the variables are not inversely related. Factor 1 is related to soil P_{res} and %K; factor 2 is related to %Mg and %N. Cluster analysis using different clustering techniques was inconsistent in assigning the clusters, and those clusters did not clearly group different farms as before. However, Figure 26 displays farm C2 with higher values in Factor 2, indicating that %Mg and %N in barley at that farm were responsible for the distinction.

When the analysis is performed without the variables straw, N, P, Ca and Mg, the result is that shown in Table 41 and Figure 27. Three factors described 69% of the variation. Negative loadings were found, indicating that the biological variables have an inverse relationship between themselves (root and soil P-ase in factor 1) and with other variables such as soil P_{res} (factor 2). The cluster analysis also failed to allocate the clusters consistently. The number of clusters varied from 2 to 6, depending on the clustering method. The group composed of data from farm O1, the oldest organic farm, formed on top of the graph. This may suggest that the oldest organic farm (O1) has some "identification" with the biological parameters studied, whereas the conventional farm C2 is more identified with the more chemically related parameters.

The above analysis, comprising all the variables (Figures 24 and 25) may indicate that my definition of the farms based according to the intensity of chemical use should be changed. In this case, the terminology C2 and C3 would have to be interchanged, since C2 was found to be more diametric to O1 than C3. In other words, C2 would be more "chemically intensive" than C3.

Table 40. Factor pattern for principal component analysis performed with a sub-set of variables from Table 39.

VARIABLES	FACTOR 1	FACTOR 2	FACTOR 3
Grain yield	0.04	0.08	0.96
Straw	0.29	0.34	0.77
Soil P(res)	0.52	0.76	0.25
% N	0.79	0.14	0.41
% P	0.82	0.31	0.00
% K	0.04	0.78	0.48
% Ca	0.05	0.97	0.02
% Mg	0.88	-0.05	0.05
Eigenvalues	2 4	2.4	2.0
Proportion	0.30	0.3	0.25
Cumulative	0.30	0.60	0.85

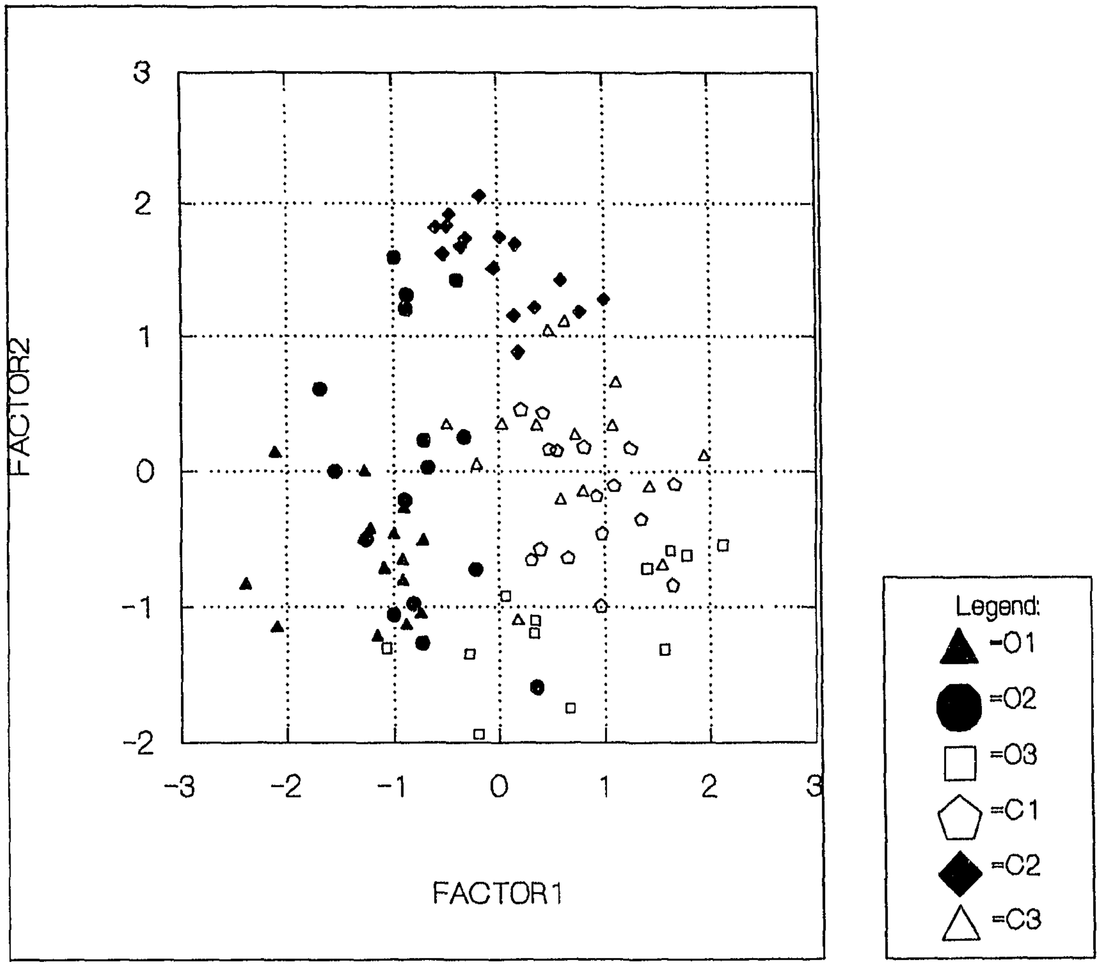


Figure 26. Position of the principal component scores for each of the 6 farms, 4 treatments and 4 replicates on principal components 1 and 2 when only the variables grain yield, straw yield, soil P_{res}, % N, % P, % K, % Ca, and % Mg were used.

Table 41. Factor pattern for principal component analysis performed with a sub-set of variables from Table 39.

VARIABLES	FACTOR 1	FACTOR 2	FACTOR 3
Grain yield	0.61	-0.16	-0.20
Soil P_{res}	0.23	0.88	-0.11
Soil P-ase	0.73	0.03	0.05
Root P-ase	-0.78	-0.16	0.04
% Hyphae	0.45	-0.68	-0.34
% Arbuscules	-0.04	0.04	0.97
Eigenvalues	1.78	1.29	1.11
Proportion	0.30	0.21	0.18
Cumulative	0.30	0.51	0.69

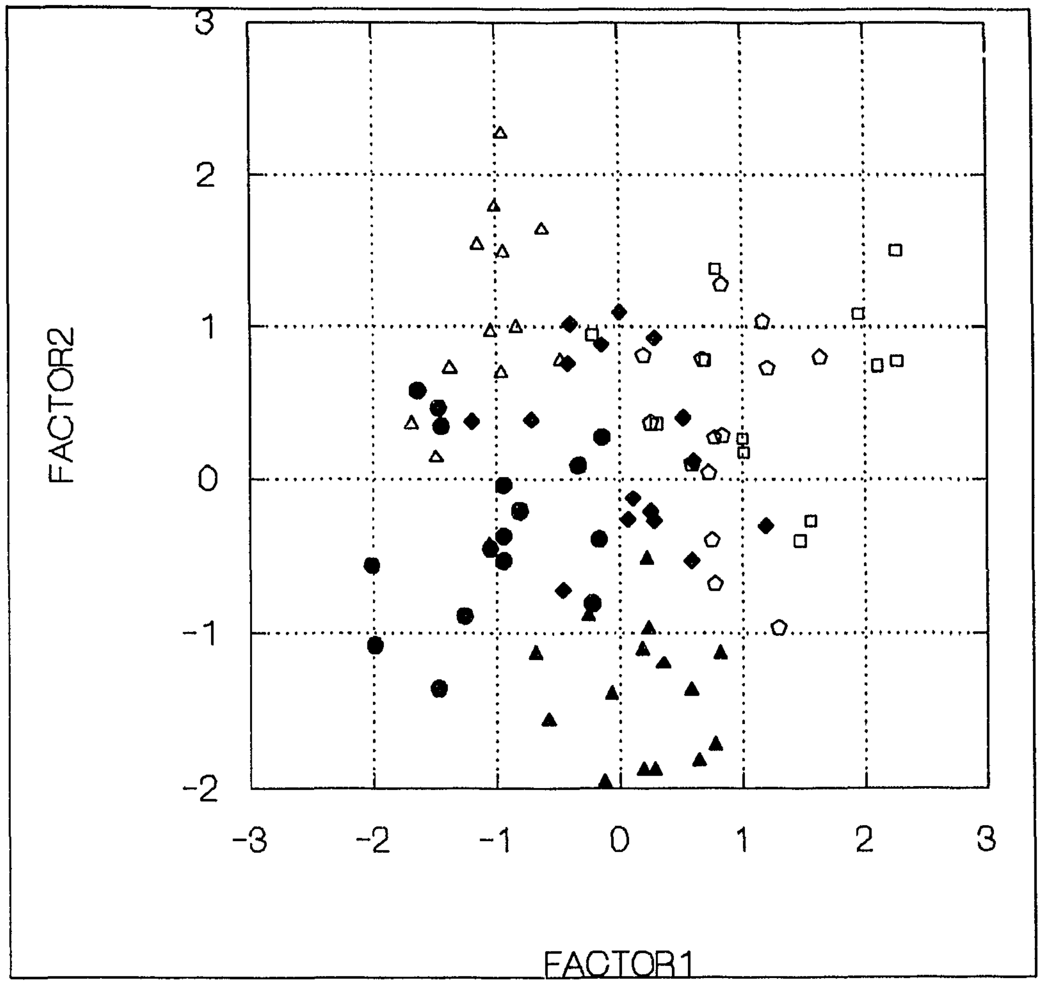


Figure 27. Position of the principal component scores for each of the 6 farms, 4 treatments and 4 replicates on principal components 1 and 2 when only the variables grain yield, soil and root P-ase activities, and VAM infection (hyphae and arbuscule) were used.

1.4. DISCUSSION

1.4.1. MEASURES OF SOIL P

One of the questions of interest in this study is what are the appropriate measures of soil P over different types of farming systems. i.e. which parameters of soil P are the best predictors of plant P status? The standard method to assess soil P in Ontario involves a bicarbonate extraction (Olsen et al., 1954). In this study soil P_{res} extracted more P and was more sensitive than soil P_{bicarb} to fertilizer treatments (Table 5) although both methods were highly correlated (Figure 1). Resin extraction resembles plant uptake more than chemical extractants (Amer et al., 1955; Sibbesen, 1977; Hedley et al., 1982a). Jianguo & Shuman (1991), studying P status in the rhizosphere of rice, found that some components of P extracted with sodium bicarbonate could not be utilized by the rice seedlings.

Soil P_{res} was highly correlated with the percentage of P in the early stage. The present study suggested that % P in the early stage was better related to soil P than was % P at heading (Table 24). P at heading is the more usual stage to assess P adequacy (Ontario Ministry of Agriculture and Food, 1987). Other results suggest that P supply is more important in the early stages of development of different crops than in later stages (Avnimelech & Scherzer, 1970; Romer & Schilling, 1986; Barry & Miller, 1989). These studies indicated that when P supply was adequate for several species (wheat, lettuce, radish and maize) in the early stages of development, yields were highest. For wheat, Romer & Schilling (1986) suggested that the high uptake of P in the early stages is related to high demand rather than a luxury consumption.

Measures of soil total P (acid extraction) and soil total P (acid + alkaline extraction) were more highly correlated with variables related to P mobilization than was soil P_{res}. In the fractions from the acid extraction, correlations were higher for the organic than for the inorganic fraction. This supports the contention that the organic P fraction should be included in the measures of soil available P. In a survey of a large number of soils in the U.S.A., Tiessen et al. (1984) found that available P was closely related to organic P.

In contrast to the acid fraction, the alkaline fraction, which was almost entirely organic, was not well correlated with the variables related to P mobilization and use. According to the extraction method of Hedley et al. (1982a) that separates different fractions according to their biological availability, the alkaline (NaOH) extracts are considered the fractions strongly bound by chemical sorption with soil minerals. In my study, the alkaline extracts contained mostly organic P (Table 18), in accordance to the results of Trasar-Cepeda & Carballas (1991), who found that organic P predominated over inorganic P in the alkaline extract when the methodology of Hedley et al. (1982a) was used.

The alkaline and the acid fractions were negatively related (R=-0.670). The alkaline fraction was positively related to the sand fraction and negatively related to the clay. It is not understood why this was the case.

1.4.2. EFFECTS OF FERTILIZERS

Only at farm O1 was there a statistically significant effect of the fertilizers on yields, super-P having the statistically significant effect ($P<0.05$). There was an indication that farm O2 was strongly N limited but not the other farms, but even there, all fertilizers increased yields somewhat (numerically). When correlations between soil P_{res} and grain yield are examined, there are clear trends for an increase in yield in response to increasing levels of soil P_{res} on farms where soil P_{res} is initially low; where soil P_{res} is higher there is no change or there is a decline in yield with decreasing soil P_{res} levels. Higher soil P_{res} levels at each farm are associated with super-P and compost applications. Similar relationships are found for the percentage of plant P and grain yields.

These trends suggest that amounts of P applied on farms 03 to C3 are excessive, i.e., have no effect or a negative effect. Based on the provincial recommendation of fertilizers (Table 42), P applied in the fertilizers used in the experiment was excessive, even for compost. K and N application was also excessive, but those nutrients were not responsible for the negative effects of compost on yields, as similar positive and negative effects were observed with super-P.

Table 42. Fertilizer recommendations for selected crops, based on soil analysis results according to the "Field crop recommendation manual" (Ontario Ministry of Agriculture and Food, 1987) and crop yield responses to compost and super-P.

CROP: BARLEY 1989

	Soil fertility ratings		P fertilizer (kg/ha)		K fertilizer kg/ha		N fertilizer (kg/ha)		Crop Yield responses	
	P	K	Recommended	Applied as Compost	Recommended	Applied as Compost	Recommended	Applied as Compost	compost/ control	Super-P/ control
O1	M	H	50	49.5	0	61.0	45	88.0	1.14	1.09
O2	M	V	20	49.5	0	61.0	45	88.0	1.59	1.25
O3	M	L	20	49.5	40	61.0	45	88.0	0.90	0.96
C1	M	H	20	49.5	0	61.0	45	88.0	0.83	0.75
C2	M	M	20	49.5	20	61.0	45	88.0	0.84	0.96
C3	H	H	0	49.5	0	61.0	45	88.0	0.96	1.00

V: very high; H: high; M: medium; L: low

A significant effect of fertilizer on VAM was observed only on farm O3, which was also the farm where fertilizer had the greatest effect on soil P_{res}.

Except for farm C1, in 1988 there was no effect of fertilizer treatment on soil or root P-ase. Fertilizer effects at C1 could be explained as follows: super-P addition, and to a lesser extent the other treatments (values are numerically lower than the control), increased P uptake and consequently decreased the root P-ase activity. Similarly, at the soil level, the treatments may have induced the soil microorganisms to excrete less P-ases, which was detected by the soil P-ase assay. Spiers & McGill (1979) observed that P fertilizer additions decreased soil P-ase activity by the inhibition of new enzyme production rather than by inhibition of the existing enzyme. This was probably the case at farm C1 in 1988, where all three treatments decreased soil P-ase activity at that site only (Table 14). The observation by the same authors that long term P fertilizer application decreases soil P-ase activity, was not verified in this study when the 3 organic and the 3 conventional farms are compared as 2 groups, although farm C3 had the lowest value (Table 16). The fact that all farms use manure or plough down legumes to some extent, may override any possible negative effects of the fertilization.

There was no difference between compost and super-P for most variables, except for root P-ase in 1988 when super-P decreased P-ase activity compared to control at farm C1, and for soil P-ase in 1989, when compost decreased P-ase activity compared to super-P at farm C2.

There was no indication that RP had any effect on the variables studied.

The high pH of all farms, and the limited period of time between application and evaluation of RP (4 months), may account for its ineffectiveness. The main reason for the restricted direct use of RP as fertilizer is their slow dissolution. The dissolution of RP using fluorapatite as an example (Hammond et al., 1986), is described by the reaction: $[Ca_{10}(PO_4)_6F_2] + 12\ H^+ \rightleftharpoons 10\ Ca^{2+} + 6\ H_2PO_4^- + 2\ e^-$. The driving forces for the dissolution of rock phosphates can be summarized in 3 soil-related components (Khasawneh & Doll, 1978): (i) gradient in pH, where solubility increases with the decrease of pH; (ii) gradient in pCa, where solubility increases with the decrease of the activity of Ca in solution and (iii) gradient in $H_2PO_4^-$ in soil solution, where solubility is enhanced if there is a sink to reduce $H_2PO_4^-$, and hampered if $H_2PO_4^-$ is at an elevated level. One factor related to the composition of the rock, is the degree of carbonate substitution for phosphate. This factor will also control the reactivity (Khasawneh & Doll, 1978, McClellan & Gremillion, 1980).

1.4.3. BIOLOGICAL PROCESSES INVOLVED IN THE MOBILIZATION OF P

1.4.3.1. VAM

The VAM showed no significant relation to plant P or P deficit and was negatively related to early plant growth between farms. The VAM had a negative weak correlation with final yield. It is possible that in the early stage when VAM assessments were made, the symbiosis was still in the process of establishment and its benefits were not yet fully taking place, making the detection of relationships more difficult. Another explanation is that at the levels of P on these farms, especially on farms O3 through C3, there was not sufficient P stress for the benefit to be realized. Possibly, there was a benefit on farm O2 which had the highest levels of arbuscules in both years. This farm had low soil P_{res} and was a stockless farm that did not receive any material inputs of any kind. This farm would appear to have the highest degree of P stress. Farm O1 had equivalent (low) levels (3%) of soil P_{res} and low levels of arbuscules in 1988; in 1989, it had the lowest arbuscule values of all farms. O1 is a mixed livestock/arable farm and has a long history of compost application. The percentage of P in barley plants versus soil P_{res} units was about 50% higher for farm O1 than that of farm O2 (Figure 7), and the barley grain yield per unit of plant P was approximately 3 times greater than that for farm O2 (Figure 8). These observations suggest that P is highly mobilized in this system without the action of mycorrhizae. At the other farms, the evidence suggests that the background levels of soil P are adequate. In such situations, negative effects of mycorrhizae can be expected. In summary, it appears that the mycorrhizae had benefit only at the stockless farm; there were no benefits on the other farms either because other processes were involved in P mobilization (O1) or the background soil P levels were adequate.

Negative relationships have been found between percentage of colonization by VAM fungi and total dry weight in 4 week old grasses (*Phleum pratense* and *Agropyron trachycaulum*) (Clapperton & Reid, 1992). Also, VAM plants translocate more C to roots than non-mycorrhizal plants (Wang et al., 1989). According to Volkmar & Woodbury (1989), root lengths were 40 to 80% lower in mycorrhizal compared to non-mycorrhizal barley plants at stage 10.1 on the Feeke's scale (beginning of heading stage). Barley has been found to be resistant to infection by mycorrhizal fungi species that are aggressive on other plants, and infection level and growth promotion can be unrelated (Black & Tinker, 1979).

1.4.3.2. SOIL AND ROOT P-ASE ACTIVITY

No relationships of soil P-ase with soil or plant variables were found. Negative relationships between root P-ase and plant P are expected (Bieleski & Ferguson, 1983, McLachlan, 1976, 1980 a and b; Goldstein et al., 1988a). Root P-ase had a negative but not significant correlation with soil P_{res} and P in barley plants. However, inorganic P in barley leaves, which is a fraction of the total P that is directly related to the metabolic P pool (Bieleski & Ferguson, 1983) was somewhat negatively correlated with root P-ase (Figure 13).

When P deficits and net root P-ase activities were plotted, a good relationship was obtained (Figure 14). The concept of an "active" and a "basal" portion of the root P-ase applied to my calculations of P deficits, is substantiated by the results of McLachlan et al. (1987) who isolated 2 P-ase isoenzymes in plants, one found in P-sufficient and P-deficient plants and another found only in P-deficient plants. Although there is no direct evidence for root P-ase contributing to P nutrition, these observations suggest that there is a role of P-ase in P nutrition.

Soil P-ase activity was 2-3 times higher at farm C1 than at O1 and O2 in

1988 (Table 14). This could be related to C1 having the lowest soil pH (Table 2). According to Halstead (1964), Eivazi & Tabatabai (1977), and Juma & Tabatabai (1977), alkaline P-ases are predominant in alkaline soils while acid P-ases are predominant in acid soils. According to Trasar-Cepeda & Carballas (1991), the optimum pH for P-ase activity was close to the soil pH. Rojo et al. (1990) made similar observatons: in a soil with pH=8.4, the optimum pH for P-ase activity was 10.3, whereas in a soil with pH=4.3, optimum pH was 5.2. In contrast, Herbien & Neal (1990) studied the optimum pH (O_{pH}) for P-ase activity in soils that had been under forest, grassland and agriculture (maize) for 20 years. In forest soil (pH=4.9), O_{pH} was around the same value as soil pH; in grassland soil (pH=6.6), O_{pH} varied widely between 4.7 and 7.0; and in the agricultural soil (pH=7.2), an alkaline P-ase (O_{pH}=11.0) was found with a much higher activity than an acid P-ase with O_{pH}=4.7.

These results indicate that, unlike the O_{pH}=6.5 for acid P-ase proposed by Tabatabai (1982) (whose methodology was used in this study), and by Eivazi & Tabatabai (1977) and Trasar-Cepeda & Gil-Sotres (1987), other O_{pH} may occur in nature and they are not always related to the soil pH. Therefore, if realistic measurements of the contribution of P-ases to P cycling are to be made, the actual soil pH and temperature should be used as opposed to optimum values of these variables. Soil pH may also vary within soil microsites, for instance between the rhizosphere and bulk soil. Plant roots can modify the pH of surrounding soil by releasing H^+ or OH^- in response to differential uptake of cations and anions, in order to maintain a slight negative electropotential in the cell (Mengel & Kirkby, 1979). Even for the same root system, zones with different reactions, acid or alkaline, can be found as demonstrated by the *in vivo* technique developed by Marschner & Romheld (1983), which has obvious implications for P turnover in the rhizosphere. This factor, may require that P-ase activity be determined for a larger array of pH as opposed to one fixed pH, if it is to be considered associated with the microbial biomass or rhizosphere of different plant species.

A strong negative relationship between soil pH and soil P-ase activity was found in 1989 (Figure 12). However, this relationship held for only 5 out of 6 farms (farm C1 was an exception). Regardless of the higher soil pH at C1 in 1989 compared to 1988, soil P-ase activity was still highest at C1 compared to the other sites with similar soil pH. An explanation for the deviation in the relation between soil pH and P-ase activity at farm C1 in 1989 could be that the enzyme accumulated in 1988 by the addition of organic material (which also caused the low pH - see page 147), and stayed active until 1989. Protection of soil enzymes against microbial degradation may leave free enzymes active in the soil. Results of Dick & Tabatabai (1987), suggest binding by clay particles of P-ases results in a decrease on the enzyme V_{max} but K_m is maintained. Another possibility, would be the adsorption of the substrate itself to the soil colloidal fraction as discussed by Skujins (1967).

There is some indication that soil P-ase was related to soil P_{res} when the ratio soil P_{res}:soil organic P was used (Figure 11). These results are in agreement with those obtained by Sharpley (1985), who used the same relationship to demonstrate involvement of P-ase activity in the process of soil P availability. Trasar-Cepeda & Gil-Sotres (1987) also found a correlation between soil P-ase activity with more labile fractions such as resin-P and bicarbonate-extracted organic P. Halm et al. (1971) found that soil organic P was related to P-ase activity and proposed an index of availability of organic P based on P-ase activity. The same results could not be confirmed by Speir & Cowling (1991).

Due to the ubiquitous occurrence of P-ases in the soil, the total P-ase activity in the soil may not be very closely related to P cycling because of the lack of suitable substrates surrounding the areas where, for instance, the soil free enzyme is located. Tarafdar & Claassen (1988) suggested that the availability of suitable organic substrate is likely to be the limiting factor for plant P uptake from organic fractions. Also the low solubility of P in the soil solution and the fast equilibrium reactions between phosphate anions and the soil solid phase (Olsen & Kasawneh, 1980) may conceal some of the relationship of P-ase activity with P cycling.

1.4.3.3. ROOT LENGTH

Root length had no relationship or negative relationships with variables related to P nutrition, such as percentage of P at the heading stage and leaf Pi (Figures 19 and 20). Soil P from the alkaline extraction was the only soil variable that was positively related to root length and therefore this soil fraction was negatively related to the other variables associated with P nutrition.

Root length was related to soil texture (Figure 18). Farm O2 had the sandiest soil (Table 2). In figures 19 and 20 (the relation between root length and plant P, and between root length and leaf Pi) the values for farm O2 are always deviating considerably from the general linear trend followed by the other farms. This is probably so because at that farm, the roots had less of a mechanical barrier to overcome, due to a lower percentage of clay and a higher percentage of sand. According to Bamford et al. (1991), increasing the number of large soil pores allowed barley roots to proliferate faster. According to Braim et al. (1992), compaction caused by minimizing tillage resulted in reduction of root length in barley, however, the root length reduction was compensated by an increase in the inflow rates of N. Farm O2 was also exceptional in having a high rate of return of crop residues and in not using manures, but with no livestock, straw was recycled.

The negative relationships of root length with variables associated with P nutrition suggests that the root system responded to the P limitation with the production of longer roots. The occurrence of root length response even when soil P was not in the strongly limiting range, suggests that biological feedback of this sort is operative over a broad range. In general, plants respond to P deficiency by increasing root:shoot ratios (Haynes & Ludecke, 1981; Mouat, 1983). Wheat cultivars subject to decreasing P concentrations responded by extending the root system and/or developing a more effective P uptake per root unit (Romer et al., 1988). Jackson et al. (1990) demonstrated increased physiological uptake capacity for P in P-enriched patches. The increase in P uptake velocity after periods of P deficiency has been well demonstrated (Bieleski & Ferguson, 1983).

Root length is thus, an important variable to be considered in this type of study. The fact that soil P_{res} was low at farm O1, and yet plant P levels and yields were in the same range as the farms where soil P_{res} levels were higher, may be due in part to feedback processes. At farm O2, however, other nutrients such as N were limiting the crop (indicated by a significant response to N fertilizers- data not shown). Organic matter additions improve soil physical properties (Cooke, 1977; Buchanan & Gliessman, 1990; Martens et al., 1992); organic farms tend to have better soil structure than conventional farms (Reganold et al., 1987). This would allow a better root development and result in a more efficient use of the existing soil nutrient by plants growing in organic farms.

1.4.4. COMPARISONS BETWEEN ORGANIC AND CONVENTIONAL FARMS

The data from the fertilizer experiments did not illustrate differences between the sets of organic and conventional farms with respect to yields, soil P, plant P, P-ase and VAM. Furthermore, data from the control plots for root length, various soil P fractions and plant Pi showed no difference between the two sets of farms. The lowest soil P_{res} values were found in the old organic farms.

When the variables were examined under the same environmental conditions on the greenhouse, no single variable was consistently higher or lower for one group or another. The most consistent differences between the two sets of farms was on the seasonal patterns of uptake of N, P and K.

Comparisons between farms of the percentage of different nutrients in the 6 farms at the early stage and the heading stage (Figures 2 and 3), suggest that mobilization of nutrients occurred at different rates in the organic compared to the conventional farms. For all farms, these figures show the percentages of N, K and Ca at the early stage were higher than at the heading stage, and the levels of nutrients at the latter stage are similar on all farms. The percentages of these nutrients in the early stage, however, are generally lower on the organic than on the conventional farms. This is an indication that the plants from all farms achieved similar final levels of nutrients, but at the conventional farms the plants probably took up more than necessary for the growth in the early stage. The biological significance of lower nutrient status in the earlier stages of plant development would be the maintenance of a P deficit for a longer period of time, increasing the chances that biological mechanisms such as VAM infection or P-ase activity would increase P supply. It is commonly assumed that this is the case (organic versus conventional) but there appears not to be any specific data to support that contention.

In conventional farms, a high status for all nutrients was achieved early in the cycle and it should be noticed that these are results from control plots where only the native soil fertility was involved. In the organic farms, the plant nutrient levels were kept down, although they reached a similar threshold at the heading stage. This is probably a consequence of the constant use of synthetic fertilizers in the conventional farms, resulting in larger pools of readily available nutrients, while in organic farms, the process occurs more slowly, relying on more modest equilibrium reactions and microbial activity throughout the growing season.

When yields of different crops at O1 are compared to the provincial averages (Table 43) over 3 years, lower averages for O1 than for the County or for Southern Ontario are found (Table 43). The differences between Oak Manor yields and yields from County Oxford or Southern Ontario ranged from -7.5 to -31.2% for barley, +30 to -70% for oats and -20.3 to -29.2 for maize. These results agree with other reports of lower yields at organic farms than at conventional farms (Berardi, 1978; Lockeretz et al., 1980; Liebhardt et al., 1989).

On the other hand, when the quadrat barley yields for O1 are compared with quadrat yields of the other farms (Tables 7 and 8), organic farm yields were not necessarily always lower than conventional farm yields. A drought occurred in 1988 (Appendix B). Although maize yields in 1988 were lower than the published average for the county, that crop was, by simple visual assessment, much taller and healthier than that of immediately neighbouring farms, where maize was stunted and severely chlorotic.

In 1989, farm O1 was the only site where significant increases in yields occurred in response to the fertilizer treatments. This site was also the one with the lowest soil P_{res}, and no increases in soil P_{res} occurred in response to the treatments. Units of grain yield per unit of plant P (Figure 8B) were highest at O1. This anomalous relation indicates the existence of a unique factor at O1.

Table 43. Average yields of barley, oats and maize in selected areas of Ontario (Ontario Ministry of Agriculture and food, 1988, 1989, 1990) and at Oak Manor.

	Barley (kg/ha)			Oats (kg/ha)		
	1987	1988	1989	1987	1988	1989
County Oxford	3497	2528	3604	2703	1752	2513
County Waterloo	3389	2313	2040	2475	1675	2246
Southern Ontario	2851	2205	3120	2132	1561	2284
Oak Manor Farm*	2405	1772	2885	2780	459	1735

	Maize (kg/ha)		
	1987	1988	1989
County Oxford	8029	6227	7251
County Waterloo	7527	4767	5330
Southern Ontario	7402	5583	7339
Oak Manor Farm	5901	4405	na

* Data from control plots of different fields, corrected to 14% moisture and reduced to compensate for differences between quadrat/combine yields (barley yields were reduced 18% and others, 30%).
na: not available.

The multivariate analysis for 1988 data shows that farm C1 was distinct from O1 and O2. The distinctiveness is related to low soil pH, low soil Ca and high soil K, and high soil P-ase. These features were transient, as illustrated by the fact that the pH increased to normal levels the following years. Soil P-ase was still the highest, although the differences were much less. Therefore the features that distinguish C1 in 1988 appear to be transient. This can presumably be explained as follows:

At farm C1, red clover was ploughed down in the fall of 1987 and liquid manure (33,700 l/ha) was applied in the spring of 1988. This could explain both the high soil P-ase activity and the low pH at farm C1 in 1988. Low pH would be expected, because of intensive nitrification of N mineralized from the clover plough-down and from the liquid manure, combined with restricted uptake of nitrate by barley because of the drought (Ulrich, 1987; Patriquin et al., in press). That the effect was transient, was indicated by pH increasing again in 1989. Martens et al. (1982) found an increase in P-ase activity and other soil enzymes for 31 months in response to incorporation of several organic materials into the soil such as poultry manure, alfalfa and barley straw. Rojo et al. (1990) also found that soil P-ase was highly associated with large soil aggregates and with less humified organic matter. Addition of barley straw increased P-ase activity in the first year with a peak about 1 month after the amendment. This suggests that a trigger or a promoter in the organic material stimulated soil organisms to secrete high levels of the enzyme (Martens et al., 1992). Other results confirm the increase in soil P-ase activity after the addition of organic material (Dalal, 1982; Perucci et al., 1988).

An important result of the multivariate analysis is that it illustrates no clustering by fertilizer treatment for either the 1988 or 1989 data.

For the 1989 data, there are distinct clusters for each of farm O1, O2 and C2, while O3, C1 and C3 form one cluster. Farm O1 seemed to be separated by having high yields and low nutrient values; O2 by having low yields and low nutrient values and C2 had the highest yields in 1989 and also the highest contents of N, Ca, Mg and P (Figures 24 and 25). Possibly, C2 should be considered the most intensive.

Hardiman et al. (1990) used cluster analysis for identification and classification of farming systems in China. Although most of the variables used by them were socio-economically and geographically related, those authors concluded that the method allows comparisons across farming system groups, and can be used as a pre-sampling technique for selection of a farm survey area. Similarly, when biological and physiological variables are used, farming systems can be classified on that basis. Further investigation on the method should be done, in order to identify the variables that are more suitable for the study of farming systems. Much of early work tried unsuccessfully to establish relationships of soil microflora data with conservationist management practices. These types of studies might have been more successful if multivariate approaches were adopted because it seems that in those systems, many variables are responsible for their distinctiveness and thus, univariate approaches would not be satisfactory.

The multivariate analysis for the 1989 data seems to separate the oldest organic from the rest, separates the old organic with livestock from old organic without livestock, and there is some suggestion that amongst the rest, the most intensive is also distinctive.

In summary, the main features revealed by the multivariate analysis are (1) the lack of clustering according to fertilizer treatments and (2) the cluster of individual farms particularly the oldest organic farm in 1989.

CHAPTER 2

EFFECTS OF SOME CURRENT MANAGEMENT PRACTICES ON P NUTRITION AND CROP PERFORMANCE AT OAK MANOR FARM

2.1. INTRODUCTION

Crop rotations, green manuring, mixed livestock/arable farming, recycling of crop and animal residues through composting, and the operation of a mill, are features of Oak Manor farm. These are management practices commonly adopted in organic farming (Lampkin, 1990), although some organic farmers may exclude one or another of these practices. These practices are also performed on conventional farms to various extents.

The selection of crops, organic fertilizers, tillage and other management practices at Oak Manor have been based of the farmer's experience and popularly enunciated principles of organic farming; they were maintained or not, according to the farmers' judgement as to whether or not the practices proved beneficial or detrimental.

Three aspects of the system's management practices were selected for this study which was conducted from 1987 to 1990: tillage/crop residue (straw) managements, green manuring and use of residues from the mill (oat hulls).

It is known that tillage/straw management practices can affect mobilization of P (e.g., soil P losses (Mueller et al., 1984)) and that different green manure crops have different effects on the mobilization of P. N_2 fixation can enhance P mobilization by acidifying the rhizosphere (Aguilar-Santelises & Van Diest, 1981). It is expected that these effects would be most beneficial in high pH soils such as Oak Manor. It was postulated that the carbon sources available on the farm (oat hulls from milling) could be managed so as to reduce the soil nitrate levels through immobilization. This would increase biological N_2 fixation of legumes which in turn could mobilize P through acidification of the rhizosphere.

The three experiments were conducted on three separated fields at Oak Manor farm. The crop sequences and management practices that were not experimental variables were performed according to the farmer's current custom.

The experiments will be dealt with in different sections. They were designed considering the following questions:

EXPERIMENT	QUESTIONS
Effects of three tillage/straw treatments (straw removed, mouldboard ploughed; straw removed, disced; straw retained, disced) on soil and crop P status over several crops.	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?
Effects of 4 different green manures and RP on P status of soil and crops	3. Are RPs reactive in a long term cropping sequence? 4. Do different green manures affect the solubility of the RP? 5. How do different crops respond to both RP and green manures?

Effects of carbon addition (as oat hulls) on N_2 fixation and P nutrition of hairy vetch and their effects on maize.	6. Can carbon additions (oat hulls) increase N_2 fixation of a legume crop? 7. Does this legume crop have a better P nutrition when fixing more N_2? 8. Does this legume affect P nutrition of a following crop?

2.2. MATERIAL AND METHODS

2.2.1 EFFECTS OF THREE TILLAGE/STRAW TREATMENTS ON SOIL P AND CROP NUTRITION

2.2.1.1. OUTLINE OF THE EXPERIMENT

LOCATION: Oak Manor Farm

YEARS: 1987 (Summer)[1]

1987 (Fall) to 1989

SOIL TREATMENTS: After harvesting barley, the field was divided into 9 strips in which (i) straw was removed and soil mouldboard ploughed, (ii)straw was removed and soil disced and (iii) straw was retained and soil disced.

In 1988 four fertilizer treatments (no fertilizers, super-P, RP and compost, as described on the previous experiment) were superimposed on the main treatments.

CROPS: The field was divided into 2 strips, perpendicular to the tillage/straw treatments: strip A was 270 X 15 m and strip B was 270 X 58 m. Two different cropping sequences were followed in each strip. Initial soil properties are given in Table 44.

The layout of the experiment is displayed in Figure 28.

SEQUENCE OF CROPS:

Period	Strip A	Strip B
Fall 87	Oilseed radish	Faba beans
Spring 88	Peas	Maize
Fall 88	Winter wheat+clover	Maize
Spring 89	Clover	Oats
Fall 89	Clover	Clover

---

[1] In the Summer of 1987, a preliminary study was conducted on the farm. Some results of this study are presented in this chapter. Details and material and methods for these experiments are found in Appendix A.

PLOT SIZE: Tillage/straw plots: 30 X 15 m (strip A)
30 X 58 m (strip B)
Fertilizer plots: 2 X 2 m

EXPERIMENTAL DESIGN: In 1987, the 3 tillage/straw treatments were applied in a randomized complete block design with 3 replicates (Figure 28).

In 1988, when the 4 fertilizer treatments (control, super-P, RP and compost) were superimposed on the tillage/straw treatments, the design consisted of a split-plot with tillage/straw treatments as the main plot variable and the P fertilizers as the subplot variables.

In 1989 and 1990 observations were made on the tillage/straw treatments but not on the fertilizer treatments.

OBSERVATIONS:
1987. Crop and weed biomass
ARA (acetylene reduction activity) of faba beans
Soil respiration (evolution of CO_2)
Soil nitrate
Soil P_{res}, exchangeable K, Ca, Mg and pH
1988. Pea yields and weed biomass
Maize roots P-ase activity
Maize roots VAM infection
Soil P-ase activity
Nutrients in maize grain (N, P, K, Ca, Mg)
Soil P_{res}, exchangeable K, Ca, Mg and pH
1989. Nutrients in wheat grain (N, P, K, Ca, Mg)
Nutrients in clover leaf tissues (N, P, K, Ca, Mg)
Oats yields, oat root P-ase
Soil P-ase
VAM infection
Soil P_{res}, exchangeable K, Ca, Mg and pH
1990. Clover biomass
Soil P and percentage of nutrients

2.2.1.2. DETAILS OF EXPERIMENTAL METHODS

Soil respiration was measured as follows (Anderson, 1982): 100 g of soil were incubated for 4 hours in closed 1 l Mason jars containing a vial with 20 ml of 0.1N NaOH. After the incubation, $BaCl_2$ was added in the NaOH solution and it was titrated with a standard HCl solution in the presence of phenolphthalein indicator. The amount of CO_2 was calculated using the formula:

mg CO_2= (B-V)NE, where B=volume of HCl used for the titration of a NaOH blank solution; V=volume of HCl used for the titration of NaOH exposed to the soil sample; N=HCl normality; E= equivalent weight of CO_2.

Soil nitrate was analyzed using an ORION nitrate electrode and pH meter. The extractant used was a 0.035N solution of $Al_2(SO_4)_3.18H_2O$.

ARA (acetylene reduction activity) was determined as follows: the root systems of three faba plants (at flowering stage) were incubated in the field for 40 min in 1000 ml sealed jars with 100 ml acetylene produced *in situ* from calcium carbide and water. After incubation, gas samples were taken from the jars and inserted into 6 ml vacutainers. The samples were taken to the lab and ethylene was measured by gas chromatography. The measurement was done in the morning, on a sunny day. Two jars (with 3 plants each) per plot were used. Nodules were separated from roots and shoots weighed. All the other determinations followed the methods described in Chapter 1.

2.2.1.3. EXPERIMENTAL PROCEDURES

In 1987 barley was harvested from the field in the last week of July. The field was then cultivated in three different ways: (i) straw was removed and soil mouldboard ploughed, (ii) straw was removed and soil disced and (iii) straw was retained and soil disced. The field was then split in two sections perpendicular to the tillage treatments (Figure 28), and in the first week of August, two crops were established: oilseed radish and faba beans. Different crop sequences followed thereafter in each strip.

Measurements of soil respiration were performed at 20 days (when the plants had just emerged) and 35 days after the tillage treatments were imposed. Composite soil samples were collected from 8 points within each plot from the top 20 cm. Two composite sub-samples per plot were used for the respiration measurement. Similarly, 8 plants were collected from different points within each plot for ARA measurements when the plants reached the flowering stage.

Faba bean and oilseed radish biomass production were measured at 30 and 75 days after planting. The second measurement coincided with the flowering stage for both species and the time when the farmer ploughed down the biomass. The biomass of faba beans and oilseed radish were assessed by sampling 3 quadrats of 35 X 35 cm within each plot. Soil samples were taken at this time.

In 1988, four P fertilizer treatments were superimposed on the strips of different tillage/straw regimes: (a) no additions; (b) RP; (c) super-P; (d) compost. Peas and maize were planted on strips A and B, respectively. For strip A, only the final yields and the weed biomass were assessed, because the crop (peas) performed poorly in the drought. One quadrat of 1 X 1 m per plot was used for the yield and weed biomass sampling. On strip B, maize plants were sampled at the 5 leaf stage for root and soil P-ase activity and VAM infection. Maize was harvested at the end of the cycle using quadrats of 1 X 1 m. Two quadrats per plot were taken; the cobs were then dried at 60 C, and hulled mechanically.

In 1989, winter wheat underseeded with clover (both planted in the fall of 1988) and oats were grown on strips A and B respectively. The percentage of nutrients in wheat leaves at heading and the percentage of nutrients in grains were measured. For the leaf measurement, the top two leaves of 12 wheat plants per plot were sampled. For the grain measurement, 10 wheat heads were randomly picked and manually hulled in the summer of 1989. Both leaf and grains were dried at 60 C prior to the chemical analyses. Clover leaf tissues were collected in the same way: 12 leaves per plot were randomly picked and dried at 60 C prior to the chemical analyses.

Oats were sampled once at heading for leaf tissue analyses. The leaf sampling procedure followed that of winter wheat. Oat plants were also sampled at this stage for VAM infection, root and soil P-ase activities. Five plants were taken randomly from each plot. The plants were dug out in a way that a large part of the root system was maintained. The shoots were cut off and the roots and the adhering soil were put into plastic bags and stored in a cooler until the end of the sampling. The root system and adhering soil were immediately taken to the lab, washed, and analyzed for root and soil P-ase activity, as described in Chapter 1. The roots were kept in F.A.A. (formalin, acetic acid and ethanol) until the VAM infection determinations were performed. Oat yields were estimated by manually harvesting three 1 X 0.5 m quadrats per plot. Soil samples were taken at the same time.

In 1990, clover was planted on strip B. Strip A was already covered by clover that had been undersown with wheat the year before. Measurements of clover biomass were taken in September of 1990. Three quadrats of 1 X 1 m per plot were taken. The plants were clipped and the fresh biomass was measured in the field. Sub-samples were taken for moisture determination. Soil samples were taken at that same time.

Initial soil analysis data are given in Table 44.

2.2.1.4. STATISTICAL ANALYSIS

For all variables, except those from 1988, ANOVAs were performed to test the difference among the three tillage/straw treatments. In 1988, the ANOVAs were used to test the differences among the three tillage/straw treatments, among the four fertilizer treatments, and the interaction between tillage/straw and fertilizer treatments. Then a Tukey test (HSD) was used for mean separation, in the cases where the ANOVA resulted in significant F values ($p < 0.05$).

Table 44. Soil properties and their ratings* for the experimental field.

SECTIONS	Organic matter (%)	pH	Available P (Bray I)	Soil exchangeable nutrients K	Ca	Mg
			(mg/kg soil)			
A	4.7	7.7	8 (Low)	90 (Med-Low)	6300 (High)	340 (Medium)
B	4.8	7.7	10 (Low)	120 (Med-Low)	6200 (High)	270 (Medium)

	Texture	CEC (meq/100g)	Aggregate stability (%)
A	Silt clay loam	17.2 (Good)	48 (Excellent)
B	Silt clay loam	16.9 (Good)	64 (Excellent)

Soil samples were taken in October 1987 and analyzed by Woods End Laboratory, Maine).

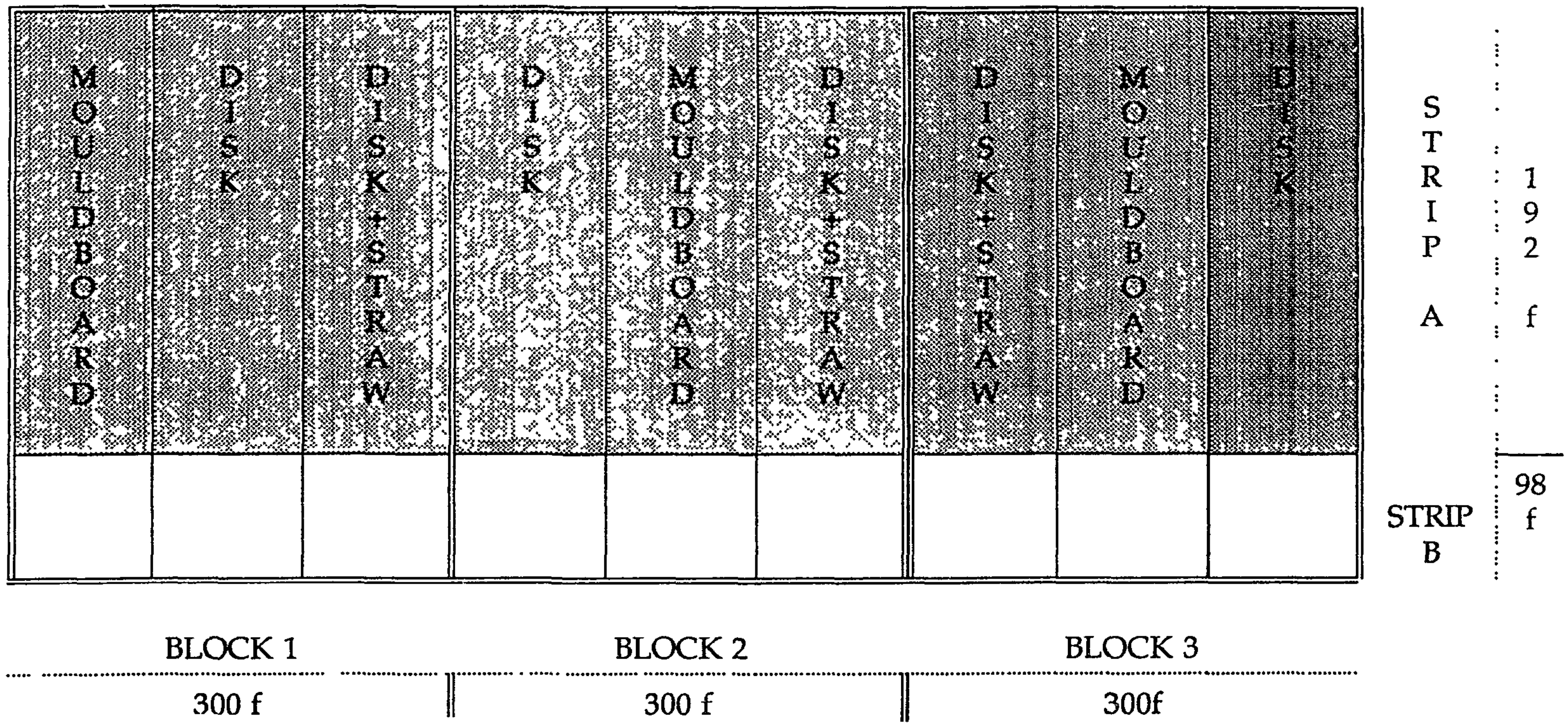


Figure 28. Layout of the tillage and crop treatments.

2.2.2. EFFECTS OF GREEN MANURING AND ROCK PHOSPHATE ON P NUTRITION OF DIFFERENT CROPS

2.2.2.1. OUTLINE OF THE EXPERIMENT

LOCATION: Oak manor Farm

YEARS: 1987 to 1990
TREATMENTS: RP (180 kg P_2O_5/ha) and no RP.
Green manures: oilseed radish, buckwheat, faba beans and weeds

PLOT SIZE: 5 X 9m (subplots)

EXPERIMENTAL DESIGN: split plot with RP 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
Summer 90 - Maize

OBSERVATIONS:
1987. Green manure and weed biomass
Percentage of P in green manures
Soil P_{res}, exchangeable K, Ca, Mg and pH
VAM spore counts
1988. Oat yields
VAM infection in oat roots
Root and soil P-ase activity
Soil P_{res}, exchangeable K, Ca, Mg and pH
Nutrients in oat straw and grain (N, P, K, Ca and Mg)
1989. Green manure biomass
Nutrients in green manures (N, P, K, Ca, Mg)
Soil P_{res}, exchangeable K, Ca, Mg and pH
1990 Maize yields
VAM infection
Nutrients in maize leaf tissues (N, P, K, Ca, Mg)

2.2.2.2. DETAILS OF EXPERIMENTAL METHODS

The VAM spores were obtained by the sucrose centrifugation method (Jenkins, 1964) and counted under a dissection microscope. Two composite samples per plot were used for the determinations. The composite samples were obtained from 4 sub-samples per plot.

The other methods used have been previously described in section 2.2.1.2.

2.2.2.3. EXPERIMENTAL PROCEDURES

The experiment was set up in 1987. It was a split plot design with two levels of RP assigned to the main plots: no RP and one rate of RP equivalent to 180 kg P_2O_5/ha. Three green manure crops, i.e. oilseed radish (common), buckwheat (var. Mancan) and faba beans (var. Pride), and a control (weeds only) were assigned to the subplots.

1987

RP was broadcast by hand and ploughed down with a disk at the end of July. The green manure seeds were broadcast by hand, in the first week of August, followed by one pass of a harrow to incorporate the seeds into the ground. The seeding rate for faba beans was 160 kg/ha; buckwheat 80 kg/ha; oilseed radish 20 kg/ha. The green manures were cut down at ground level in mid-October. The fresh biomass was assessed using quadrats of 1.5 X 1.5 m (2 quadrats per plot). Sub-samples were taken for determination of dry weight. The plant material was left on the field over the winter.

1988

In the spring of 1988, the green manures were worked into the soil and oats were planted. Samples for measurement of oat root P-ase activity, VAM infection and soil P-ase activities were taken when the plants reached the heading stage. Grain yield, straw yield and weed biomass were assessed at harvest. The crop was harvested with a combine. The whole area of each plot was harvested. Weeds were sampled before the harvest using two 1 X 1 m quadrats. All plant material was dried at 60 C. Two weeks after harvest, new seedlings of oats started to germinate from grains left over from the previous harvest. When those seedlings were two weeks old, they were sampled for VAM infection and biomass production. P-ase and VAM determinations followed the same methodology as described for Chapter 1.

In the fall of 1988, the same green manures were again planted on the respective plots. Because of the drought. the seedlings did not establish well and the area was left fallow until 1989.

1989

The field remained fallow from the fall of 1988 until July 1989. At the end of July 1989, the green manures were once again planted and cut down in mid September when the biomass production was assessed.

1990

In the spring of 1990, maize was planted by the farmer and grain yields were assessed. Maize cobs were harvested before maturity (percentage of moisture = 64%). Two rows of 5 m per plot were sampled. The number of plants per plot was determined, the fresh weight of cobs taken and sub-samples of cobs were collected and dried at 60 C.

The initial soil analysis is presented in Table 45.

2.2.2.4. STATISTICAL ANALYSIS

ANOVAs were used to test for differences between the two RP treatments, among the four green manure treatments, and the interaction between both factors. A Tukey test (HSD) was used for mean separation in the cases where the ANOVA resulted in significant F values ($p < 0.05$) for the green manure treatments. No *a posteriori* test for mean separation was used when F values were significant for the RP treatments. This procedure was taken because in this case there were only 2 treatments (1 degree of freedom) being tested.

Table 45. Soil properties and their ratings* for the experimental field.

Organic matter (%)	pH	Available P (Bray I)	Soil exchangeable nutrients K	Ca	Mg
		(mg/kg soil)			
5.4 (fair)	7.5	24 (Med-Low)	120 (Medium)	4900 (High)	370 (Medium)

Texture	Bulk density (g/cm^3)	CEC (meq/100g)	Aggregate stability (%)
Silt clay loam	1.18 (High)	14.0 (Good)	59.0 (Excellent)

* Soil samples were taken in October 1987 and analyzed by Woods End Laboratory, Maine.

2.2.3. EFFECTS OF CARBON ADDITION ON NITROGEN FIXATION AND P NUTRITION OF HAIRY VETCH AND FOLLOWING CROP

2.2.3.1. OUTLINE OF THE EXPERIMENT

LOCATION: Oak Manor Farm

YEAR: 1989

TREATMENTS: Oat hulls incorporation: 5 and 10 t/ha and no oat hulls
RP: 180 kg P_2O_5/ha and no RP

PLOT SIZE: 15 X 9m

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

OBSERVATIONS:
ARA (acetylene reduction activity) of hairy vetch
Weed biomass
VAM infection
Soil nitrate
Soil P_{res}, exchangeable K, Ca, Mg and pH
Nutrients in vetch and weed biomass (N, P, K, Ca,Mg)

2.2.3.2. EXPERIMENTAL PROCEDURES

This experiment was set up in May of 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_2O_5) of RP. Treatments were arranged in a split-plot design with 4 replicates. RP levels were assigned to the main plots and oat hulls levels were assigned to the subplots. RP and oat hulls were applied onto the field on May 6 and incorporated on May 15. Oat hulls were surface applied on the plots by a manure spreader and RP was spread by hand. They were both incorporated into the soil with a disk. Hairy vetch (*Vicia villosa* Roth) was planted on May 24. A non N_2-fixing reference crop, sunflower (*Helianthus annus L.*) was planted in 2 X 1 m sub-plots at a density of 40 plants/m^2 in the vetch field so that growth responses of a non N_2-fixing dicotyledonous plant could be compared with those of the N_2-fixing legume.

Soil samples for nitrate determinations were taken on four different dates: June 6, June 9, June 14 and August 7. One composite sample made of from 5 sub-samples per plot was obtained. Samples were taken from the top 20 cm and taken immediately to the laboratory. For the first and third dates, all of the composite samples were analyzed individually; for the other two dates, the samples were combined by treatment. Soil samples for fertility analysis were taken in late September, following the same sampling procedure, and all the composite samples were analyzed individually. Sunflower and vetch biomass were sampled on July 12. Six sunflower plants per plot were taken; vetch was sampled by taking 3 0.5 X 0.5 m quadrats per plot.

Vetch biomass and ARA were assessed on September 13. For the biomass, two 1 X 1 m quadrats per plot were taken. The vetch biomass was separated from the weeds. The fresh biomass was weighed in the field, and smaller sub-samples were taken for moisture determination and for the chemical analysis. Individual plants were taken for the ARA assay. The root system of three plants were incubated in 1000 ml jars with 10% acetylene for 30 min. Gas samples were then stored in 6 ml vacutainers for determination of ethylene by gas chromatography. Two jars per plot and three vacutainers per jar were used.

In the spring of 1990, maize (field corn) was planted and the residual effects of the treatments were evaluated. Soil nitrate levels were measured in the first week after planting. Soil samples were taken at the tassel stage. Percentage of nutrients in maize leaves and VAM infection in maize roots were measured at the 8 leaf stage. For the leaf tissue analysis, the shoots of 6 plants per plot were taken. The tops were chopped in small pieces, homogenized, and a sub-sample taken for the nutrient analysis. For the VAM infection, roots from 5 out of the 6 plants sampled for leaves were dug out. The adhering soil was removed, the roots were washed and chopped in smaller portions, the thickest roots were discarded, and sub-samples were stored in FAA prior to determination of VAM infection.

Maize yields were determined before maturation (cob moisture level approximately 30%). Two rows of 5 m length were sampled per plot and the number of plants per plot determined. The fresh weight of cobs was taken and sub-samples of cobs were collected to be dried at 60 C. Results of soil analyses performed on samples taken from the experimental field in 1987 are shown on Table 46.

Table 46. Soil properties and their ratings* for the experimental field.

Organic matter (%)	pH	Available P (Bray I)	Soil exchangeable nutrients K	Ca	Mg
		mg/kg soil			
5.5 (fair)	7.6	23 (Low)	110 (Med-Low)	5200 (High)	440 (Medium)

Texture	Bulk density (g/cm^3)	CEC (meq/100g)	Aggregate stability (%)
Silt clay Loam	1.15 (High)	15.0 (Good)	48 (Excellent)

* Soil samples were taken in October 1987 and analyzed by Woods End Laboratory, Maine)

2.3. RESULTS

2.3.1. EFFECTS OF THREE TILLAGE/STRAW TREATMENTS ON SOIL PHOSPHORUS AND CROP NUTRITION

PRELIMINARY STUDY (SUMMER OF 1987) AND FIRST CROP (FALL OF 1988).

Barley was grown in the field in 1987. The effects of weeding and addition of bloodmeal on barley yields (see Appendix A for details of this trial) suggest that some nutritional limitations existed in the field (Table 47). The straw left on the field after the harvest of barley in the disk + straw treatment was 2616 kg/ha; on all treatments there were 617 kg of stubble/ha.

The respiration data indicate that the addition of straw tended to decrease the evolution of CO_2 as well as the levels of nitrate (Table 48). The mouldboard treatment increased the production of faba biomass compared to other treatments (Tables 48 and 49). The N_2 fixation variables (ARA and nodule weight) were not affected by the treatments (Table 48).

The data in Table 49 illustrate the positive effect of the mouldboard treatment on the faba beans biomass production. The effects of the tillage treatments were more pronounced on oilseed radish than on faba beans (Table 50). The mouldboard treatment increased the biomass production.

Table 47. Effects of weeding and addition of blood meal on barley grain yield, straw and weed biomass in 1987 (averages of 4 replicates)§.

TREATMENTS	Grain	Straw	Weeds
		kg/ha	
Control	2818b	2606b	584a
Weeding	2500b	2479b	180c
Blood meal	3353a	2897a	206b
F value	3.5+	3.9*	14.6**
C.V. (%)	21.0	13.0	57.3

+, *, ** significant at 0.1, 0.05 and 0.01 probability levels, respectively.
Values followed by the same letter in each column are not significantly different (Tukey test, p<0.05).
§ The details for this trial can be found in Appendix A.

Table 48. Effects of tillage treatments on soil respiration, soil nitrate, and faba bean N_2 fixation in the fall of 1987 (averages of 3 replicates).

TREATMENTS	Soil respiration (mg CO_2 $100g^{-1}$ soil h^{-1}) Aug 20 (20)	Soil respiration Sept 5 (35)	Soil nitrate (mg NO_3 N/ kg soil) Aug 8 (8)	Faba beans Oct 18 (78)¶ ARA§	Faba beans Nodule weight (mg/3 plants)	Faba beans Top fresh weight(g/ 3 plants)
Mouldboard	4.4	5.3	17.0	3.6	38.7	128.3a§§
Disk	6.7	10.2	15.7	4.9	30.5	118.3a
Disk+straw	2.9	3.7	8.0	4.6	28.4	108.3a
F value	1.2	4.5+	4.79+	0.8	0.8	5.1*
C.V.(%)	64.1	43.1	28.3	30.5	32.6	6.45

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

Values followed by the same letter in each column are not significantly different (Tukey test, $p<0.05$).

§§ In this case, the treatment effect was significant in the ANOVA but HSD did not separate the means.

§ μmol C_2H_4 $plant^{-1}$ h^{-1}

¶ the numbers in parentheses below the dates are the number of days after the treatments were imposed.

Table 49. Effects of tillage treatments on the biomass production of faba beans in the fall of 1987 (averages of 3 replicates).

TREATMENTS	# of faba plants/quadrat		Faba top length (cm)	Weeds fresh biomass (t/ha)	Faba fresh biomass (t/ha)	
	Sept 5	Oct 18	Oct 18	Sept 5	Sept 5	Oct 18
Mouldboard	8.0b	6.2	94.0a	1.8	5.7a	20.0
Disk	11.2a	7.0	84.2ab	3.2	4.2b	14.7
Disk+straw	8.2ab	5.0	82.7b	3.8	3.5b	13.1
F value	8.58*	4.05+	7.64*	5.4+	33.0**	1.5
C.V.(%)	11.5	14.3	4.4	26.0	7.8	32.6

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

Table 50. Effects of tillage treatments on the biomass production of oilseed radish in the fall of 1987 (averages of 3 replicates).

TREATMENTS	# of oilseed radish/quadrat	Oilseed radish top length (cm)	Oilseed radish fresh biomass (t/ha)		Weeds fresh biomass (t/ha)
	Sept 5	Oct 18	Sept 5	Oct 18	Sept 5
Mouldboard	32.7	102.0a	8.5a	24.0a	0.3
Disk	34.7	83.3ab	4.0b	18.5ab	0.7
Disk+straw	25.7	73.3b	3.7b	13.1 b	0.6
F value	0.9	10.0*	34.5**	8.16*	3.63
C.V.(%)	27.0	9.25	14.8	17.7	93.9

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

SECOND CROP (1988).

No interaction between tillage/straw treatments and fertilizers were found for any dependent variable (highest F value for interaction =1.99 - probability level = 0.19), therefore, only the single effects are presented. The disk+straw treatment increased soil P_{res} in 1988. Soil nutrients other than P were not affected by the tillage treatments (Table 51). As occurred in Chapter 1, no significant effect of tillage or fertilizer treatments were detected when soil P was extracted by sodium bicarbonate. Grain yields were highest under mouldboard and disk + straw treatments (Table 52). The percentage of P in maize grains (Table 53) also tended to be highest under the disk + straw treatment. The disk + straw treatment tended increase the soil P-ase activity (Table 54). Root P-ase activities were not affected by any of the fertilizer treatments.

Four variables were affected by the fertilizer treatments. Compost and super-P increased soil P_{res} compared to control (Table 51); maize biomass at the 5 leaf stage tended to be highest under compost (Table 52); the percentage of P in maize grains was significantly higher under compost than in the control (Table 53) and the VAM infection (arbuscules) was higher under compost in comparison to super-P (Table 55).

No effects of either fertilizer or tillage treatments on the yields of field peas were obtained (Table 56). The yields were very low, probably due to the drought occurred on that year (Appendix B). Because of that, other measurements were not taken for this crop.

Table 51. Effects of tillage and fertilizer treatments (1987) on soil nutrients in 1988 (averages of 3 replicates).

TILLAGE TREATMENTS	SOIL NUTRIENTS (mg/kg soil)				
	P_{bicarb}	P_{res}	K	Mg	Ca
Mouldboard	6.0	11.0b	82.6	193.5	3242
Disk	5.8	10.1b	74.6	195.5	3395
Disk + straw	6.3	15.4a	73.1	283.9	3408
F value	1.75	103**	0.47	2.52	1.24
FERTILIZER TREATMENTS					
Control	5.7	10.6b	77.2	229.2	3357
Super-P	5.8	12.6ab	74.5	220.4	3382
RP	6.0	11.5b	78.9	217.3	3421
Compost	6.8	13.9a	76.4	230.22	3234
F value	3.01+	3.92*	0.43	0.12	1.04
C.V.(%)	17.9	14.3	10.7	25.2	7.1

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

Table 52. Effects of tillage and fertilizer treatments on maize biomass in the 5-leaf stage and grain yields (averages of 3 replicates).

TILLAGE TREATMENTS	Maize fresh biomass (g/2 plants)	Grain yield (kg/ha)
Mouldboard	35.8	5785a
Disk	39.9	4909b
Disk + straw	45.4	5546ab
F value	0.8	20.2**
FERTILIZER TREATMENTS		
Control	38.6ab	5475
Super-P	40.5ab	5574
RP	34.7b	4834
Compost	47.8a	5778
F value	3.3*	2.0
C.V.(%)	22.7	16.1

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

Table 53. Effects of tillage and fertilizer treatments on the percentage of nutrients in maize grain (averages of 3 replicates)

TILLAGE TREATMENTS	% NUTRIENTS IN MAIZE GRAIN N	P	K	Ca	Mg
Mouldboard	1 39	0.22	0.32b	0.006	0.10
Disk	1.38	0.22	0.33ab	0.004	0.09
Disk + straw	1 42	0.24	0.34a	0.005	0.09
F value	0.42	6.28+	2.71	0.48	0.90
FERTILIZER TREATMENTS					
Control	1.37	0.22b	0.33ab	0. 04ab	0.092
Super-P	1.37	0.23ab	0.33ab	0. 02b	0.101
RP	1.41	0.22b	0 32b	0. 05ab	0.092
Compost	1.44	0.25a	0.35a	0.009a	0.094
F value	0.77	4.39*	2.88+	3.00*	2.24
C.V.(%)	8.6	7.3	5.9	91.2	14.0

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

Table 54. Effects of tillage and fertilizer treatments on maize root and soil P-ase activity at the 5 leaf stage (averages of 3 replicates).

	Root P-ase activity (µg PNP g root^{-1} h^{-1})	Soil P-ase activity (µg PNP g soil^{-1} h^{-1})
Mouldboard	2909	302.0
Disk	2958	286.2
Disk + straw	3110	364.6
F value	1.21	4.74+
FERTILIZER TREATMENTS		
Control	2817	331.0
Super-P	3003	321.0
RP	3093	295.3
Compost	3056	323.1
F value	2.06	1.50
C.V.(%)	8.5	12.0

+, significant at the 0.1, probability level.

Table 55. Effects of tillage and fertilizer treatments on the VAM infection of maize plants (averages of 3 replicates).

TILLAGE TREATMENTS	% Arbuscules	% No-infection
Mouldboard	29.5	62.5
Disk	39.1	54.9
Straw	34.9	60.2
F value	2.02	0.76
FERTILIZER TREATMENTS		
Control	33.8ab	61.1
Super-P	27.0b	65.9
RP	37.0ab	56.4
Compost	37.4a	56.6
F value	4.72*	2.97
C.V.(%)	15.4	11.6

* significant at the 0.05 probability level.
Values followed by the same letter in each column are not significantly different (Tukey test, p<0.05).

Table 56. Effects of tillage and fertilizer treatments on field peas in the fall of 1987 (averages of 3 replicates).

TILLAGE TREATMENTS	FIELD PEAS Weeds (kg/ha)	Grain yield (kg/ha)
Mouldboard	362	849
Disk	337	728
Disk + straw	261	673
F value	2.64	1.41
FERTILIZER TREATMENTS		
Control	322	768
Super-P	358	745
RP	306	762
Compost	294	724
F value	1.51	0.08
C.V.(%)	21.0	28.1

No significant F values were found.

THIRD CROP (1989).

No effects of the treatments were observed on nutrient uptake by oats in 1989 (Table 57). Soil P_{res} levels were still numerically higher on the disk +straw treatment, but the differences were non-significant (Table 58). The disk + straw treatment increased the biomass of oat plants at the heading stage (Table 58) but the grain yields were not affected by the treatments. All the other variables studied were not affected by the treatments.

Similarly, on the other half of the field, where winter wheat undersown with clover was growing, no effects of the tillage treatments were observed on the nutrient uptake by both winter wheat and clover (Table 59 and 60).

FOURTH CROP (1990).

The tillage treatments appeared to have some effect on the production of clover in 1990 (Table 61). The mouldboard treatment and the disk+straw treatment increased the production of biomass ($p<0.10$). The percentage of Mg was higher under the disk+straw treatment than under the others. Soil P_{res} was numerically higher under the disk+straw treatment as occurred in the previous years.

Composite soil samples were taken at the end at the completion of the experiment. Soil pH in the disk + straw treatment was 0.4 units lower than in the mouldboard and 0.2 units lower than in the disk treatment (Table 62).

Table 57. Effects tillage treatments on nutrient content in oat leaves and grains in 1989 (averages of 3 replicates).

TREATMENTS	N	P	K	Ca	Mg
		% Nutrients in oat leaves (heading)			
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 value	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			
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 value	0.50	4.24+	1.88	0.40	0.40
C.V. (%)	2.6	2.1	3.4	6.4	5.0

+ significant at the 0.1 probability level.

Table 58. Effects of tillage treatments on soil and plant variables in 1989 (averages of 3 replicates)

TREATMENTS	1989 - OATS					
	Soil P_{res} (mg P/kg soil)	Soil P-ase(μg PNP g soil^{-1} h^{-1})	Root P-ase(μg PNP g root^{-1} h^{-1})	Shoot biomass heading (g/plant)	Arbuscules (%)	Grain yield (kg/ha)
Mouldboard	15.2	201.0	413.0	2.3 b	3.0	2039
Disk	12.2	186.2	451.6	2.0 b	6.4	2112
Disk + straw	17.3	209.0	400.0	2.8 a	7.3	2233
F value	2.63	0.96	0.12	19.75**	3.76	0.53
C.V.(%)	18.2	10.4	31.3	10.9	42.0	10.9

** significant at the 0.01 probability level.
Values followed by the same letter in each column are not significantly different (Tukey test, p<0.05).

Table 59. Effects of tillage treatments on nutrient content of winter wheat leaves at heading and in grains in 1989 (averages of three replicates).

TREATMENTS	N	P	K	Ca	Mg
	% Nutrients in winter wheat leaves (heading stage)				
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	1.7[illegible]	0.78	0.21
F value	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				
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 value	0.54	0.11	1.06	1.86	0.76
C.V.(%)	3.1	7.3	5.6	9.7	3.6

All F values are non-significant

Table 60. Effects of tillage treatments on nutrient content of clover in 1989 (averages of 3 replicates).

TREATMENTS	N	P	K	Ca	Mg
	% Nutrients in clover leaves				
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 value	1.27	1.16	1.02	3.50	1.89
C.V.(%)	8.6	6.3	3.4	8.7	6.0

All F values are non-significant.

Table 61. Effects of tillage treatments on soil P and on the production of biomass and percentage of nutrient in clover on strip B in 1990 (averages of 3 replicates).

TREATMENTS	1990 - Clover						
	Soil P_{res} (mg P/kg soil)	Dry weight (kg/ha)	% N	% P	% K	% Ca	% Mg
Mouldboard	6.0	8873	2.20	0.21	2.62	1.43	0.32b
Disk	7.3	6622	2.45	0.24	2.30	1.45	0.31b
Disk + straw	8.2	8345	2.53	0.30	2.66	1.66	0.37a
F value	1.05	8.50^{+}	1.58	1.62	0.90	1.20	43.6^{**}
C.V.(%)	26.2	10.9	9.8	23.4	13.7	13.1	2.7

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

Table 62. Soi' exchangeable nutrients in 1990 (results from one composite sample).

TREATMENTS	Soil exchangeable nutrients (mg/kg soil) K	Ca	Mg	Available P_{bicarb} (mg/kg soil)	Soil pH
Mouldboard	59 2	3700	175	4	7.9
Disk	52.3	3600	174	5	7.7
Disk + Straw	53 5	3000	218	3	7.5

2.3.2. EFFECTS OF GREEN MANURING AND ROCK PHOSPHATE ON PHOSPHORUS NUTRITION OF DIFFERENT CROPS

The amount of biomass produced by the green manures in 1987 was not affected by the application of RP (Table 63). Oilseed radish produced the highest amount of biomass. There was no effect of either previous green manures or RP application on the amount of VAM spores in the soil measured in 1988. The highest values numerically were found after one mycorrhizal (faba) and after one non-mycorrhizal (buckwheat) species. RP tended to increase the percentage of P in the green manure biomass (Table 63).

Soil P_{res} and soil P_{bicarb} were significantly correlated (r=0.92**, data not shown). As observed in Chapter 1, the effect of treatments (in this case RP) on soil P_{res} levels was only detected when the resin was the extractant. RP applied in 1987 increased soil P_{res} measured in 1988 (Figure 29). RP decreased the amount of soil Mg in 1988. There was no effect of the green manures on the soil variables examined in 1988, i.e., P, K, Ca, Mg and pH (Table 64). Application of RP in 1987 increased soil P_{res} for all plots in comparison to plots without RP over the subsequent 3 years (Figure 29). The absolute levels of soil P_{res} declined over the years. In untreated plots, soil P_{res} declined continuously. In RP treated plots, P increased above 1987 levels in 1988 but fell below those levels in 1989 and 1990.

There were no differences in the percentage of nutrients in oat grains with or without RP application (Table 65). There was a response of oats to the previous green manure. An increase in N and P in oat grains occurred following faba beans (Table 65). An increase in Ca and Mg in oat straw was found following buckwheat (Table 66). Buckwheat is reported to be a good Ca feeder (Bauer, 1921; Truog, 1922; Bekele et al., 1983) and may have contributed to the Ca absorption by oats. Significant effects of RP on total N and P in oat straw were observed (Table 66).

Table 63. Biomass production and percentage of P in green manures, and number of VAM spores in the soil cultivated with those green manures in 1987 (averages of 4 replicates).

	Green manure biomass (t/ha)		% P in biomass	Number of VAM spores/10g soil
GREEN MANURE TREATMENTS	Sept 4	Oct 19	Oct 19	
Faba	nd§	1.3b	0.33	17.0
Buckwheat	4.2a	2.7b	0.27	30.5
Oilseed radish	2.5b	4.6a	0.28	16.5
Weeds	3.1ab	2.6b	0.28	31.7
F value	7.00**	9.15**	6.27**	1.49
RP TREATMENTS				
+RP	3.4	2.7	0.30	28.2
-RP	3.0	2.9	0.28	18.3
F value	0.4	0.1	6.52+	0.82
C.V.(%)	27.7	42.8	9.8	26.4

+, ** significant at 0.1, and 0.01 probability levels, respectively.
Values followed by the same letter in each column are not significantly different (Tukey test, $p<0.05$).
§ plants were too small to be sampled.

Table 64. Effect of RP applied in 1987 and green manures on soil nutrients in the fall of 1988 (averages of 4 replicates).

	Soil nutrients (mg/kg soil)				
1987 GREEN MANURE TREATMENTS	P_{bicarb}	K	Ca	Mg	pH
Faba	10.1	217.1	3302	263.9	7.3
Buckwheat	10.6	179.7	3286	249.0	7.3
Oilseed radish	10.5	219.0	3277	256.7	7.2
Weeds	9.5	195.5	3261	297.2	7.3
F value	0.81	0.98	0.21	2.45+	0.14
1987 RP TREATMENTS					
+ RP	10.8	226.4	3257.2	261.3a	7.2
- RP	9.6	179.2	3306.5	272.1a	7.3
F value	1.22	2.96	0.20	9.75*§	0.70
C.V.(%)	15.5	26.3	3.2	14.3	2.1

+, * significant at 0.1 and 0.05 probability levels, respectively.
Values followed by the same letter in each column are not significantly different (Tukey test, p<0.05).
§For this particular comparison (df=1) Tukey test was not used.

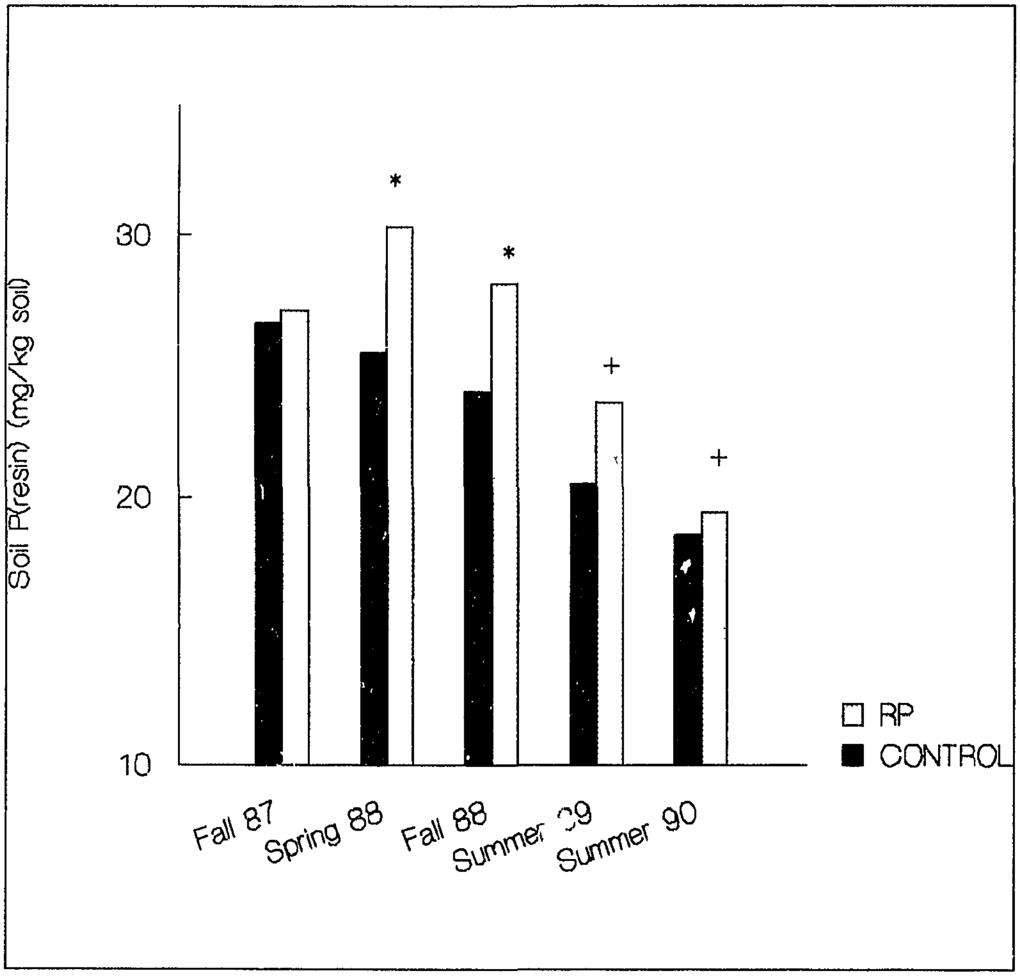


Figure 29. Effect of RP applied in 1987 on soil P_{res} (averages of 4 replicates and 4 green manures).

+,* significant F values at 0.1 and 0.05 probability levels, respectively.

Table 65. Effect of RP and green manures in 1987 on the percentage of nutrients in oat grain in 1988 (averages of 4 replicates).

1987 GREEN MANURE TREATMENTS	% Nutrients in oats grain				
	N	P	K	Ca	Mg
Faba	2.38a	0.44a	0.58	0.13	0.12
Buckwheat	2.37a	0.38b	0.56	0.15	0.12
Oilseed radish	2.33a	0.40b	0.56	0.13	0.12
Weeds	2.35a	0.41ab	0.56	0.13	0.12
F value	3.62*	6.54**	0.23	0.66	0.86
1987 RP TREATMENTS					
+ RP	2.35	0.40	0.56	0.14	0.12
- RP	2.36	0.41	0.56	0.13	0.12
F value	0.03	0.37	0.41	0.70	0.02
C.V.(%)	1.4	5.9	8.9	28.6	5.3

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

Table 66. Effect of RP and green manures in 1987 on nutrients in oat straw in 1988 (averages of 4 replicates).

1987 GREEN MANURE TREATMENTS	N	P	K	Ca	Mg
	% Nutrients in oats straw				
Faba	1.27a	0.20	2.43	0.74b	0.24b
Buckwheat	1.27a	0.18	2.65	1.11a	0.32a
Oilseed	1.10b	0.18	2.64	0.89ab	0.26b
Weeds	1.19ab	0.18	2.69	0.89ab	0.26b
F value	4.98**	0.88	0.59	3.49*	5.87**
1987 RP TREATMENTS					
+ RP	1.21	0.19	2.68	0.91	0.27
- RP	1.20	0.19	2.52	0.91	0.27
F value	0.03	0.02	1.28	0.00	0.06
C.V.(%)	8.5	15.0	16.4	25.2	15.2
1987 GREEN MANURE TREATMENTS					
	Total nutrients in oats straw (kg/ha)				
Faba	9.2	1.5	18.1	5.4b	1.8b
Buckwheat	10.8	1.6	22.4	9.7a	2.2ab
Oilseed radish	9.1	1.5	22.6	7.5ab	2.8a
Weeds	8.3	1.3	18.6	6.2b	1.9b
F value	1.18	0.70	0.82	4.85**	4.32*
1987 RP TREATMENTS					
+ RP	9.9	1.5	22.2	7.5	2.3
- RP	8.8	1.4	18.7	6.8	2.0
F value§	12.5*	32.5*	2.44	0.92	0.60
C.V.(%)	28.3	28.1	36.6	33.3	30.0

*, ** significant at 0.05 and 0.01 probability levels, respectively.
Values followed by the same letter in each column are not significantly different (Tukey test, $p<0.05$). § For this particular comparison, Tukey test was not used.

There was no effect of the green manure crop (1987) on the VAM infection of the succeeding oat crop in 1988 (Table 67). The percentage of arbuscules was very low, probably because of the drought in 1988 (Appendix B). Supporting evidence that drought was involved in the low VAM infection, was that the oats remaining on the field after harvest sprouted after the drought had ended and the values for percentage of arbuscules were higher at that time. Weeds tended to decrease the percentage of oat roots with no VAM infection. The oat yields were very low and neither the green manures nor the RP had any effect on the crop performance (Table 67).

In 1989, buckwheat produced the highest biomass and the percentage of P was higher than in 1987. No effects of RP was observed on the production of biomass (Table 68).

In 1990, soil P_{res} was still elevated as a result of the RP applied in 1987 ($p<0.10$) (Table 69). Buckwheat decreased the percentage of P in maize leaves (Table 70) and final yield (Table 71). The percentage of maize roots with no VAM infection tended to be higher under non-VAM green manures (buckwheat and oilseed radish) and lower under the weeds (Table 69).

Composite soil samples were taken at the end of the experiment. The oilseed radish treatment seems to have decreased soil pH compared to other treatments (Table 72).

Table 67. Effect of the previous green manures on the VAM infection in oats crop and in oats sprouted after harvest in 1988 (averages of 4 replicates).

	OATS CROP					OATS SPROUTED AFTER HARVEST		
1987 GREEN MANURE TREATMENTS	Arbuscules (%)	No infection (%)	Grain (kg/ha)	Straw (kg/ha)	Weeds (kg/ha)	Arbuscules (%)	No infection (%)	Dry weight (mg/plant)
Faba	5.2	62.1	486	729	556	10.6	76.8	97.5
Buckwheat	5.0	63.0	305	851	908	13.7	74.4	86.2
Oilseed radish	3.2	64.0	484	837	770	14.7	72.5	82.5
Weeds	5.8	57.1	418	695	727	15.3	68.3	106.2
F value	1.2	0.3	0.36	1.38	0.89	1.1	2.5+	2.4+
1987 RP TREATMENTS								
+ RP	4.2	62.5	442	820	779	12.9	75.1	82.5
- RP	5.5	60.6	405	764	721	14.3	71.0	103.7
F value	2.7	4.01	0.25	2.51	0.81	0.36	1.52	1.41
C.V.(%)	68.0	15.7	41.1	25.7	58.1	41.5	8.8	21.3

+ significant at the 0.1 probability level.

Table 68. Production of dry matter and percentage of nutrients in the green manures in 1989 (averages of 4 replicates).

GREEN MANURE TREATMENTS§	Dry weight (kg/ha)	% of nutrients				
		N	P	K	Ca	Mg
Faba	615 c	3.9a	0.4a	1.6b	1.1b	0.43b
Buckwheat	2861 a	1.7b	0.3b	2.2b	2.1a	0.58ab
Oilseed radish	1810 b	2.0b	0.3b	3.8a	2.6a	0.72a
Weeds	1813 b	1.8b	0.3a	4.3a	2.5a	0.73a
F value	43.2**	64.1**	8.9**	15.0**	24.4**	5.88**
1987 RP TREATMENTS						
+ RP	1874	2.4	0.3	2.9	2.1	0.61
- RP	1674	2.4	0.3	2.9	2.0	0.60
F value	0.45	0.2	0.1	0.0	0.2	0.04
C.V.(%)	22.5	15.1	11.2	30.3	19.0	26.3

** significant at the 0.01 probability level.

Values followed by the same letter in each column are not significatly different (Tukey test, $p<0.05$).

§ Green manures planted in 1987 and repeated in 1989; RP applied only in 1987.

Table 69. Effects of previous green manures and RP on soil P_{res} and VAM infection in maize roots in 1990 (averages of 4 replicates).

GREEN MANURE TREATMENTS§	Soil P_{res} (mg P/kg soil)	% of VAM infection	
		Arbuscules	No infection
Faba	20.3	46.1	32.1a
Buckwheat	16.8	43.0	42.5a
Oilseed radish	19.1	40.4	39.5a
Weeds	19.8	48.9	29.8a
F value	0.61	0.83	3.34*
1987 RP TREATMENTS			
+ RP	19.4	45.2	34.1
- RP	18.6	11.1	37.7
F value	5.97+	0.03	0.65
C.V.(%)	29.5	25.0	25.8

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

Values followed by the same letter in each column are not significantly different (Tukey test, $p<0.05$).

§ Green manures planted in 1987 and repeated in 1989; RP applied only in 1987.

Table 70. Effects of previous green manures and RP on the percentage of nutrients in maize leaves at the tassel stage in 1990 (averages of 4 replicates).

GREEN MANURE TREATMENTS§	% Nutrients in maize leaves				
	N	P	K	Ca	Mg
Faba	3.11	0.38	2.04	0.38	0.21
Buckwheat	3.04	0.35	2.05	0.37	0.20
Oilseed radish	3.34	0.38	2.07	0.38	0.21
Weeds	2.05	0.39	2.14	0.37	0.22
F value	1.13	2.48+	0.45	0.13	0.67
1987 RP TREATMENTS					
+ RP	3.10	0.38	2.12	0.38	0.21
- RP	3.06	0.38	2.03	0.37	0.21
F value	0.03	1.65	0.47	0.18	1.06
C.V.(%)	17.3	8.7	9.9	13.3	13.8

+ significant at the 0.1 probability level.

§ Green manures planted in 1987 and repeated in 1989; RP applied only in 1987.

Table 71. Effects of previous green manures on yield components of maize in 1990.

GREEN MANURE TREATMENTS§	Maize population (X 1000 plants/ ha)	Maize yield (dry cobs)♠	
		t/ha	g/plant
Faba	34.1a	3.29a	96.7
Buckwheat	29.5b	2.60 b	88.0
Oilseed	37.4a	3.47a	93.2
Weeds	35.8a	3.32a	92.9
F value	11.82**	8.51**	1.02
1987 RP TREATMENTS			
+ RP	34.22	3.20	93.3
- RP	34.22	3.15	92.1
F value	0.00	0.09	0.03
C.V.(%)	8.2	11.9	10.7

** significant at the 0.01 probability level.

Values followed by the same letter in each column are not significantly different (Tukey test, $p<0.05$).

♠ Yields were determined before maturation; cob moisture level approximately 30%.

§ Green manures planted in 1987 and repeated in 1989; RP applied only in 1987.

Table 72. Soil exchangeable nutrients in 1990 (results from one composite sample).

TREATMENTS		Soil exchangeable nutrients (mg/kg soil)			Available P_{bicarb}	
Green manure	RP	K	Ca	Mg		Soil pH
Faba	+	111	2000	248	13	7.4
	-	94	2300	266	10	7.4
Buckwheat	+	81	2100	245	9	7.7
	_	95	2300	217	11	7.5
Oilseed radish	+	107	2200	278	12	7.2
	_	102	2900	228	11	7.4
Weeds	+	106	2750	252	10	7.6
	_	113	2050	255	12	7.8

2.3.3. EFFECTS OF CARBON ADDITION ON NITROGEN FIXATION AND PHOSPHORUS NUTRITION OF HAIRY VETCH AND FOLLOWING CROPS

Incorporation of oat hulls in mid summer 1989 resulted in lower soil nitrate under vetch (Figure 30), higher N_2 fixation rates, more biomass of vetch and fewer weeds (Figure 31) than in plots without oat hulls. No effects of the treatments on other soil nutrients were noted (Table 73). The percentage of nutrients in vetch was not significantly affected by the addition of oat hulls, except for Mg (Table 76). The percentage of N tended to be higher and Ca lower under 10 t oat hulls/ha than in the control. The percentage of Mg was significantly lower under 10 t/ha. The total nutrients accumulated by the vetch biomass were approximately twofold higher under both levels of oat hulls than with no oat hulls (Table 77).

No effects of oat hulls (10 t/ha) on nutrient accumulation in sunflower (non N_2-fixing crop) was observed. In some cases, the numerical value was lower under oat hulls (Table 78). A negative relationship between soil nitrate and percentage of N in vetch was found (Figure 32). RP addition did not affect the nutrition of vetch except by decreasing the amount of Mg absorbed by vetch (Table 77).

In 1990, neither oat hulls nor RP had an effect on soil P_{res} (Table 80). Similarly, no effects on plant nutrient levels were observed (Table 81). The VAM infection variables indicated a high level of infection (arbuscules) for all treatments (Table 80). The root P-ase activity tended to be lower in the control (no oat hulls) treatment. There was no indication of any effects of the treatments on the yield components (Table 82).

Analyses of composite soil samples taken in 1990 indicate that there were no large differences between treatments (Table 83).

Table 73. Effects of oat hulls and RP on soil nutrients (averages of 4 replicates).

	Soil nutrients (mg/kg soil)				
	P_{bicarb}	K	Ca	Mg	pH
OAT HULLS TREATMENTS (t/ha)					
0	6.5	116.7	2619	245.0	7.3
5	6.1	114.7	2501	234.1	7.4
10	6.1	128.5	2453	251.6	7.2
F value	0.57	0.51	2.59	0.31	0.61
RP TREATMENTS					
+ RP	6.2	117.7	2946	247.8	7.3
- RP	6.3	122.2	2553	239.3	7.3
F value	0.07	0.13	1.55	0.68	0.02
C.V.(%)	24.3	25.6	4.5	10.3	2.2

All F values are non-significant

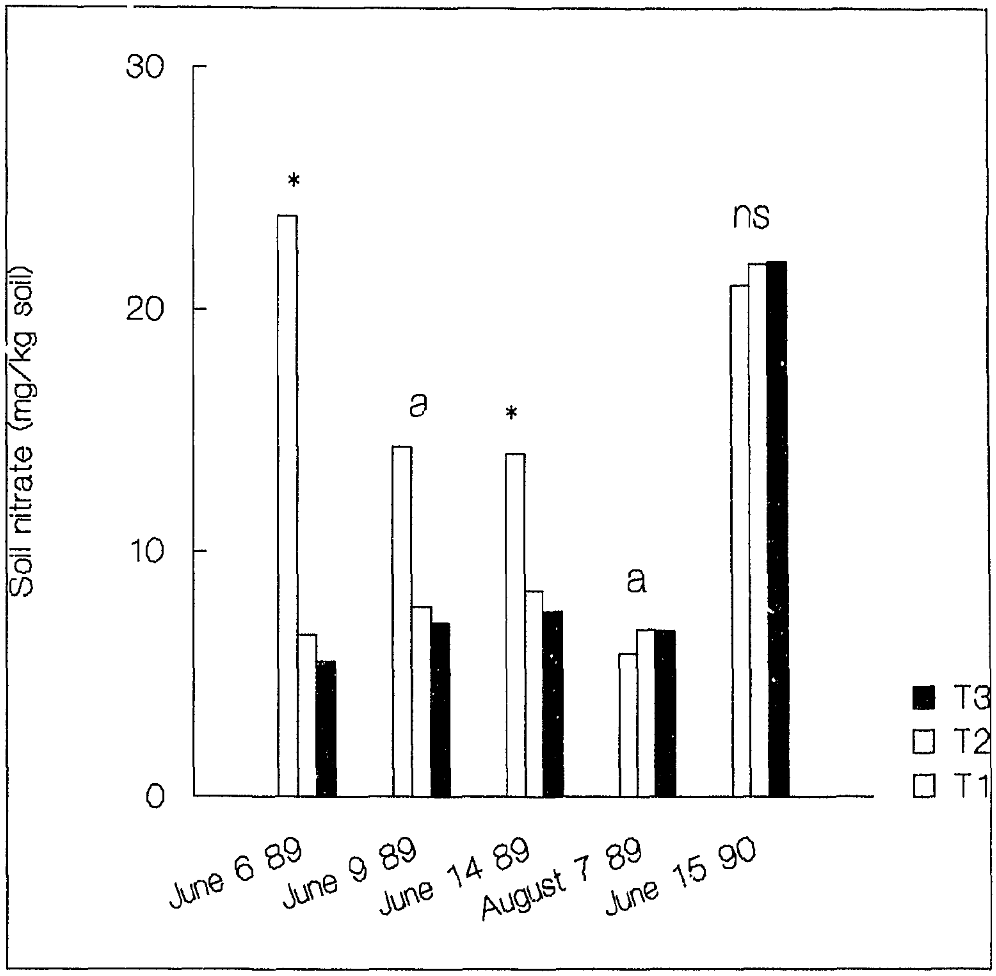


Figure 30. Effect of oat hulls on soil nitrate levels (June 6 1989, June 14 1989 and June 15 1990: values are averages of 4 replicates and 2 levels of RP; others are composite samples from the oat hull treatments (averages of 2 RP levels).

T1: control; T2: 5 t oat hulls/ha; T3: 10 t oat hulls/ha.
*: Different from control (Tukey test, $p<0.05$); NS non-significant.
a: composite samples were used for the measurements (no statistics available).

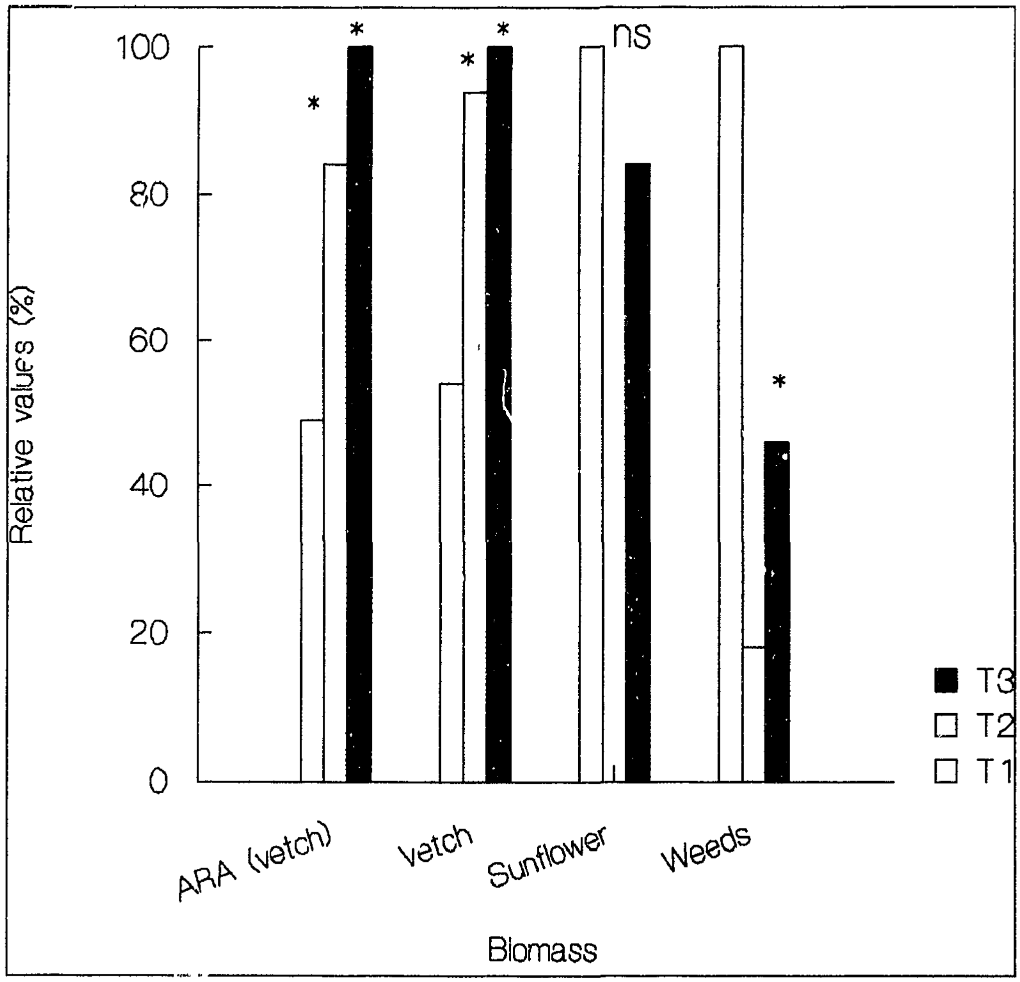


Figure 31. Effect of oat hulls on nitrogenase activity (acetylene reduction), and vetch, sunflower and weed biomass production (averages of 4 replicates). Relative values are based on the highest value for each variable being 100%.

T1: control; T2: 5 t oat hulls/ha; T3: 10 t oat hulls/ha.
*: Different from control (Tukey test, $p<0.05$); NS non-significant.

Table 74 Effects of oat hulls and RP on the production of biomass of vetch and sunflower (averages of 4 replicates).

	Dry biomass (kg/ha)		
	Sunflower	Vetch	
	July 12	July 12	September 13
OAT HULLS TREATMENTS(t/ha)			
0	2486	1503	1711b
5	-	1265	2958a
10	1957	1603	3122a
F value	1.91	2.06	7.59 **
RP TREATMENTS			
+RP	2250.6	1546.8	2490 5
-RP	2192.4	1367.5	2704 2
F value	0.04	1.31	1.62
C V.(%)	26.7	26 4	15 8

** significant at the 0.01 probability level.

Values followed by the same letter in each column are not significantly different (Tukey test, p<0.05).

Table 75. Effects of oat hulls and RP on the percentage of nutrients in hairy vetch on July 12 (averages of 4 replicates).

	% Nutrients in vetch biomass (July 12)				
	N	P	K	Ca	Mg
OAT HULLS TREATMENTS(t/ha)					
0	4.77	0.44	3.05	1.49	0.32
5	4.97	0.44	3.25	1.47	0.31
10	4.95	0.45	3.47	1.46	0.33
F value	0.86	0.19	1.84	0.16	1.27
RP TREATMENTS					
+RP	4.96	0.45	3.30	1.47	0.33
-RP	4.86	0.43	3.20	1.48	0.31
F value	0.45	0.67	0.03	0.06	1.18
C.V.(%)	9.3	10.1	17.6	7.9	10.6

All F values are non-significant.

Table 76. Effects of oat hulls and RP on the percentage of nutrients in hairy vetch on September 13 (averages of 4 replicates).

	% Nutrients in vetch biomass (September 13)				
OAT HULLS TREATMENTS (t/ha)	N	P	K	Ca	Mg
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**
RP TREATMENTS					
+ RP	4.65	0.40	2.92	1.70	0.30
- RP	4.47	0.37	2.90	1.65	0.32
F value	3.09	1.07	0.01	0.14	1.36
C.V.(%)	5.6	15.6	19.7	18.3	12.4

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

Table 77. Effects of oat hulls and RP on the accumulation of nutrients in hairy vetch on July and September (averages of 4 replicates).

	Nutrients accumulated in vetch biomass (kg/ha)									
	N		P		K		Ca		Mg	
	July	Sept	July	Sept	July	Sept	July	Sept	July	Sept
OAT HULLS TREATMENTS (t/ha)										
0	73.1	74.7b	6.6	6.1b	45.5	47.9b	22.2	27.9b	4.8	6.2
5	63.67	134.8a	5.6	11.4a	41.6	88.5a	18.5	52.9a	3.9	8.6
10	78.7	150.8a	7.2	12.9a	55.4	90.9a	23.8	45.6a	5.3	8.4
F value	1.06	8.12*	1.45	9.34**	2.12	4.14+	3.01	6.28*	2.54	2.63
RP TREATMENTS										
+RP	77.4	117.5	7.0	10.1	50.3	74.8	22.8	41.7	5.1	7.1b
-RP	62.2	122.7	6.0	10.1	44.8	76.8	20.2	44.4	4.2	8.4a
F value	13.9	0.32	1.74	0.00	1.57	0.06	0.99	2.00	2.66	9.01**
C.V.(%)	32.1	18.7	28.0	23.2	22.6	26.8	28.9	13.3	27.8	13.2

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

Table 78. Effects of oat hulls and RP on nutrient uptake by sunflower (averages of 4 replicates).

	TOTAL NUTRIENTS IN SUNFLOWER - kg/ha				
	N	P	K	Ca	Mg
OAT HULLS TREATMENTS♠ (t/ha)					
0	48.1	7.2	80.9	53.0	15.4
10	35.6	6.6	82.5	44.2	10.8
F value	5 43+	0.37	0.01	0.23	3.95
RP TREATMENTS					
+ RP	40.8	6.8	78.8	46.2	12.5
- RP	42.9	7.0	84.6	50.8	13.8
F value	0.15	0.03	0.36	2.16	0.16
C.V.(%)	26.9	27.7	23.7	35.7	48.3

♠ Sunflower was only cultivated on two rates of oat hulls.
+ significant at the 0.1 probability level.

Table 79. Total nutrients in oat hulls (kg/ha). Values are averages of 2 oat hull sub-samples.

TREATMENTS (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

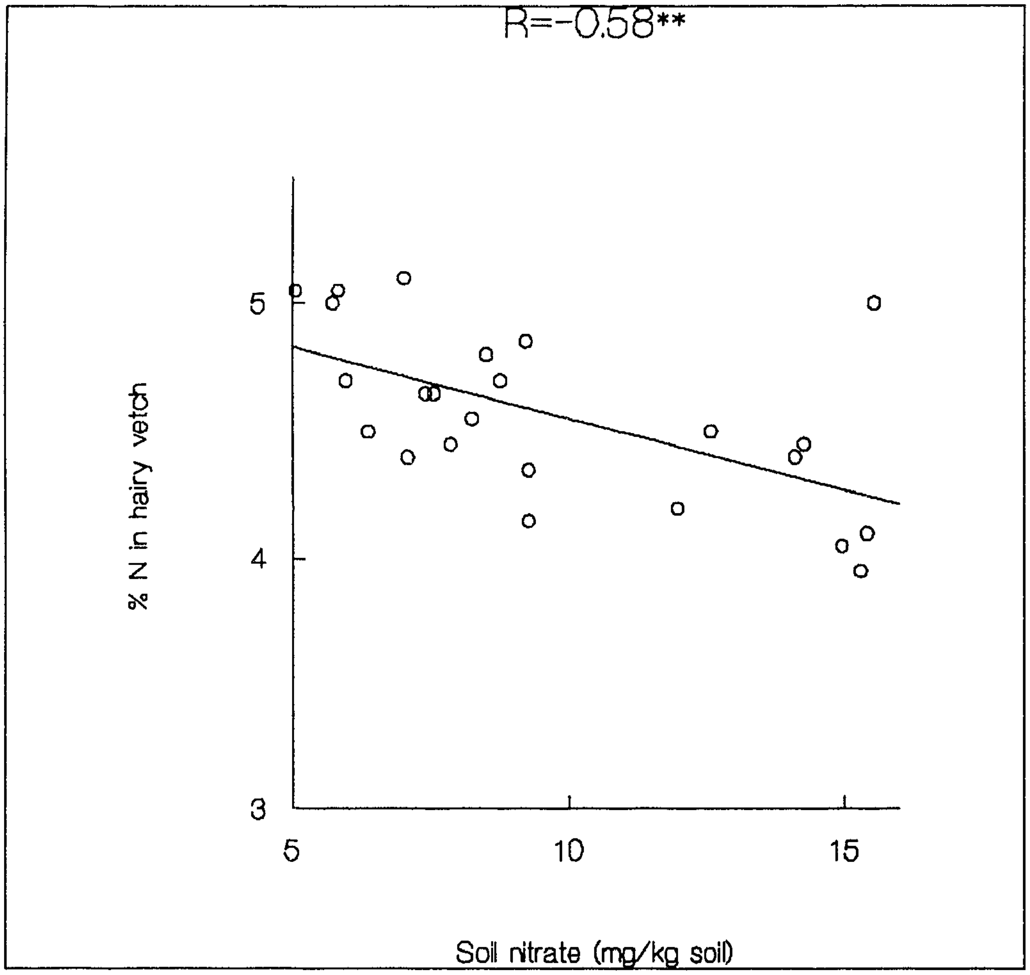


Figure 32. Relation between percentage of nitrogen in vetch tissue and soil nitrate levels (n=24).

Table 80. Effects of oat hulls and RP on soil P_{res}, maize root P-ase activity and VAM infection in maize roots in 1990 (averages of 4 replicates).

	Soil P_{res} (mg/kg)	Maize root P-ase (µg PNP g $root^{-1}$ h^{-1})	% Arbuscules
OAT HULLS TREATMENTS (t/ha)			
0	15.4	1345 a	75.1
5	17.7	1452 a	74.6
10	16.0	1643 a	66.4
F value	0.26	4.85*	2.38
RP TREATMENTS			
+RP	17.0	1399	72.2
-RP	15.7	1545	71.2
F value	0.40	0.80	0.16
C.V.(%)	30.1	30.6	13.5

* significant at the 0.1 probability level.

Values followed by the same letter in each column are not significatly different (Tukey test, p<0.05).

Table 81. Effects of oat hulls and RP on the percentage of nutrients in maize leaves in the tassel stage in 1990 (averages of 4 replicates).

	% Nutrients in maize				
	% N	% P	% K	% Ca	% Mg
OAT HULLS TREATMENTS (t/ha)					
0	3.81	0.46	2.27	0.41	0.21
5	3.71	0.47	2.22	0.44	0.21
10	3.86	0.45	2.25	0.41	0.21
F value	0.53	0.96	0.07	0.51	0.10
RP TREATMENTS					
- RP	3.9	0.47	2.28	0.42	0.21
+ RP	3.7	0.46	2.22	0.42	0.20
F value	4.20+	1.41	0.66	0.00	0.49
C.V.(%)	7.8	5.2	9.6	11.8	12.8

+ significant at the 0.1 probability level.

Table 82. Effects of oat hull and RPs on maize yield components in 1990 (averages of 4 replicates).

	Maize population (X 1000 plants/ha)	Maize yields (cobs dry weight, t/ha)	Maize yields (cobs dry weight, g/plant)
OAT HULLS TREATMENTS (t/ha)			
0	52.7	5.1	120.3
5	51.2	5.0	122.9
10	49.4	5.1	130.4
F value	1.60	0.09	2.68
RP TREATMENTS			
+ RP	50.4	5.0	125.1
- RP	51.9	5.2	123.9
F value	0.97	1.62	0.06
C.V.(%)	5.8	5.3	7.8

All F values are non-significant.

Table 83. Soil exchangeable nutrients in 1990 (results from one composite sample)

TREATMENTS		Soil exchangeable nutrients (mg/kg soil)			Soil available P_{bicarb}	Soil pH
OAT HULLS (t/ha)	RP	K	Ca	Mg		
0	+	72.5	2310	213	7	7.5
	_	61.6	2850	242	7	7.5
5	+	62.0	2385	220	7	7.5
	_	51.8	2200	178	7	7.6
10	+	72.4	2585	239	9	7.4
	_	78.6	2522	268	8	7.4

2.4. DISCUSSION

2.4.1. EFFECTS OF THREE TILLAGE/STRAW TREATMENTS ON SOIL PHOSPHORUS AND CROP NUTRITION

Negative effects of the disk + straw treatment (DS) on soil nitrate and on soil respiration were observed during the first month after the treatments were imposed. Although these effects were detected only at the 10 % level of significance, it is possible that they are valid. Increased respiration would have been expected.

The tillage/straw treatments had effects on soil and plant variables which carried over several years (Table 84). Most of these effects were measured in the second year (1988). Significant effects on soil P_{res} were found only in 1988. The DS treatment increased soil P_{res} levels by 40% in comparison to the mouldboard treatment, and 52% in comparison to the disk alone treatment. Soil P-ase activity was also affected ($p<0.10$) by the DS treatment, suggesting that soil P-ase may have had a direct effect on P mobilization. Similar effects on P-ase were observed by Perucci et al. (1988) with additions of maize residues. Straw has been shown to increase soil P-ase activity in other experiments (Martens et al, 1992).

Compost that was used as a sub-plot treatment also increased soil P_{res}, but to a less extent than the DS treatment. Soil P-ase was not affected by that treatment. Compost may have increased soil P_{res} levels by a different mechanism than did the straw incorporation.

Maize plants seemed to have benefited from these shifts in soil P_{res}.

Compost increased the biomass of the young maize plants (5-leaf stage) but not the final yields compared to the control. Responses in grain yield and percentage of P in maize grain were observed for the DS treatment. This indicates that the effect of compost was limited to the early stages, but the effect of the DS treatment carried over until the end of the crop.

There seemed to be a suppression of the weeds by the mouldboard treatment in the faba bean field in 1987 at the earlier sampling. The weed biomass was equivalent to that of faba beans in the earlier sampling for both disk treatments, whereas it was less than half of that value for the mouldboard treatment (Table 49). Similar competition of weeds and faba beans was observed in the summer of 1987 in another field (Appendix A).

Table 84. Summary of the effects of the tillage/straw treatments on some of the measured variables from 1987 to 1990 §

	Strip B				
	1987	1988	1989		1990
MEASURED VARIABLE	CROP				
	Faba beans	Maize	Oats		Clover
Soil P_{res}	-	**	NS		NS
Soil P-ase	-	+	NS		-
Root P-ase	-	NS	NS		-
VAM	-	NS	NS		_
% P (grains)	-	+	+		-
% P (leaves)	-	-	NS		NS
Plant Biomass¶	*	NS	**		-
Final yields	NS	**	NS		+
Weeds	+	-	-		-
	Strip A				
Crop	Oilseed radish	Peas	Winter wheat	Clover	Clover
% P (grains)	-	-	NS	-	-
% P (leaves)	-	-	NS	NS	-
Plant Biomass	**	-	-	-	-
Final yields	NS	NS	-	-	-
Weeds	NS	NS	-	-	-

§ -: not measured; NS, +, *, ** are the significance level of the F test: non-significant; significant at p<0.1, 0.05 and 0.01 respectively.

¶ Plant biomass refers to measurements of vegetative biomass at a stage prior to the harvest.

On strip A, weeds were also reduced by the mouldboard treatment (Table 50). The suppression of weeds by the mouldboard ploughing is expected since it inverts the soil layers, burying weed seeds from the soil surface. There were few weeds in the following years except for in peas in 1988 (Table 56). No effect of the tillage was found then, and weed biomass was consistently high (around 50% of the grain yield) in all three tillage systems.

As was postulated, the data indicate, that tillage/straw regimes influence natural fertility cycles. The DS treatment tended to reduce nitrate in the first year when compared to both disk alone and mouldboard (Table 48). This decrease could contribute to the nitrogen economy of the farm by reducing leaching. N_2 fixation was not higher when soil nitrate was reduced by barley straw. This could be because the soil nitrate levels were not high enough to inhibit nodulation or N_2 fixation. It is not possible to infer whether the effect of the DS treatment was due to the straw alone or to an association of DS, since all possible combinations of tillage and straw regimes were not tested. The stimulatory effect of the mouldboard treatment is associated with more factors than just soil nitrate, since nitrate levels were similar to the disk treatment, and yet, the faba bean and oilseed radish yields were still higher under the mouldboard treatment.

The measured effects are the result of a single tillage/straw treatment. If the tillage systems were applied every year, the effects might have been cumulative, and therefore, more nitrogen would be mineralized under the mouldboard compared to the DS treatment. The latter, on the other hand, would contribute to a conservation of soil N and to an increase in the availability of native soil P.

The mouldboard treatment reduced weeds and increased green manure yields in the first year when compared to disk (Tables 48 and 49). In the following years, however, the DS treatment conferred greatest benefits, i.e. soil P_{res} (Table 51), maize yields (Table 52) and %P in maize grain in 1988 (Table 53); oats biomass in 1989 (Table 58) and clover yields and %Mg in clover in 1990 (Table 61). This illustrates the importance of looking at long term effects of residue/tillage regimes.

Besides the above effects, other negative effects of mouldboard (Mueller et al., 1984), would have an impact on a long term basis. The use of straw combined with discing seemed to be beneficial in this study. In order to maximize the benefits from that practice, it would be important that a crop producing large amounts of straw be used in the rotation. Preferably, N_2-fixing crops should be grown immediately afterwards. Results from section 2.3.3 (page 207) illustrate the benefits to legume N_2 fixation after the addition of high carbon-containing material to soil. Mouldboard ploughing seems to be adequate when a serious weed infestation occurs, or when a crop with a high nutritional demand, such as maize is to be grown. As was shown in this study, however, other measures such as growing an aggressive crop (e.g. oilseed radish), can retard weed multiplication as effectively as mouldboard ploughing.

2.4.2. EFFECTS OF GREEN MANURING AND ROCK PHOSPHATE ON PHOSPHORUS NUTRITION OF DIFFERENT CROPS

The main finding in this experiment was the consistently higher level of soil P_{res} in 1988, 1989 and 1990 in plots that received RP in 1987 compared with plots without RP (Figure 29). No responses to the application of RP were observed in the green manure biomass (1987 and 1989) or in yields of the crops (oats in 1988 and maize in 1990). The levels of soil P_{res} (Table 64) were rated low for oats, with a recommendation of 30 kg P_2O_5/ha; the levels of soil K were rated high to very high (Ontario Ministry of Agriculture and Food, 1987), which indicates that the crop should be responsive to soil P increases. As indicated by the low yields and relatively high weed biomass in oats (Table 67), the crop performed poorly, probably because of the drought. This was probably one reason for the lack of plant responses to the soil P_{res} increases.

Since the differences in soil P_{res} between RP and control plots were highest in 1988, this was the time when responses would have been more likely to occur, but none did. In 1990, there was no effect of the RP except for soil P_{res} ($p<0.10$).

According to the theory of dissolution of RP, dissolution responds to: (i) a gradient in pH, with solubility increasing as pH decreases; (ii) a gradient in pCa, with solubility increasing as soil Ca decreases and (iii) a gradient in $H_2PO_4^{-2}$ activity in soil solution, with solubility increasing if there is a sink to reduce $H_2PO_4^{-2}$ levels (Khasawneh & Doll, 1978). The first two conditions were not met in this experiment but the third one occurred to some extent. RP was solubilized in the soil, while P_{res}

decreased steadily over the years. Since the effect seemed to be consistent from 1988 to 1990, regardless of the type of green manure, and since during this period, two different crops were grown, it is possible that some soil-borne factor was involved in the immobilization of native soil P, which favoured RP dissolution. As speculation, an increase in the microbial biomass P and the activity of phosphate solubilizing microorganisms could be involved.

Although other authors have observed that RP dissolution increases with an increase in the P-sorption capacity of soils (Mackay et al., 1986; Wright et al., 1992), RP dissolution does not necessarily mean an increase in the amount of plant-available P, especially in acid soils (Hammond et al., 1986). Chien et al. (1980) found that water-soluble P levels of North Carolina RP increased with increasing soil pH (from 4.80 to 5.85), contradicting the common belief that soil acidity is the most important factor controlling RP availability.

The hypothesis that the green manures would interact with RP and affect crop nutrition, was not verified. Instead, even with drought being a major limitation, green manures alone affected the percentage of nutrients in oat grain (Table 65). Increased N and P percentages in oat grains following faba beans was probably due to the fact that, despite a lower total biomass, higher percentages of N and P were found in the faba bean tissue compared to the other green manures (Table 68). Jung et al. (1990) observed that faba bean green manure increased N uptake of spring wheat and oats; N leaching increased two-fold with faba beans as compared to oilseed rape.

In 1990, the only observed effect of the green manures on maize, was a negative effect of buckwheat on the plant population and on the grain yields, due to an infestation of buckwheat plants from seeds left from the year before. Other than that, the percentage of root length containing no VAM infection tended to be higher on the plots where the two non-mycorrhizal green manures, buckwheat and oilseed radish, were grown. A negative effect of non-mycorrhizal species on VAM infection of following plants has been reported by other authors (Black & Tinker, 1979; Thompson, 1987).

Results from Chapter 1 and from the previous experiment in this chapter, show that the RP was not reactive in the year of application. Results from the next section will also show that the same RP was not even reactive in the second year, in another field of the same farm. Further studies would be necessary to determine the causes and extents of RP solubilization on this particular field and other fields of Oak Manor farm. Studies with increasing levels of the same RP, over a longer period of time and with different crops, would help to clarify the importance of its use on a regular basis at this farm.

2.4.3. EFFECTS OF CARBON ADDITION ON NITROGEN FIXATION AND PHOSPHORUS NUTRITION OF HAIRY VETCH AND FOLLOWING CROPS.

As expected, addition of oat hulls reduced soil nitrate levels (Figure 30). Soil nitrate levels under the higher rate of oat hulls were 1/3 of those under the no oat hulls treatment in the beginning of the experiment. N_2 fixation (acetylene reduction) was increased under the higher level of oat hulls (Figure 31), as were the percentages and total amounts of N accumulated by vetch (Tables 75 to 77). Elevated soil nitrate in the early stages of legume growth can reduce yields by inhibiting early nodulation, resulting in insufficient N supply during the later stages (Herridge & Brockwell, 1988).

The data on vetch biomass production (Table 74) and the total nutrient accumulation (Table 77) indicate that at the 0 addition of oat hulls, increases in biomass and nutrients from July to September were practically nil, whereas under 5 and 10 t oat hulls/ha, biomass and nutrients were approximately doubled in September compared to July.

The amount of nutrients carried into the system by the oat hulls (Table 79) was smaller than the surplus of nutrients accumulated in the vetch biomass under 5 t oat hulls/ha (Table 77). This indicates that oat hulls stimulated plant growth by a mechanism other than through the addition of nutrients. In the case of nitrogen, biological fixation was probably involved. Presumably N_2 fixation stimulated root growth, which resulted in greater uptake of other nutrients.

The data on the accumulation of N in vetch and in the non-N_2 fixing control (sunflower), can be used to roughly estimate N_2 fixation. The N_2 fixation under 10 t oat hulls/ha until July ($FIX_{T1,10}$) can be estimated as:

$$FIX_{T1,10} = N_{vet,\ 10,\ July} - N_{SF,\ 10}$$
$$FIX_{T1,10} = 78.7 - 35.6 = \mathbf{43.1\ Kg\ N/ha}$$

Where $N_{vet,\ 10,\ July}$ is the amount of N accumulated by vetch until July under 10 t oat hulls/ha, and $N_{SF,\ 10}$ is the amount of N accumulated by sunflower.

The N_2 fixation under 0 t oat hulls/ha until July ($FIX_{T1,10}$) can be estimated as:

$$FIX_{T1,0} = N_{vet,\ 0,\ July} - N_{SF,\ 0}$$
$$FIX_{T1,0} = 73.1 - 48.1 = \mathbf{25.0\ Kg\ N/ha}$$

Where $N_{vet,\ 0,\ July}$ is the amount of N accumulated by vetch until July under 0 t oat hulls/ha, and $N_{SF,\ 0}$is the amount of N accumulated by sunflower.

The N_2 fixation under 10 t oat hulls/ha until September (FIX_{T2}) can be estimated:

$$FIX_{T2} + N_{OH,10} = N_{vet,10,\ Sept} - N_{vet,\ 0,\ Sept}$$
$$FIX_{T2} + 45 = 150.8 - 74.7 = \mathbf{31.1\ kg\ N/ha}$$

Where $N_{OH,10}$ is the amount of N contained in 10 t of oat hulls; $N_{vet,10,\ Sept}$ is the amount of N accumulated by vetch until September under 10 t oat hulls/ha, and $N_{vet,\ 0,\ Sept}$ is the amount of N accumulated by vetch until September under 0 t oat hulls/ha.

The N_2 fixation in both periods, under 10 t oat hulls/ha is then:

$$43.1 + 31.1 = \mathbf{74.2\ Kg\ N/ha}.$$

The N_2 fixation due to the application of 10 t oat hulls/ha is:

$$74.2 - 25.0 = \mathbf{49.2\ kg\ N/ha.}$$

These estimates of N_2 are probably conservative. It is possible that under 0 t oat hulls/ha, the initial N accumulation came from the soil nitrate that was high under that treatment (Figure 30). Furthermore, it is likely that the 45 kg N/ha coming from the addition of 10 t oat hulls/ha was not readily available, as was shown by the levels of soil nitrate under that treatment.

This method of estimating N_2 fixation is based on the assumption that the two plant species take up the same amount of soil N. If there is a larger amount of soil N available for plant uptake, and soil contributes to a larger part of the N in the plant, error will be greater because the estimate of N_2 fixation is based on a small difference between two large numbers (Giller & Wilson, 1991).

As an indirect benefit, the better performance of vetch seemed to have suppressed the weeds. The use of a non-legume crop (sunflower) as a non N_2-fixing control, confirmed that N fixation occurred in vetch. Vetch biomass, but not sunflower was significantly higher than the control in the 5 t oat hulls/ha treatment (Figure 31).

As postulated, there was an indication that vetch P nutrition was boosted under the higher level of oat hulls, although RP addition did not affect most of the variables studied (Table 76 and 77).

Use of vetch as a green manure has been reported to increase maize yields (Ebelhar et al., 1984; Neely et al., 1987). Between 37 and 187 kg N/ha were found in hairy vetch biomass (Sullivan et al., 1991). Maize yields following the application of this biomass were similar to maize yields produced by a rate of 140 kg N fertilizer/ha. In this study between 134 and 150 kg N/ha were obtained when oat hulls were applied, which is roughly twice the amount of N in the biomass of vetch with no addition of oat hulls.

The effects of previous treatments on the yield of maize could not be assessed as planned for the following reasons: (i) the farmer cut the vetch in the fall for use as hay; and (ii) he applied compost to the fields prior to planting maize. Hence, the effects measured in the 1990 maize crop were those of the oat hulls, RP and the below ground biomass of vetch. No significant effects of treatments on the measured variables were found in 1990.

Contrary to the green manure experiment, RP addition did not increase soil P_{res} in the second year. It is not clear why, since fields are similar and have been under the same management for the same period of time.

The use of mill residues as a source of carbon to the fields at Oak Manor, followed by a legume crop, can reduce soil nitrate levels in the summer. The temporary decline in soil available N will lead to a higher rate of N_2 fixation, which will contribute to the economy of N in the farm in two ways: by reducing nitrate leaching, and by increasing N_2 fixation. This contribution could be a systemic solution to reduce the deficit of N in the farm suggested by the nutrient budget (Appendix A).

SUMMARY

1. A study was conducted to examine the effects of 4 fertilizer treatments (compost, superphosphate, rock phosphate and control) on several variables related to P nutrition in barley. In 1938 the study was conducted on two organic (designated as O1 and O2) and one conventional farm (designated as C1). In 1989 the study was conducted on six farms: the same farms as above with the addition of one organic (designated as O3) and two conventional farms (designated as C2 and C3). In 1990, the study was conducted in the glasshouse, using soils from the six farms studied in 1989. Overall the farms provided a gradient of conditions ranging from long term organic to moderately intensive conventional

   In 1988 the following variables were measured when barley reached the heading stage: soil available P (sodium bicarbonate - P_{bicarb} - and anionic resin - P_{res}); soil exchangeable K, Ca, Mg, and soil pH; VAM infection and root and soil P-ase activity. The following variables were measured at harvest: percentage of N, P, K, Ca, Mg in barley grain and straw, and grain, straw and weed biomass.

   In 1989 the variables measured were: soil P_{bicarb} and soil P_{res} (early stage[1]); soil organic and inorganic fractions (heading[2] stage); soil exchangeable K, Ca, Mg, and soil pH (heading stage); percentage of N, P, K, Ca and Mg in plants (early and heading stage); VAM infection (early stage); root and soil P-ase activity (early an heading stage); root length (heading stage) and grain, straw and weeds biomass at harvest;

   In 1990 the variables measured (all plant variables were measured on the early stage) were: soil P_{res} and soil P_{bicarb}; soil exchangeable K, Ca, Mg and pH; percentage of N, P, K, Ca, Mg in barley; VAM infection; root and soil acid P-ase activity; soil alkaline P-ase activity; root length and root weight.

2. There was a good correlation between the results of the two methods used for estimation of the available soil P. The sodium bicarbonate method, which is the standard method used in Ontario, extracted about half of the amount of P extracted by the anionic resin. The effects of the treatments on soil P were more pronounced for the resin method.

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[1] Stage 31 of the Zadok's scale (first node of stem visible).

[2]The measurements at the heading stage were done only on the control plots.

3. In 1988 and in 1989, compost and super-P raised soil P_{res} numerically on all farms, significantly on 3 out of 9 (super-P) and 4 out of 9 (compost) comparisons. Other soil nutrients were not affected by the treatments except at O1, where the soil K levels were lowest with super-P and highest with compost.

4. There were no significant effects of P fertilizers on yields in 1988 (a drought year); in 1989, all P fertilizers had a positive effect on yields at O1.

5. In 1989, compost and super-P raised the levels of P in the plants at the early stage compared to controls at farm C1. On the other farms, there was no effect of the treatments on plant P. Effects of treatments on other nutrients were found only at farm C1, where super-P had a negative effect on the percentage of N and Mg.

6. In 1988, the percentage of arbuscules was less than 4% at farm O1 and C1. At farm O2, it was 17.7% (control) and no effects of treatments were observed in any of the three farms.

7. In 1989 the absolute values for VAM were greater than in 1988. Effects of treatments were found at farm O3 where super-P and rock P significantly reduced $p < 0.05$) the VAM infection compared to control. VAM infection was numerically lower under compost, compared to control. Again, farm O2 had the highest infection as in 1989.

8. In 1988 root and soil P-ase activities were only affected by the treatments at farm C1. That farm had the highest soil P-ase and the lowest root Pase activity. Super-P decreased root P-ase and all treatments decreased soil P-ase at farm C1. In 1989, no effect of treatment on root P-ase was found. For soil P-ase, compost decreased the activity compared to control. Again, farm C1 had the highest value for soil P-ase and the second lowest for soil P-ase. The occurrence of high soil P-ase activity at C1 was attributed to the previous incorporation of organic material in the field (clover plough-down and liquid manure) and to the temporary fall in soil pH in 1988.

9. Values of soil nutrients, grain yields, VAM infection, root and soil P-ase activities were not consistently higher or lower on one group of farms (organic versus conventional).

10. The variables that were measured only at the heading stage and on the control plots were: organic and inorganic soil P fractions, root length and leaf inorganic P (Pi). Values for those variables were not consistently higher or lower on one group of farms (organic versus conventional).

11. The variables that were compared at both stages were: plant biomass, the percentage of nutrients in barley, and root and soil P-ase activities. For the percentage of N and K, differences between the two groups of farms were evident. The three organic farms had the lowest levels of those nutrients at the early stage. The levels at the heading stage were similar for all farms. For the percentage of P in plants, the values at the early stage tended to be lower at the two oldest organic farms O1 and O2, compared to the heading stage, whereas for the other 4 farms, percentages of P were similar or higher in the early compared to the heading stage.

12. Relationships between variables were examined using univariate correlations. The relationships between grain yield, soil P_{res} and percentage of P in plants were established using data for all treatments, whereas the other relationships were established using only the averages of the control plots.

    The levels of nutrients at the heading stage are normally used to assess P status. In this study, the percentage of P at the early stage had stronger correlations with soil P_{res} (R=0.716) and grain yields (R=0.628) than did percentage of P at heading (R=0.310 and 0.012, for soil P_{res} and grain yields, respectively).

13. The relationships of the percentage of P (early stage) with soil P_{res}, grain yield with soil P_{res}, and grain yield with the percentage of P (early stage) were positive (R=0.74,0.12 and 0.49, respectively) when all farms were considered together.

14. When the data are examined for each farm separately, correlations between P_{res} and plant P are all positive, as was the correlation for all farms together and all treatments. However, correlations of plant P with yields are very low on two farms and strongly negative for farm C1. High positive correlations are observed for farms O1 and O2.

15. There was a positive relationship between the percentage of roots with no VAM infection and plant dry weight (early stage), indicating a possible negative effect of VAM on plant growth at the early stage. Ca was the only plant nutrient that was significantly related to the plant weight at the early stage.

16. Soil P-ase activity was not significantly correlated with any of the variables measured. However, when the ratio soil P_{res}:soil organic P was calculated, a positive relationship between this ratio and soil P-ase activity was found, as was reported by Sharpley (1985).

17. A strong negative relationship between soil pH and soil P-ase was found when

farm C1 was excluded. C1 was anomalous regarding that relationship, probably as a result of the incorporation of organic material (Summary item #8).

18. Negative relationships of root P-ase with plant P were expected. Trends but not significant relationships were observed. Root P-ase activities were transformed into a new variable called "net P-ase" that does not include the basal P-ase activity; plant P was transformed into a variable that expresses 'P deficit'. When those variables were plotted, a good relationship between the two variables were found, indicating that root P-ase responds to plant P stress.

19. When percentage of arbuscules was plotted against the calculated P deficit, no significant correlation was found but trends were evident.

20. No significant relationships between soil organic P fractions (organic P from acid and alkaline extraction) and soil P_{res} were found. The soil organic P from the acid extraction was negatively correlated with soil organic P from the alkaline extraction (R=-0.670). The fraction from the alkaline extraction was positively correlated with the percentage of sand.

21. Overall, the correlations of soil total P (acid extraction) and soil total P (acid + alkaline extraction) with variables directly related to P nutrition (such as percentage of P in both stage, leaf Pi and P deficit) are higher than for P_{res}. The R values for the organic fraction (acid extraction) are greater than those for the inorganic fractions (acid extraction), suggesting that organic fractions contributed significantly to plant P.

22. Root length was significantly correlated with the percentage of sand in soil and was negatively correlated with leaf inorganic P.

23. The glasshouse experiment was designed to: (i) compare soil and plant variables from different farming systems related to P nutrition under a single environmental regime, and (ii) evaluate whether the relationships between variables studied in the previous experiments were affected by the glasshouse environment as compared to the field. Rock P was not included as a treatment in the experiment because of the short term nature of the experiment and, NPK was included to determine whether N or K was limiting.

24. There were no consistent differences between groups of farms in regard to any of the variables measured at the glasshouse experiment.

25. Of the correlations that can be compared to the field data, only pH, soil acid

25. Of the correlations that can be compared to the field data, only pH, soil acid P-ase, root length and plant dry weight had R values greater than 0.8. The relationship between soil pH and soil acid P-ase was negative (R=-0.85) as in the field (R=-0.27). The relationship of root length with plant dry weigh was positive (R=0.85), while in the field it was negative (R= -0.619).

26. Multivariate methods (PCA and cluster analysis) were used to examine relationships between variables and to define the factors that discriminate most between farms, if any. Data from 1988 and 1989 were used for that purpose.

27. In both years, there was a clustering of the variates by farms and not by fertilizer treatments.

28. For 1988, the multivariate analysis separated farm C1 from the other two farms (O1 and O2). The factor responsible for that separation was strongly related to soil pH (with a high positive loading) and soil Ca, soil K and soil P-ase (with high negative loadings). This is possibly due to the above incorporation of organic material into the soil, and its alleged effect on the soil pH decline (Summary, item #8).

29. For 1989, there were 4 distinct clusters. Three of these clusters were each composed of variates from farms O1, O2 and C2; the other cluster contained variates from farms O3, C1 and C3. Farm O1 seemed to be separated by having high yields and low nutrient values; O2 by having low yields and low nutrient values and, C2 had the highest yields in 1989 and also the highest contents of N, Ca, Mg and P. It is possible that C2 should be considered the most intensive and not C3, as was first implied.

30. A second set of three experiments, examined how crop, soil and residue management practices on Oak Manor farm affect mobilization of native and applied phosphate. Oak Manor farm (O1) is the oldest organic farm of the group. Three aspects of the system's management practices were selected for this study which was conducted from 1987 to 1990: tillage/crop residue (straw) managements, green manuring and use of residues from the mill (oat hulls). The experiments involved the long term effect of different tillage/straw regimes, different green manures and of addition of a carbon containing residue (oat hulls), on soil P, P uptake, crop yields and other variables related to soil fertility and plant nutrition.

31. The first experiment examined the effects of three tillage/straw treatments (straw removed, mouldboard ploughed; straw removed, disced; straw retained, disced) on soil and crop P status over several crops. The objectives were: (i) to study how different tillage/straw conservation methods

affect P nutrition over several successional crops and (ii) to examine how different P fertilizers (super-P, rock P and compost) interact with these tillage methods.

The tillage/straw treatments were imposed in the fall of 1987. The field was divided in two sections so that two cropping sequences could be evaluated. In 1988, the fertilizer treatments (super-P, RP and compost) were superimposed on the tillage treatments.

32. In 1987, the disk + straw treatment tended to decrease the levels of soil nitrate 8 days after the treatments were imposed and, decrease the evolution of CO_2 at 20 and 35 days. The mouldboard treatment increased the biomass of the two crops growing in the fall of 1987 (faba beans and oilseed radish) compared to the other two treatments.

33. In 1988, the disk + straw treatment increased soil P_{res}, but not the other soil nutrients measured (P_{bicarb}, K, Ca and Mg). The disk +straw treatment tended to increase the soil P-ase activity compared to the other two treatments. Of the two crops grown in 1988, maize and peas, only maize was affected by the treatments. The lack of effects on the peas was attributed to the 1988 drought. The disk +straw and the mouldboard treatments increased maize yields compared to the disk alone treatment.

    Four variables were affected by the fertilizer treatments. Compost and super-P increased soil P_{res} compared to control; maize biomass at the 5 leaf stage tended to be highest under compost; the percentage of P in maize grains was significantly higher under compost than in the control and the VAM infection (arbuscules) was higher under compost in comparison to super-P.

34. In 1989, soil P_{res} was still numerically highest under the disk + straw treatment. The disk + straw treatment increased the biomass of oats at the heading stage but not grain yield. No effects of the treatments on the other variables measured for oats (root and soil P-ase, VAM infection, percentage of nutrients in leaves and grains) were observed. No effects of the tillage treatments were observed on the percentage of nutrients in winter wheat and clover.

35. In 1990, clover was grown in the both sections of the field. The mouldboard and the disk + straw treatment tended to increase clover biomass compared to the disk alone treatment. Soil P_{res} was still numerically higher under the disk + straw treatment.

36. The second experiment examined the effects of 4 different green manures

(faba beans, buckwheat, oilseed radish and weeds) in combination or not with one level of rock P, on P status of soil and crops. The objectives were (i) to determine whether rock P was reactive in a long term cropping sequence; (ii) to study how different green manures affect the solubility of the rock P and (iii) to determine how different crops respond to both RP and green manures?

The rock P treatments were applied once in the summer of 1987. The green manures were first planted in the summer of 1987 and the biomass remained in the field until the spring of 1988, when it was incorporated into the soil. The green manures were grown again in 1989.

37. The application of rock P did not affect the production of green manure biomass in 1987. The dry biomass production varied from 1.3 t/ha (faba beans) to 4.6 t/ha (oilseed radish).

38. In 1988, rock P increased the levels of soil P_{res}. This effect carried on through 1990. RP also decreased the levels of soil Mg. The other soil nutrients studied (P_{bicarb}, Ca and Mg) were not affected by the application of rock P. Effects of rock P on oats, the first crop grown after the green manures, were only observed on the total N and P in oat straw. The other variables studied, (percentage of nutrient in straw and grains, VAM infection, yields of grain, straw and weeds) were not affected by rock P addition.

39. Effects of the 1987 green manures on oats in 1988 were only observed in the percentage of Ca and Mg in oat straw, where buckwheat tended to increase those percentages compared to the other green manures.

40. In 1989, there were no effects of the rock P applied in 1987 on the biomass production of the second green manure crop. The biomass production varied from 615 kg/ha (faba beans) to 2861 kg/ha (buckwheat). Soil P_{res} was higher ($p<0.10$) in the plots that received rock P.

41. In 1990, there were no effects of the rock P applied in 1987, on any of the variables measured in maize, the crop growing after the incorporation of the 1989 green manures. Soil P_{res} was higher ($p<0.10$) in the plots that received rock P.

42. Buckwheat tended to decrease the percentage of P in maize leaves and final yield. The percentage of roots with no VAM tended to be higher under the effect of the non mycorrhizal green manures (buckwheat and oilseed radish) and lower under the effects of the weeds.

43. Overall there was no indication of any interaction between species of green

manures and rock P.

44. The third experiment examined the effects of 3 levels of oat hulls (0, 5 and 10 t/ha) with or without RP, on N_2 fixation and P nutrition of hairy vetch and their effects on maize planted after hairy vetch. The objectives were (i) to determine whether carbon additions (oat hulls) can increase N_2 fixation of a legume crop in the field; (ii) to determine whether hairy vetch has a better P nutrition when fixing more N_2 and (iii) to determine the effects of hairy vetch on P nutrition of a following crop (maize).

45. Incorporation of oat hulls in mid summer 1989 resulted in lower soil nitrate under vetch, higher N_2 fixation rates, more biomass of vetch and fewer weeds than in plots without oat hulls. No effects of the treatments on other soil nutrients were noted.

46. The percentage of nutrients in vetch was not significantly affected by the addition of oat hulls, except for Mg. The percentage of N tended to be higher and Ca lower, under 10 t oat hulls/ha than in the control. The percentage of Mg was significantly lower under 10 t oat hulls/ha.

47. The total nutrients accumulated by the vetch biomass were approximately twofold higher under both levels of oat hulls than with no oat hulls.

48. A negative relation between soil nitrate and percentage of N in vetch was found.

49. The amount of nutrients carried into the system by the oat hulls was smaller than the surplus of nutrients accumulated in the vetch biomass under 5 t oat hulls/ha. This indicates that the oat hulls stimulated nutrient uptake by a mechanism other than the addition of nutrients. Biological N_2 fixation was probably involved.

50. It was estimated that the N_2 fixation by the vetch crop, due to the application of 10 t oat hulls/ha was 49.2 kg N/ha.

51. There was no indication of any effects of the treatments on the yield components of maize. The effects of the previous treatments on the yield of maize could not be assessed as planned for the following reasons: (i) the farmer cut the vetch in the fall to be used as hay; (ii) he applied compost to the fields prior to planting maize. Hence, the only effect that was really measured in the 1990 maize crop was that of the oat hulls, rock-P and the below ground biomass of vetch. No significant effects of the treatments on the measured variables were found in 1990.

APPENDIX A

Background observations and experiments at Oak Manor Farm

INTRODUCTION

In 1987, a series of experiments and observations were performed at Oak Manor farm with the collaboration of D. Patriquin, R. Jannasch and S. Campbell. The objectives were (i) to determine how yields at Oak Manor compare with those for conventional farms in the region; (ii) to identify major limitations to yields, examining specifically, weeds, pests, nutrients and soil structural characteristics; (iii) to examine the efficacy of techniques that tend to be peculiar to organic systems, e.g. use of compost and various biological amendments such as seaweed-based sprays; (iv) to determine to what extent the nutrient limitations are a function of systemic properties of the farm, i.e., could they be resolved by structural rearrangements within the farm, as opposed to imported nutrients. Information on the farm operation was obtained from the farmer, David Reibling Some comparisons are made with data for Tunwath farm, Nova Scotia, the only other organic farm in Canada for which comparable data are available (Patriquin et al., 1981, 1986 and 1988).

GENERAL DESCRIPTION OF THE FARM

Area under crops

The farm includes approximately 54 ha in cultivated crops and pasture, and an additional 8 ha in wood lot (Figure 1). The acreage under various crops in 1987 is shown in Table A1. Grains were grown for direct marketing as organically grown grain. The grain is processed in the farm by a milling operation also run by the farmer, D. Reibling. Besides grains grown on the farm, large quantities of organically grown grain are imported and processed for resale as certified organic products. Forages are fed to livestock, as are by-products from the milling operation. In 1987, 50% of the hay for livestock was imported.

Livestock

Livestock in 1987 included a breed of "beefalo" (obtained by crossing a beefalo bull which is 3/8 bison, with his herd - these are low fat animals); 28 cows, 17 calves, 7 steers; 50 laying hens, approximately 400 broilers were finished (chicks were purchased at one day and kept 15-16 weeks); 39 pigs were raised (from 25 kg at purchase to approximately 100 kg).

Cattle are housed in an open shed on deep litter. Steers are kept in the feedlot, while cows and calves have access to pasture during the summer. Steers are fed free choice hay and grain year round; the grain is a mixed ration depending on leftovers from the mill. In the fall, the hay/grain is supplemented with silage made from maize stalks and silage made from sorghum and alfalfa. Cows and calves have a similar ration, but receive less grain, more hay and occasional silage. They also receive diatomaceous earth, kelp meal and mineral supplements.

Table A1. Crops and acreage in 1987.

Crops	Acreage
Alfalfa, clover (hay)	14.8
Maize	3.7
Fall cereals: winter wheat, triticale and buckwheat (after harvest of cereals)	6.6
Fallow then buckwheat	5.7
Sorghum	1.2
Spring cereals: oats, barley and oilseed radish (after cereal harvest)	7.4
Summer pulses: faba beans and peas	12.0
Vegetable garden	1.8
TOTAL	53.2

Compost

Compost is made from a mixture of manure and straw bedding, and a small portion of milling wastes. Manure is handled with a 140 H.P. tractor and loaded into a common manure spreader, after which it is spread onto 2 m basal width by 1.5 m high windrows. Ideally, it is turned about two weeks later, depending on the temperature, but often weather or workload prevent this being done until 4-6 weeks. It is then turned once more, 1-2 months later. Depending on state of maturity, it is applied within 10 months, at a rate of approximately 17 tonnes/ha (fresh basis), and the farmer attempts to apply it to fields every 2.5 years, usually before winter wheat (in the fall prior to planting), and sometimes to maize fields in the spring. It is immediately worked in with a chisel plough.

Green manures

Oilseed radish and occasionally faba beans and buckwheat are grown as green manure crops after harvest of grain crops.

Tillage and weed control

Tillage implements in use on the farm are given in Table A2. Crop residues are incorporated with an offset disc (straw is usually removed). This may be followed by chisel ploughing, especially if necessary for weed control, but often one discing is sufficient to prepare a seedbed. If chisel ploughing is done in the spring, then sweeps are set at 3-4 inches to avoid bringing clay to the surface. Later in the year, e.g., when incorporating red clover, sweeps are lowered to 6 inches. If tillage is carried out in the fall, sweeps can be lowered to 8 inches because the frost will break apart any clods that form.

A packer is used to provide a firm seedbed, particularly during dry weather. It is also used in weedy areas to encourage germination of weeds in freshly tilled soil, which can then be killed by discing prior to planting.

For control of weeds, maize is scuffled once with a rotary hoe when 2-3" high, and further cultivated with a row cultivator. In spring grain, one or two passes are made with a diamond tooth harrow before plants reach 15 cm; a pre-emergence pass may also be made. In vegetables, weeds were controlled by hoeing, handpicking, and between rows, by rototilling.

Pest control

No pesticides are used on field crops. Commercial vegetable operations were only in their second year in 1987, and the necessity for and means of controlling pests were still being worked out. A commercial botanical pesticide comprised of rotenone, pyrethrum and ryania was applied to vegetables when potential pest problems were anticipated or in progress; it was applied as a dust or spray, sometimes with D.E. (diatomaceous earth) mixed in. D.E. is added to grain storage bins as they are being filled. It is also added to cattle feed to protect the meal against insects, and it is thought to prevent flies hatching and breeding in the manure.

Agrikelp, a commercial kelp extract produced in Australia, was applied to field crops and vegetables. The rate of application was 1.25 pints/acre. It was applied with a truck mounted sprayer to field crops, and by back-pack to vegetables. Spraying was done before 11 am or after 7 pm. "Basic H", a biodegradable household cleaner, was mixed with Agrikelp in a ratio of 1:3; it acts as an emulsifier.

Potatoes were dipped in Agrikelp before planting. In 1987, maize was sprayed with agrikelp when it was about 14" high, faba beans at early flowering, and peas at full bloom. Vegetable crops were sprayed at approximately weekly intervals.

Table A2. Tillage implements and uses for field crops at Oak Manor.

Implement	Uses
Offset disk	Used for incorporation of green manures and straw stubble after harvest. Occasionally used for seedbed preparation or weed control.
Chisel plough	Used as an alternative to the mouldboard plough, often functioning as a subsoiler as well as for weed control. Main function is the control of deep rooted weeds such as canada thistle, milkweed, and couch grass; often used before planting. Also used for incorporation of compost.
Rotary hoe	Only used in maize, until 2-3" high.
Row cultivator	Also used only in maize, until approximately 12" high. Operates at low speed and cultivates soil extremely close to plants.
Diamond tooth harrow	Weed control in standing grain such as oats and barley less than 6" in height. Occasionally used to build an even seed bed prior to planting.
Packer	Compaction of seed bed prior to planting.
Rototiller	Seed bed preparation and weed control for the vegetable garden.
Adapted horse drawn cultivator	Weed control in potatoes, and occasionally used for other vegetables
Hilling implement	Hilling potatoes.

EXPERIMENTS

Methods

Plots set up:

The experiments were set up in the existing crops in the spring of 1987. The treatments consisted of: (i) addition of blood meal (BM, 15% N) at a rate equivalent to 75 kg N/ha, (ii) weeding (WD), (iii) addition of Microp (MC) and (iv) Agrikelp (AK). Blood meal was used as a substitute for N fertilizers, since they can not be used in the farm. It was chosen because of its high percentage (15%) of N. Not all crops received all treatments. In some crops, just the yield of the field as it was (no treatments - NT) was recorded. The plots were arranged in a randomized complete block design with 10 replicates, except for the field peas that had the treatment (AK) applied along one single strip. Details for each field are given below:

Faba beans: twenty 1.5 x 1.5 m plots consisting of two treatments (WD and NT) were set up along a transect placed along the field, 5 m from the edge, on June 5. Faba beans were in the vegetative stage, about 30-35 cm tall, with approximately 5 nodes. Weeding was done by hand on June 5; a second weeding was done 2 weeks after the first one. Plants were harvested on August 8.

Maize: Fifty 2 x 3.2 m plots consisting of 5 treatments (BM, WD, MC, AK and NT) were set up on June 19 when maize plants were 25 cm tall. The first weeding was done on June 29 and the second, 2 weeks later. Agrikelp was applied in the evening of June 20 at a rate of 1 pint/acre; plots were sprayed with 100 ml/plot of a solution consisting of 2.6 ml Agrikelp/l tap water + emulsifying agent. All other plots were sprayed with water+ emulsifying agent. Microp was applied after rain on June 22, at a rate of 30 g/sq m. The crop was harvested on September 3.

Winter wheat: Thirty 1 sq m plots consisting of three treatments (BM, WD and NT) were set up along a transect placed along the field, 2 m from the edge, on June 5. The crop was at the beginning of the filling grain stage, approximately 75 to 100 cm in height. Treatments were imposed on June 5. A second weeding was unnecessary. The crop was harvested on July 7.

Triticale, oats: No treatments. Yields were estimated by ten randomly selected quadrats per field on July 30.

Barley: Thirty 1 sq m plots consisting of three treatments (BM, WD and NT) were set up along a transect placed along the field, 5 m from the edge, on June 2. First weeding was done at this time and a second one two weeks after. The crop was harvested on July 7.

Field peas: Twenty 1.5 x 1.5 m plots consisting of two treatments (AK and NT) were set up in the field on June 16 when the plants were at the beginning of the flowering stage. The field was sprayed by the farmer. The unsprayed plots were located along a 9 m wide strip left by the farmer. The crop was harvested on july 15.

Weeds:

The weed composition was evaluated by a ranking system that visually estimated the relative contribution of different species accounting for the 80% of the weed biomass (Patriquin et al., 1986). Weed species were ranked 1 for most abundant, 2 for second and, so on, until an estimated 80% of the biomass was accounted for. Generally, four or five species accounted for most of the biomass.

Aphids:

The number of "aphid plants" (Patriquin et al., 1987) was estimated by counting the number of plants with 2 or more aphids in a 1 m^2 quadrat in weeded and non-weeded plots. Nodule dry weight, number of pods per plant, and pod fresh weight per plant were determined for 10 aphid plants as well as 10 adjacent non-aphid plants along the field.

Penetrometer measurements:

A EIJKELKAMP penetrometer #06.01 was used to measure soil resistance in two fields. In the corn field, plants were in the beginning of the tassel stage. Measurements were performed at 4 soil depth intervals: 0-5, 5-10, 10-15 and 15-20 cm. Ten plots were measured, five where Microp had been used, and five where Microp had not been applied. Measurements were made at two points in the centre of the plot for each interval. The soil was moist, as there had been 12.5 mm precipitation the day before.

In the winter wheat field, measurements were made in areas were the maximum heights of wheat plants were approximately 55, 75 and 100 cm. Measurements were made at 6 depth intervals (the same as above, plus 25-30 cm).

Soil nitrates:

Composite samples from the surface horizon (0-15 cm) were taken in different fields for determination of nitrates. The soil samples were taken in the morning, kept refrigerated while in the field, and analyzed immediately for nitrates. Nitrates were determined using ORION electrodes (ORION, 1978).

Potassium experiments:

2 X 2 m plots were set up in the fields of alfalfa, maize and rye, and 1 X 1 m plots for barley. 100 kg K_2O/ha was applied as potassium sulphate. The fertilizer was applied to alfalfa in May, and biomass samples were taken in June and August. Four replicates were used in all fields. For the other crops, fertilizers were applied on June 1.

Soil audits:

In October, soil samples were taken from all fields and analyzed for the major nutrients and other properties at the Woods End Laboratory, Mt Vernon, Maine. At least 30 cores (1.8 cm diameter by 15 cm depth) were taken from each field.

Results and Discussion

Yields:

For 3 fields, all the grain harvested by combine was weighed at a weighing station at the farm and moisture levels were determined. The combine yields were 18, 36 and 33% lower than the yields estimated from control plots in barley, winter wheat and triticale experiments, respectively. The average difference was 29 %. Patriquin et al. (1981, 1986) reported that combine yields averaged about 25% lower than quadrat yields.

Our estimates of yields, discounted for differences from combine yields and adjusted for 14% moisture, were 47% (wheat), 35% (barley), 30% (maize), and 1% (oats) below the published averages for Oxford County (Table A4).

Weeding did not have much effect in barley, winter wheat and maize (Table A3). In faba beans, however, there were very large weed biomass values, and a very large increase in yield occurred in beans when weeds were removed. Microp (soil conditioner) and Agrikelp (seaweed extract) had no effects on maize yields.

In the non-legumes barley and winter wheat, yields were increased significantly by adding blood meal, but not to the average provincial levels (Table

A3). Some factor besides the nutrient supply (as represented by blood meal) is limiting the yields of those crops in the particular fields.

Weeds:

Canada Thistle (*Cirsium arvense)*, a rhizomatous perennial weed, was ranked in the top 4 species in 6 out of 7 fields (Table A5); this compares with ranking in the top 4 species in 3 out of 23 fields on Tunwath farm (Patriquin et al., 1986). Infestation of this weed is probably associated with the multiplication of rhizomes by closely spaced cultivation operations in the predominantly annual crop system.

Chenopodium album was the most abundant summer annual weed at harvest and ranked in the top 4 weeds in 5 out 7 fields (versus 6/24 at Tunwath) (Patriquin et al., 1986). There is a notable lack of winter annuals compared to at Tunwath; this could be due to a better cleaning of seed compared to Tunwath, where seed was the major source of winter annual weed seed (Patriquin et al., 1986).

Table A3. Yields of crops and responses to treatments in 1987 (averages of dry weight from control plots, estimated from quadrat sampling, unless otherwise stated).

Crop		Control plot yields kg/ha	Treatment effects (percentage of control)			
			Weeded	Blood meal	Microp	Agrikelp
Alfalfa[b]	Hay	10130 (5000)[c]	-	-	-	-
Barley	Grain	2819	88.7	118.9*[a]	-	-
	Straw	2606	95.0	111.2	-	-
Buckwheat	Grain	1077	-	-	-	-
Clover	Hay	3386 (1723)[c]	-	-	-	-
Corn	Grain	6925 (4250)[d]	104.7	102.5	104.9	103.2
	Straw	7894 (4845)[d]	-	-	-	-
Faba beans	Grain	3461	154.1*	-	-	-
	Straw	3042	115.6*	-	-	-
Oats	Grain	3328	-	-	-	-
	straw	3098	-	-	-	-
Peas	Straw	2041	-	-	-	-
	Straw	1054	-	-	-	-
Winter triticale	Grain	3502	-	-	-	-
	Straw	5054	-	-	-	-
Winter wheat	Grain	2559	89.9	123.2*	-	-
	Straw	3308	85.7	107.0	-	-

a. Differences from control (LSD at $p < 0.05$)) **b**. Averages of 2 cuts **c.** Number in parentheses is the average of selected bales **d**. Farmer's estimates.

Table A4. Biomass production of fields, harvest index and grain yields as a percentage of the provincial averages.

Crop	Biomass in control plots (kg dry/ha)		Harvest index (%)	Grain yields[a] as a percentage of County average[b]
	Crop	Weeds		
Barley	5425	584	51.9	65
Corn	44800	1670[c]	38.4[c]	70
Faba beans	7784	2796	44.5	na
Oats	6426	173	51.8	99
Peas	3135	3284	65.1	na
Winter triticale	8856	173	39.5	na
Winter wheat	5830	109	43.3	53

a. Yields were adjusted to 14% moisture and reduced to account for observed differences between quadrat and combine yields (barley yield was reduced 18%, triticale 33%, wheat 36% and others, the average of the three observed values 29%).
b. County yields from Agriculture Canada (1989).
c. Fresh weight values.

Table A5. Ranking of weeds making up an estimated 80% of the weed biomass in field crops, 1987.

Weed species	BARLEY	OATS	MAIZE	W WHEAT	TRITICALE	FABAS	PEAS
PERENNIALS							
Cirsium arvense	3	3		3	4	4	2
Convolvulus arvensis			5	3	4		
Plantago major							1
Taraxacum officinale				1		1	1
Sonchus arvense							5
GRASSES, all	1	2	2	2	3	1	
SUMMER ANNUALS							
Ambrosia artemisifolia	2	5	4			3	
Amaranthus retroflexus			1	5		4	3
Chenopodium album	4	1	2	1			1
Medicago lupulina					1		4
Myosotis sp					2		
Polygonum convolvulus		4		4			
Sinapsis arvensis						2	
Thlaspi arvense					5		
Viola arvensis	5						
WINTER ANNUAL							
Vicia sp.	5						

1= most abundant; 5= less abundant.

Pests

(i) Aphids:

In studies at Tunwath farm in Nova Scotia (Patriquin et al., 1987), more "aphid plants"(plants with 2 or more black aphids/plant) were found in weeded than in non weeded plots, in plots without cereal intercrops compared to plots with them, and in plots fertilized with N compared to plots without N; N contents of leaves were highest in plots with highest numbers of aphid plants. It was suggested that weeds consume excess soil N, thereby restricting luxury uptake of N by the crop, and making it less attractive or nutritious to aphids. It was suggested also that these effects could be mediated by effects of N on nodulation and N_2 fixation.

Although differences were not statistically significant, on average, there were more aphid infested plants in weeded than in non weeded plots of faba beans at Oak Manor (Table A6). Numbers of aphids on infested plants and damage to plants by aphids on infested plants were subjectively assessed as much greater than at Tunwath. Comparison of adjacent infested and non infested plants of equivalent stature indicated significant damage by aphids. Aphid plants had a lower nodule biomass than plants without aphids, supporting the hypothesis of Patriquin et al. (1987) that effects of N on aphids could be mediated by nodulation/N_2 fixation.

(ii) Other pests:

There was a large amount of smut on barley in 1987, and it was more pronounced in plots treated with blood meal than in adjacent untreated plots. Large sections of that field had lodged (which also seemed to be worse in the blood meal treated plots), leaving only large lambsquarter (*Chenopodium album*) plants standing.

Pest problems were evident in the vegetable field, and included Colorado potato beetles in potatoes, flea beetles in cabbages, and cucumber beetles in zukinis and cucumbers. A mixed botanical pesticide (containing rotenone, pyrethrum and ryania) was applied regularly to control these pests, and losses were assessed by the farmer as "not serious".

There was no evidence of serious pest problems in maize to which no pesticides had been applied.

Table A6. Occurrence of aphids in weeded and unweeded plots of faba beans, and nodule weights and yield components of infested and non-infested plants. Numbers in brackets are standard deviations.

Variables	Weeded plots	not weeded
# aphid plants/m^2	78 (2.1)[a]	48 (2.8)
	Aphid plants	Aphid-free plants
Nodule dry weight (mg/plant)	258 (33)	384 (44) *[b]
# pods/plants	7.30 (0.82)	3.80 (0.87) **
Pod fresh weight (g/plant)	33.7 (3.6)	10.8 (2.45) **

a. Numbers in parentheses are standard deviations.
b.*, ** Differences significant at 0.05 or 0.01 probability levels as assessed by paired t-tests. Count data were transformed as square root of (x+0.5).

Soil structural factors:

All soils of the farm are riddled with earthworm channels and it was noted that during heavy rains, surface water disappeared faster from the Oak Manor fields than from those of nearby farms.

The field where winter wheat was growing was sampled for soil resistance with a penetrometer (Table A7). More resistance to penetration was found in regions where plants were of small stature. It was also observed that a higher incidence of mustard occurred at the sites of short wheat plants.

Application of microp (a biological soil conditioner) to maize field soil did not appear to significantly reduce soil resistance (Table A8) although lower values of resistance were found on all 4 five cm intervals. Yields were not significantly different.

Table A7. Soil penetrometer measurements from adjacent stands of the wheat field (June 5 1987).

Maximum height of wheat	55 cm		75 cm	100 cm	
	(i)	(ii)		(i)	(ii)
Soil profile (cm)	Resistance (N/cm^2)				
0-5	155	180	85	80	55
5-10	255	270	190	130	140
10-15	xx[a]	230	300	240	195
15-20		xx	xx	210	240
20-25				205	240
25-30				300+	340

a. The instrument could not penetrate.

Table A8. Soil penetrometer measurements[a] from microp treated and control plots from the maize field (July 27 1987).

Soil profile (cm)	+ Microp	- Microp
	Resistance (N/cm^2)	
0-5	30	40
5-10	65	78
10-15	130	159
15-20	160	216
	Maize yields (kg/ha)	
	7200	6925

Soil nitrates:

Levels of soil nitrates were measured on 3 occasions in 9 fields (Table A9). These were much higher than at Tunwath where almost all values were less than 10 mg/kg and most were below 5 ppm, even after manure application and cultivation (Patriquin et al., 1981; 1986).

The higher levels of soil nitrate were found on those fields where cultivation was more intense, e.g. maize, garden and buckwheat.

Table A9. Soil nitrate (mg NO_3-N/kg soil) in selected fields of Oak Manor.

	June 10	June 26	July 23
Barley	18	12	18
Buckwheat	-	90	75
Clover	-	23	50
Corn	52	93	20
Faba	18	21	5
Garden	60	118	40
Oats	-	23	18
Peas	-	20	20
Woodlot	-	0	5

Soil Audits:

Soil samples were taken from all fields in October 1987 and sent to Woods End laboratory, Mt. Vernon, Maine. The Woods End Laboratory considered the aggregate stability values to be excellent in all samples. Bulk density was assessed as high. However, the measurements were considered to be rough, since measurements were made on processed rather than unprocessed samples.

In 12 out of 13 soils, the available P was ranked as low or moderately low, and cited as a limitation; however, reserve P values were generally close to or better than the "desired" values. Potassium is cited as a limitation in all samples.

The Wood's End assessments indicate no N limitations. This is in marked contrast to their assessment of Tunwath soils where most were assessed as N deficient (Patriquin et al., 1986).

Soil samples were taken from one field of an immediate neighbour (conventional) farm. Corn had been grown on that field for at least 3 years. The values were within the ranges of Oak Manor values, except for phosphorus which was in the "moderate" category.

Table A10. Summary of soil audit data for soil samples taken from Oak Manor farm in the October of 1987 (13 fields sampled).

Variable	Mean value	Range	Woods Ends Remarks
pH	7.5 (0.2)[a]	7.0 - 7.8	-
pH in salt	7.1 (0.2)	6.7 - 7.4	-
Organic matter(%)	5.3 (0.4)	3.8 - 6.2	marginal-fair[b]
Aggregate stability (%)	54.1 (7.5)	44 - 69	excellent-excellent[b]
Cation exchange capacity (meq/100g)	15.5 (2.53)	12.6 - 19.8	good-good[b]
% Exchange saturation			
As Ca	88.9 (1.8)	87 - 93	desired= 61.2 (6.1)[c]
As Mg	9.8 (1.48)	7 - 12	desired= 10.3 (0.8)
As K	0.9 (0.27)	0.7 - 1.7	desired= 2.0 (0.0)
As H^+	0.38 (0.96)	0 - 2	desired= 26.8 (7.8)
Phosphate (kg/ha)			
Available (Bray I)	26.76 (14.6)	8.9 - 54.8	desired= 52.8 (11.4)
Reserve (Bray II)	167.8 (66.88)	89.5 - 335.7	desired= 112.7 (37.2)
Nitrogen (kg/ha)			
In soil	51.5 (18.8)	29.1 - 95.1	desired= 83.5 (42.5)
Estimated annual release[d]	66.23 (24.8)	44.7 - 100.7	-

a. Numbers in parentheses are standard deviations. **b.** Remarks are based on the minimum and maximum values. **c.** The desired levels are dependent on the crop. The values used were based on each field's previous crop. **d.** Annual release of

N is based on the climatic zone and content of humus and it is an approximation of the amount of N to be expected over the season (Woods Ends laboratory description).

Nutrient Budgets:

Net N, P and K input/output balances for all fields considered together were estimated using (i) the farmer's figure for sustainable rates of application of compost, (ii) data on the yields of grains and straw (Table A3) (iii) the measured or estimated (from figures in the literature) N, P and K contents of field products and compost (Table A11 and A12), and (iv) estimates of N_2 fixation, leaching, erosion and denitrification based on literature data.

Calculation of the budget

INPUTS

Nitrogen fixation:

The average of values of nitrogen fixation compiled by LaRue & Patterson (1981) was used for the estimation of nitrogen fixation. The values were reduced by 25% to account for some suppression of N_2 fixation by the modest levels of soil nitrate found in the summer for the faba, peas and clover fields (Table A9). The values used were: 147, 90, 13 and 8 kg N/ha fixed by alfalfa, faba beans, peas and clover, respectively).

Precipitation:

The values of Schindler & Nighswander (1970) for Eastern Ontario were used for estimating the inputs of N, P and K in precipitation. The values were 9.9, 0.35 and 1.0 kg ha^{-1} $year^{-1}$ of N, P and K respectively. They are within the ranges quoted by Ovington (1968) for North America (0.2 - 0.6 kg ha^{-1} year^{-1} for P and 1 - 10 kg ha^{-1} year^{-1} for K).

Compost:

The nutrients carried into the field as compost was calculated based on the total production of 100 ton in 1987 (the amount was given by the farmer). The composition of compost can be found in Table A11.

OUTPUTS

Grain, forages and straw:

The grain and straw yields (Tables A3 and A12) and respective percentages of nutrients (Table A11) were used to calculate total nutrient outputs (Tables A12).

Leaching and runoff:

Bolton et al. (1970) calculated losses of nutrients through tile drains in Ontario. Where no fertilizers were used, those values were 5.6, 0.3 and 0.62 kg ha^{-1} year^{-1} for N, P and K respectively. Similar values for nitrogen were obtained (5 kg ha^{-1} year^{-1}) by Jaakola (1984) in Finland, when fallows were excluded.

Losses of P from leaching can be insignificant (Miller et al., 1982; Coelho et al., 1990) although fertilization can significantly increase the amounts (Miller, 1979). Results of a compilation (Ryden et al., 1973) of P losses in surface runoff from different production systems in the U.S. from 1953 to 1969 showed that P losses ranging from 0.02 to 2.0 kg/year were found in 22 cases; losses ranging fro[illegible] to 10 kg ha^{-1} year^{-1} were found in 3 cases and losses higher than 10 kg ha^{-1} year^{-1} were found in 1 case. Another literature survey (Sharpley and Menzel,

1987) indicated the same trends for experiments performed from 1975 to 1979. In the majority of cases, P losses from surface runoff alone, fell into the range from 0.02 to 2 kg ha^{-1} $year^{-1}$. Blevins et al. (1990) found P loss values by runoff around 137 g/ha in 8 months, which corresponds to 0.2 kg P/ha/year if extrapolated to 12 months.

Coote et al. (1982) and Miller et al. (1982) calculated the total loads of nutrients for selected watersheds in SW Ontario. These values seem to be the most appropriate to use since they were obtained from the same region in which Oak Manor is located. The values for P found in the study were within the range found by the other authors discussed above. For potassium, there was no results for comparison. The value of Coote et al. (1982) for the Oak Manor area (10.3 kg kg ha^{-1} $year^{-1}$) was used.

Considering that leaching of P is insignificant compared to runoff losses, the average values of P loads from watersheds for the Oak Manor area (Miller et al. 1982), 0.95 kg P ha^{-1} $year^{-1}$ seem to be satisfactory, and was used to estimate the losses of P.

For nitrogen, the average values of N loads of 27.7 kg N ha^{-1} $year^{-1}$ from the same watersheds mentioned for P (Coote et al., 1982) was used.

The results found in the literature are generally from conventional production systems. The primary tillage at Oak Manor, is done mostly by chisel rather than by mouldboard (like the majority of conventional farmers); and the crop rotations at Oak Manor, probably result in less erosion than in conventional farms. Also, most fields are completely level. Chisel ploughing significantly reduced soil loss when compared with mouldboard (Blevins et al., 1990). Therefore, the values for nutrient losses by runoff at Oak Manor are probably overestimated somewhat.

Denitrification:

Due to the lack of specific data on gaseous losses of nitrogen from the area of study and to the large spatial and temporal variability of denitrification rates (Coulborn & Dowdell, 1984; Parsons et al., 1991) it is not possible to infer this parameter accurately. Based on the study of Rheinbaben (1990), denitrification rates in various sites were not more than 10% of the fertilizer inputs. Based on that result, the denitrification was estimated from the levels of nitrate during June (probably the highest of the year). Denitrification is not likely to occur when temperatures are below 5 C (Chalamet, 1985; Rheinbaben, 1990). The average values for June 23, excluding the values found in the garden (Table A9) was transformed into kg N/ha and denitrification was calculated as 10% of this value.

Table A11. Percentages of N, P and K of the farm field products and compost.

		N%	P%	K%
Alfalfa	Biomass[d]	2.95	0.21	1.62
Barley	Straw[a]	0.933	0.105	1.21
	Grain[a]	1.98	0.355	0.576
Buckwheat	Straw	Not harvested		
	Grain[f]	2.3	0.48	0.59
Clover	Biomass[b]	3.6	0.27	1.90
Compost		1.12	0.90	1.11
Corn	Stalk[f]	0.40	0.07	0.39
	Grain[a]	1.37	0.22	0.33
Faba beans	Straw[f]	1.5	0.28	2.1
	Grain[e]	4.0	0.52	1.1
Field peas	Straw[f]	1.1	0.1	1.2
	Grain[f]	4.1	0.55	1.15
Oats	Straw[b]	1.21	0.19	2.68
	Grain[c]	1.95	0.40	1.14
Triticale	Straw	Values for winter wheat were used		
	Grain			
Vegetables[g]	Peas	1.5	0.24	2.3
	Potatoes	0.95	0.20	1.97
Winter wheat	Straw[f]	0.5	0.07	0.67
	Grain[b]	1.46	0.34	0.42

a) Percentages from OM crops in 1988. **b**) Same as a, 1989.
c) Same as b, averages from 1988 and 1989. **d**) Same as a, average of two cuts.
e) From organic farms in P.E.I., (Patriquin et al., 1989). **f**)From National Academy of Science (1971a) **g**)Due to the diversity of the garden, it was assumed that 0.9 ha of potatoes (15000 kg, 23% determined D.M.) and 0.9 ha of fresh pea pods (4000 kg, 13% determined D.M.) were produced. Percentages are from National Academy of Sciences (1971 b).

Table A12. Grain yields and total nutrient (N, P and K) contents for 1987 crops. Yields are based on the values of table A3 and reduced to account for differences between quadrat and combine yields (reduction of 18% for barley, 33% for winter wheat, 36% for triticale and the average value of 29% for others).

Crop		Yields (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Area (ha)
Alfalfa	Hay	6096[a]	179.8	12.8	98.7	7
Barley	Grain	2311	45.7	8.2	13.3	3
	Straw	1850	17.3	1.9	22.4	
Buckwheat	Grain	1077[b]	24.8+	5.2	6.3	5.7 (+6.6)[b]
Clover	Hay	2063[a]	74.3	5.6	39.2	7.8
Corn	Grain	4583[c]	62.8	10.1	15.1	3.7
	Stalks	5224	21.0	3.7	20.4	
Faba	Grains	2457	98.3	12.8	27.0	6.0
	Straw	2160	32.4	6.0	45.4	
Oats	Grains	2362	46.1	9.4	26.9	4.4
	Straw	2199	28.4	4.2	58.9	
Peas	Grains	1449	59.4	8.0	16.7	6.0
	Straw	748	20.3	0.8	9.0	
Triticale	Grains	2346	34.2	8.0	9.8	3.6
	Straw	3588	17.3	1.9	22.4	
Vegetables peas						
	Pods	520	51.7	8.3	79.3	0.9
potatoes	tubers	3450	32.8	6.9	67.9	0.9
Winter wheat						
	Grains	1638	23.9	5.6	6.9	3.0
	Straw	2348	11.7	1.6	15.7	
GRAND TOTAL (kg/total area)			4601	616	2595	53.2

Legend to Table A12

a. Average of the bale weight estimate and the corrected quadrat estimate. **b.** Farmer's estimate. The 6.6 ha corresponds to the cereal area that was planted with buckwheat. **c**. Average of the farmer's estimate and the corrected quadrat estimate.

Table A13. Nitrogen, phosphorus and potassium budgets for the fields under crop production at Oak Manor Farm in 1987.

	N	P	K
		(kg/53.2 ha)	
		MAJOR INPUTS[a]	
Nitrogen fixation	1882.4	-	-
Precipitation	526.7	18.6	53.4
Compost	1120.0	900.0	1110.0
		MAJOR OUTPUTS[a]	
Grain forages, vegetables and straw	4600.7	616.4	2494.9
Leaching and runoff	1474.2	34.58	547.96
Denitrification	428.6	-	-
		DIFFERENCE	
53.2 ha	-2973.7	+ 267.6	- 1979.5
Average/ha	-55.9	+ 5.0	- 37.2

a.See the section "Calculation of the budget" for details on each component.

Comments on the Budget

The amount of compost produced by the farm (100 tonnes of dry compost), if applied at a rate of 10 tonnes/ha/year would be sufficient to cover 10 ha/year (18% of the fields). In other words, a 5.5 year interval would be necessary for a field to receive two compost applications at such rates. If an interval of 2.5 year between applications is to be maintained (as stated as ideal by the farmer), provided the compost production is constant every year, the rate of compost applied should then be, approximately 4.5 ton of dry compost/ha.

Considering that compost is applied to winter wheat and maize (farmer's information), the annual area grown with these crops should be around 10 ha, if the rate of 10 ton/ha is to be maintained. In 1987, 6.7 ha of these crops were grown.

At this level of compost production, it appears that soil phosphorus levels could be maintained. However, the soil audit indicates low levels of available P in most fields. This is an indication that the mobilization of P in the farm is an important factor for the nutrition of the crops. The high pH of the soils must be part of the reason for the low available P values.

The annual deficit of 55.9 kg N/ha, is probably due in part to overestimation of the losses by leaching, runoff and denitrification. Furthermore, possible inputs of asymbiotic and rhizospheric nitrogen fixation were not considered. Symbiotic nitrogen fixation can also be increased in the farm if management practices, such as addition of straw or other high carbon residues as oat hulls (Chapter 3), are adopted. Hence, the total N balance does not seem to be a potential limiting factor at Oak Manor Farm.

The amounts of K in grains, forages and vegetables alone (without considering straw and other outputs) surpasses the K inputs. Potassium emerges as the potentially critical nutrient. This is supported by the results of soil audits (Table A10) and by the results of K fertilizer experiments (Table A14). In the alfalfa field, where responses to K fertilizers occurred, the percentages of K in the tissues was 1.6, below the critical value of 1.7.

Table A14. Effects of K fertilizer (potassium sulphate) application (100 kg K_2O/ha) on different crops.

Crop and measured variable	+ K	- K
Alfalfa, first cut, yield (kg/ha)	3650 +	3160
Alfalfa, second cut, yield (kg/ha)	3200	3000
Alfalfa, %K in first cut tissue§	2.21*	1.61
Alfalfa, %K in second cut tissue	1.8	1.6
Barley, head weight/quadrat in 1988	36.2	34.1
Barley yield in 1989	3388	3320
Corn, fresh weigh of cobs/quadrat	3852+	2783
Rye, %K in grain	0.53	0.53
Rye, grain yield	2311	1745

*, + statistically significant at 5 and 10% probability levels.

§ The critical value for % K in alfalfa is 1.7 %(Ontario Ministry of Agriculture and Food, 1987).

General conclusions:

1. **High levels of soluble N**. Several types of observations (weeds, nodulation, pests, analyses of nitrates) provide indications of excess soluble N in this system. It is not completely clear why this should be, given the apparently modest amounts of compost being applied. The levels of organic matter are not exceptional, but they are not low either. The high levels of mineral N in Oak Manor soils could be related to the removal of straw from the fields. The high levels of nitrogen is a systemic problem and requires systemic solutions. These need to incorporate considerations related to crop rotations, cover cropping, residue management/tillage, the number of animals and how they are fed, and the form of other nutrient additions to the system.

2. **Phosphorus status.** In contrast to N, available P was assessed by soil analyses to be low, but reserve P was high. The budget also showed a slight positive balance for P, which indicates that P is building up. Mobilization of P in the farm, e.g. through biological activity, arises as an important factor for the adequate P nutrition of the crops.

3. **Potassium.** In regard to input/output balances, or potential balances, it appears likely that Oak Manor is in approximate balance with respect to P, and has a sufficient proportion of legumes to satisfy N needs. However, for potassium, there is strong evidence for there being a large annual deficit, and for soil being generally K deficient. Low K could be contributing to other problems, i.e. pests, excess N, low nodulation, etc.

4. **Weeds and pests.** Weed problems in legumes, and pest problems where they exist (aphids, smut), could be related to excess of soil N and low levels of K.

5. **Crop rotations.** The excess of nitrate in the summer, especially in the ploughed fields, could be modified by crop rotations where perennial crops such as clover and alfalfa are grown more often. Another advantage of these perennial forage crops, would be the possibility of the deep roots of these crops bringing into the surface nutrients such as K. The use of winter cereals, such as wheat and triticale would also prevent losses of N during the month of June where highest nitrate levels occur, besides protecting against erosion during the winter.

APPENDIX B

Rainfall data for the study area. Data obtained from the Waterloo/Wellington meteorological station (numbers in parentheses are the percentage of the normal rainfall for each month).

	1987	1988	1989
	mm of precipitation		
Days		MAY	
1-7	0.0	0.0	17.4
8-14	16.8	12.1	17.6
15-21	7.4	35.8	7.6
22-28	4.0	0.2	15.6
29-30	6.2	0.0	30.8
Total May	34.4 (48)	48.1 (67)	89.0 (124)
		JUNE	
1-7	22.6	0.0	28.8
8-14	5.7	0.0	20.2
15-21	4.8	3.6	28.8
22-28	57.2	0.0	0.0
29-31	0.0	0.0	0.0
Total June	90.3 (117)	8.8 (11)	108.4 (141)
		JULY	
1-7	74.0	0.0	0.0
8-14	54.0	34.3	1.2
15-21	22.4	49.8	1.4
22-28	45.0	51.4	19.6
29-30	0.0	87.5	0.2
Total July	195.4 (259)	223.0 (296)	22.4 (30)

	AUGUST		
1-7	89.2	18.5	6.6
8-14	24.6	40.4	11.2
15-21	1.0	2.0	0.8
22-28	8.2	31.4	0.4
29-31	10.0	0.2	0.0
Total August	133.0 (150)	92.5 (104)	19 (21)

APPENDIX C1

Pearson correlation matrix and probability levels for variable measured on the control plots in 6 farms in 1989 (n=6 for all variables except for PDW1 and PFW1 where n=5).

	ACPI	ACPO	ACPT	ALPT	ARB
ACPI	1.000				
ACPO	-0.460	1.000			
ACPT	0.297	0.711	1.000		
ALPT	0.234	-0.671	-0.536	1.000	
ARB	0.521	-0.069	0.340	0.198	1.000
CA1	0.619	-0.042	0.444	-0.419	0.108
CA2	0.269	0.234	0.462	-0.338	-0.507
CLAY	-0.030	0.758	0.792	-0.865	0.261
K1	0.407	-0.397	-0.103	-0.211	0.354
K2	0.775	-0.422	0.161	0.204	0.426
LEN	0.254	-0.552	-0.392	**0.966**	0.397
MG1	**0.973**	-0.376	0.366	0.022	0.468
MG2	0.693	0.055	0.608	0.253	0.417
N1	0.721	-0.297	0.251	-0.364	0.211
N2	0.651	-0.188	0.312	0.088	-0.215
NO	0.185	0.179	0.337	-0.193	-0.553
PDEF	-0.088	-0.701	-0.822	0.647	0.112
PDW1	-0.120	0.470	0.482	-0.557	-0.670
PDW2	0.430	0.272	0.631	-0.594	-0.212
PFW1	-0.805	0.153	-0.335	-0.303	-0.832
PFW2	0.375	0.173	0.482	-0.616	-0.133
PH	-0.312	-0.102	-0.357	0.090	-0.610
PI	0.084	0.797	**0.924**	-0.587	0.398
POT	-0.475	**0.977**	0.675	-0.498	-0.022
P1	0.276	0.447	0.700	-0.862	0.154
P2	0.606	0.412	**0.922**	-0.274	0.388
PRES	0.101	0.350	0.458	-0.747	0.053
PT	0.453	0.567	**0.968**	-0.321	0.455
ROOT1	0.574	-0.452	-0.033	0.725	0.050
ROOT2	0.229	-0.905	-0.791	0.685	0.231
SAND	0.118	-0.351	-0.285	0.883	-0.018
SOIK	0.338	-0.674	-0.457	0.803	0.101
SOIL1	0.127	-0.596	-0.540	0.299	0.254
SOIL2	0.102	-0.516	-0.472	0.043	0.407
SOIMG	0.537	0.174	0.612	0.310	0.515
YIELD	-0.165	0.170	0.051	-0.727	-0.319

	CA1	CA2	CLAY	K1	K2
CA1	1.000				
CA2	0.510	1.000			
CLAY	0.449	0.161	1.000		
K1	0.232	-0.241	0.153	1.000	
K2	0.165	0.144	-0.118	0.653	1.000
LEN	-0.386	-0.443	-0.713	-0.244	0.155
MG1	0.753	0.333	0.136	0.493	0.734
MG2	0.191	0.431	0.031	-0.094	0.640
N1	0.834	0.331	0.325	0.708	0.563
N2	0.592	0.852	-0.134	-0.154	0.391
NO	0.211	**0.933**	-0.023	-0.206	0.277
PDEF	-0.619	-0.682	-0.718	0.366	0.244
PDW1	0.862	**0.948**	0.298	-0.201	0.042
PDW2	0.837	0.862	0.511	0.042	0.170
PFW1	0.488	0.270	-0.038	-0.478	-0.821
PFW2	**0.949**	0.630	0.550	0.099	-0.035
PH	-0.552	0.240	-0.442	0.060	0.226
PI	0.165	0.215	0.835	0.025	0.157
POT	-0.170	0.170	0.639	-0.526	-0.442
P1	0.740	0.392	0.880	0.404	0.150
P2	0.547	0.569	0.546	-0.057	0.409
PRES	0.234	0.246	0.639	0.653	0.438
PT	0.457	0.432	0.651	-0.153	0.242
ROOT1	-0.015	0.354	-0.625	-0.260	0.489
ROOT2	-0.266	-0.599	-0.712	0.465	0.345
SAND	-0.380	-0.007	-0.755	-0.603	0.003
SOIK	-0.453	-0.133	-0.804	0.167	0.624
SOIL1	0.233	-0.562	-0.245	0.213	-0.220
SOIL2	0.053	-0.718	-0.034	0.740	0.148
SOIMG	0.229	0.238	0.100	-0.419	0.216
YIELD	0.622	0.187	0.509	0.197	-0.420

	LEN	MG1	MG2	N1	N2
LEN	1.000				
MG1	0.041	1.000			
MG2	0.301	0.596	1.000		
N1	-0.389	0.852	0.170	1.000	
N2	-0.004	0.642	0.636	0.451	1.000
NO	-0.341	0.204	0.480	0.166	0.774
PDEF	0.561	-0.204	-0.291	-0.229	-0.448
PDW1	-0.668	0.003	0.241	0.211	0.637
PDW2	-0.619	0.569	0.340	0.664	0.737
PFW1	-0.383	-0.805	-0.688	-0.319	0.005
PFW2	-0.604	0.544	0.056	0.723	0.551
PH	-0.121	-0.351	-0.045	-0.253	0.054
PI	-0.434	0.152	0.465	0.103	-0.018
POT	-0.367	-0.438	0.131	-0.455	-0.201
P1	-0.789	0.472	0.086	0.712	0.185
P2	-0.168	0.629	0.828	0.392	0.592
PRES	-0.764	0.254	0.066	0.533	-0.034
PT	-0.167	0.477	0.747	0.243	0.409
ROOT1	0.652	0.406	0.735	-0.033	0.701
ROOT2	0.612	0.130	-0.212	0.076	-0.223
SAND	0.853	-0.094	0.400	-0.534	0.298
SOIK	0.684	0.161	0.386	-0.127	0.189
SOIL1	0.344	0.132	-0.494	0.201	-0.261
SOIL2	0.072	0.151	-0.514	0.364	-0.541
SOIMG	0.451	0.430	0.842	-0.044	0.477
YIELD	-0.733	0.044	-0.603	0.481	-0.038

	NO	PDEF	PDW1	PDW2	PFW1
NO	1.000				
PDEF	-0.451	1.000			
PDW1	**0.917**	-0.720	1.000		
PDW2	0.662	-0.813	**0.999**	1.000	
PFW1	0.109	-0.327	0.287	0.257	1.000
PFW2	0.331	-0.758	0.837	0.910	0.673
PH	0.543	0.376	0.711	-0.152	0.050
PI	0.176	-0.629	0.349	0.382	-0.413
POT	0.146	-0.633	0.395	0.143	0.100
P1	0.183	-0.691	0.522	0.767	-0.033
P2	0.457	-0.723	0.482	0.687	-0.523
PRES	0.283	-0.245	0.474	0.439	-0.287
PT	0.305	-0.758	0.357	0.580	-0.463
ROOT1	0.460	0.126	0.076	0.057	-0.348
ROOT2	-0.478	0.912	-0.706	-0.613	-0.281

	NO	PDEF	PDW1	PDW2	PFW1
SAND	0.109	0.284	-0.212	-0.370	-0.100
SOIK	0.139	0.716	-0.217	-0.435	-0.575
SOIL1	-0.738	0.376	-0.836	-0.304	0.211
SOIL2	-0.758	0.582	-0.720	-0.392	-0.175
SOIMG	0.161	-0.421	-0.039	0.223	-0.474
YIELD	-0.078	-0.431	0.218	0.502	0.757

	PFW2	PH	PI	POT	P1
PFW2	1.000				
PH	-0.433	1.000			
PI	0.224	-0.217	1.000		
POT	0.024	-0.099	0.761	1.000	
P1	0.797	-0.356	0.645	0.275	1.000
P2	0.498	-0.330	0.754	0.398	0.583
PRES	0.307	0.242	0.603	0.192	0.749
PT	0.431	-0.437	0.844	0.567	0.575
ROOT1	-0.167	0.198	-0.238	-0.326	-0.466
ROOT2	-0.480	0.114	-0.722	-0.860	-0.555
SAND	-0.482	0.118	-0.413	-0.158	-0.818
SOIK	-0.627	0.524	-0.425	-0.563	-0.672
SOIL1	0.081	-0.569	-0.607	-0.604	-0.159
SOIL2	-0.097	-0.270	-0.329	-0.586	0.059
SOIMG	0.099	-0.460	0.419	0.290	0.006
YIELD	0.753	-0.327	-0.029	-0.007	0.647

	P2	PRES	PT	ROOT1	ROOT2
P2	1.000				
PRES	0.332	1.000			
PT	**0.969**	0.287	1.000		
ROOT1	0.313	-0.430	0.170	1.000	
ROOT2	-0.595	-0.316	-0.675	0.231	1.000
SAND	-0.056	-0.813	-0.084	0.817	0.279
SOIK	-0.177	-0.238	-0.311	0.737	0.678
SOIL1	-0.477	-0.471	-0.455	-0.183	0.623
SOIL2	-0.490	0.118	-0.480	-0.446	0.700
SOIMG	0.766	-0.305	0.784	0.608	-0.295
YIELD	-0.108	0.294	-0.096	-0.685	-0.280

	SAND	SOIK	SOIL1	SOIL2	SOIMG
SAND	1.000				
SOIK	0.633	1.000			
SOIL1	0.008	-0.076	1.000		
SOIL2	-0.412	0.029	0.746	1.000	
SOIMG	0.517	0.101	-0.198	-0.499	1.000
YIELD	-0.729	-0.791	0.347	0.287	-0.481

MATRIX OF PROBABILITIES

	ACPI	ACPO	ACPT	ALPT	ARB
ACPI	0.000				
ACPO	0.3[illegible]9	0.000			
ACPT	0.567	0.113	0.000		
ALPT	0.655	0.144	0.273	0.000	
ARB	0.289	0.897	0.510	0.707	0.000
CA1	0.190	0.937	0.378	0.408	0.839
CA2	0.607	0.656	0.356	0.512	0.305
CLAY	0.955	0.081	0.060	0.026	0.617
K1	0.423	0.435	0.846	0.689	0.491
K2	0.070	0.404	0.761	0.698	0.400
LEN	0.628	0.256	0.442	0.002	0.436
MG1	0.001	0.462	0.476	0.967	0.350
MG2	0.127	0.917	0.200	0.629	0.411
N1	0.106	0.567	0.631	0.478	0.689
N2	0.161	0.722	0.547	0.869	0.683
NO	0.725	0.735	0.513	0.714	0.255
PDEF	0.869	0.120	0.045	0.165	0.833
PDW1	0.848	0.424	0.411	0.330	0.216
PDW2	0.395	0.602	0.179	0.214	0.687
PFW1	0.100	0.806	0.582	0.620	0.081
PFW2	0.463	0.744	0.333	0.193	0.801
PH	0.547	0.848	0.487	0.865	0.199
PI	0.875	0.058	0.008	0.220	0.434
POT	0.341	0.001	0.142	0.315	0.966
P1	0.596	0.374	0.121	0.027	0.771
P2	0.202	0.417	0.009	0.599	0.447
PRES	0.848	0.496	0.361	0.088	0.921
PT	0.367	0.241	0.002	0.534	0.365
ROOT1	0.233	0.368	0.951	0.103	0.926
ROOT2	0.662	0.013	0.061	0.133	0.660
SAND	0.824	0.495	0.584	0.020	0.973
SOIK	0.513	0.142	0.362	0.054	0.849
SOIL1	0.811	0.212	0.269	0.565	0.626
SOIL2	0.847	0.295	0.345	0.936	0.424
SOIMG	0.272	0.741	0.196	0.550	0.296
YIELD	0.755	0.748	0.923	0.101	0.538

	CA1	CA2	CLAY	K1	K2
CA1	0.000				
CA2	0.301	0.000			
CLAY	0.372	0.761	0.000		
K1	0.659	0.645	0.772	0.000	
K2	0.754	0.786	0.824	0.160	0.000
LEN	0.449	0.378	0.112	0.641	0.770
MG1	0.084	0.519	0.797	0.320	0.097
MG2	0.716	0.393	0.954	0.860	0.171
N1	0.039	0.521	0.530	0.115	0.244
N2	0.216	0.031	0.800	0.771	0.443
NO	0.689	0.007	0.965	0.696	0.595
PDEF	0.190	0.136	0.108	0.475	0.642
PDW1	0.060	0.014	0.626	0.746	0.946
PDW2	0.038	0.027	0.301	0.937	0.747
PFW1	0.405	0.660	0.952	0.416	0.089
PFW2	0.004	0.180	0.258	0.852	0.948
PH	0.256	0.647	0.380	0.910	0.667
PI	0.754	0.683	0.039	0.962	0.767
POT	0.747	0.747	0.172	0.283	0.381
P1	0.093	0.442	0.021	0.428	0.777
P2	0.262	0.239	0.263	0.915	0.421
PRES	0.655	0.638	0.172	0.160	0.385
PT	0.362	0.392	0.162	0.772	0.645
ROOT1	0.978	0.491	0.185	0.618	0.325
ROOT2	0.611	0.208	0.112	0.352	0.503
SAND	0.457	0.990	0.083	0.205	0.996
SOIK	0.367	0.801	0.054	0.752	0.185
SOIL1	0.657	0.246	0.640	0.686	0.675
SOIL2	0.920	0.108	0.949	0.093	0.780
SOIMG	0.662	0.649	0.850	0.408	0.681
YIELD	0.188	0.722	0.302	0.708	0.407

	LEN	MG1	MG2	N1	N2
LEN	0.000				
MG1	0.939	0.000			
MG2	0.562	0.212	0.000		
N1	0.446	0.031	0.748	0.000	
N2	0.995	0.170	0.175	0.370	0.000
NO	0.509	0.698	0.335	0.753	0.071
PDEF	0.246	0.698	0.576	0.663	0.373
PDW1	0.218	0.997	0.697	0.733	0.248
PDW2	0.190	0.238	0.510	0.151	0.095
PFW1	0.525	0.100	0.199	0.601	0.994
PFW2	0.204	0.264	0.916	0.105	0.258
PH	0.819	0.495	0.933	0.628	0.919
PI	0.390	0.774	0.353	0.846	0.974
POT	0.474	0.385	0.805	0.365	0.703
P1	0.062	0.345	0.871	0.113	0.726
P2	0.751	0.181	0.042	0.442	0.215
PRES	0.077	0.628	0.901	0.276	0.948
PT	0.752	0.339	0.088	0.642	0.420
ROOT1	0.160	0.425	0.096	0.950	0.120
ROOT2	0.197	0.806	0.687	0.886	0.671
SAND	0.031	0.860	0.431	0.275	0.566
SOIK	0.134	0.761	0.450	0.811	0.720
SOIL1	0.505	0.804	0.319	0.703	0.617
SOIL2	0.893	0.775	0.296	0.478	0.267
SOIMG	0.369	0.395	0.036	0.934	0.339
YIELD	0.098	0.934	0.205	0.334	0.943

	NO	PDEF	PDW1	PDW2	PFW1
NO	0.000				
PDEF	0.369	0.000			
PDW1	0.029	0.170	0.000		
PDW2	0.152	0.049	0.000	0.000	
PFW1	0.861	0.591	0.640	0.676	0.000
PFW2	0.521	0.081	0.077	0.012	0.213
PH	0.265	0.463	0.178	0.773	0.936
PI	0.739	0.181	0.565	0.455	0.489
POT	0.783	0.177	0.510	0.787	0.872
P1	0.729	0.129	0.366	0.075	0.958
P2	0.362	0.104	0.411	0.132	0.366
PRES	0.587	0.640	0.420	0.384	0.640
PT	0.556	0.081	0.556	0.227	0.432
ROOT1	0.358	0.812	0.903	0.914	0.566
ROOT2	0.337	0.011	0.182	0.195	0.648

	NO	PDEF	PDW1	PDW2	PFW1
SAND	0.837	0.586	0.732	0.471	0.872
SOIK	0.793	0.109	0.725	0.389	0.311
SOIL1	0.094	0.463	0.078	0.558	0.733
SOIL2	0.081	0.225	0.170	0.443	0.778
SOIMG	0.760	0.406	0.950	0.672	0.420
YIELD	0.883	0.393	0.725	0.310	0.139

	PFW2	PH	PI	POT	P1
PFW2	0.000				
PH	0.391	0.000			
PI	0.670	0.680	0.000		
POT	0.963	0.852	0.079	0.000	
P1	0.057	0.489	0.166	0.598	0.000
P2	0.314	0.523	0.083	0.435	0.224
PRES	0.554	0.644	0.205	0.716	0.087
PT	0.393	0.386	0.035	0.240	0.233
ROOT1	0.752	0.706	0.649	0.528	0.352
ROOT2	0.335	0.830	0.105	0.028	0.253
SAND	0.333	0.824	0.416	0.764	0.047
SOIK	0.182	0.286	0.401	0.245	0.144
SOIL1	0.878	0.238	0.201	0.204	0.763
SOIL2	0.855	0.605	0.524	0.222	0.911
SOIMG	0.853	0.358	0.408	0.577	0.990
YIELD	0.084	0.527	0.957	0.990	0.165

	P2	PRES	PT	ROOT1	ROOT2
P2	0.000				
PRES	0.521	0.000			
PT	0.001	0.582	0.000		
ROOT1	0.546	0.395	0.748	0.000	
ROOT2	0.212	0.542	0.142	0.660	0.000
SAND	0.916	0.049	0.874	0.047	0.592
SOIK	0.737	0.650	0.549	0.095	0.139
SOIL1	0.339	0.345	0.365	0.729	0.186
SOIL2	0.323	0.824	0.335	0.376	0.122
SOIMG	0.076	0.557	0.065	0.200	0.570
YIELD	0.838	0.571	0.856	0.134	0.591

	SAND	SOIK	SOIL1	SOIL2	SOIMG
SAND	0.000				
SOIK	0.177	0.000			
SOIL1	0.989	0.886	0.000		
SOIL2	0.417	0.956	0.089	0.000	
SOIMG	0.294	0.849	0.707	0.313	0.000
YIELD	0.100	0.061	0.500	0.581	0.335

LEGEND

ACPI - Soil inorganic P, acid extraction
ACPO - Soil organic P, acid extraction
ACPT - Soil total P, acid extraction
ALPT - Soil total P, alkaline extraction
ARB - % of roots infected with arbuscules
CA1 - % Ca in barley, early stage
CA2 - % Ca in barley, heading
CLAY - % of clay in soil
K1 - % K in barley, early stage
K2 - % K in barley, heading
LEN - Root length
MG1 - % in barley, early stage
MG2 - % in barley, heading
N1 - % in barley, early stage
N2 - % in barley, heading
NO - % roots with no VAM infection
PDEF - Calculated P deficit
PDW1 - Plant dry weight, early stage
PDW2 - Plant dry weight, heading
PFW1 - Plant fresh weight, early stage
PFW2 - Plant fresh weight, heading
PH - soil pH
PI - inorganic P in barley leaves, heading
POT - Soil total organic P
P1 - % in barley, early stage
P2 - % in barley, heading
PRES - Soil P (resin)
PT - Soil total P
ROOT1 - Root P-ase activity, early stage
ROOT2 - Root P-ase activity, heading
SAND - % sand in soil
SOIK - Soil exchangeable K
SOIL1 - Soil P-ase activity, early stage
SOIL2 - Soil P-ase activity, heading
SOIMG - Soil exchangeable Mg
YIELD - Barley grain yield

APPENDIX C2

Pearson correlation matrix and probability levels (n=6) for variables measured on the control plots in the glasshouse experiment.

	ACASE	ALKASE	ARB	CA	DW
ACASE	1.000				
ALKASE	-0.362	1.000			
ARB	-0.318	-0.044	1.000		
CA	-0.365	0.433	-0.031	1.000	
DW	0.750	-0.597	0.200	-0.398	1.000
K	-0.183	-0.382	0.377	0.545	0.278
LEN	0.603	-0.409	0.125	0.139	**0.848**
MG	-0.071	0.146	-0.064	**0.842**	0.073
N	-0.210	0.224	0.352	0.771	0.127
PH	**-0.847**	0.675	0.459	0.600	-0.673
P	-0.054	-0.007	-0.301	0.486	0.149
PRES	0.300	-0.484	-0.717	-0.048	0.234
RASE	0.254	-0.520	0.079	0.324	0.612
RW	0.543	-0.397	0.386	0.074	**0.868**
SOICA	-0.554	0.686	-0.159	0.485	**-0.927**
SOIK	0.577	-0.611	0.161	-0.520	0.460
SOIMG	**0.808**	-0.303	-0.671	-0.032	0.548

	K	LEN	MG	N	PH
K	1.000				
LEN	0.610	1.000			
MG	0.740	0.583	1.000		
N	0.780	0.570	**0.903**	1.000	
PH	0.186	-0.417	0.264	0.481	1.000
P	0.564	0.511	**0.818**	0.648	0.012
PRES	0.186	0.315	0.285	-0.072	-0.608
RASE	**0.862**	**0.873**	0.733	0.661	-0.253
RW	0.607	**0.957**	0.461	0.565	-0.309
SOICA	-0.319	-0.746	-0.041	-0.078	0.654
SOIK	-0.137	0.147	-0.527	-0.499	-0.584
SOIMG	0.027	0.626	0.324	0.010	-0.770

	P	PRES	RASE	RW	SOICA
P	1.000				
PRES	0.656	1.000			
RASE	0.721	0.512	1.000		
RW	0.305	0.055	0.783	1.000	
SOICA	-0.300	-0.416	-0.644	-0.730	1.000

	P	PRES	RASE	RW	SOICA
SOIK	-0.681	-0.150	-0.060	0.269	-0.282
SOIMG	0.466	0.734	0.492	0.414	-0.476

	SOIK	SOIMG
SOIK	1.000	
SOIMG	0.126	1.000

MATRIX OF PROBABILITIES

	ACASE	ALKASE	ARB	CA	DW
ACASE	0.000				
ALKASE	0.480	0.000			
ARB	0.539	0.934	0.000		
CA	0.477	0.391	0.954	0.000	
DW	0.286	0.211	0.704	0.435	0.000
K	0.728	0.455	0.462	0.264	0.593
LEN	0.205	0.420	0.814	0.793	0.033
MG	0.894	0.783	0.904	0.036	0.891
N	0.690	0.669	0.494	0.072	0.811
PH	0.033	0.141	0.360	0.208	0.143
P	0.919	0.989	0.562	0.329	0.778
PRES	0.564	0.331	0.109	0.927	0.655
RASE	0.628	0.290	0.881	0.530	0.196
RW	0.265	0.435	0.450	0.890	0.025
SOICA	0.254	0.132	0.763	0.329	0.008
SOIK	0.231	0.198	0.761	0.290	0.358
SOIMG	0.052	0.559	0.144	0.952	0.261

	K	LEN	MG	N	PH
K	0.000				
LEN	0.198	0.000			
MG	0.093	0.224	0.000		
N	0.067	0.237	0.014	0.000	
PH	0.724	0.411	0.613	0.334	0.000
P	0.243	0.301	0.047	0.164	0.983
PRES	0.724	0.543	0.584	0.892	0.200
RASE	0.027	0.023	0.097	0.153	0.628
RW	0.202	0.003	0.358	0.243	0.551
SOICA	0.538	0.089	0.939	0.883	0.159
SOIK	0.796	0.781	0.282	0.313	0.223
SOIMG	0.959	0.184	0.531	0.984	0.073

	P	PRES	RASE	RW	SOICA
P	0.000				
PRES	0.157	0.000			
RASE	0.106	0.299	0.000		
RW	0.557	0.917	0.066	0.000	
SOICA	0.563	0.412	0.168	0.100	0.000
SOIK	0.136	0.776	0.910	0.606	0.589
SOIMG	0.351	0.097	0.322	0.414	0.340

	SOIK	SOIMG
SOIK	0.000	
SOIMG	0.812	0.000

LEGEND

ACASE - Acid soil P-ase activity
ALKASE - Alkaline soil P-ase activity
ARB - % of roots infected with arbuscules
CA - % Ca in barley
DW - Plant dry weight
K - % K in barley
LEN - Root length
MG - % Mg in barley
N - % N in barley
PH - Soil pH
P - % P in barley
PRES - Soil P_{res}
RASE - Root P-ase activity
RW - Root weight
SOICA - Soil exchangeable Ca
SOIK - Soil exchangeable K
SOIMG - Soil exchangeable Mg

APPENDIX D
TOTAL NUTRIENTS ACCUMULATED BY BARLEY IN 1988

Table D1. Effects of soil treatments on nutrient uptake by barley at the organic farm O1 in 1988 (averages of 6 replicates).

FARM O1					
	N	P	K	Ca	Mg
	Nutrients in barley straw (kg/ha)				
Control	22.2	2.4	29.2	13.5	5.0
Super P	21.7	2.6	29.3	13.7	4.8
RP	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	22.0
	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
RP	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
RP	55.5	8.4	38.9	12.5	6.8
Compost	65.2	9.9	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.

Table D2. Effects of soil treatments on nutrient uptake by barley at the organic farm O2 in 1988 (averages of 6 replicates).

FARM O2					
	N	P	K	Ca	Mg
	Nutrients in barley straw (kg/ha)				
Control	19.5	2.6	46.3	13.7	4.7
Super P	15.8	1.3	35.2	10.5	3.8
RP	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
RP	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
RP	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. Values followed by the same letter in each column are not significantly different (Tukey test $p<0.05$).

Table D3. Effects of soil treatments on nutrient uptake by barley at the conventional farm C1 in 1988 (averages of 6 replicates).

FARM C1					
	N	P	K	Ca	Mg
	Nutrients in barley straw (kg/ha)				
Control	19.7	2.0	43.7	10.3	4.1
Super P	18.8	1.8	40.3	10.6	3.9
RP	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)				
Control	28.3	4.9	7.7	0.9	1.5
Super P	25.6	4.2	6.7	0.8	1.6
RP	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
RP	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. Values followed by the same letter in each column are not significantly different (Tukey test $p<0.05$).

APPENDIX E

DESCRIPTION OF THE FARMS

ORGANIC FARMS

O1 (Reibling's, County Oxford)

The Reibling's family farm - Oak Manor - is the longest standing organic farm in the area. It was converted to organic practices in 1972. Cereals and maize (*Zea mays* L.), legumes like faba beans (*Vicia faba* L.), peas (*Pisum sativum L.),* hairy vetch (*Vicia villosa* Roth) and red clover (*Trifolium pratense* L.), as well as minor crops, such as buckwheat (*Fagopyrum esculentum* Moench) and oilseed radish, are grown 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 (prepared mostly from cattle manure and bedding from crop residues) and green manuring are the only fertilizers currently being used. Compost is used on non-legumes. Legumes are rotated with non-legumes whenever possible. Weeds are controlled by cultivation. Details of the operations and features of this farm can be found on Appendix A.

History of the field used for the experiment:

1987 - Maize with compost (10 t/ha)
1988- Barley

O2 (Pfenning's, County Waterloo)

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 (*Triticum aestivum* L.) 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 since 1982.

<u>History of the field used for the experiment</u>:

As stated above, no fertilization is used on this farm.

1986 - Soybeans
1987 - Cabbage
1988 - Barley

O3 (Bender's, County Perth)

This is the most recently converted farm. Organic management started in 1987. It is similar to O1 but there are more animals, such as pigs, cows, fowl and sheep. Part of the feed is imported from other farms. Compost is used every 2 years on winter wheat (before planting) and on maize in the spring. Fresh manure is used every 2 years on spring grains or on wheat stubble in late summer. The rates of both manure and compost were estimated by the farmer to be a "moderate to heavy". Legumes such as alfalfa and clover are grown. Hay is grown every 3-4 years for a 3 year period. Oilseed radish and buckwheat are also grown as green manures. Tillage is done in the fall, followed by discing (twice) in the spring. The farmer started to compost more manure and has been trying to do less fall ploughing in recent years.

History of the field used for the experiment:

1987 - Barley
Fall plough, manure in September
1988 - Mixed grains (barley + oats)
Fall plough, spring discing and cultivation;
underseeding with sweet clover;

CONVENTIONAL FARMS

C1 (Gingerich's, County Oxford)

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 on a regular basis.

History of the field used for the experiment:

1985-1986 - Maize.
Liquid 9 - 18- 9 fertilizer and manure @ 45,000 l/ha
Atrazine

1987 - Mixed grain underseeded with red clover
Red clover ploughed down in the fall
Manure in the spring - 33,700 l/ha

C2 (Stock's, County Oxford)

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

History of the field used for the experiment:

1987 - Maize

Manure: heavy
Fertilizers (bulk spread)
Urea: 160 kg/ha
11-52-0 fertilizer: 122 kg/ha
potash: 172 kg/ha
6-24-6 liquid fertilizer: 73 kg/ha with seed
28% N solution: 322 kg/ha
Herbicide: atrazine @ 1.4 kg/ha (product) preplant incorporated

1988 - Barley
Urea: 125 kg/ha bulk spread
Potash: 138 kg/ha bulk spread
6-24-6 liquid fertilizer: 73 kg/ha with seed.
Herbicide: none
Tillage (Fall): mouldboard plough
Spring: 1 pass with disc and harrows
1 pass with cultivator and harrows
cultipacker towed behind seed drill

1989 - Barley underseeded to alfalfa/timothy
Fertilizer: none
Herbicide: Butyric 400 @ 1.9 l/ha
Tillage (Fall): 2 cultivations with mouldboard plough
Spring: 2 passes with cultivator and harrows
cultipacker towed behind seed drill

C3 (Cressman's farm, County Oxford)

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.

History of field used for the experiment:

The field has been under continuous maize with fertilizers (various levels) and atrazine for the last 5 years.

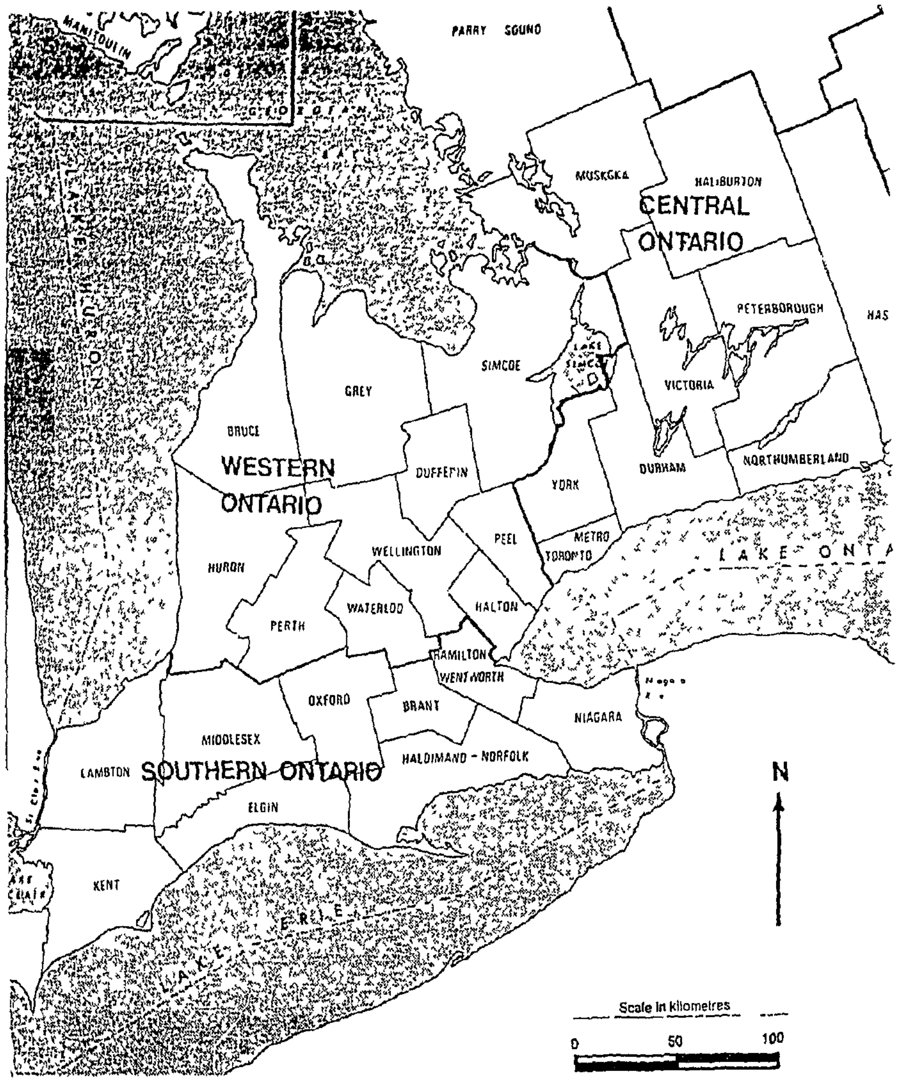

Figure E1. Map of Southwestern Ontario showing the area where the experiments were conducted (boundary of Counties Perth, Oxford and Waterloo).

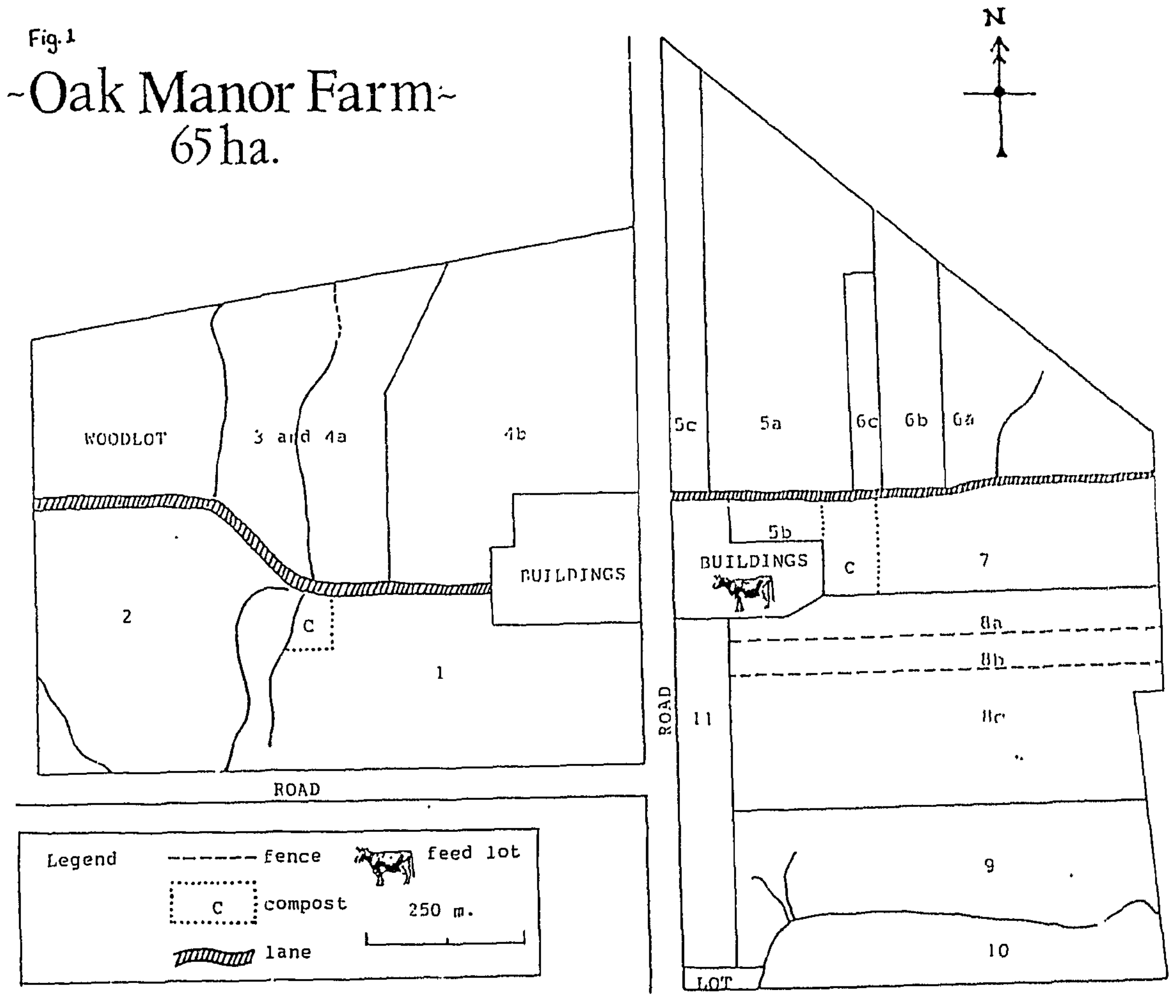

Figure E2. Map of Oak Manor Farm.

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