Proceedings of the

Sanborn Field Centennial

A

celebration of 100 years

of agricultural research

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Those Who Have Contributed Time and Effort

Date	Scientist in Charge	Workers
1888-1889	J.W. Sanborn	
1989-1904	H.J. Waters	M.W. Harper
1905-1917	M.F. Miller	C.A. LeClair R.R. Hudelson R. Carruth
1918-1925	F.L. Duley	R. Carruth
1926-1936	H.H. Krusekopf	R. Carruth L.B. Stuckey N.C. Smith Albert Fulkerson
1937-1942	Geo. E. Smith	N.C. Smith Albert Fulkerson
1943-1948	Wm. A. Albrecht	N.C. Smith Albert Fulkerson
1949-1966	Geo. E. Smith	Theo Dean Milton Brown Earl Calvin
1966-1976	C.M. Woodruff	Theo Dean Earl Barnes
1976-1984	Wm. Upchurch	Earl Barnes
1985-	J.R. Brown	Steve Breight Gary Wyman

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Preface

The planning for the Celebration of the centennial year of operations on Sanborn Field started in 1984 under the leadership of Dr. William Upchurch then director of Sanborn Field and chair of the Sanborn Field Committee. This proceedings is the culmination of that planning in written form.

In January 1985, J. R. Brown, the editor of these proceedings, acquired responsibility for Sanborn Field upon the retirement of Dr. Upchurch. In June 1985, Dean Roger Mitchell obtained funds to send Dr. Brown to the Rothamsted Agricultural Experiment Station for a two week visit to observe operations. A. E. (Johnny) Johnston was host and spent considerable effort explaining both the history and current operations of the Rothamsted Station and its satellite stations. The visits to the classical fields at Rothamsted as well as to Woburn and Saxmundham started to formulate a plan for the Sanborn Field Centennial Celebration.

Upon return to the States, planning started in earnest. This publication is the first of several planned around the 100 years of continuous cropping on Sanborn Field. The authors have spent many hours beyond their regular duty hours acquiring data, analyzing those data, and preparing these manuscripts. The editor takes this opportunity to publicly thank each participant for action above and beyond their regular duties.

Many persons have contributed great effort to Sanborn Field over the century. Those are listed on page ii, which is a copy of material placed upon a plaque awarded to the UMC Agronomy Department by the American Society of Agronomy on June 27,1989. Without the efforts of these persons, it would have been impossible to write the papers devoted to Sanborn Field in these proceedings.

In addition, there are many persons and organizations that have made contributions to the centennial celebration. While it is hazardous to attempt such a list, thanks are due these listed below:

University of Missouri personnel
Steve Breight, Gary Wyman, Paul Koenig
Associate Dean William Pfander (retired),
Dr. Bob Volk, Dean Roger Mitchell, Dr. Wm. Stringer,
Dr. Zane Helsel, Dr. Gary Allee, Jerry Clevenger, Alice
Schawo, Greg Horstmeier, Sam Indorante,
Linda Mann, Carol Smith,Bill Ruppert,
Hal Shaffer, Barb Corwin
John White

Campus Facilities Personnel
Larry Edwards and crew

Governor John Ashcroft (Sanborn Field Week Proclamation)
Senator Roger Wilson, (Proclamation from the State Senate)

Mr. and Mrs. Ted (Pat) Jones

American Cyanamid
Lederle Laboratories - Myrle Myers and Jeff Raser
Agricultural Division - David Butterfield

John Deere Company and Lawn and Leisure,
Greg Hart, C. D. Gough, and Bill Burnett

Fertilizer and Agricultural Limestone Advisory Committees

Missouri Limestone Producers Association
N. A. (Bud) McDonald and Steve Rudloff

Those in attendance were rewarded by having two persons serve as session moderators who had long-term Sanborn Field activity. Dr. George Smith chaired the morning session. Dr. Smith wrote the 50-year summary of Sanborn Field and, except for military service and a short period with Campbell Soup Company, was an active leader of Sanborn Field activities until the 1960's. Dr. C. M. Woodruff, who chaired the afternoon session, has had many projects on Sanborn Field and directed operations during the 1960's and 1970's.

This volume contains papers filling in the details of the oral presentations. Each senior author was asked to contribute a paper. These manuscripts were entered on a word processor and then transferred to the Extension and Agricultural Information Office. Linda Mann and Greg Horstmeier deserve special recognition for typing the manuscript and laying out the publication.

J. R. Brown
9/6/89

The Value of Long-Term Experiments in Agricultural Research

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Introduction

On the occasion of the Centennial of the Sanborn plots, it is appropriate to question the importance of long-term experiments in agricultural research. This question, however, must be considered together with current concerns that intensively managed husbandry systems are putting soil fertility at risk. A fertile soil is one of a country's most important natural resources on which the well being of future generations depends. Fertility develops slowly over many decades but inept management can destroy it rapidly. Small, less obvious, but insidious changes can be equally damaging in the long-term. It is essential then that long-term experiments are made to quantify the effects of man's farming practices and anthropodgenic activities on soil fertility. This paper seeks to expand this last statement with some general comments and more detailed examples. It takes as the rational for long-term experiments that they must: (1) continue to supply data to improve farming practices, (2) become a resource capable of being exploited to better understand plant and soil processes, and (3) allow measurement of long-term changes in soil fertility.

Long-Term Experiments - Some General Features

A long-term experiment must never be allowed to become a fossilized monument to the past achievements of its founders. It can, and must have, a continuing output of valuable data. To achieve this aim, the tenure of the site must be secured to ensure continued input by research workers. The management of the experiment must be flexible and preferably multidisciplinary. This enhances the diversity of the data collected and allows many possible interactions to be explored. Management changes should be made when appropriate to enhance the value of the data base. Care should be taken to measure variable factors if they cannot be controlled.

Yields on the short-term are of considerable importance provided they relate to current farming practices. In the longer-term, their value is in following long-term trends. This is because cultivars change and husbandry may be modified. Rothamsted experience at attempts to assess effects of weather by not changing cultivars over long periods has not been promising. If there is interest in assessing the benefits to be derived from plant breeding programmers by growing cultivars under identical conditions, then it is best to retain a seed bank of old cultivars and make comparisons at appropriate time scales.

The design of long-term experiments should allow for the opportunity to subdivide plots to test treatments which are unlikely to affect soil processes in the long-term. The inclusion of such tests, especially of new agrochemicals, makes the yields of even greater interest to practicing farmers and can often be used as a justification for funding. One of Lawes and Gilberts' major contributions to long-term experimental techniques was to have large plots. These have recently been subdivided to test amounts of nitrogen and weed, disease, and pest control.

Nutrient balances can be prepared from recorded yields if harvested crops are analyzed. Such balances show whether nutrient additions in fertilizers and manures are less than, or exceed, offtakes in harvested produce. Such information can be readily extrapolated to farm practices and inform farmers how to manage their use of fertilizers more efficiently. In addition, if the balance is negative, the ability of the soil to support crop growth can be assessed. If positive, the ability of the soil to retain nutrients in plant available forms can be estimated. Johnston and Poulton (1976) gave examples.

In long- as opposed to short-term experiments, soils under different treatments will be nearer to equilibrium. This applies, for example, to soil organic matter and where reactions between soluble amendments, like phosphorus and potassium, take time to equilibrate within the soil. Such soils are a precious resource. They can be exploited to advance our understanding of soil processes.

Only in long-term experiments can slow changes in soil properties be measured. Examples given below follow such changes over a 20 to 100 year time scale. The longer period is needed to measure the cumulative effects of the small annual atmospheric deposition of pollutants. Accumulation in soil can be measured and effects on crop comparison estimated.

At a time when many farmers are willing to modify their management practices to increase yields, long-term experiments are unlikely to initiate new techniques. However, different management systems incorporated into long-term experiments allow the possibility of offering quantitative explanations of effects which may be observed in commercial practice. This is especially so, for example, of the effect of residue management on soil erosion, of the benefits to be derived from the accumulation of nutrient residues in soil or the differential build up of pest and diseases under different crop rotations. Johnston (1989) gave an example of the latter where pest build up differed under different rotations over more than 20 years and differentially effected the yield of potatoes and sugar beets.

Crop samples taken at harvest should be retained and soil samples should be taken periodically. Lawes and Gilbert did this and the unique archive they started has been much used recently to analyze crops and soils for components like zinc, copper, nickel, and cadmium and polynuclear aromatic hydrocarbons which were not considered in the past century. Retained samples can always be analyzed for other constituents or reanalyzed if analytical techniques improve. For soil samples, it is essential to adhere to an agreed protocol for sampling. On some soils, it is essential to be aware that soil cultivation over many years may move much soil across plot boundaries (Christensen, this conference).

The Rothamsted and Woburn Experiments - The Sites and Soils

Rothamsted farm is about 330 ha at grid reference TL 130 137. It is in a "semi-rural" location about 42 km in a northerly direction from Central London. The immediately surrounding area is primarily agricultural. Woburn Experimental Farm is about 70 ha at grid reference SP 962 360. It is in a rural location lying about 27 km in a north-westerly direction from Rothamsted. The farm is adjacent to the Woburn Abbey Park and the surrounding area is agricultural.

The Rothamsted experiments were started by Lawes and Gilbert from 1843 onwards on silty clay loam soils developed in drift over clay-with-flints which overlies chalk. These superficial deposits were acid but arable soils on the Rothamsted estate were given large dressings of chalk (up to 250 t/ha $CaCO_3$) in the 18th and early 19th centuries. This raised soil pH above 7 and provided a reserve of free $CaCO_3$ which remains in some fields to this day. The current policy is to maintain all soils at, or just above, pH 7 by applying 5 t/ha chalk once in 7 years. Soils under permanent grassland have received the earlier large dressings of chalk and some are now very acid.

The experiments at Woburn were started from 1876 onwards by the Royal Agricultural Society of England (Johnston, 1977). In 1926, the farm and experiments became the responsibility of Rothamsted. The soils at Woburn are sandy loams developed in drift over Greensand. They have probably always been slightly acid and their pH is now maintained at 6.5 to 7.0 by applying 7.5 t/ha magnesium limestone once every 6 years.

Both soils are free draining. In recent years, average annual rainfall has been 700 and 640 mm at Rothamsted and Woburn respectively. The pH values given in this paper were measured in a 1:2.5 soil:water suspension.

Rothamsted - The Broadbalk Experiment

In relation to the rationale set out in the Introduction, I want to discuss first the yields of winter wheat on Broadbalk. Yields until 1967 have been discussed in detail (Garner and Dyke, 1969) and those from 1968 to 1978 by Dyke et al. (1983).

Sustainability of Yields

Figure 1 shows yields of the different cultivars grown since 1843 on both the unmanured plot and that given 144 kg N/ha each year together with PKMg as inorganic fertilizers. Until about 1910, yields on both plots remained relatively constant, They then declined appreciably because of competition from weeds. These had been initially controlled by hand-hoeing but labor was not available to do this during, and after, World War I. After the 1920s, weeds were controlled by fallowing part of each plot in rotation every fifth year (Johnston and Garner, 1969). Yields then recovered to those at the turn of the century. Weedkillers were used for the first time in 1959 and are now used on nine-tenths of the experiment.

Squarehead's Master was grown from the 1890s to 1967 but had become outclassed by newer cultivars well before the 1960s. It was not replaced because of a perceived need for continuity to try to relate the variation in yield from year to year to relatively simple meteorological differences. This could not be done (Yates, 1969).

In 1968, Capelle Desprez was grown for the first time. Yields immediately improved (Figure 1). New cultivars, introduced when appropriate, have yielded even more and the best yields are now larger than the national average yield. Compared with Squarehead's Master, the newer cultivars do not produce more total dry matter. Plant breeding has produced cultivars with improved grain:straw ratios and more photosynthate now goes to grain production.

Throughout the experiment, yields on plots given 144 kg N/ha (with PK fertilizers) and those given 35 t/ha farmyard manure (FYM) annually have been essentially the same. A clear answer to an early fear of practicing farmers, namely could yields be maintained using fertilizers in the absence of organic manures. On this soil, they have been.

Sustainability of yields of winter wheat grown continuously on Broadbalk has been much publicized — not unreasonably. But it is not possible to carry this generalization too far. The same did not happen at Woburn. I doubt if it would have happened in the mid-western states of America. This highlights a major need. There is a requirement for a better national/global coverage of long-term experiments.

Information of Value in Farming Practice

The early results demonstrated the sustainability of yields on this soil when only inorganic fertilizers were used provided that competition from weeds could be minimized. Fallowing one year in five from 1925 to 1968 was successful in controlling weeds (Garner and Dyke, 1969) but was not the best solution economically. Weedkillers, first tested in 1959, now increase yield by as much as 1 t/ha grain where most nitrogen is given. The size of the benefit from using weed killers can only be estimated in long-term experiments where the seed bank in both treated and untreated soils more nearly reflects what will happen in commercial practice.

In 1968, the plots were further divided to compare yields of wheat grown continuously with those after a two-year break (Bawden, 1969). The aim was to estimate the effect of soil bourne diseases on wheat yields and the value of a two-year break from cereals, in controlling such diseases.

Figure 2 gives yields in two periods, 1970-78 cv. Cappelle Desprez and 1979-84 cv. Flanders. There was only a small difference in yield potential between these two cultivars. When both were grown after a two-year break, they invariably yielded more than when grown continuously. Farmers, therefore, would be advised to grow as many first wheats as possible in their rotations.

The nitrogen response curves were very different in the two periods (Figure 2). In the first, there was little response to fertilizer nitrogen above 96 kg/ha on PK fertilized plots and a decrease in yield where 96 kg N/ha was applied to FYM-treated soils. In the second period, there was a much larger benefit from extra nitrogen especially on FYM-treated soils with their additional content of organic matter. The major difference between the two periods was in the regular use of fungicides to control plant pathogens in the second period. Maintaining green leaf area and hence photosynthate supply was important for grain fill. Again, a clear demonstration to farmers of the value of fungicides. A very recent further modification has been to introduce a test of fungicides each year.

Although grain yield on Broadbalk declined with the largest applications of nitrogen, grain percent N did not (Figure 3). This is an important fact for farmers seeking to produce grain of milling quality for bread making.

A Scientific Resource

i) Response of wheat to nitrogen. During 1970-78 winter wheat was grown in four rotations: as a first wheat after a two-year break; as a first wheat after a one-year fallow; as a second wheat after a one-year fallow; and continuously. The four nitrogen response curves were very different and the differences were difficult to explain (Figure 4a). This was because there seems to be no biochemical or physiological reasons why wheat should not respond in only one way to nitrogen. Dyke et al. (1983) described how by suitable horizontal and vertical shifts the peer curves were brought into coincidence; (Figure 4b) — the response to nitrogen was the same. The reason for the different curves for the four crops was because of the different amounts of available soil nitrogen (horizontal shifts) and other factors (vertical shifts). The latter probably included the effects of soil bourne pathogens and different amounts of foliar pathogens when fungicides were not used regularly.

ii) Effects of soil organic matter. Figure 2 shows that there was a response to nitrogen during 1979-84 on both fertilizer and FYM-treated soils, for both wheat grown continuously and after a two-year break. (In 1979, the rotation with fallow was abandoned and a five-year rotation was introduced together with continuous wheat. The rotation was a two-year break followed by three wheat crops. Yields of second and third wheats can now be compared with those of continuous wheat to see whether soil bourne pathogens are more damaging after a two-year break than in continuous wheat.)

Again the yields of the two crops grown on fertilizer-treated plots could be brought into coincidence (Figure 5a) and using the same curve letting function a response curve to nitrogen on FYM-treated soils was produced (Johnston, 1987). The two curves in Fig. 5a were then brought into coincidence by the shift shown by the arrow (Figure 5b). This diagonal shift could be resolved into vertical and horizontal components. The FYM-treated soils contained about 2.5 times as much organic matter as fertilizer treated soils as a consequence of applying 35 t/ha FYM each year during more than 130 years. The horizontal and vertical components of the shift in Figure 5b indicate that the extra organic matter was benefiting yields by the equivalent of 69 kg/ha nitrogen and by an unexplained benefit equivalent to 1.39 t/ha grain. The latter could have been because of improved soil physical conditions or the availability of nitrate mineralized from organic matter and released at times or positions in the soil profile which could not be initiated by a single application of fertilizer nitrogen in the spring.

Such results pose challenges to research workers to provide explanations.

iii) The value of having soils in equilibrium. In many regions with intensively managed agricultural systems, fertilizer nitrogen inputs have increased especially in the last 20-30 years. At the same time, there have been reports of increasing amounts of nitrate-nitrogen in potable waters. The latter has been a cause for concern and the increasing nitrate concentrations have been linked simplistically and directly with the increased use of nitrogen fertilizers. But is this correct?

For long we have calculated the apparent percentage recovery of a nutrient applied at A kg/ha as:

$$\frac{\textbf{amount in crop given A - amount in crop not given A x 100}}{\textbf{A}}$$

Table 1 gives four examples from experiments made on wheat at Rothamsted.

Apparent percent of recovery was much the same in experiments 1, 2, and 3 although yields varied from 6.8 to 11.1 t/ha grain. The very small recovery in experiment 4 was related both to the small yield and much nitrogen being available from the soil. In fact, soil nitrogen supply varied considerably, from 23 to 96 kg N/ha. For all but experiment 2, the total amount of nitrogen removed in the crop was equal to, or exceeded, that applied as fertilizer. Such data, therefore, do not readily identify the source of nitrate at risk to loss by leaching to potable waters.

In Britain, modellers at the Water Research Center use average percent recoveries of nitrogen by different crops in rules for predicting nitrate loads in potable waters. This seemed unreasonable and led to research described below.

An important feature of the Broadbalk experiment is that the soil organic matter content of many plots is at its equilibrium value, annual inputs are balanced by losses on average. This allowed us to do 15_N experiments on subplots over a number of years in the near certain knowledge that mineralized nitrate from soil organic matter would not vary appreciably from year to year (Powlson et al., 1986). Crops and soils were sampled immediately after harvest and the distribution of labelled nitrogen from the fertilizer dressing is shown in Table 2. Lost nitrogen had to be estimated by difference because denitrification and leaching could not be measured directly. However, most of the loss was probably by denitrification if it was a soil-based process because the nitrogen fertilizer was not applied until mid-April when the soils were no longer at field capacity and any rainfall was unlikely to result in through drainage. The other, speculative, source of loss was as ammonium nitrogen from the standing crop.

Fertilizer-derived nitrogen in soil was found in various fractions (Figure 6) but less than 2% of the applied nitrogen was there as free nitrate. This finding has been confirmed for other experiments (Macdonald, 1989).

The appearance of much nitrate in soil during the 4 to 6 weeks following cereal harvest suggests that this nitrate, which is at risk to loss by leaching as the soil wets up, has come from the mineralization of soil organic nitrogen. Such a process would be difficult to control. The suggestion that the increasing use of nitrogen fertilizers has directly increased the amounts of nitrate in soil in autumn is no longer tenable.

The Broadbalk results add further insight to the complexity of the various soil processes involved in the nitrogen cycle. Table 3 shows the apparent percent of recovery of different amounts of fertilizer nitrogen by wheat crops grown in different periods. Apparent percent of recoveries have increased appreciably because new cultivars with improved grain:straw ratios remove more nitrogen in grain. However, in each period, the recovery of each amount of applied nitrogen varies little. This implies some consistent loss mechanism, perhaps denitrification but more probably competition for nitrate by the soil microbial biomass responding to the input of carbon to the soil via the roots. It should be obvious, therefore, that decreasing nitrogen inputs will lessen the amount of nitrogen unaccounted for at harvest but this will lead to a yield penalty.

Assessing Long-Term Changes in Soil Fertility

Long-term experiments with control treatments, i.e. those receiving no purposeful inputs, are often the only way of detecting the accumulation of atmospheric inputs. Johnston (1990) gave examples of the effects of acidifying inputs on tree growth and comparison of mixed deciduous woodland. The effect of the acidity on the "natural" accumulation of nitrogen, carbon, phosphorus and sulfur in the soil was also discussed.

Selected samples of the archived crops and soils taken since the start of the Broadbalk experiment have recently been analyzed for their cadmium content (Jones et al., 1987) and polynuclear aromatic hydrocarbons (PAHs) content (Jones et al., 1989a). Figure 7a shows changes in cadmium and Figure 7b changes in PAH burden in the unmanured plot. The amount of both pollutants has increased appreciably since the 1940s and 1950s for cadmium and PAHs, respectively. Figure 7a also shows that the changes in soil cadmium concentrations compared well with predicted increases in plough layer cadmium burden based on assumptions about temporal trends in atmospheric cadmium emissions. The increase in PAH content probably arises from increases in the low temperature combination of organic compounds.

The data clearly indicate the difficulty of defining accurate background levels of such pollutants. It is only with such data derived from archived soils that much of the present pollutant burden can be ascribed to man's anthropodgenic activities over the last 40-50 years.

Analysis of archived grain samples indicates that little of these pollutants are found in the grain and there is little change with time. However, similar data are available for the herbage samples taken from the Park Grass experiment. This experimental site has been in undisturbed grassland for at least 300 years and under experimental treatments for the last 130 years. The concentrations of both cadmium and PAHs are much larger than in the grain samples. This could be surface contamination in part, but wherever located, these pollutants will be a source of dietary intake for grazing herbivores. (See Jones and Johnston, 1989b for Cd and Jones et al. 1989c for PAHs.)

Rothamsted and Woburn - Changes in Soil Organic Matter

Assessing Long-Term Changes in Soil Fertility

It is now generally accepted that the amount of soil organic matter moves towards an equilibrium value that depends on: (1) the rate of turnover of existing soil organic matter; (2) the input of fresh organic matter and its rate of turnover; (3) soil texture; and (4) climate. Figures 8 and 9 show how slowly these changes occur under temperate climatic conditions.

Figure 8 shows changes in soil carbon during 130 years on four differently treated plots in the Hoosfield Barley experiment. This experiment was started in 1852 on an old arable soil. Where the soil has been unmanured or received NPK fertilizers, soil carbon has been in equilibrium for the last hundred years. There is more organic matter in the soil given NPK fertilizers than in that which has been unmanured because larger crops are grown and the quantity of residues returned each year is larger. Where FYM (35t/ha) has been applied each year, soil organic matter is still increasing albeit slowly now. Equally striking is the slow decline in soil organic matter on the plot given FYM for the first 20 years and none since. After more than 100 years, the amount of organic matter has not declined to that in the soil given NPK fertilizers (Jenkinson and Johnston, 1977).

The sandy loam soil at Woburn contained more organic matter where experiments were started in 1976 (Figure 8) than did the soils under long-term experiments at Rothamsted. This was because they had had a long period in grassland. However, under all arable cropping and manuring treatments tested (FYM applied every year was not a treatment), soil organic matter declined (Mattingly et al., 1975). An equilibrium value has apparently not yet been reached and even the present amount of organic matter is much less than that in the silty clay loam at Rothamsted. The effect of soil texture is clearly apparent.

Difficulties in building up soil organic matter on light-textured soils are also seen in Figure 9. There is now more organic matter in soils under a five-year crop rotation, which consisted of a three-year hay followed by two arable crops, one of which received 37.5 t/ha FYM. However, even after seven cycles of this rotation, the soil still contains less organic matter than does a soil in continuous arable crops at Rothamsted. In the Patter soil, the organic matter content has remained approximately constant during 30 years.

Where plots were put down to permanent grassland at the start of the experiment, soil organic matter has increased only slowly. Even after 30 years, the quantity is still much less than that in soil which has been in permanent grassland for at least 200 years. Old grassland soils ploughed out at the start of the experiment, and kept in continuous arable cropping since, have slowly lost organic matter over the 30-year period. Although the rate of loss is slow, the amount of nitrogen lost is large. During the first 20 years, the average annual rate of loss was 120 kg N/ha. In Britain, such large losses of nitrogen, probably as nitrate, could well explain the increases in nitrate in potable waters. Much old grassland was ploughed to grow arable crops in the 1940s, 1950s, and at a rate of water movement to the saturated zone in the aquifers of between 0.5 and 1.0 meter each year, it could take 20 to 30 years for this nitrate to begin to appear in abstracted water.

A Scientific Resource

Data from long-term experiments like those shown in Figures 8 and 9 have been used by Jenkinson and his co-workers to model the rate of turnover of organic matter in the soil (Jenkinson et al., 1987). For the Broadbalk experiment, the fitted model for the change in organic nitrogen is in good agreement with the observed values (Figure 10) and the authors showed other good fits in their paper. Data from other long-term experiments under different climatic conditions and farming systems is now required to extend the applicability of the model. For example, Jenkinson and Aryanaba (1977) showed that the decline of 14C labeled plant material followed the same decay curve provided that the time scale was adjusted to allow for the more rapid decay at higher temperatures.

Information of Value in Farming Practices

The changes in soil organic matter discussed above are of interest scientifically but farmers would wish to know whether the organic matter content of the soil is important as far as yield is concerned. Because soil organic matter changes so slowly, long-term experiments are needed to get plots with different levels of organic matter.

Table 4 shows the yields of potatoes and sugar beet roots on two silty clay loam soils at Rothamsted. The soil treated with FYM since 1843 contained about 4.3% organic matter; the two soils receiving inorganic fertilizers had about 1.7% organic matter. Irrespective of the amount of nitrogen applied, the yields were always large on the soils with organic matter.

Table 5 shows yields of potatoes, spring barley, and winter wheat on the sandy loam at Woburn. For potatoes and spring barley, there was a positive interaction between soil organic matter and fertilizer nitrogen. The largest amount of nitrogen was not justified at the lower levels of soil organic matter. Winter wheat, however, did not apparently benefit from the extra organic matter nor did it respond to the largest amount of applied nitrogen.

The most probable reason for this is that autumn sown crops produce an extended root system capable of exploiting the deeper subsoil for water during periods of summer drought. Shallow rooted, spring sown crops are more dependent on water in the surface horizons and extra organic matter will help retain extra moisture.

Other examples of the benefits of extra organic matter were given by Johnston (1986). All point to the need for farmers to attempt to maintain soil organic matter levels wherever possible. If this is difficult, then they should consider adjusting the amounts of nitrogen that they use and relate them to the yield potential of the soil.

Saxmundham - Soil Phosphorus

Saxmundham Experimental Station is approximately 177 km east of Rothamsted in a rural situation (grid reference TM 361639). Experiments were first started there in 1899 by East Suffolk County Council and the Station has been run by Rothamsted since 1965 (Johnston, 1987). The soil is a slowly permeable, sandy clay loam which is underdrained with tiles.

The Rotation I experiment, testing rates and times of applying superphosphate and FYM to a Norfolk 4-course Rotation, was started in the first year. By 1965, the treatments had built up four different amounts of bicarbonate-soluble P in the soils. During the next four years, these were increased to eight different amounts by applying further dressings of superphosphate and FYM to four large plots.

As in many of the older experiments, the plots were large and in 1969, each was split into 20 subplots in four groups of five. Potatoes, barley, sugar beets, and barley were grown in rotation on each group of five plots. Within each group of five, those subplots received three amounts of freshly applied superphosphate while two received no new P. The nil plots allowed the relationship between yield and bicarbonate-soluble P in soil to be explored (see Johnston et al., 1985).

Information of Value in Farming Practices

Figure 11 shows the yields of potatoes (Figure 11a) and sugar (from sugar beets) (Figure 11b) related to the level of bicarbonate-soluble P in soil. For both crops, yields differed by a factor of two during the six year period. However, this did not affect the level of bicarbonate-soluble P at which yields approached the asymptote.

Figure 12 shows that where different amounts of nitrogen were applied to winter wheat, they also did not affect the level of bicarbonate-soluble P above which the rate of increase in yield declined appreciably. The small increases in yield of wheat above about 10 mg/kg soluble P would not justify on economic grounds adding superphosphate to raise soluble P levels and hence yield. However, they do justify a manuring policy which assured an adequate positive phosphorus balance which would increase soluble P slowly.

The fact that the major inflection in the response curves always occurred at the same level of soluble P, irrespective of the yield potential of the season, mainly governed by rainfall, encouraged us to test rotational versus annual phosphate manuring. This can offer a cost savings to the farmer and, for winter sown cereals, can allow earlier drilling within a preferred window of soil conditions. Figure 13 shows yields of spring barley grown as a first and second cereal after either potatoes or sugar beets.

The root crops and barley received either no new P or the root crops received 82 kg P/ha and the following barley none (rotational manuring) or the root crops and both barley crops received 27 kg P/ha (annual manuring). At the lower levels of soluble P, annual applications of phosphate always gave larger yields than where rotational manuring was practiced.

At higher levels of soluble P, both rotational and annual manuring maintained soluble P levels above those at which a response to phosphate would have been expected and the same yield was obtained with all three treatments.

The data in Figure 13 also show another result which can only be obtained from long-term experiments. This is the benefit to be gained from increasing soluble P and K residues in soil to a level above which a response to a fresh dressing is unlikely. Adding a fresh dressing of phosphate to soils with least soluble P did not increase yields to those grown on soils with adequate phosphate reserves. This has been found also in many other experiments and is of vital importance to practical farming but it required long-term experiments to demonstrate it (Johnston et al., 1970; Johnston et al. 1985).

Assessing Long-Term Changes in Soil Fertility

Figure 14 shows how bicarbonate-soluble P in the soils of the experiment described above changed with time when no fresh phosphate was applied. Over the 16 year period, the rate of decline varied with the starting level of soluble P and it was possible to estimate rates of change towards the inflection point values shown in Figures 11 and 12.

A Scientific Resource

The overall picture of declining soluble P in soil in Figure 14 invited attempts to produce a unified curve for the rates of change of soluble P with time. Figure 15 shows that suitable horizontal shifts brought the eight individual curves into coincidence. This gave a picture of the rate of decline in soluble P over a 50 year period in soils which were cropped annually but received no new fertilizer phosphate. From the curve in Figure 15, it was possible to calculate a half life of 9 years for the soluble P in this particular soil. The number of years during which a soil of known P status can now supply P before reaching the inflection point values in Figures 11 and 12 can now be predicted.

A full P balance was also prepared for this experiment (Table 6). It is possible to convert concentrations of soluble P in mg/kg to amounts per hectare because soil weights to plough depth have been determined accurately. The offtake of phosphorus in the harvested crops have much exceeded the decline in soluble P. That is, non-soluble P reserves have buffered phosphorus offtakes very effectively. Similar results for both phosphorus and potassium have been given by Johnston and Poulton (1977).

Need for Additional Long-Term Experiments

As funding for agricultural research becomes scarer and long-term experiments more expensive, funding sources look at the need to maintain existing experiments more closely and are apprehensive about starting new ones. There appears to be a belief that short-term experiments will suffice. This is a fallacy clearly demonstrated above. There is a need for new experiments on well selected sites with carefully considered treatments.

Johnston (1989) gave an example of how acidifying inputs to soils under deciduous woodland on sites only 2 km apart gave soils with very different pH values after 100 years. This was because of the presence of free calcium carbonate in one soil. He also showed how the difference in acidity affected not only the rate of tree growth and composition of the stand but also the rate at which carbon, nitrogen, phosphorus, and sulphur accumulated in the two soils.

A further example concerns the effect of ammonium sulfate on the yields of winter wheat and spring barley at Woburn and Rothamsted. After the first 15 years or so of growing wheat and barley continuously at Woburn, yields of barley but not of wheat began to decline (Table 7). The beneficial effects of nitrogen in ammonium sulfate were negated by the acidifying effects of this fertilizer and barley was more sensitive to pH than wheat. At Rothamsted, it took more than 100 years of annual applications of the same quantity of ammonium sulfate to sufficiently acidify the soil to affect yields of spring barley. These differences between the soils were due to differences in soil texture and the pH of the soils at the start of the experiment.

Such observations underline the risk of making generalizations from very limited data sets.

While some would suggest that modelling can overcome many of these problems, this is a fallacy. A model is only as good as the data used to generate and then validate it. While not undervaluing the power of models, they have to be very good if they are going to describe on a global basis the underlying chemical, physical, and biological processes taking place in soil and the complexity of their interactions.

Conclusions

To provide a summary of this paper is impossible because it is itself a summary of some aspects of the many hundreds of researchers — years of work done on the long-term experiments at Rothamsted. The paper does, however, give examples to support the rational for long-term experiments set out in the Introduction. Namely, that such experiments should: 1) continue to supply data of value to improve farm practices; 2) be a precious resource capable of being exploited to better understand plant and soil processes; and 3) allow slow changes in soil fertility to be quantified. Hopefully, the examples will be useful illustrations for those planning and seeking funding for long-term experiments.

The need for quantitative data that can only be provided by a long-term commitment to research has been highlighted recently by a spate of papers in the professional/popular press. They discuss such subjects as global warming, the greenhouse effect, effects of soil erosion on the yield potential of soil, and effects of organic farming. In many cases, predictions are based on the scantiest of data bases. There is always scope for different interpretations of well-founded data, especially that for complex biological and physio-chemical processes like those occuring in soil. The thought that today many researchers are trying to infer data, then model it and make global predictions is frightening in the extreme. It does little to enhance the reputation of scientific disciplines.

At a time of perceived surplus of some foodstuffs in many developed countries, agriculture does not have a very high profile. Some husbandry systems are even accused of degrading soil and damaging the environment. However, results given here show that man's anthropodgenic activities produce pollutants which are accumulating in the soil. All of those who profess to be interested in our ecosystem, from whatever point of view, should unite to seek funding for multidisciplinary research programs, in which long-term experiments, providing quantitative data, will be the core. An understanding of the processes affecting plant growth and soil fertility is essential if future generations are to make the correct management decisions to provide both food and a pleasant environment in which to live.

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Table 1. Apparent percentage recovery of nitrogen fertilizer by winter wheat grown in four experiments at Rothamsted.

Experiment Number	Applied Fertilizer N	Yield Grain	N Uptake by Crop		Apparent N Recovery
			With N	Without N	
	kg/ha	t/ha	kg/ha	kg/ha	%
1	192	8.19	186	50	71
2	192	7.69	156	23	69
3	175	11.07	217	96	70
4	150	5.22	150	86	43

Table 2. Percentage distribution at harvest of fertilizer-derived nitrogen applied at 144 kg N/ha labelled with 15N, Broadbalk, Rothamsted.

	Fertilizer Nitrogen In			
Year	Grain	Straw	Soil	Unaccounted For
		%		
1980	55	13	17	15
1981	37	16	20	27
1982	45	23	24	8
1983	44	13	16	27
Mean	45	16	19	19

Adapted from Powlson et al., 1986.

Table 3. Apparent percentage recovery of fertilizer nitrogen applied to winter wheat grown continuously on Broadbalk, Rothamsted.

		N Applied		
Period	48	96	144	192
		Apparent % Recovery		
1852-71	32	33	32	29
1966-67	32	39	36	-
1970-78	56	63	59	52
1979-84	69	83	76	69
1985-87	67	77	67	57

Table 4. Effect of extra organic matter in a silty clay loam and in the presence of similar amounts of readily soluble phosphates and potassium. Rothamsted 1968-73.

		N Applied (coded)†			
Crop	% Soil Organic Matter	0	1	2	3
		t/ha			
Barley	4.7	4.6	6.0	5.9	6.1
grain	1.7	1.6	3.8	5.1	5.6
Sugar Beets	4.7	27.4	44.0	48.2	49.0
roots	1.7	15.5	26.7	39.0	45.5
Potatoes	4.7	25.0	36.0	45.7	41.0
tubers	1.7	11.5	21.5	30.0	36.2

† N applied (coded)

Crop	0	1	2	3
	kg/ha			
Spring Barley	0	48	96	144
Potatoes	0	72	144	216
Sugar Beets	0	72	144	216

Table 5. Effect of soil organic matter on the yields of potatoes, spring barley, and winter wheat on a sandy loam soil. Woburn

Crop	% Soil Organic Matter	N Applied(coded)†			
		0	1	2	3
		t/ha			
Potatoes	3.5	28	40	50	61
tubers	1.2	24	33	44	41
Spring barley	3.4	2.6	5.1	6.9	7.8
grain	1.2	2.5	5.0	6.7	7.1
Winter wheat	3.4	4.8	7.2	8.1	8.1
grain	1.2	3.5	7.3	8.1	7.8

† N applied (coded)

Crop	0	1	2	3
	kg/ha			
Potatoes	0	100	200	300
Spring barley	0	50	100	150
Winter wheat	0	50	100	150

Table 6. Relationship between P balance and decline in $NaHCO_3$-soluble P in an experiment on a sandy clay loam. Saxmundham 1969-82.

NaHCO-soluble P mg/kg 1969	3	7	21	28	39	44	54	67
P removed in crops kg/ha 1969-82	94	153	217	237	253	256	263	263
Decrease in soluble P kg/ha 1969-82	8	12	27	50	65	78	87	120
Change in soluble P as a % of crop uptake	8	8	12	21	26	30	33	46

Table 7. Effect of increasing acidity, from the use of ammonium sulphate, on the yield of spring barley and winter wheat grain t/ha, on a sandy loam soil. Woburn 1877-1906.

Treatment	1877-86	Period 1887-96	1897-1906
		t/ha	
Spring barley*			
Ammonium sulphate	2.57	2.10	0.44
Sodium nitrate	2.73	2.42	2.14
Unmanured	1.33	1.03	0.82
Winter Wheat			
Ammonium sulphate	2.04	1.94	1.68
Sodium nitrate	2.12	1.94	1.67
Unmanured	1.11	0.93	0.78

*Both nitrogen fertilizers supplied the same amount of nitrogen and were applied with PK fertilizers.

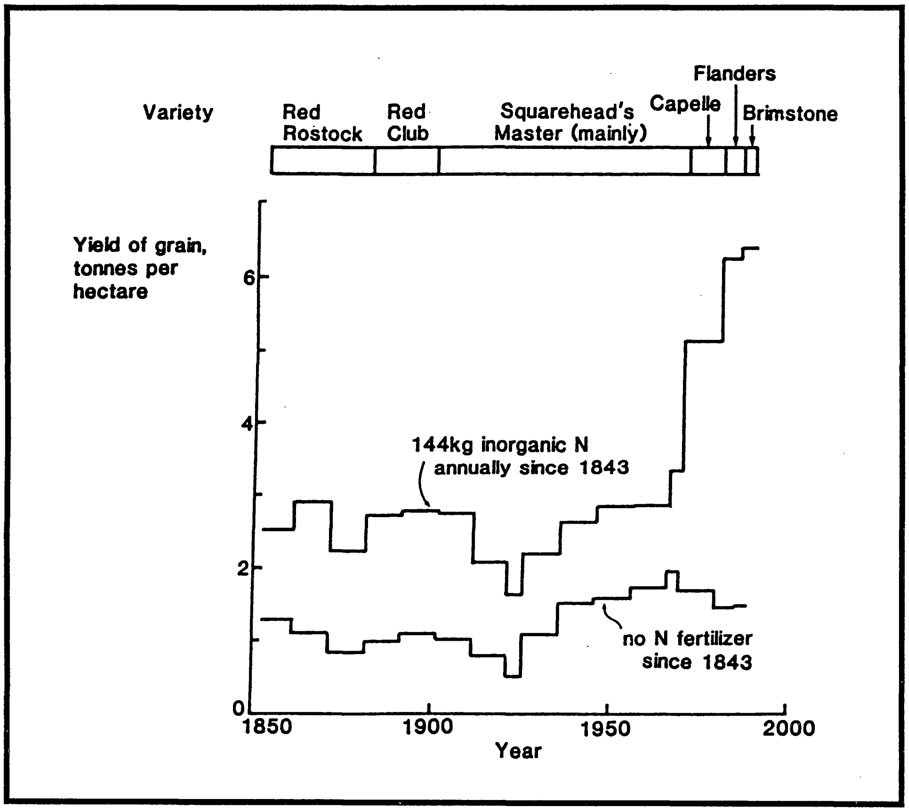

Figure 1. Change with time in the variety of winter wheat grown and the yield of grain on two plots which both receive phosphorus, potassium and magnesium and are limed regularly, one with 144 kg N/ha each year, one without nitrogen on the Broadbalk experiment at Rothamsted.

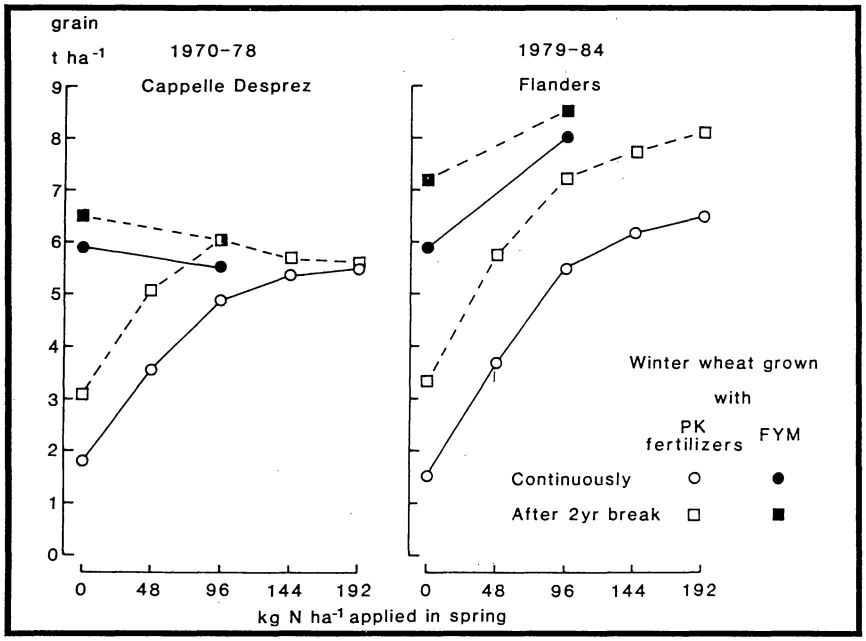

Figure 2. Average yields of winter wheat, grain t/ha, grown in 1970-78 and 1979-84 on Broadbalk at Rothamsted.

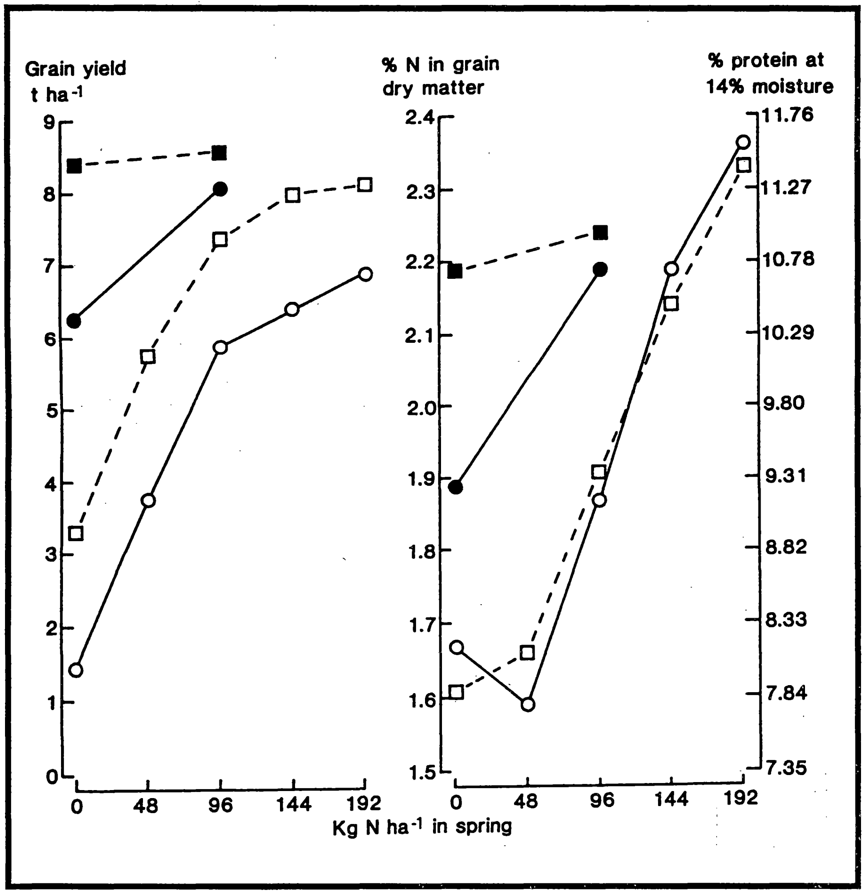

Figure 3. Effect of nitrogen on yield and on the nitrogen and protein concentration in winter wheat grain on Broadbalk at Rothamsted, 1979-84. Wheat grown continuously is represented by circles, wheat after a two-year break by squares. Open symbols fertilized with nitrogen, closed symbols with farmyard manure.

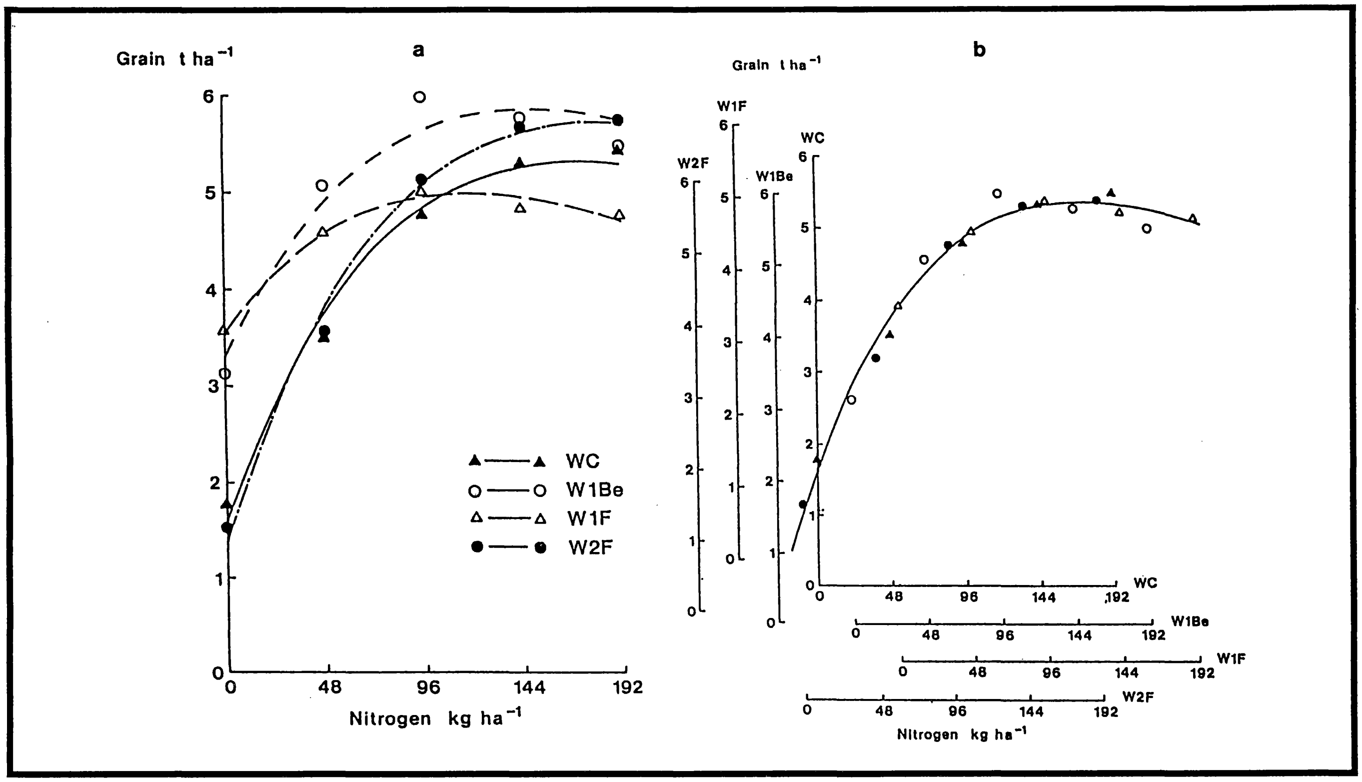

Figure 4. Effect of nitrogen on yields of winter wheat grown in four rotations: i) Continuous wheat (WC), ii) Wheat after beans (WI Be), iii) First wheat after fallow (WIF), iv) Second wheat after fallow (W2F) grown on Broadbalk at Rothamsted 1970-78. Figure 4a: mean resonse to nitrogen in each rotation. Figure 4b: Four curves in 4a brought into coincidence by suitable horizontal and vertical shifts.

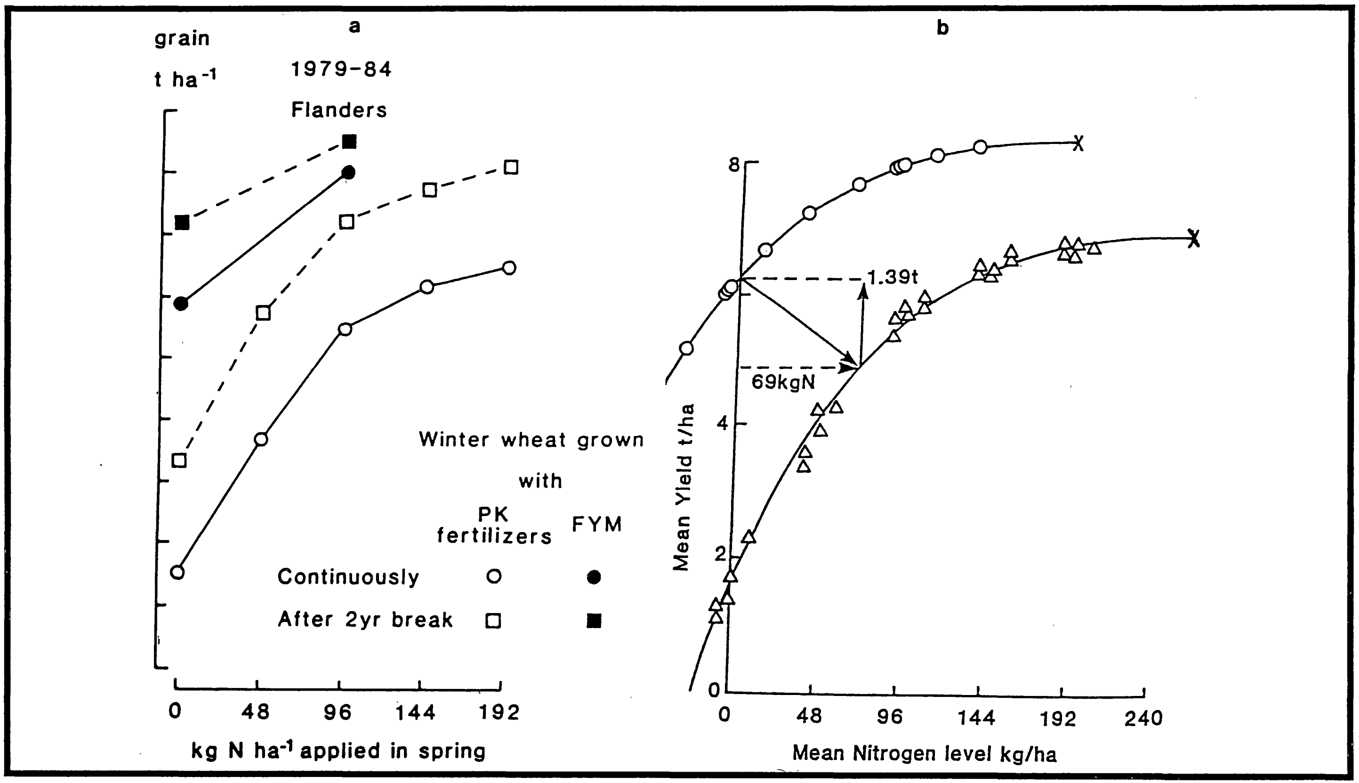

Figure 5. Effect of extra organic matter in soil from annual applications of FYM on the response to nitrogen by winter wheat grown on Broadbalk at Rothamsted. Figure 5a: Average response over 6 years on plots with FYM (solid symbols) and without FYM (open symbols) and in rotation (squares). Figure 5b: Annual response curves on soils with FYM (circles) and without FYM (triangles) brought into coincidence and the horizontal and vertical components of the shift required to bring these curves into coincidence.

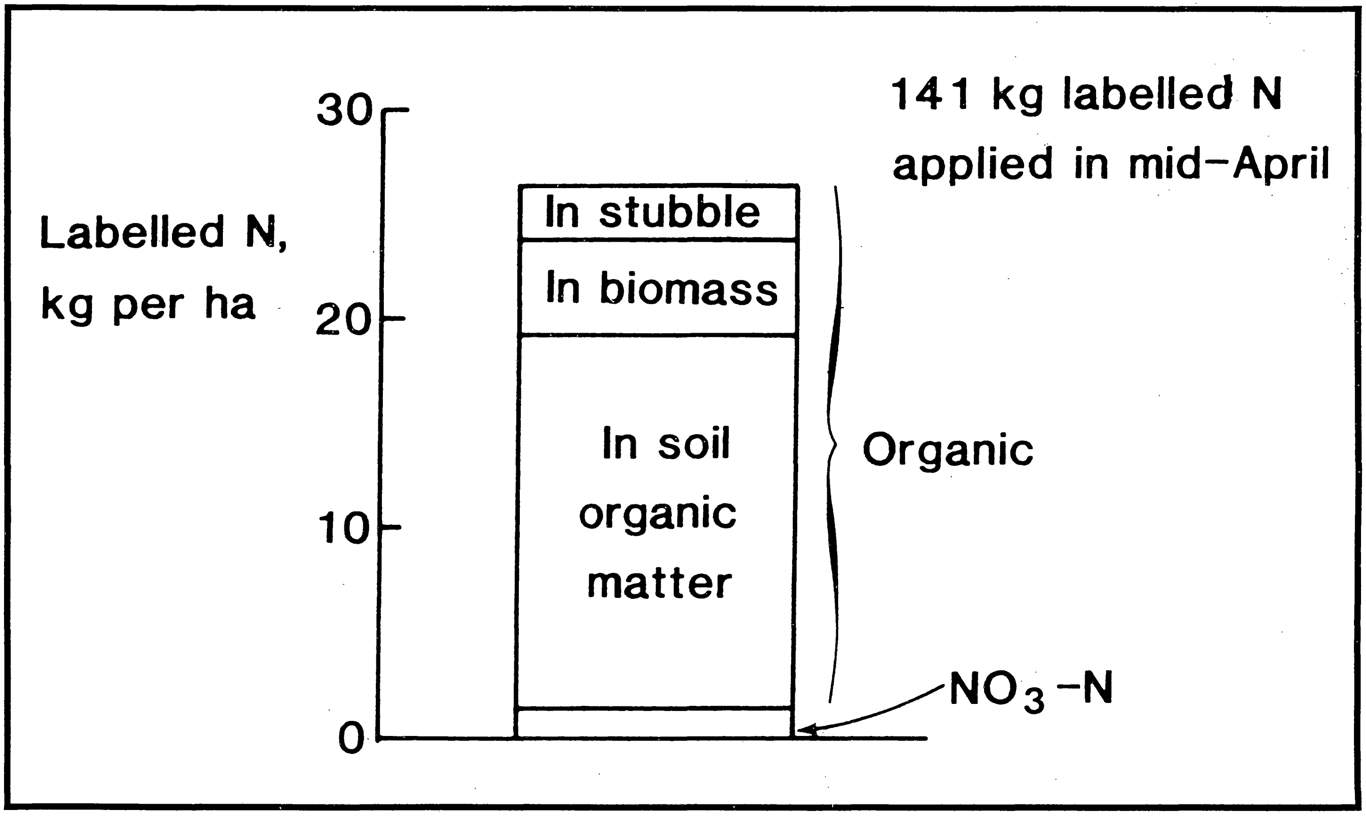

Figure 6. Distribution immediately after harvest of the ^{15}N labelled fertilizer nitrogen found in soil following the applicaiton of 144 kg N/ha in April.

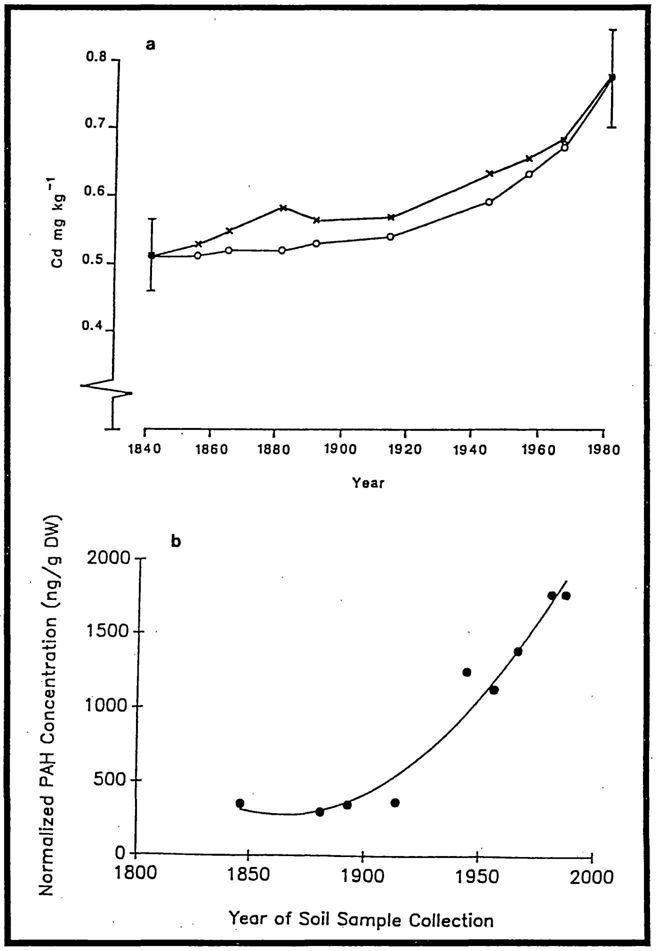

Figure 7. Changes with time in the concentration of cadmium (Fig.7a) and polynuclear aromatic hydrocarbons (Fig. 7b) found in the plough layer of the manured soil on Broadbalk at Rothamsted.

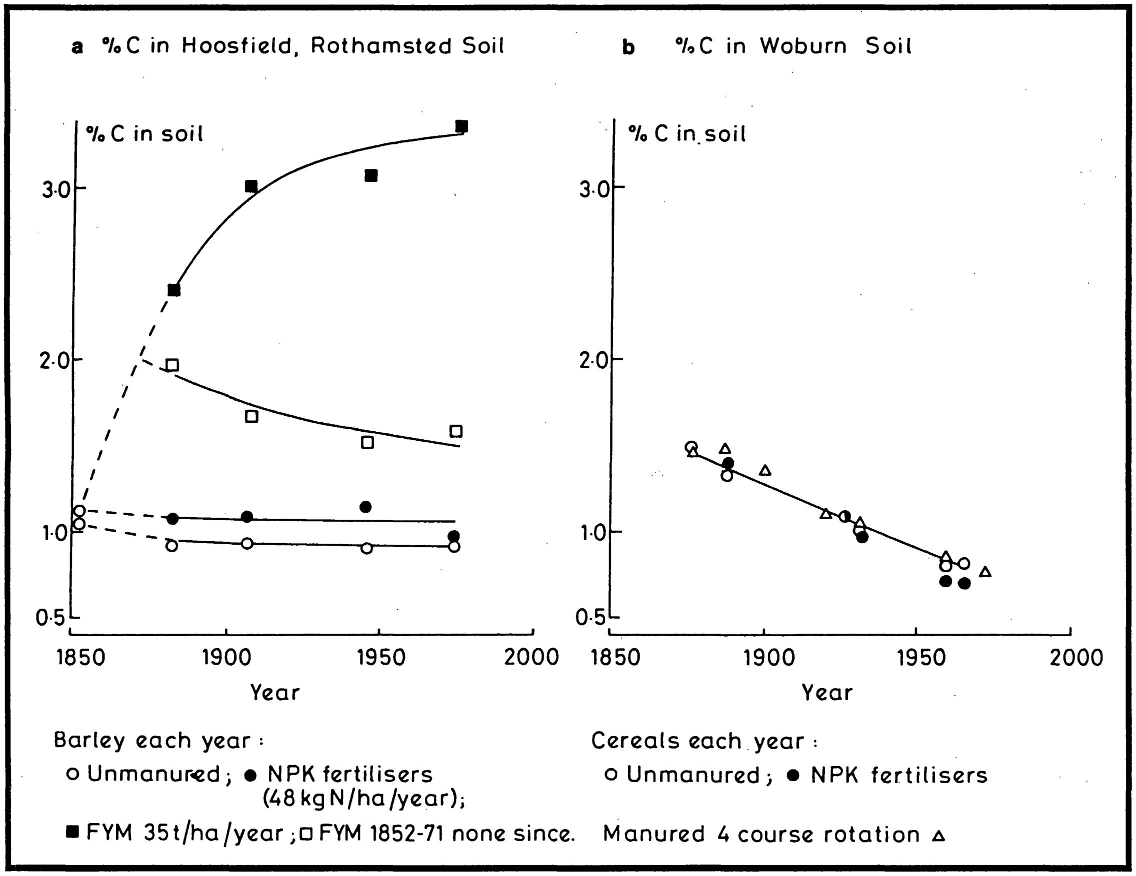

Figure 8. Changes with time in the concentration of carbon in Rothamsted soil (Fig. 8a) growing continuous cereals and Woburn soil (Fig. 8b) growing both continuous cereals and a 4-course rotation of arable crops.

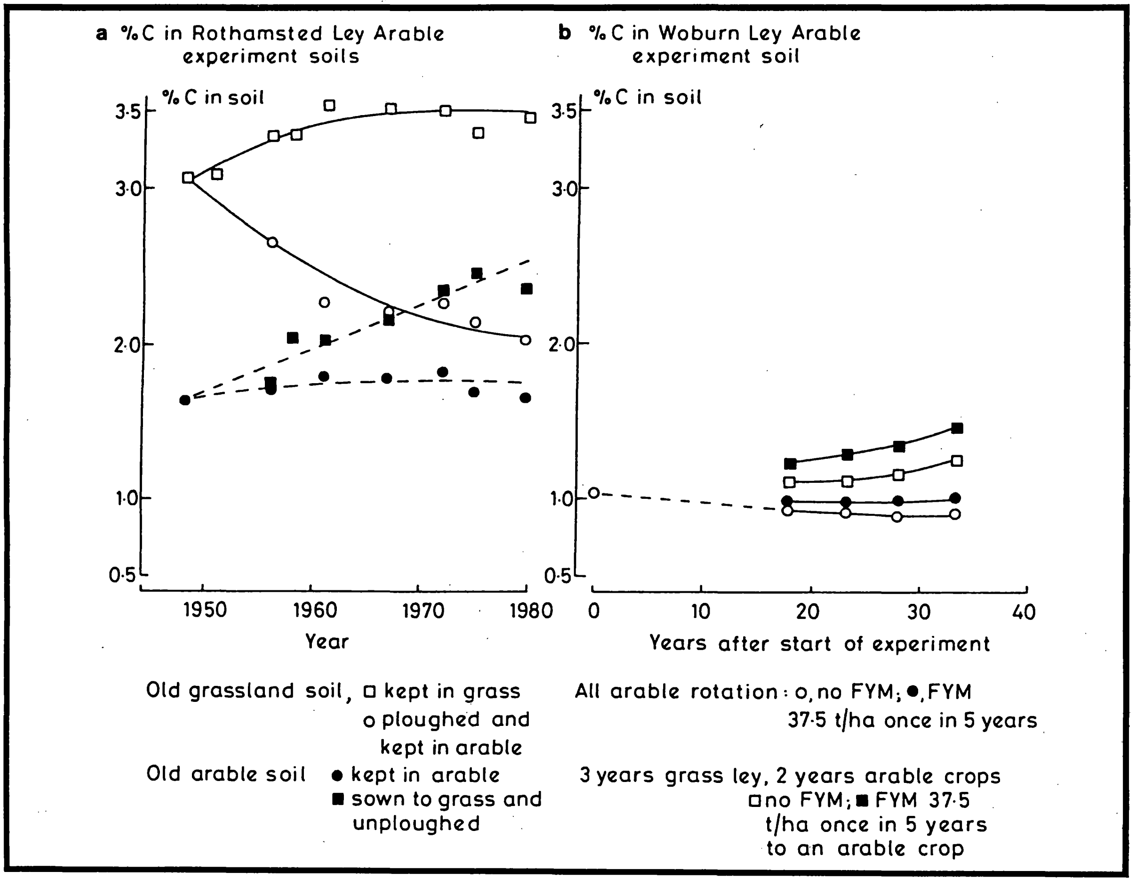

Figure 9. Changes with time in the concentration of carbon in soils testing various grassland and arable treatments at Rothamsted (Fig. 9a) and Woburn (Fig. 9b).

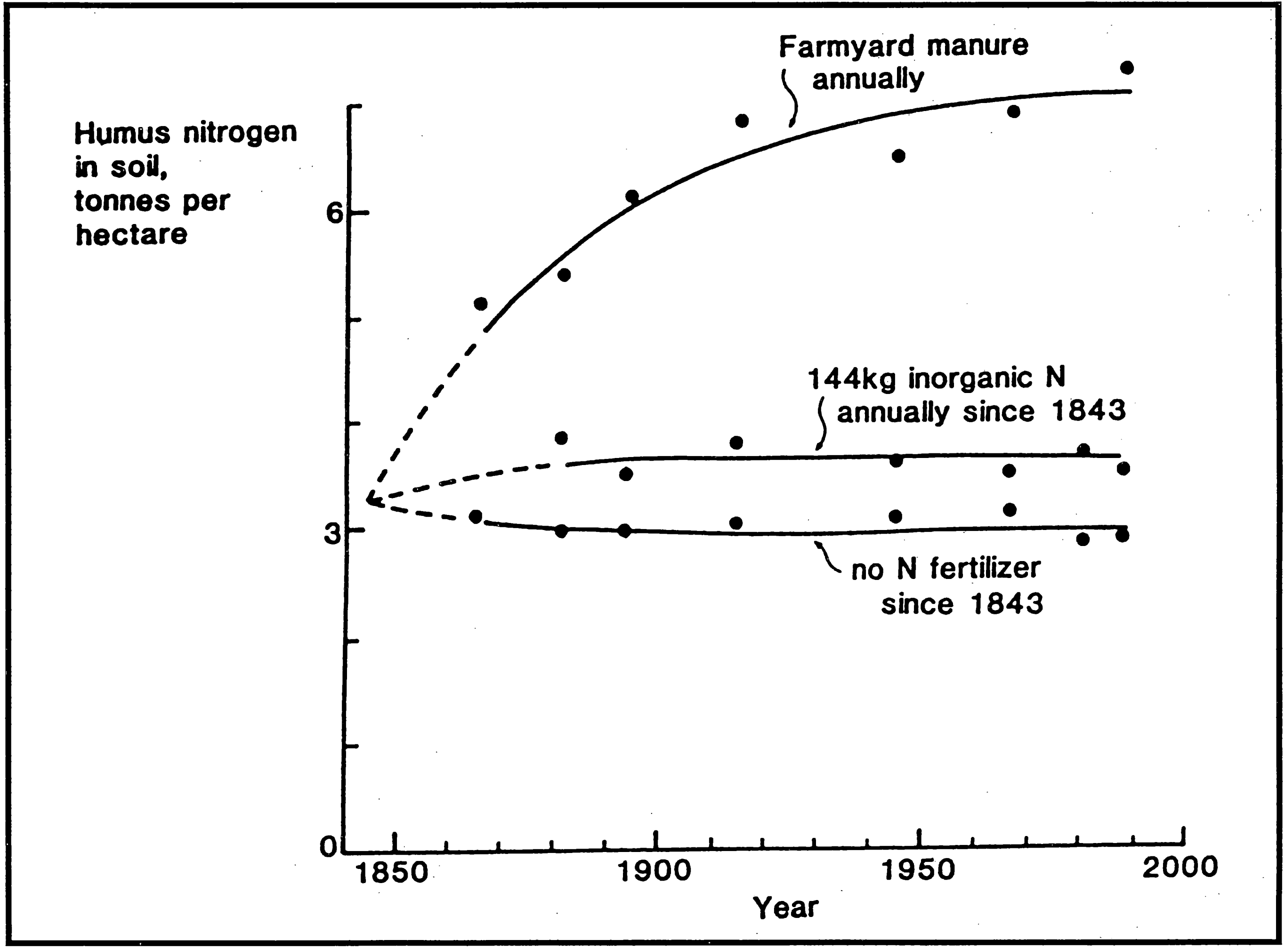

Figure 10. Experimental values (points) and fitted model describing the changes with time in the nitrogen content of the top-soil (0-23 cm) in three plots from the Broadbalk experiment at Rothamsted.

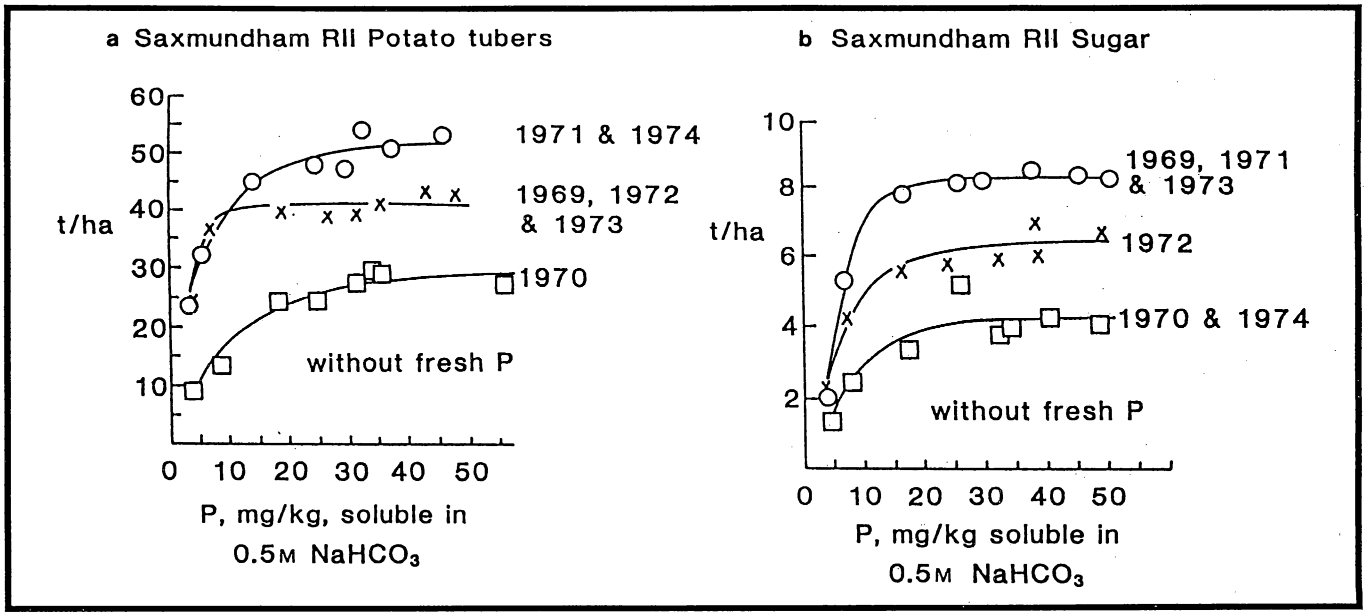

Figure 11. Relationship between yield of potato tubers (Fig. 11a) and sugar (Fig. 11b) and phosphorus soluble in 0.5M $NaHCO_3$ for three groups of years in the Rotation II experiment at Saxmundham.

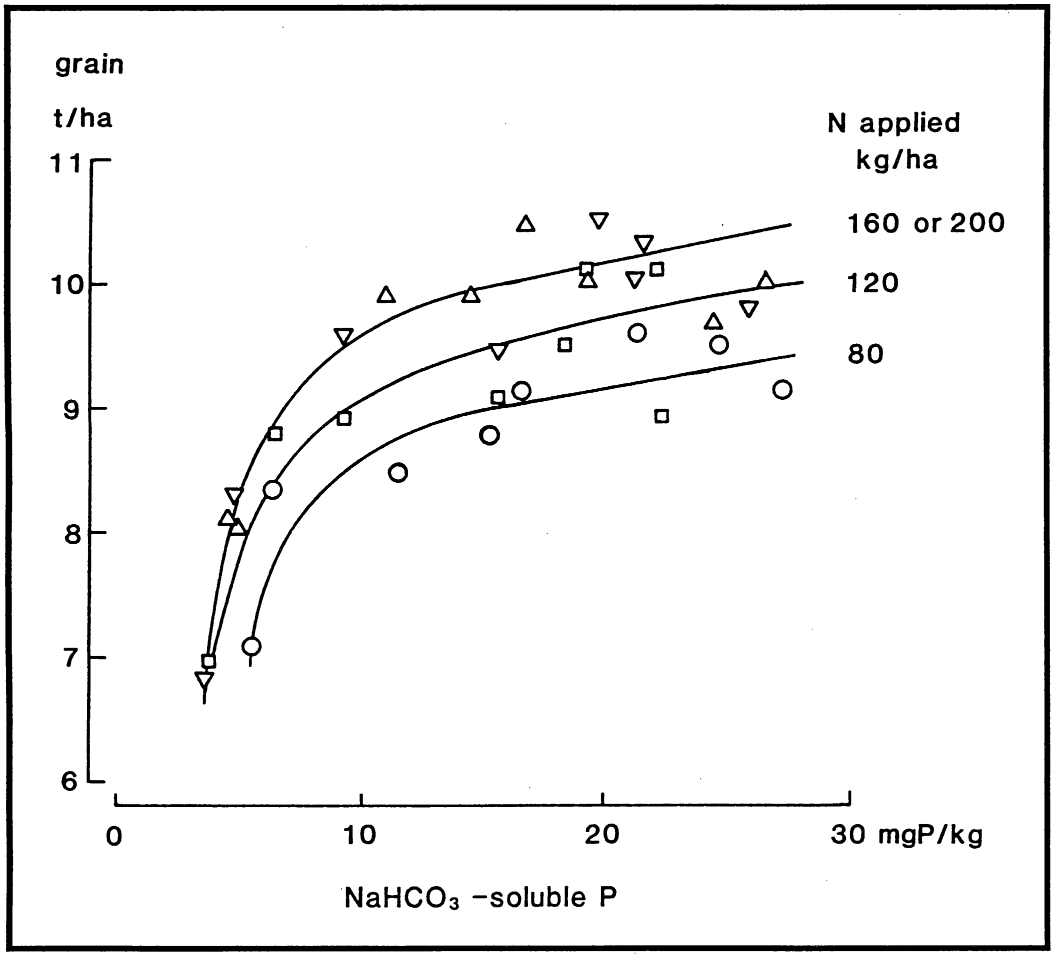

Figure 12. Relationship between wheat yields and phosphorus soluble in 0.5M $NaHCO_3$ in the Rotation II experiment at Saxmundham.

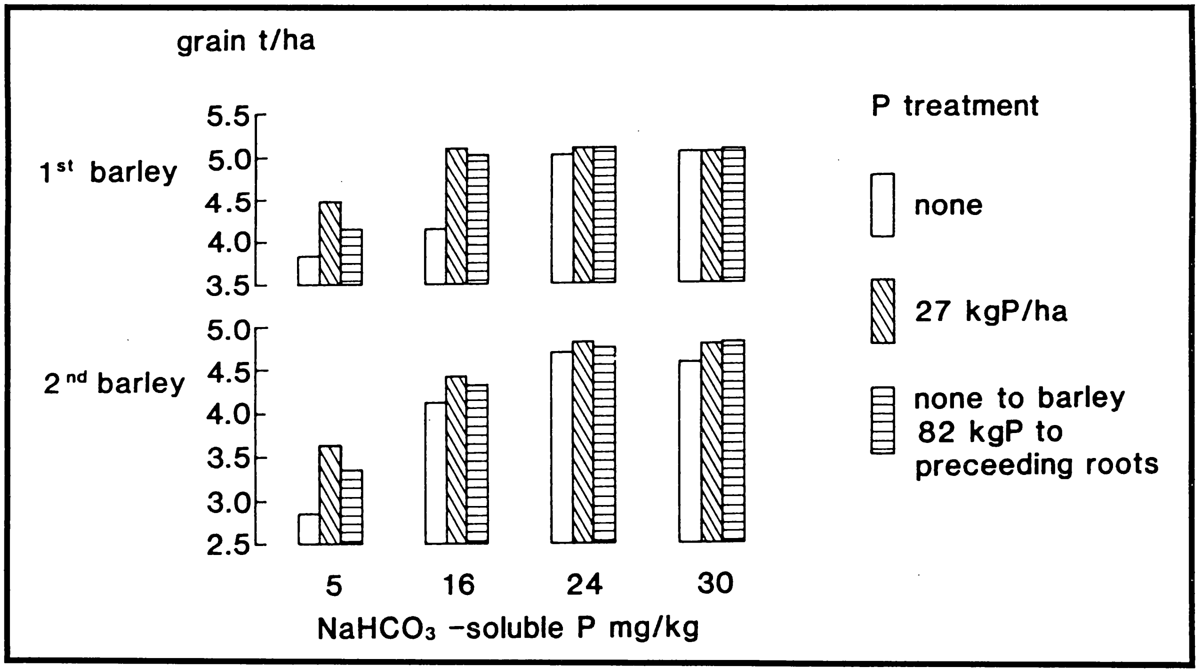

Figure 13. Effect of soluble P in soil and fresh and residual fertilizer P on barley yields in the Rotation II experiment at Sazmundham.

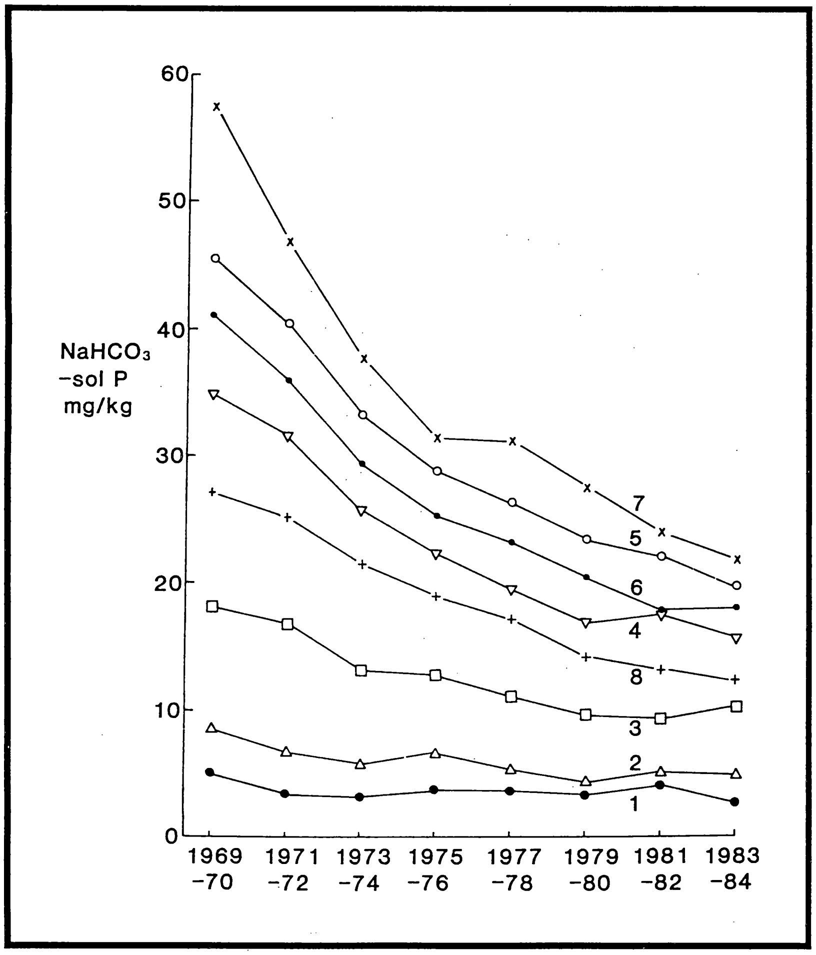

Figure 14. Change with time in phosphorus soluble in 0.5M NaOHC)$_3$ insoils in the rotation II experiment at Saxmundham when no phosphorus was applied between 1969 and 1984.

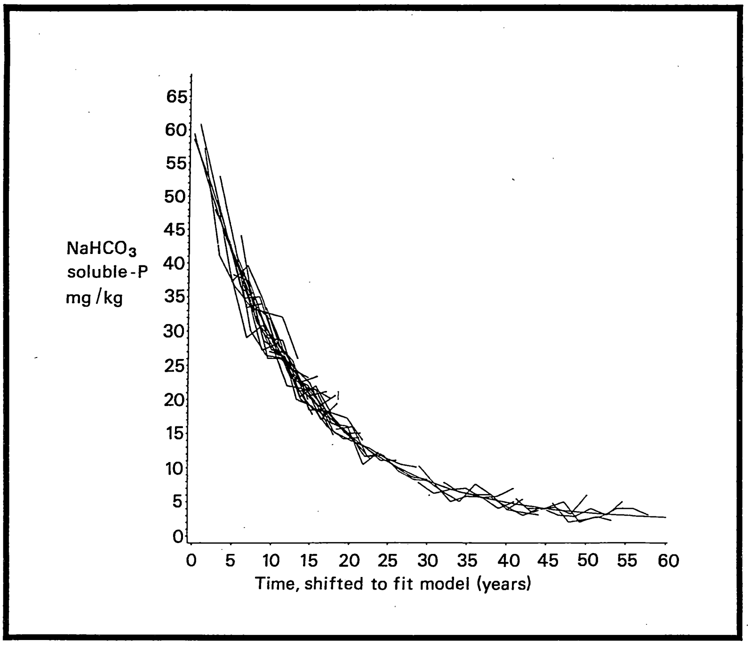

Figure 15. Data for each plot in Fig. 14 shifted horizontally to bring the curves for decline in soluble P with time into coincidence.

Sixty Years' Research at the Breton Plots

J. A. Robertson[1]

Introduction

By Rothamsted standards, the Breton Plots are very youthful. This results, of course, from the much shorter agricultural history of western Canada compared to southern England. The first recorded European to visit present-day Alberta was Anthony Henday who explored for the Hudson's Bay Company in 1754. Fur trading posts were built, especially along the North Saskatchewan River and the first one in the vicinity of present-day Edmonton was established in 1795. While there were gardens or small arable fields associated with some of the trading posts, active settlement did not commence in Alberta until about 1885 when the transcontinental Canadian Pacific Railway was completed across southern Alberta. Population expanded rapidly thereafter, from about 7000 in 1885 to 30,000 in 1895, 185,000 in 1906 and 470,000 in 1914 (MacGregor, 1972).

The earliest agricultural settlement occurred in the prairie or parkland belts where Chernozemic soils (Mollisols) and Brown and Black Solonetzic soils (Natric great groups of Mollisols) dominated. Settlement was favoured in these regions because of access from the rapidly expanding railroad system and the ease of preparing the land for arable agriculture. Expansion into the forest belt became significant in the period 1910-1920, often following clearing by lumbering companies. Of the settlers who came to the forest belt, some were sons of families who had pioneered earlier in more easterly parts of Canada and the United States, some were abandoning recently acquired homesteads in the arid prairies, some were veterans of World War I and many were escaping from crowded and depressed conditions in Europe. They settled an area where there was very little experience with arable agriculture and almost no information about the soils. Indeed, it was apparently assumed that the soils must be very productive because they supported good stands of white poplar (Populus tremuloides) and white spruce (Picea glauca). It did not take many years to discover otherwise!

The Department of Soil Science at the University of Alberta was established in 1919 and Dr. F. A. Wyatt, coming from Illinois, was its first staff member. He was joined in 1922 by Dr. J. D. Newton who had studied plant physiology at the University of California. Some early projects of the Department of Soil Science were:

- delineation of the province into broad soil-climatic zones.
- survey of soils in areas where wind erosion was already very severe.
- of land in the unsettled forest belt.
- determination of the need for soil amendments and fertilizers.

Establishment of the Breton Plots

The inception of the Breton Plots seems to have resulted from the coming together of three events. First, the soil survey of the forest belt alerted Wyatt and colleagues to management problems arising when Luvisolic soils are broken for arable agriculture. Secondly, field tests with fertilizers and amendments had been conducted in central Alberta for several years and in 1929 one such test was placed at the present site of the Breton Plots. Thirdly, Dr. Wyatt had come from the University of Illinois, home of the Morrow Plots, and both he and Dr. Newton were quite familiar with the experimental fields at Rothamsted. Thus, in the winter of 1929-30, Drs. Wyatt and Newton drew up plans for a more complex and presumably longer term experiment involving two cropping systems and several soil amendments. They convinced the farm operator, Mr. Ben Flesher, to cooperate in the venture and until 1946 the land was owned by the Flesher family. Wyatt, Newton, and Mather (1930, p. 15) wrote, "A system of farming suitable for the wooded soil belt, generally, is as yet to be established."

The original plots consisted of five blocks (series) of land accommodating two cropping systems, namely continuous wheat and a four-course rotation of wheat, oats, barley, and forages. Across these five blocks of land ran 11 strips with different soil amendments including manure, several commercial fertilizers, and lime. As was the custom in the pre-statistical days, the amendment treatments were not randomized and most were not replicated. Several modifications have occurred over the years. In 1939, an additional block of land was added permitting the four-course rotation to be extended to a five-course rotation with forage crops occupying two years instead of one. In 1940, the continuous wheat block was divided in half to accommodate a wheat-fallow rotation which became necessary to control weeds. The crop cultivars have, of course, changed from time to time. In particular, the forage species have varied considerably. Until 1955, the forages consisted of legumes alone (sweet clover and red clover, or alfalfa, and red clover). From 1956-1966, the forage mixture consisted of alfalfa, red clover, creeping red fescue, brome, and either timothy or alsike clover. After 1966, the forage mixture was alfalfa and brome grass, a mixture commonly used by farmers. Herbicides were introduced after about 1960, first to control broad leafed weeds and later to control wild oats as well.

Little or no information was collected about soil properties at the commencement of the experiment and soil samples were not taken for posterity! Small samples were taken in 1936 from the plow layer of two plots, and two similar samples were taken in 1938 from another two plots. Thus, effects of various practices can only be judged by comparing among samples of soils taken more recently (a detailed set was taken in 1979) or by reference to nearby virgin sites under forest vegetation.

Some Lessons from the Breton Plots

Nutrient Deficiencies

By the time that Wyatt was establishing a Department of Soil Science at the University of Alberta, physiologists had shown that plants need about 15 chemical elements. Only three of these nutrients — nitrogen (N), phosphorus (P), and potassium (K) — were considered agronomically important, as is evident from the traditional labelling of fertilizers by three numbers. Wyatt's experience in Illinois probably led him to suspect that deficiencies of N, P, and K would occur in some Alberta soils. Knowledge about nutrient deficiencies on Luvisolic soils evolved as follows.

Very early, Wyatt and Doughty (1928) reported as follows: "If any of our soils needed sulphur (S), it would seem reasonable to expect responses in crop yields when this fertilizer was applied to the wooded soil since the soils of the wooded belt are lower in sulphur than other Alberta soils. Consequently, a series of experiments was conducted with this soil, but we failed to obtain any influence on yields for any of the crops here used (wheat, barley, and sweet clover)." Only two years later, Wyatt, Newton, and Mather (1930) wrote: "Results from experiments in the greenhouse with the poorer phases of wooded soils have shown that the average increases of several crops were as follows: nitrogen 14, lime 33, manure 55, phosphorus 70, mixed fertilizer 69, lime and phosphorus 79 percent, respectively. Potassium and sulphur treatments gave yields identical with the controls." Here was evidence that phosphorus and nitrogen, in that order, were the crop-limiting nutrients. But, further work caused a revision of their thinking (Wyatt and Newton, 1932): "Nitrogen is the first limiting element in the production of cereals, whereas phosphorus is in greatest need for legumes on these wooded soils." Two years later, McAllister (1934) wrote: "This would appear to indicate that in order of scarcity, nitrogen, phosphorus, and potassium are all necessary on these soils if satisfactory yields (of wheat) are to be obtained." Newton (1931) had commented briefly, and apparently with some skepticism, that "In this connection, it should be stated that Alberta soils are, apparently, not deficient in sulphur." Thus, by 1932, the various workers had rated nitrogen deficiency greater than phosphorus deficiency on Luvisolic soils. They noted some evidence of a shortage of potassium but none of a sulphur deficiency. At this point there begins an intriguing chapter about the sulphur situation, a chapter whose conclusion was not written until around 1970. Early reports noted no evidence of sulphur deficiency, and Wyatt (1936) still held to that view when he wrote: "The best fertilizers for both the clovers and the grains were those carrying a high content of nitrogen...However, greater returns were obtained in the case of the clover and the first crop after clover when the fertilizer contained phosphorus in addition to the nitrogen." Note that there is no reference to sulphur being in any of the fertilizers nor to its requirement by crops. Meanwhile, Newton (1936), writing in the same scientific journal as Wyatt, presented some strikingly contradictory information: "Fertilizer experiments carried out during the past few years have shown that the leached, gray wooded soils or podzols of Alberta are deficient in sulphur. The treated field plots at Breton (plots used to study potato-scab control) were seeded down to red clover in 1932, and it was observed that where sulphur had been applied... in 1930, the growth of red clover was greater than on adjacent soil where it had not been applied."

How could such contradictory conclusions emanate simultaneously from one small department? In retrospect, the answer is startlingly simple. All of the nitrogen fertilizers to which Wyatt referred also contained sulphur. What he interpreted as an effect of nitrogen, Newton saw as a response to sulphur! It was Newton's potato-scab plots, on which only sulphur had been applied and on which a subsequent clover crop grew very well, that resolved the problem so that Wyatt, Newton, and Ignatieff (1939) wrote: "On the gray wooded soils, nitrogen is the most essential element for the grains and grasses, whereas for the legumes, sulphur is of first importance."

However, the sulphur problem was still note entirely resolved. For nearly three decades, the notion prevailed that sulphur was not very important for cereal crops and grasses. It is true that Newton, Ward, and Bentley (1948) wrote: "Fertilizers containing a high percentage of sulphur and nitrogen, such as 16-20-0 and ammonium sulphate, gave the largest increases of grain crops, especially where the grain was not grown in rotation with clovers." But in the same bulletin, they also said: "All fertilizers and soil amendments containing high percentages of sulfur...have given large increases in yields of legumes such as clovers and alfalfa...Substantial increases in yield of grain following these fertilized legumes were obtained also." Newton (1952) stated: "Application of flowers of sulphur and non-nitrogenous sulphates...to cereal or grass crops proved of little value except in a few cases, but were of great value to legumes which fix their own nitrogen."

Today it seems curious that the workers in the early

1950's did not conclude that for non-legumes, nitrogen and sulphur should be added simultaneously. It was left for Nyborg and Bentley (1971) to clarify the situation: "Application of S to cereal grains not grown in legume rotations has usually given little increase in yield. Consequently, cereal grains have been considered rather insensitive to deficiency of sulphur. At seven sites...increases in yield (of barley and oats) from a combined application of N and S were large...At four of the sites the application of N alone or of S alone, had little effect, but the two nutrients together produced very large increases in yield."

Thus, we now conclude that many Luvisolic soils are normally deficient in both nitrogen and sulphur. Application of both is usually required for non-legumes, but for properly inoculated legumes only sulphur is needed. The many seemingly contradictory observations can be rationalized within this general conclusion.

Besides nitrogen and sulphur, phosphorus has usually been beneficial on Luvisolic soils. Potassium has not figured very prominently in fertilizer recommendations for Luvisolic soils since McAllister (1934) concluded that potassium was next most important after nitrogen and phosphorus. Wyatt, Newton, and Ignatieff (1941) wrote: "Practically no response was seen for such fertilizers as...potassium sulphate and potassium chloride for the grain crops." Later, Bentley et al. (1971) said: "Sulphur and phosphorus are the most commonly deficient elements for legumes grown on Gray Wooded soils...Grasses have a very high requirement for nitrogen and this element is by far the most limiting for grass production on Gray Wooded soils. Phosphorus and sulphur may also be required...Phosphorus deficiency occurs on many Gray Wooded soils as on other soils in the province, while potassium, manganese and boron deficiencies have been found only occasionally." Current evidence, based on soil test results and field observations, suggests that potassium deficiencies will likely become much more common as these soils are cropped longer and as the levels of other nutrients are increased by suitable fertilization.

Soil Acidity and Liming

The understanding of acidity in Luvisolic soils has also evolved considerably over the years. Wyatt, Newton, and Mather (1930) reported that "the wooded soils have suffered rather extensive leaching. This explains the fact that they are at present slightly acid in reaction. ...the system of farming suitable for the wooded soil belt in general is as yet to be established. There are strong indications that it must be a system of mixed farming involving the growing of clovers and other legumes to increase the fertility of the soil, supplemented in many cases by the use of limestone." Later, Wyatt and Newton (1932) noted that "lime has likewise given a considerable response for the legume crops. From the beginning it is necessary to grow soil enriching crops and apply phosphate and lime or marl." Two years later, however, Wyatt had apparently had some second thoughts about the importance of soil acidity because he wrote (1934): "On the other hand, these soils are not sufficiently acid to prevent the growth of any of the legumes." Also, in 1937, the 1932 statement about the need for phosphate and lime was rephrased, deleting any reference to lime (Wyatt and Newton, 1937).

What were the reasons for these contradictory statements? First, while the soils were usually acidic as judged by the pH test, most of them were likely not acidic enough to harm most of the crops the farmers grew. Secondly, after a few years of use, the soils became so deficient in nitrogen and sulfur that lime alone could not have much benefit. In many of the earlier experiments, including the Breton Plots, lime was tested without insuring the adequacy of nitrogen and sulfur. Thus, the conclusions of the researchers were based on experiments which, judged by hindsight, were incomplete in their design!

Recently there has been a revival of interest in the acidity of Luvisolic soils. Bentley and his colleagues (1971) wrote as follows: "until recently soil acidity was not considered a problem for Alberta soils. However, extensive field experiments conducted during the past ten years by the Research Station, Beaverlodge, have shown that soil acidity seriously restricts crop growth on certain soils of the Peace River region...The soil acidity problem extends to areas of Alberta outside of the Peace River region."

Why has there been a return to the notion that soil acidity is, after all, a problem? First, there are some localized areas, especially in northwestern Alberta, where the soils were initially so acidic that few crops would grow on them. Secondly, the "extensive field experiments" referred to above were designed so that all limiting nutrients were supplied, thus insuring that the need for lime was being fairly assessed. Thirdly, the chemistry of soil acidity was now understood more clearly. Up to this time, most workers thought that acidic soils were harmful either because of the acidity itself or indirectly because such soils were deficient in calcium. Thus correction of acidic soils by lime (calcium carbonate) was thought to be beneficial because of the calcium added. That this notion prevailed is clear from two statements published by Alberta workers in the 1950's. Newton (1952), writing on another topic altogether, said: "...there was a tendency in the earlier years to attribute the beneficial effects of gypsum (calcium sulfate) to its lime (i.e. calcium) content rather than to its sulphur." Later, Newton and his colleagues (1959) stated: "However, liming is not known to be very beneficial on any Alberta soils now being farmed. This is readily understood... The average Gray Wooded soil contains over ten tons of calcium ("lime") in the surface acre-foot." Thus, it was thought that because

Alberta's acidic soils contained considerable calcium, they would not be harmful to plants. What was not realized, and only became widely understood after about 1950, was that the main cause for adverse effects of soil acidity were toxic levels of aluminum or manganese in the soil solution. Hoyt and his colleagues at Beaverlodge demonstrated that this was generally true for Alberta soils (Hoyt and Nyborg, 1972).

A fourth very important reason for the renewed concern about soil acidity is that many soils have become, and are becoming, more acidic because of the use of ammonium-containing fertilizers. McCoy and Webster (1977) concluded that: "...relatively small amounts of fertilizer nitrogen and sulphur applied over a 40-year period to a Luvisol at Breton have resulted in an increase of soil acidity sufficient to reduce alfalfa production. Infrequent applications of small amounts of lime prevented these developments." The work of McCoy and Webster showed that the increased acidity caused by the fertilizer treatments resulted in an increase in extractable aluminum and manganese, and undoubtedly it was these toxic components that reduced crop yields.

Thus, over the lifetime of the Breton Plots, our thinking has come full circle about liming. Work at these plots has helped us to understand the acidity problem and how to manage it.

Soil Tilth

There has been essentially no debate on the subject of soil tilth over the years. Wyatt, Newton, and Mather (1930) recognized very early that Luvisolic soils have poor physical condition and they wrote: "Under field conditions the farmers have experienced difficulty in getting a satisfactory stand of the legume crops on the wooded soils owing largely to the undesirable physical condition of the soil. This is due to a great tendency of the wooded soils to bake when they become dry. The difficulty above mentioned can largely be overcome by generous application of farm manure...The most practical way to insure the improvement of the physical condition of the wooded soils is to introduce organic matter into the soil. This could best be done by the growth of legume crops." Again, Wyatt and Newton (1932) wrote that "Since most of the colloidal material has been removed from the leached layer, this layer is ashy and bakes rather badly when it dries." Later, Newton et al. (1959) described the same problem as follows: "When dry, the materials in the A2 horizon are hard and they crush to an ash-like or flour-like powder. If the gray mineral material of the A2 is very wet, it behaves like a heavy paste and becomes very firm and hard when dried." Also, Toogood and Lynch (1959) wrote: "Being thus naturally low in clay, and with less than 2 percent organic matter in the top 6 inches of soil, the soil may be expected to be poorly aggregated. This is evident in the field. The soil puddles easily, packs hard after wetting, and quickly forms a hard crust after a rain. The physical condition of the soil is thus one of its major problems." They reported that their measurements on samples from the Breton Plots "...demonstrate a definite improvement in stability of soil aggregates in the (wheat, oats, barley, and forage) rotation plots." Later, Toogood and coauthors (1962) wrote: "It can be stated without qualification that at Breton the five-year rotation has improved the tilth and the physical properties of the soil. However, the improvement has been gradual."

More recently, Pawluk (1980) did a micromorphological study of samples from various treatments of the two cropping systems. He noted that aggregates found in the cultivated layers "...expressed a variable degree of granularity. The granules were most discrete and strongly developed in plots receiving organic fertilizer and where grasses and cereals were grown in rotation..." Subsequently, Berg and Pawluk (1984) examined the micromorphology and mesofaunal distribution in the cultivated layer under seven vegetative regimes. They noted that "...a major portion of the fabric in the upper 7 cm was reorganized by faunal activity during the time span (2 years) of the experiment. The greatest changes were observed under alfalfa and fescue, and the least under fallow." We note that it has been casually observed that less tractor power is required to do various tillage operations on the grain-forage plots than on the grain-fallow plots.

Thus, the long-term plots at Breton have shown clearly that a five-year rotation of grains and forages leads to a marked improvement of tilth when compared to a grain-fallow rotation, just as the early workers had suggested.

Organic Matter and Biological Activity

The Breton Plots are located on Gray Luvisolic (Cryoboralf) soils. In the virgin state, these soils have a L-H (H) horizon 5-10 cm thick and it is underlain by a strongly leached, platy Ae (E) horizon with a thickness of 10-25 cm. The L-H horizon contains 30 to 40 percent organic carbon while the Ae horizon contains 0.5-1.0 percent. When broken from the virgin condition, the Ap horizon comprises a mixture of the L-H and Ae horizons. The organic material of the L-H horizon readily decomposes, however, so that the Ap horizon commonly contains only 1.0-1.5 percent organic carbon.

There can be little doubt that the early workers recognized the low organic matter content of the Ap horizons of cultivated Gray Luvisols but there is little explicit reference to that fact in the literature of the first thirty years. There was, however, early reference to the poor fertility of these soils and the observation that the total nitrogen and phosphorus in the upper 60 cm (2 feet) of the Gray Luvisolic soils was much lower than that found in Black Chernozemic (Udic Borolls) soils (Wyatt, Newton, and Mather, 1930). The lower "productive power" of these soils was also attributed, in part, to the undesirable physical condition and, as pointed out earlier, "the most practical way to improve this physical condition is to introduce organic matter into the soil" (Wyatt, Newton, and Mather, 1930). The first definitive statement about the low organic matter content of Gray Luvisolic soils appears to have been made in 1959 (Newton et al.) as follows: "Grey Wooded (= Gray Luvisolic) soils contain comparatively small amounts of humus. The leaves and leaf mould on their surface disappear very quickly when they are cultivated." In 1957, a set of soil samples from the Ap horizons of all plots was analyzed for total nitrogen (and other components) "...to determine whether the cropping practices and fertilizer treatments had caused any measurable differences in the soils there" (Newton et al., 1950). Organic carbon was not measured directly but it would be very closely related to total nitrogen. Their results were not analyzed statistically, but it appears reasonably safe to conclude that the total nitrogen content of soils in the five-year cropping system (0.13%) was greater than that in the two-year system (0.12%). It is even more certain that the plots which yielded well due to application of various NS fertilizers had higher total nitrogen (0.14%) than did those which yielded poorly (0.12%).

A complete set of samples was taken from all plots again in 1979 and organic carbon was determined on all Ap samples (Cannon et al., 1984). These carbon results showed trends very similar to those for total nitrogen on the 1957 samples. The mean carbon content for the five-year cropping system, averaged across all fertilizer treatments, was 1.59% while that for the two-year system was 1.25%. The mean carbon content for the "high" yielding fertilizer treatments, averaged across the two cropping systems, was 1.66% compared to 1.40% on the "low" yielding (essentially control) fertilizer treatments.

As noted earlier, regular sampling of the plots has not been done and therefore following changes in soil properties over the years is not possible. There was one opportunity to do so, however. Total nitrogen was determined, albeit by different workers, on many of the plots in 1957, 1968, 1969, and 1979. Further, four samples of soil taken in 1936 or 1938 are still available and total nitrogen was determined on them recently. These samples taken at five different dates show that there was no change in total nitrogen (and hence organic carbon) on the control and NPKS plots of the two-year cropping system, a trend for increased nitrogen on the manured plot of the two-year system and the control plot of the five-year system, and a significant increase in nitrogen in the NPKS and manured plot of the five-year system. Thus, it appears certain that the soil organic matter content has increased from appropriate crop and fertilization practices and has not increased (perhaps decreased) under the two-year cropping system. We must note, however, that all crop materials (straw, grain, hay) have been removed from the field. The Breton Plots did not include a management system of continuous annual crops where all residues were left on the soil. We could speculate that such a system would result in higher organic carbon than is found in the grain-fallow system without crop residue returned, but we do not know if it would be equal to the grain-forage system. We recently added a few plots to the experiment to test this question.

Considerable attention has been given in the last three decades to "quality" of organic matter under various cropping and fertilizer treatments. Toogood and Lynch (1959) examined the polysaccharide content on some selected samples. Their results indicated that the polysaccharide content was invariably higher in soil samples from the five-year system than from the two-year system. There seemed to be no clear relationship between polysaccharide content and fertilizers applied. Later, Khan (1969) reported that "...hexose, pentose, uronic acid, hexosamine and hexosamine-N contents were significantly greater in soils from plots in a five-year rotation of grains and legumes than in a wheat-fallow sequence...The contents of... carbohydrate materials in soils increased considerably following the manure and fertilizer applications..." Khan (1969/1970, 1970) also studied the humic acid fraction of samples from some of the plots. He stated that "The humic acid content of soils under a five-year rotation of grains and legumes was significantly greater than those from wheat-fallow system. ...Continued use of manure on soils in the Breton Plots resulted in a significant increase of humic acid content. ...It was postulated that humic acid isolated from Breton plot soils under the wheat-fallow sequence was more humified than that from a 5-year rotation of grains and legumes." Khan (1971) reported on the nitrogen fractions in some of the Breton plots. His results led him to conclude that "...the long-term rotation of grains and legumes and also the continued application of manure on Breton plots provided conditions which increased the relative amounts of some of the hydrolyzable organic N fractions. However, long-term applications of mineral fertilizers did not cause any marked change. ...More research is warranted to ascertain whether these quantitative differences are of any practical significance."

In very recent years, there have been several attempts to assess the biological activity in soils of the different cropping and fertilizer plots. McGill et al. (1986) measured amounts and turnover rates of biomass and water-soluble organic carbon. They reported that "the 5-year rotation contained ... 117% more microbial N than did the 2-year rotation, and manured treatments contained twice as much microbial N as did NPKS or control plots. ...Average turnover rates of biomass ... (were) 1.5-2 times faster in the 2-year rotation than in the 5-year rotation. ...Management practices and environmental conditions therefore affect amount of organic matter by controlling both input of C and biomass turnover." Fyles et al. (1888) examined microbial biomass, nematode and microarthropoid populations under oat and alfalfa crops in the 5-year rotation. They found that "overall activity of the biological components measured...was higher in the oat system than in the alfalfa system. Significant biological differences...have...arisen...in response to differences in management within the rotation. ...microbial biomass C, nematodes and microarthropoid populations differed in their responses to changes in the biotic and abiotic environment."

Mishra and Juma (1989) studied the population dynamics of nematode groups under barley and second-year clover-grass plots of a new eight-year agroecosystem at the Breton Plots. The mean nematode abundance was similar for the two crops but there was a higher density of adult nematodes in the barley plot than in the clover-grass plots. The authors hypothesized that "food supply as affected by root morphology, rhizosphere size and moisture regime may have controlled the abundance of plant parasites, microbivores, and juveniles."

The legume seeds have always been inoculated with appropriate rhizobia at sowing. Casual observations of nodulation and free-living nitrogen-fixing organisms have been made but nitrogen fixation has not been assessed directly. It is clear from the excellent production on appropriately fertilized forage plots that nitrogen-fixing organisms have been very effective. It has been noted also that the first cereal crop (wheat) following plowdown of the high yielding forages yielded well without addition of nitrogen fertilizer. The yields of second-year oats and third-year barley following the wheat have been increasingly less satisfactory, implying that the amount of nitrogen derived from the legumes declined over the three subsequent years. An attempt was made to estimate the mean annual amount of nitrogen fixed by the legume crops in the five-year cropping system using a balance sheet approach (Robertson and McGill, 1988). They compared the difference in nitrogen removals by crops, differences in nitrogen additions in fertilizers, and differences in present soil nitrogen content between the control plots of the two-year cropping system and the NS fertilized plots of the five-year cropping system. With this approach "we estimated that the amount of nitrogen fixed by each of the forage crops was about 150 kg ha^{-1} y^{-1}."

It is clear that cropping systems and fertilization have resulted in notable differences in various organic components and in biological activities in the soils of the Breton Plots. In general, organic matter status is more favorable under the five-year cropping system than under the two-year grain-fallow system. Whether this is due to a more regular addition of plant biomass (mainly roots) and shorter "fallow" period on the five-year system or to some specific contribution of the forage component of the five-year system is not entirely clear. Also, the organic matter status of the "suitably" fertilized plots is generally better than that of the control plots. In the case of synthetic fertilizers, the relatively small benefit probably derives from the greater plant biomass added to the soil. In the case of barnyard manure, the somewhat greater benefit results, no doubt, from both the direct addition of organic materials and the increased plant growth which occurs on that treatment.

The Future

The Breton Plots have contributed much to our understanding of the management of Luvisolic soils in Alberta and western Canada. Of course, we cannot claim that all of the advances in knowledge about deficient nutrients, acidity, tilth, and organic matter came from the work done at the Breton Plots. An extremely important aspect of the work done there is its long-term nature; we are able to assess effects after six decades of well-documented management, and this is important because the effects of some practices are not measurable in short periods. The plots are particularly relevant in these times of great concern about soil degradation and effects of management practices on soil quality.

The Breton Plots cannot provide answers to all soil management questions. The numbers of fertilizers and crop rotations had to be limited for practical reasons. Besides, the plots were established using the practices in vogue in 1930, and it is not possible to change them to accommodate all of the practices which have developed since. In spite of these limitations, the Breton Plots have contributed much to our understanding of soil management and they will, we expect, continue to do so. It is most unfortunate that funding for these, and other long-term plots, is difficult to secure. Many other long-term plots have been abandoned because they were considered archaic and irrelevant. It would seem very reasonable that a small portion of the research budget devoted to agronomic work would be set aside for long-term (decades) plots where effects of human activities on soil can be monitored in perpetuity.

Footnotes

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Askov 1894-1989: Research on Animal Manure and Mineral Fertilizers

Bent T. Christensen

Introduction

Askov Experimental Station is located in the South of Jutland (55°28'N, 09°07'E) and is one of the research units run by the Danish Research Service for Soil and Plant Sciences, a research organization under the Ministry of Agriculture. Selected climatic parameters of the site are given in Table 1. Annual average precipitation is 790 mm and mean temperature is 7.7°C.

As the department responsible for research in plant nutrition, the research at Askov focuses on the effect of fertilization on crop performance, on chemical and biological soil properties, and on the losses of nutrients to the environment. The main body of research involves organic manures (animal manures, plant residues, composts, and sewage sludge).

The first field experiment at Askov was initiated in 1885. The following year, financial support was obtained from governmental sources and the station was officially founded as one of the first agricultural experimental stations in Denmark. Early activities were directly related to research needs as defined by representatives of farmers. Today's research continues to embody this line of applied experimentation. During the last two decades, however, a larger proportion of the resources has been allocated to more basic research and to research addressing the impact of agriculture on the environment. This change was accomplished in response to the increased concerns of society regarding the quality of the environment, natural resources, and public health in general. During the same period, the problems addressed have increased in complexity.

This contribution focuses on the Askov long-term experiments on animal manure and mineral fertilizers, and a detailed presentation of their design is included. Based on these and two other experiments of long-term nature (started 1956), the effects of fertilizers and cropping systems on the soil organic matter content are presented. Then follows a presentation of studies on soil movement between plots, carried out at different times during 1942-1989.

The Askov Long-Term Experiments on Animal Manure and Mineral Fertilizers

The first Danish field experiment of long-term nature was set up at The Royal Veterinary and Agricultural University in Copenhagen only a few years after the University was established in 1858. They were clearly inspired by the Rothamsted experiments that had been initiated some 15 years before. The experiments were, however, terminated in 1896. Independently of the University, experiments on mineral fertilizers and farmyard manure were started at Askov in 1893 and fully implemented in 1894. Although the experiments were expected to run for several years, the initiators probably did not expect the experiments to continue for almost a century.

The background of the experiments was the rapidly growing interest in the use of mineral salts ("artificial manures") as a source of plant nutrients. Questions were, however, raised as to whether soil fertility would deteriorate in the longer run if animal manure containing organic matter was completely replaced by inorganic salts. At the same time, there was a need for more precise descriptions of the nutritive value of animal manure when applied to different crops. This need emerged from a general change in the emphasis of agricultural production, cereal growing being replaced by animal husbandry, whereby an increased volume of animal manure became available for crop production.

The experiments were placed on a coarse sand (CS-soil) and a sandy loam soil (SL-soil). The SL-soil had been cultivated for nearly a century when the experiments started, while the cropping history of the CS-soil dated back at least two hundred years. The textural composition of the soils is given in Table 2.

On each soil type, four fields were employed with plot sizes ranging from 55 to 110 m^2 (Table 3). The various treatments included in the experiments are listed in Table 4. Each treatment was generally replicated 3 times in a field.

The amount of nutrients added was changed in 1907, 1923, 1949, and 1973, but during each period almost equivalent dressings of N, P, and K were applied in mineral fertilizers (NPK) and in animal manure (FYM). Table 5 presents the amount of nutrients given in 1 NPK and 1 FYM.

The experiments grow a 4-course crop rotation of winter cereals (wheat or rye), root crops (mangolds, sugar beets, turnips, or potatoes), spring cereals (barley or oats), and a clover/grass mixture (on the CS-soil, lupins or peas were grown from 1944 and onwards). Table 6 summarizes the cropping history. All rotation elements were represented every year.

For the unmanured, 1 NPK and 1 FYM plots, the average annual crop yields obtained in the various periods are given in Table 7. The yields are presented in feed units (FU) in order to get a unified expression of the yield of the different crops in the rotation. During the period

1894-1906, yields on unmanured plots were 1420 and 2360 FU/ha/year on the CS- and SL-soil, respectively. In the succeeding period, the yields declined to 1070 and 1600 FU/ha/year on the respective plots. In the following periods, yields have tended to increase on the unmanured plots, except for the 1973-1984 period on CS-soil. At least part of the increase in crop yields may be ascribed to better crop varieties, introduction of pesticides, more efficient soil tillage, and during later periods, an increased N content in precipitation. Generally, the 1 NPK and 1 FYM treatments have demonstrated 2 to 3.5 times higher yields than unmanured plots, the greatest yield response being obtained after NPK dressings. Detailed accounts on crop yields, nutrient uptake and balances, and results from soil analyses have been presented in previous reports (Hansen & Hansen, 1913; Christensen, 1927; Iversen, 1927; Iversen & Dorph-Petersen, 1951; Kofoed & Nemming, 1976; Kofoed, 1982, 1987).

Studies on the Soil Organic Matter (SOM) Content :The Long-term Fertilization Experiments (1912/14-1984)

While numerous experiments of greater relevance to current farming practice have exposed many aspects of crop responses to dressings of mineral fertilizers and animal manure, long-term field experiments are still justified in providing time series of data for the study of slowly changing soil properties such as the SOM content. The lack of soil samples from the initial and (when discussing SOM dynamics) often very important period of the experiments is, however, an adverse feature that the Askov experiments share with other long-term experiments. In the Askov experiments, the first soil sampling recorded took place in 1912 and 1914 on the CS-and SL-soil, respectively, thus leaving out the initial 18 to 20 year period.

For the unmanured, the 1 NPK and the 1 FYM plots, the development in the N content of the plough layer (0-20 cm) during 1912/14 to 1984 is given in Fig. 1. The SOM content of the SL-soil is higher than that of the CS-soil, and during the whole period 1 FYM has resulted in higher SOM levels than 1 NPK, the unmanured plots showing the lowest content. A linear regression equation of the type y = a + bx was applied to the data for C and N content in the plough layer (Table 8). The mean annual decrease in the N content of the 0-20 cm CS-soil has been almost twice that found for the SL-soil. For the C content, annual decreases for unmanured and 1 FYM plots are larger on the CS- than on the SL-soil, while the 1 NPK differ less between the soils.

The general trend emerging from Table 8 suggests that the unmanured, the 1 NPK and the 1 FYM treatments have experienced a somewhat similar decrease in SOM content, the decrease rate on the CS-soil being faster than on the SL-soil. This could result from a general decline in the pool of "original" SOM whereas with the individual treatments already have reached an equilibrium between build-up and decomposition of SOM derived from the treatments. Soil movement between plots may also be involved (see later).

A number of factors have the potential of generating an overall decline in SOM levels which may not significantly depend on the specific cropping system and fertilization practice. The soil working of arable fields, which is repeated annually, may stimulate decomposition of SOM. Vertical transport of soil between plough layer and subsoil, mediated by deep-burrowing earthworm species, and an increased ploughing depth would also contribute to a general decline in SOM levels. Surface casting of earthworms may exceed 30 t soil/ha/year (Edwards & Lofty, 1977), corresponding to the replacement of an 0.2 cm deep soil layer. Total soil turnover may be even greater, because earthworm casts may be disposed of below the soil surface.

If the depth of ploughing is fixed, an increase in soil bulk density will cause subsoil lower in SOM to be introduced into the plough layer as the original plough layer decrease in depth. A higher soil bulk density may arise from a decline in SOM level and from an increased soil compaction, following the introduction of heavier field implements and tractors.

Based on average C contents of the CS- and SL-soil, Table 9 illustrates the effect of an increased plough depth on the C content of the resulting plough layer. An increase from 20 to 25 cm causes the C content of the CS- and SL-soil to decrease by 0.04 and 0.08%, respectively.

The general decline in the SOM content of the Askov long-term field experiments is not an outstanding observation. Long-term experiments such as the Morrow Plots (Odell et al., 1984), the Sanborn Field (Wagner, 1982), and the Woburn experiments (Johnston, 1982) also provide data showing long-term declines in SOM contents. If these results apply to present farming practice, implications for future soil fertility need to be evaluated carefully.

Experiments with Different Cropping Systems (1956-1986)

Two experiments testing the effect of cropping system on the SOM content were started in 1956. One experiment was placed on the SL-soil close to the B.3 and to the B.4 field. All plots in this experiment received nutrients corresponding to the 1 NPK dressing. Four cropping systems were included: crop rotation 1 (winter wheat, beets, spring barley, clover/grass), crop rotation 2 (as in rotation 1 but clover/grass replaced by flax), crop rotation 3 (as in rotation 2 but beets replaced by maize), and continuous fallow.

The development in the N content of the plough layer (0-20 cm) during the period 1956 to 1986 is depicted in

Fig. 2, and results of regression analyses on the C and N content presented in Table 10. All cropping systems caused the SOM content to decrease, the steepest decline being observed after continuous fallow. Differences between the effects of the three crop rotations were small although statistically significant in some cases.

In the other experiment testing the effect of cropping systems on SOM content, plots were confined in concrete cylinders having a diameter of 1 m and being 50 cm deep. Besides the effect of various crop rotations, this small-plot experiment also included the effects of straw incorporation, mineral fertilizer and animal manure. A detailed description of the experiment and results on soil C and N content has been reported by Christensen (1988). Two soils were used: top soil from a loamy sand with a relatively high SOM content (SL-topsoil) and a coarse sand subsoil with a very low SOM content (CS-subsoil).

The changes in soil C and N contents of the 0-25 cm soil layer, calculated by linear regression, is presented in Table 11, and Fig. 3 shows the development in C content for selected treatments. All treatments caused an increase in the SOM content of the CS-subsoil and a decrease in the SL-topsoil. The relative effects of the different treatments on the SOM content in the two soils were similar, however. Treatments producing the largest increases in the CS-subsoil were also those which caused the smallest reductions in the SL-topsoil. The most beneficial effect on the SOM content was observed for the treatments: cereals with straw incorporation, crop rotation with animal manure, and 3 year of clover/grass +1 year of root crops.

The initial SOM content of the SL-topsoil in the small-plot experiment was nearly twice that found for the SL-soil in the field experiment. The SL-topsoil was sampled from a field with a long record of grass leys. Comparing equivalent treatments of the two experiments (e.g. fallow of the field experiment with unmanured fallow of the small-plot experiment, rotation 1 with T4, rotation 3 with T2), the mean annual decreases in SOM content of the small plot experiment (Table 11) is seen to be almost twice as high as the corresponding values in the field experiment (Table 10).

Studies on Soil Movement Between Plots in Long-term Experiments

Many of the experiments which today have gained a long-term status were originally expected to continue for only a limited number of years. Consequently, they were not necessarily designed to meet the problems associated with field experiments that last for several decades. One such problem is the exchange between plots of soil and substances accumulated in soil, a problem that may seriously affect results extracted from experiments where soil working crosses plot borders.

The following paragraphs will present results from Danish studies on soil movement between plots carried out mainly in relation to the Askov long-term experiments.

Dorph-Petersen (1948)

An early attempt to quantify the significance of soil movement between adjacent plots was done in 1942 on two field experiments testing lime and marl (Dorph-Petersen, 1948). A 1m by 1.5 m grid with transects parallel to plot borders was used for soil sampling, samples being taken at each intersection of the grid. Plot dimensions were 7.0 by 6.66 m (Askov, sandy loam) and 7.5 m by 10 m (Lundgaard, coarse sand soil). At Askov and Lundgaard, lime and marl had been applied 10 and 20 years before soil was sampled, respectively.

Fig. 4 shows the mean pH values of samples taken along the four central transects in the direction of the primary soil tillage operations. Along this direction, sampling points were spaced 1 and 1.5 m apart at Askov and Lundgaard, respectively. The study clearly demonstrated, that soil movement across plot borders was significant, especially when neighboring plots received widely different quantities of lime or marl. It was also observed that soil movement was larger along than across the ploughing direction.

Kofoed (1960)

The movement of soil phosphorus in the CS- and SL-soil was examined in 1958 using ^{32}P-labelled superphosphate (Kofoed, 1960). Labelled superphosphate mixed with soil was uniformly applied at a rate of 1080 kg/ha to 3 by 10 m plots and worked into the top 6 cm soil by hand-held implements. The equivalent of six years of standard soil tillage (seven on the CS-soil) was then carried out within a period of two days. A one year standard tillage includes harrowing, ploughing to 8 cm depth, stubble cultivation (two passes), ploughing to 16 cm depth, and seed-bed preparations (two passes with a light harrow). The direction of tillage operations was reversed after each operation and "year", and was carried out parallel to the short side of the plots.

After each "year", soil samples were taken following 19 transects, each 8 m long. The transects were spaced 1 m apart and were erected across the direction of soil tillage. The fifteen samples from each transect were poled, the soil passed through a 1 mm mesh and the activity counted in a GM-tube.

The distribution of labelled phosphate after 1, 3, and 6 "years" is shown in Fig. 5. After 6 "years", only 46 and 49% of the activity added was found within the treated plot on the CS- and SL-soil, respectively. At the end of the experiment (6-7 "years"), labelled phosphate was detected as far as 7.5 m away from the border of the treated plot.

The displacement of labelled phosphate was confirmed in plant uptake studies using spring barley on the SL-soil and turnips on the CS-soil.

Lindhard (1976)

To evaluate the effectiveness of discard areas in reducing soil movement effects, a study based on soil and crop sampling was initiated in 1965 in the B.3 and B.4 fields on the SL-soil (Lindhard, 1976). Neighboring plots (unmanured and 1.5 NPK in the B.3 field, unmanured and 1 NPK in the B.4) were divided into 19 subplots as shown in Fig. 6. Spring barley and winter wheat were grown in the B.3 and B.4 field, respectively. Each subplot was harvested separately and crop uptake of N, P, and K determined. Soil sampled in the plough layer of each subplot was analyzed for C and N, and for extractable P and K.

The distribution of 0.2 N sulfuric acid extractable soil-P in the unmanured and 1.5 NPK treated plots of the B.3 field is shown in Fig. 6. The shaded subplots correspond to the discard area applied in 1965. It was concluded that displacement of applied fertilizers occurred along and across the direction of ploughing and that the displacement caused yield differences inside the plots. The use of discard areas reduced the effect of displaced nutrients. Taking the yield of the central 2 m^2 subplot to represent the "true" yield, the yield calculated for the net plot applied in 1965 (70 m^2) would be underestimated by 10%. The discard area was increased in 1970 whereby the net plots were reduced to 36 m2 in these fields (see Table 3).

Sibbesen (1985 & 1986)

Inspired by the results obtained by Kofoed (1960), Sibbesen et al. (1985) developed a simple model describing the dispersion of soil particles in one horizontal dimension caused by repeated tillage operations of alternating travel direction. The model assumes that soil dispersion conforms to a diffusion equation with a diffusion constant D, which in the model is termed dispersion coefficient. Thus, it is assumed that the dispersion of soil and accumulated substances initially positioned in a vertical plane follows a Gaussian normal distribution. This assumption is based on the central limit theorem. A detailed presentation of the theory behind the model is given by Sibbesen et al. (1985) and Sibbesen and Andersen (1985).

The model fitted very well to the data of Kofoed (1960). About 98% of the variation was accounted for, and the mean D-values calculated were 0.42 and 0.33 m^2/year for the CS- and SL-soil, respectively. The model was subsequently expanded to cope with two-dimensional dispersion of substances accumulating in soil (Sibbesen & Andersen, 1985). Examples on the relationship between D-values, time, and the average distance that soil particles are spread are given in Table 12.

The model can also be used to calculate the proper size of plots when new long-term experiments are planned. Before the model can be fully implemented, however, information is needed on how the size of D-values depends on soil tillage intensity, soil type, and travel direction. Table 13 gives examples on the smallest plot dimensions be accepted for field experiments expected to continue for 5, 25, or 100 years, if 95 or 99% of the added substances are to remain within the net plots at the end of the experiment. D-values included are 0.1, 0.2, and 0.4 m^2/year.

Sibbesen (1986) used the two-dimensional model for simulating soil and substance movement in a number of current more than 50 year old field experiments and estimated the mean concentration of original plot soil and accumulated substances that would remain within the net-plots in 1984. The net plot was defined as the central quarter of the total plot area, i.e. the width of the net plot was half that of the total plot.

For the majority of the 23 experiments examined, it was found that less than 50% of the original plot soil would reside in the net plots (mean 41%, range 13-72%) if the dispersion coefficient D was 0.2 m^2/year. For a substance added annually at a constant rate and not leached nor taken up by the crops, it was calculated that the substance concentration in the net plot in 1984 would range from 29 to 92% (mean of 23 experiments, 61%).

Current Research

McGrath and Lane (1989) examined the dispersion of heavy metals across plot borders in a field experiment with sewage sludge. The experiment received sludge from 1942 until 1961. In 1985, soil was sampled along transects passing through the centers of adjacent plots. Plot dimensions were 6.1 m by 8.5 m, and the direction of ploughing was always parallel to the short side of the plots.

The model developed by Sibbesen and Andersen (1985) was found to fit well to the observed dispersion of metals and produced D-values of 0.24 and 0.13 m^2 per standard tillage operation in directions parallel and perpendicular to the ploughing direction, respectively.

Stimulated by the findings of McGrath and Lane (1989), a study on the movement of SOM and total-P was initiated in 1989 on the CS-soil (G.1 and G.2 field). Soil samples were taken from 0-20, 20-40, and 40-60 cm depths at 0.5 m intervals following transects passing the centres of selected plots. The position of the three transects is shown in Fig. 7, and preliminary results on the P content of the 0-20 cm layer of transect T1 are presented in Fig. 8.

The 1 P and 1 FYM plots received similar amounts of P. It was to be expected that the 1 P plot would contain more P than the 1 FYM plot, because the annual average amount of P removed in crops during 1949-1972 was 14 kg P/ha on the 1 FYM plots and only 6 kg P/ha on the 1 P plots (Kofoed & Nemming, 1976).

Fig. 8 shows that the P level increases steadily from the border of the unmanured and 1 P plot towards the northern end of the transect. Transect T1 was positioned perpendicular to the direction of ploughing. Referring to Fig. 7, it can be seen that the neighboring plots in the ploughing direction received widely different amounts of P. Plots next to the unmanured plot received P dressings while plots adjacent to the 1 P plot received no P. Plots positioned next to the 1 FYM plot received P, the FYM + P plot being exposed to the equivalent of a 1.5 P dressing. Altogether, it appears that the P level in the various plots is significantly influenced by treatments applied to adjacent plots. The dispersion of P after 95 years of experimentation is so significant that a modification of the experiment will be considered.

Outlook on Long-term Experimentation

Franklin (1989) discussed classes of ecological phenomena for which long-term studies are recognized as essential. The classes include slow processes, rare events or episodic phenomena, processes with high annual variability, subtle processes, and complex phenomena. Subtle processes are those where small changes over time are embedded in large year-to-year variance ("noise"), whereas complex phenomena involve many interacting factors.

Compared with natural ecological systems, agroecosystems are usually "controlled" to a higher degree and therefore a larger number of the interacting factors may be quantified. The processes in force in agroecosystems are, however, of a similar nature and complexity as those found in natural ecosystems.

Accordingly, long-term agricultural experiments are a potential source of unique and irreplaceable information not only on the impact of agronomy on crop performance and soil fertility. They may also be important in assessing changes in relation to environmental quality as demonstrated by studies on the long-term accumulation of cadmium in soil (Kofoed & Klausen, 1983; Mulla et al., 1980; Rothbaum et al., 1986).

Used uncritically, long-term field experiments may, however, turn into potential sources of fallacious statements and conclusions. Examples of pitfalls include the effect of soil movement between plots caused by soil tillage across plot borders, and the introduction of subsoil into the plough layer caused by the activity of soil fauna or by increases in bulk density of initial plough layer soil. A reduction in SOM content and an increased soil compaction will cause soil bulk density to increase, thereby diminishing the depth of the initial plough layer. If a fixed ploughing depth is applied, subsoil will be introduced into the soil layer sampled. Estimates on the amount of substances accumulated in the soil will, therefore, be too low if based on concentration data. Using soil volume or area data (Dalal & Mayer, 1986; Tiessen et al., 1982) would improve estimates. By using the soil dispersion model, horizontal soil movement could be accounted for.

Movement of soil in the field may be induced by soil tillage, faunal activity, and erosion by wind and water. The soil may be dispersed vertically and horizontally. The quantity of soil exchanged between plots depends on the intensity of soil cultivations, the soil type, slope and exposure of the field, the dimensions of the plots in relation to the direction of soil tillage, and finally on the age of the experiment.

Unless soil erosion is significant, horizontal soil dispersion is probably reduced to a minimum if plots are separated by permanently installed partitions or if soil tillage across plot borders is prevented otherwise (permanent grass strips or the like). If soil tillage is crossing plot borders, large plot dimensions may reduce the effects of soil movement. Other measures include the use of discard areas, and experimental designs that place widely different treatments some distance apart.

Most long-term experiments were not planned to be long-term and were set up to serve purposes that differ from those that apply today. They were often designed to continue for a limited number of years and more or less by chance, they became long-term as time passed by. Many long-term experiments therefore suffer from weaknesses related to samples missing from early periods of the experiment, to differences in sampling and cultivation techniques applied during different periods, to sizes of plots, and to relevance of treatments applied. By taking proper precautions, useful information may nevertheless still be extracted from the long-term experiments, sometimes in unexpected ways.

The vast amount of important information, extracted through time from the existing long-term field experiments, clearly demonstrates the intrinsic value of long-term experiments as a non-renewable resource for research in very diverse areas. Some redesigning will most probably show up to be advantageous for some of the experiments. Caution should, however, be taken to ensure that existing long-term experiments are not overloaded with new treatments by subdividing existing plots. Plot sizes should be kept as large as possible.

Alternatively, new "long-term" experiments should be initiated as supplements to the existing ones and to provide working material for research needs to come. New experiments will obviously gain from the experience that has been obtained from the existing ones e.g. on plot sizes in relation to soil movement between plots. New "long-term" experiments may compare various integrated cropping systems as wholes as opposed to the factorial approach that dominates many of the experiments which today are considered long-term. The new experiments should include current farming practice and involve a diverse array of research disciplines including statistics, crop protection, soil management, plant breeding, and soil science. The experiments preferably should be placed on contrasting soil types and be preceeded by a detailed description of soils and climatic conditions.

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Table 1. Selected climatic parameters for Askov Experimental Station (55°28'N, 09°07'E; elevation: 63 m above sea level). Figures are long-term averages.

Month	Cumulated Precipitation mm	Mean Temperature, °C	Cumulated Sunshine, hours	Potential Evapotranspiration, mm
January	66	-0.2	43	5
February	48	-0.4	65	8
March	36	1.7	125	28
April	46	6.1	177	41
May	43	11.0	253	63
June	50	14.1	255	78
July	89	16.0	242	85
August	102	15.8	217	70
September	89	12.8	166	44
October	84	8.6	98	25
November	70	4.8	46	14
December	67	2.0	31	4
Annual	**790**	**7.7**	**1,718**	**465**

Table 2. Average textural composition of the coarse sand (CS) and sandy loam (SL) soils used for the long-term fertilizer experiments.

	Clay <0.002 mm	Silt 0.002-0.020 mm	Fine sand 0.02-0.20 mm	Coarse sand 0.2-2.0 mm
	-------------- % of soil dry weight --------------			
CS-soil				
0 - 20 cm	4	4	34	57
20 - 50 cm	5	6	38	51
50 - 100cm	3	1	33	63
SL-soil				
0 - 20 cm	12	13	38	37
20 - 50 cm	15	13	35	37
50 - 100 cm	24	12	36	28

According to the Soil Taxonomy System, the CS and SL-soils are classified as Inseptisol (Orchrept) and Alfisol (Typic Hapludalf), respectively.

Table 3. Size of plots in the four fields on the CS- and SL-soil of the Askov long-term fertilizer experiments.

Site	Treated Plot		Net Plot*	
	Dimension m	Area m2	Dimension m	Area m2
CS-soil				
G.1-field	7.53 x 7.30	55	5.03 x 4.80	24
G.2-field	7.53 x 7.30	55	5.03 x 4.80	24
G.3-field	8.78 x 6.25	55	6.18 x 3.75	23
G.4-field	10.03 x 5.48	55	7.53 x 2.98	22
SL-soil				
B.2-field	7.33 x 9.40	69	5.00 x 4.83	24
B.3-field	11.68 x 9.40	110	7.28 x 5.00	36
B.4-field	11.68 x 9.40	110	7.28 x 5.00	36
B.5-field	11.68 x 9.40	110	7.28 x 5.00	36

* From 1970 and onwards; before 1970 net plots were larger.

Table 4. Year of establishment of the treatments in the Askov long-term fertilizer experiments.

	Year of Establishment	
Treatment	CS-soil	SL-soil
0, unmanured	1893	1893
1/2 FYM (3 fields only)	-	1894
1 FYM	1894	1894
1 1/2 FYM	-	1894
1/2 NPK	1923	1923
1 NPK	1894	1894
1 1/2 NPK	-	1923
1 FYM + 1/2 P	1894	-
1 FYM + 1/2 K	1894	-
1 FYM + 1/2 PK	1908	-
1 PK	1894	1934
1 NK	1949	1934
1 NP	1894	1894
1 N	1894	1894
1 P	1894	1894
1 K	1894	1894

Table 5. Dressings of N, P, and K (annual mean of crop rotation) applied in the 1 NPK (mineral fertilizer) and 1 FYM (animal manure) treatments on the CS- and SL-soils. The dressings were changed in 1907, 1923, 1949, and 1973.

	kg nutrient/ha/year					
Period	FYM			1NPK		
	N	P	K	N	P	K
1894-1906	40	13	2	39	12	28
1907-1922	42	13	33	42	13	32
1923-1948	72	16	65	70	17	70
1949-1972	93*	19	58	70	18	66
1973-1988**	98	19	83	100	19	83

*FYM supplemented with N in mineral fertilizer.

**From 1973 FYM was replaced by animal slurry.

Table 6. Crops included in the 4-course rotation of the Askov long-term experiment on manure and mineral fertilizers. Four fields were used on the CS- and SL-soils, with all rotation elements being represented every year.

Rotation Element	Soil	Period	Crop
Winter cereals	S-soil	1894-1988	Rye
	SL-soil	1894-1931	Rye
		1932-1988	Wheat
Root crops	CS-soil	1894-1906	Four subplots*
		1907-1922	Mangolds and potatoes**
		1923-1948	Turnips and potatoes**
		1949-1988	Turnips or potatoes
	SL-soil	1894-1922	Mangolds and potatoes**
		1923-1943	Mangolds
		1944-1948	Mangolds and turnips**
		1949-1988	Sugar beets or turnips
Spring cereals	CS-soil	1894-1972	Oats
		1973-1988	Barley
	SL-soil	1894-1931	Oats
		1932-1988	Barley
Clover/grass (legumes)	CS-soil	1894-1943	Clover/grass mixture
		1944-1967	Lupines
		1968-1988	Peas
	SL-soil	1894-1988	Clover/grass mixture

* Plots subdivided into four parts growing mangolds, turnips, potatoes, and carrots each year.

** Plots subdivided into two parts growing both crops each year.

Table 7. Annual average crop yields obtained for the unmanured (0), 1 NPK and 1 FYM plots in the various periods and expressed as feed units (FU). One FU indicates the relative feeding value of the dry matter in various crops (e.g. 1 FU = 0.83 kg wheat grain, 4.16 kg wheat straw, 0.87 kg barley grain, 3.33 kg barley straw, 1.03 kg beet root, 1.20 kg beet tops, or 1.53 kg clover/grass).

Period	FU/ha/year					
	CS-soil			SL-soil		
	0	1 NPK	1 FYM	0	1 NKP	1 FYM
1894-1906	1420	3360	2750	2360	3790	2640
1907-1922	1070	3440	2830	1600	3820	3390
1923-1948	1310	4510	4140	1630	5310	4420
1949-1972	1360	3790	3990	2080	5860	5470
1973-1984	1060	3800	3350	2160	5890	5460

Table 8. Calculated changes in the content of C and N during 1912/14 to 1984 in the unmanured, the 1 NPK, and the 1 FYM plots of the CS-soil and SL-soil. Values were calculated by linear regression y = a + bx, where x is the number of years (x_0 = 1912/14), and y is the % C or % N in soil sampled during 1912/14 to 1984. The CS- and SL-soils were sampled 15 and 17 times, respectively. The y values used in the regression analysis are the means of the 4 fields.

Treatment	a Calculated Content 1912/14		b Mean Annual Decrease		r	
	% C	% N	% C	% N	C	N
			CS- soil			
Unmanured	0.95	0.074	0.0048	0.0004	0.927	0.973
1 NPK	1.07	0.083	0.0048	0.0003	0.934	0.881
1 FYM	1.19	0.093	0.0053	0.0004	0.892	0.884
			SL- soil			
Unmanured	1.46	0.114	0.0039	0.0002	0.813	0.603
1 NPK	1.66	0.131	0.0050	0.0002	0.899	0.742
1 FYM	1.69	0.139	0.0038	0.0002	0.849	0.691

Table 9. Calculated effect of an increased ploughing depth on the C content of the plough layer. Assumed initial C contents in the CS-soil were 0.70% C in 0-20 cm, 0.50% C in 20-25 cm, and 0.30% C in 25-30 cm; and in the SL-soil 1.40% in 0-20 cm, 1.00% C in 20-25 cm, and 0.70% C in 25-30 cm.

Ploughing depth, cm	Weight of plough layer t/ha	t C/ha		% C	
		CS-soil	SL-soil	CS-soil	SL-soil
20	3000	21.00	42.00	0.70	1.40
21	3150	21.75	43.50	0.69	1.38
22	3300	22.50	45.00	0.68	1.36
23	3450	23.25	46.50	0.67	1.35
24	3600	24.00	48.00	0.67	1.33
25	3750	24.75	49.50	0.66	1.32

Table 10. Field experiment on the effect of cropping system on soil organic matter content. Changes during 1956-1986 in the C and N content of the plough layer (SL-soil, 0-20 cm) were calculated by linear regression of the type y = a + bx, where y is the % C or % N in soil, and x is the number of years (x_0 = 1956). Soil was sampled every year (n = 30).

Cropping System*	a Calculated Content 1956		b Mean Annual Decrease		r	
	% C	% N	% C	% N	C	N
Rotation 1	1.61	0.139	0.0084a**	0.00068a	0.90	0.86
Rotation 2	1.60	0.143	0.0097ab	0.00091b	0.92	0.87
Rotation 3	1.65	0.147	0.0111b	0.00110b	0.94	0.92
Fallow	1.66	0.144	0.0179c	0.00164c	0.96	0.94

*Rotation 1: winter wheat-beets-spring barley-clover/grass
Rotation 2:as in 1 but clover/grass replaced by flax
Rotation 3:as in 2 but beets replaced by maize
**Different letters signify significant differences (95% level).

Table 11. Small-plot experiment on the effect of cropping systems on soil organic matter content. Changes during 1956-1987 in the C and N content of 0-25 cm layer were calculated by linear regression of the type $y = a + bx$, where y is the % C or N in soil and x is the number of years ($x_0 = 1956$). Soil was sampled every 4th year (n = 9). From Christensen (1988).

		b Mean Annual Change			
		SL-topsoil		CS-subsoil	
Treatment		% C	% N	% C	% N
T1:	Fallow, unmanured	-0.033	-0.0027	0.002	0.0003
T2:	All-cereals, straw removed	-0.023	-0.0017	0.010	0.0007
T3:	All-cereals, straw incorporated	-0.009	-0.0009	0.020	0.0014
T4:	Crop rotation,* mineral fertilizer only	-0.015	-0.0010	0.014	0.0013
T5:	Crop rotation, with animal manure	-0.008	-0.0006	0.019	0.0018
T6:	All root crops	-0.025	-0.0017	0.006	0.0006
T7:	3 year clover/ grass + 1 year root crop	-0.012	-0.0006	0.016	0.0013

* Crop rotation: winter cereals-root crops-spring cereals-clover/grass

Table 12. Average distance (x) that soil particles originally positioned in a vertical plane are spread by cultivations across the plane year after year. $x = (4\,Dt\pi^{-1})^{1/2}$ (Sibbesen, pers. comm.).

	Dispersion coefficient, D (m^2/year)		
Time, t (Years)	0.05	0.20 Average distance, x (m)	0.80
1	0.25	0.50	1.01
4	0.50	1.01	2.02
16	1.01	2.02	4.04
64	2.02	4.04	8.07

Table 13. The smallest plot dimensions to be accepted in long-term field experiments when 95.0 or 99.0% of the total added substance is to remain within the net-plot at the end of the experiments. Assumptions are: constant annual net-addition of substance; constant annual tillage; same D-value for both dimensions; square plots; the width of the net-plot is half the width of the treated plot. From Sibbesen and Andersen (1985).

D (m2/year)	Duration of Experiment (years)	Percentage of Added Substance Remaining in the Net Plot 95.0	99.0
		Minimum Plot Width (m)	
0.1	5	5	8
	25	10	14
	100	19	28
0.2	5	7	10
	25	14	20
	100	27	39
0.4	5	9	13
	25	19	28
	100	38	56

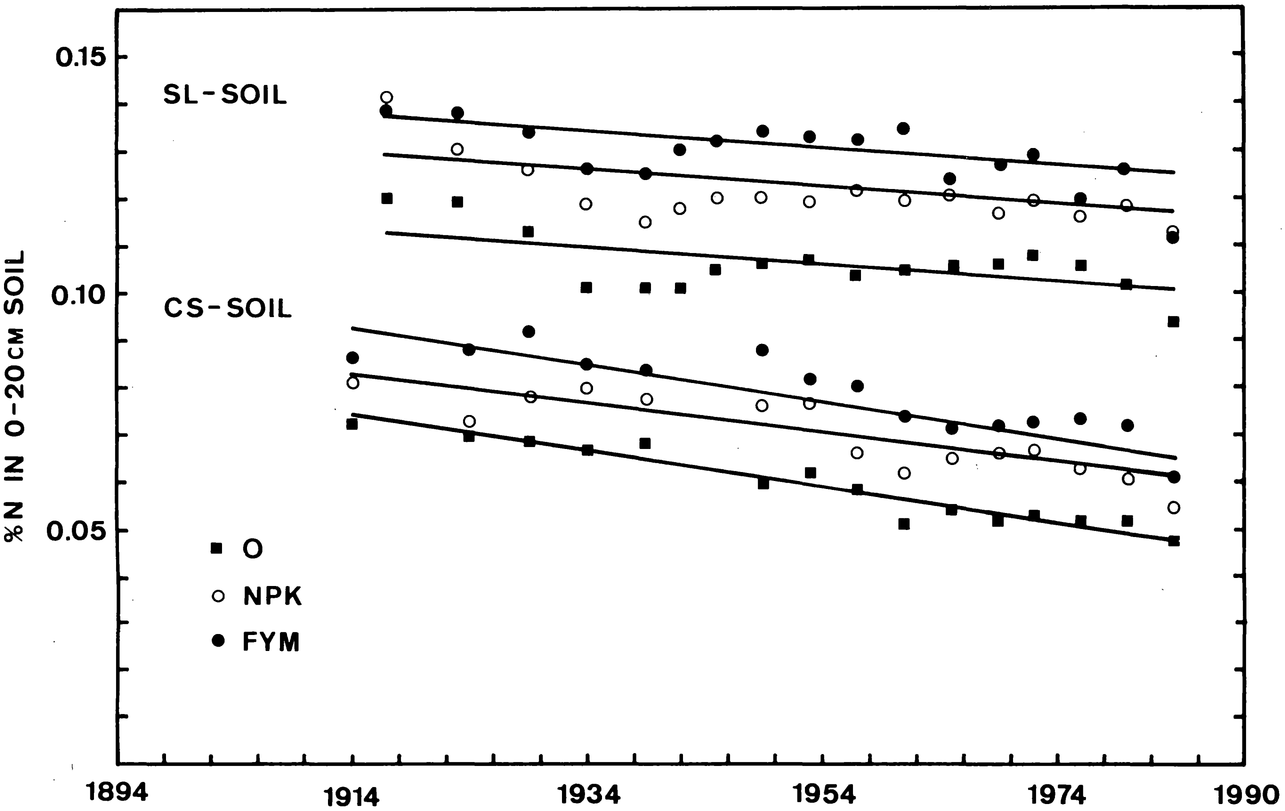


Figure 1. The effects with time of soil treatments upon soil nitrogen in a coarse sand (CS) and a sandy loam (SL) soil with a winter cereal-root crop-spring cereal-clover/grass ley.

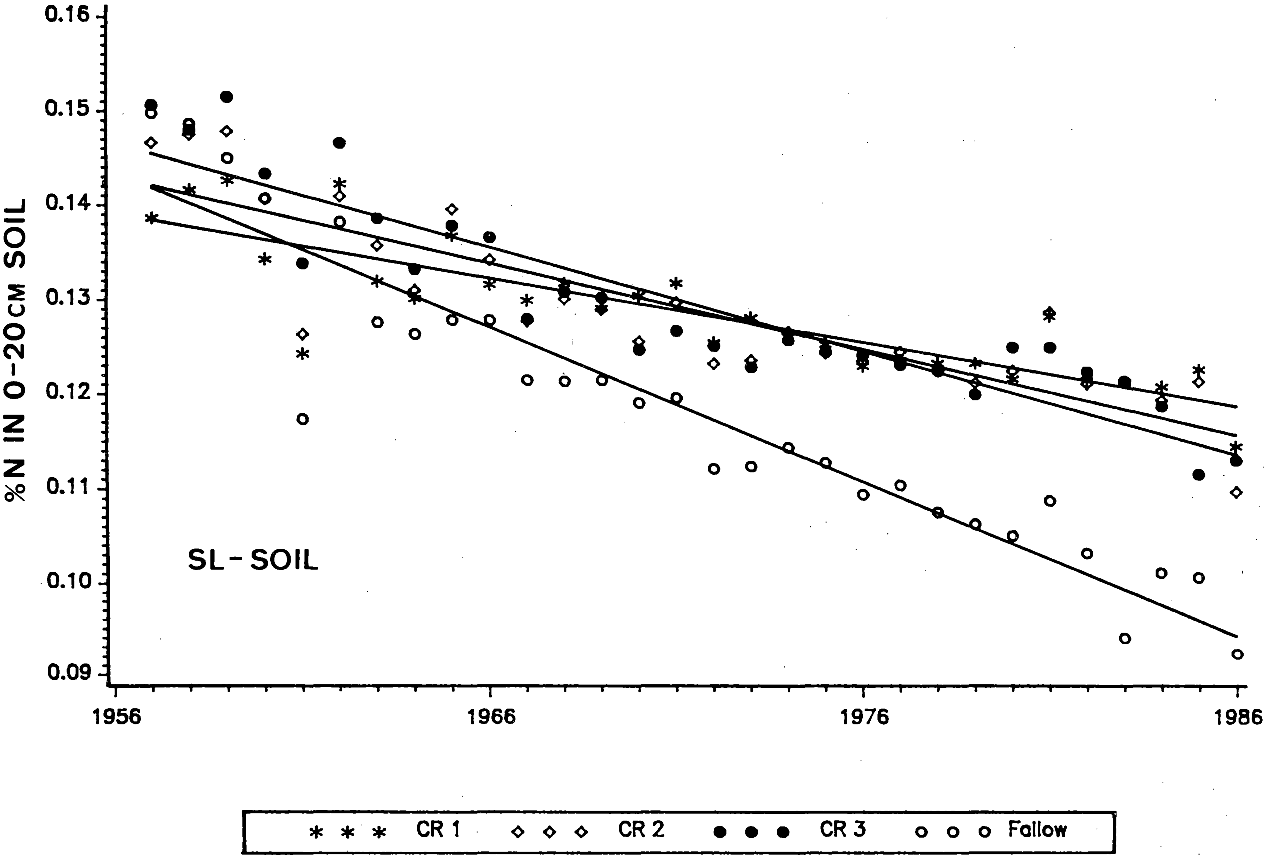


Figure 2. The effects of different cropping rotations (CR) on soil nitrogen in a sandy loam soil.

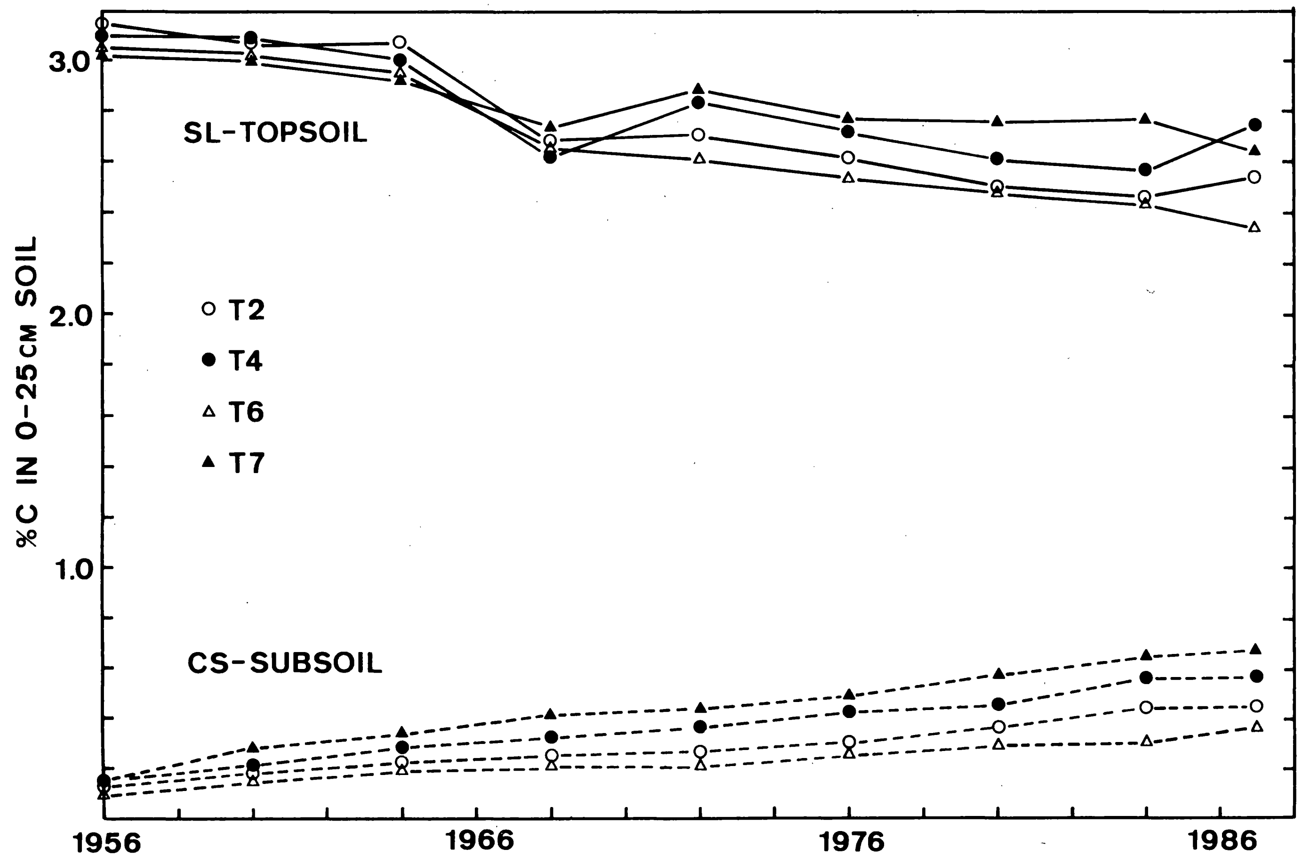


Figure 3. The effects of cropping systems on soil C in two soils (See Table 11).

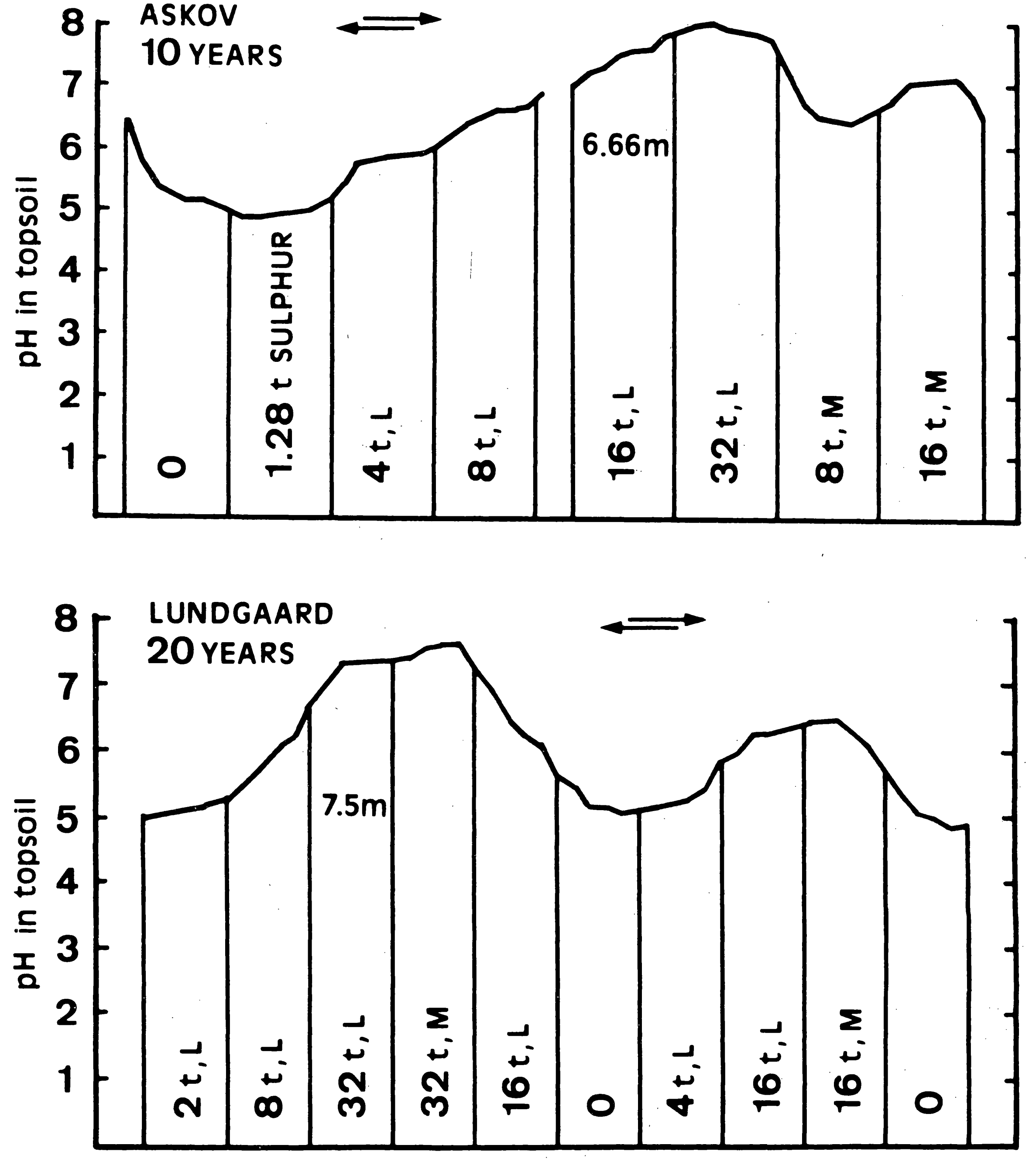


Figure 4. The movement of soil in 2 years by tillage across plots using pH as an indicator (Dorph-Peterson, 1948).

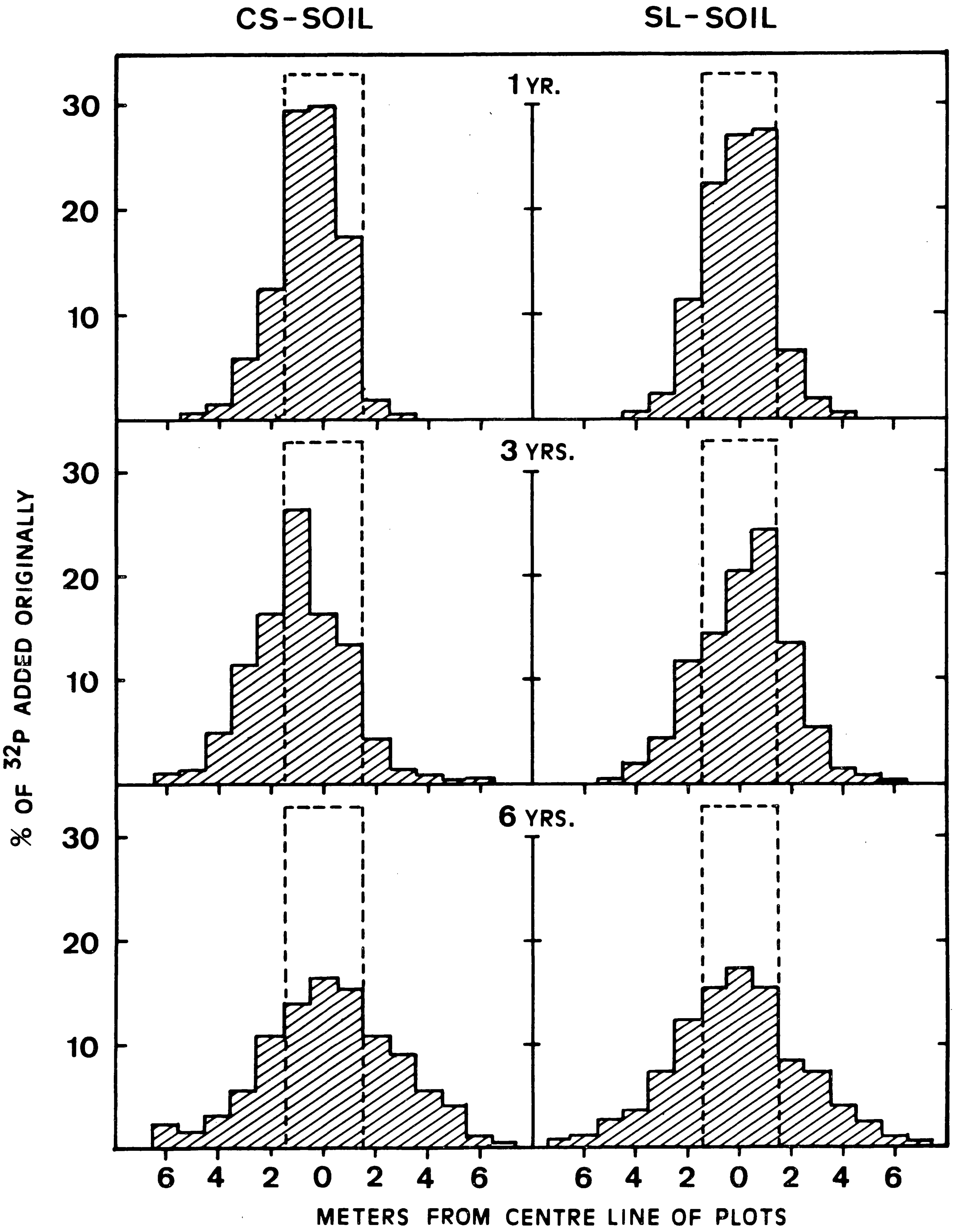


Figure 5. The movement of ^{32}P by tillage parallel to the short side of the treated plot (Kofoed, 1960).

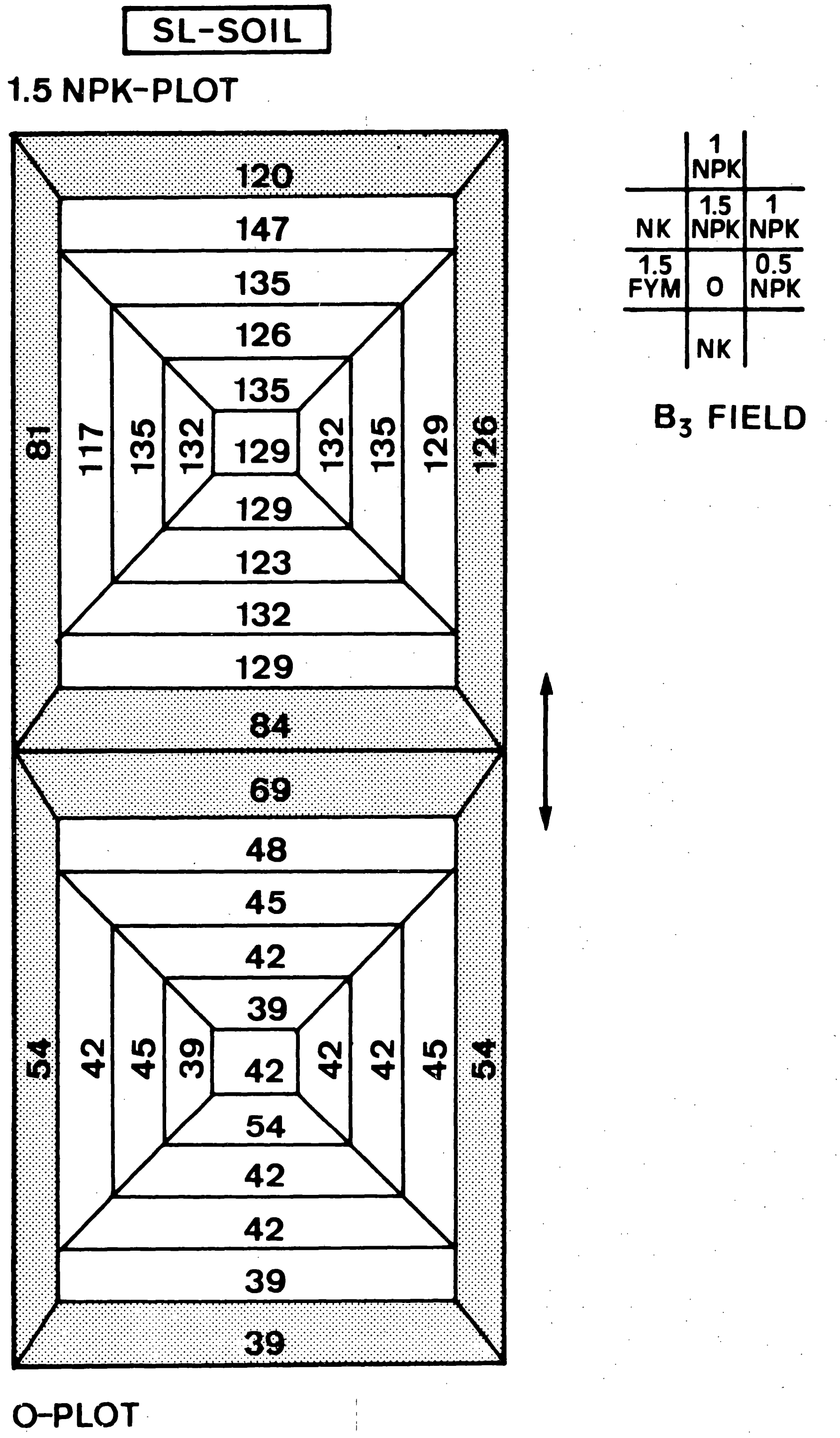


Figure 6. The distribution of 0.2N sulfuric acid extractable P in the plough layer of a sandy loam soil sampled relative to treatments and after ploughing (Lindhard, 1976).

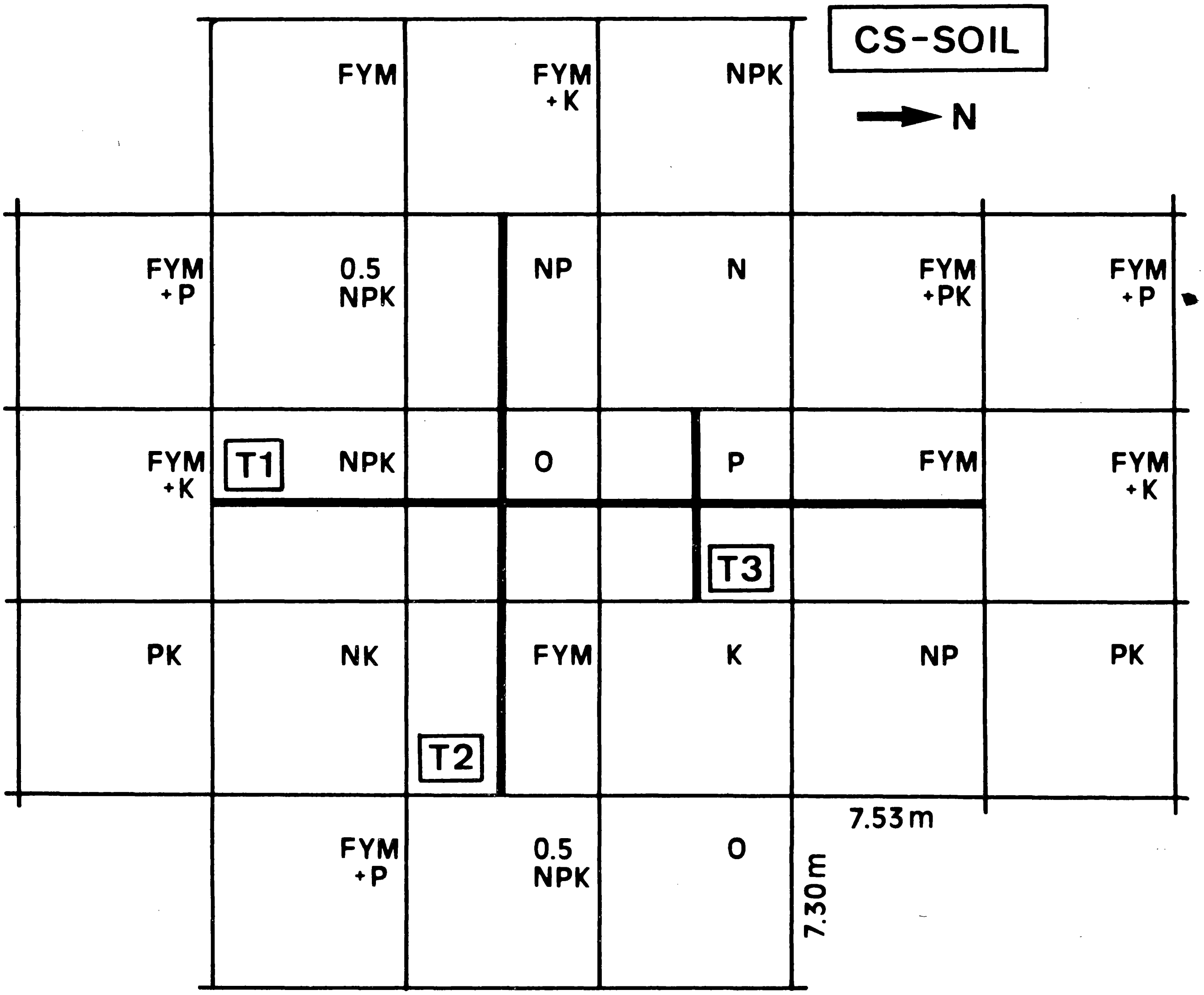


Figure 7. Locations of transects (T) used to evaluate movement of SOM and total P in a course sand soil receiving different treatments.

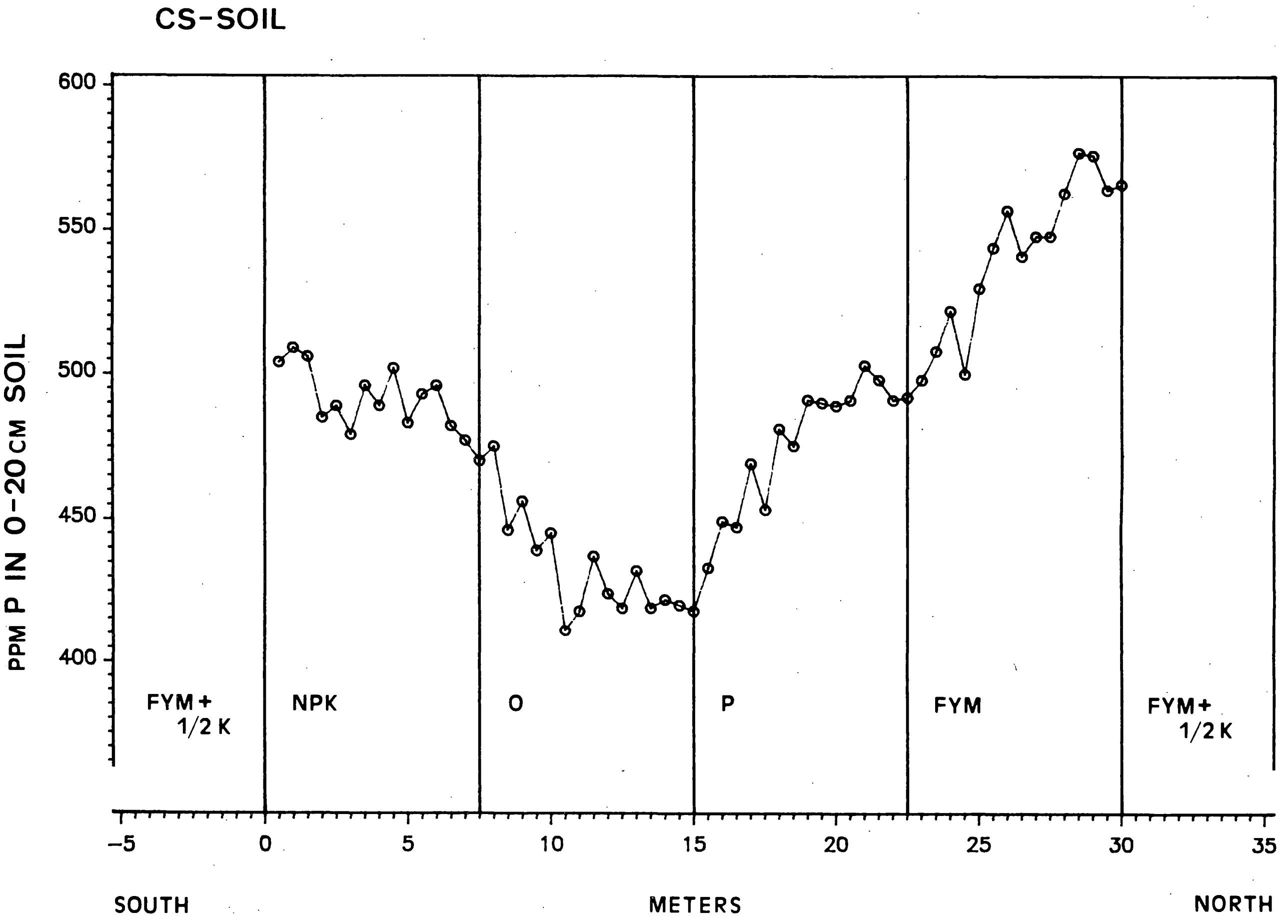


Figure 8. The P content in the 0-20 cm layer of soil along transet T1 (Figure 7).

Morrow Plots - Long-Term University of Illinois Field Research Plots, 1876 to Present

T. R. Peck
University of Illinois

Two Agronomic questions are being studied on America's oldest long-term continuous field study known as the Morrow Plots. These are: 1. the effects of crop sequence, and 2. the effects of soil fertility treatments.

The Morrow Plots are located on the University of Illinois campus at Urbana-Champaign. The area is in the southeast corner of the campus. The plots are arranged with Plot 3 on the North, Plot 4 in the middle, and Plot 5 to the south, with sub-plots North A (Northwest corner), South A, North B, South B, North C, South C, North D (Northeast corner), and South D located in each plot, respectively (Figures 1 and 2). Each subplot is one-fortieth acre.

Crop Sequence

The question of crop sequence is studied with Plot 3 cropped to continuous corn from 1876 to the present, Plot 4 cropped to corn-oats sequence from 1876 to 1966 with a change to corn-soybeans in 1967 to present, and Plot 5 cropped to a 3-year sequence of corn-oats-clover from 1876 to the present.

Soil Fertility

Soil fertility treatments have changed over the years and have been the reason for subdividing plots. During the first 18 years, 1886 through 1903, no soil fertility studies were done on the Plots. In 1904, treatments of manure and limestone were applied to the subplots designated south with rock phosphate as a carrier of P applied to subplots South A and B, and bone phosphate as a carrier of P to subplots South C and D. The second change in soil fertility treatment was the spring 1955 addition of nitrogen, phosphorus, and potassium fertilizers to the previously untreated area of North B and the treated area of South B. The last soil fertility change occurred in the spring of 1967 to manage the soil fertility program for subplots North B and South B with current soil fertility recommendations based on soil test levels, and subplot South A treated with higher soil fertility to increase soil test levels above recommended levels. Presently, subplots North A, C, and D are untreated awaiting the time when a new treatment is needed.

The soil on which the plots are located is Flanagan silt loam which is a Mollisol classified as an Aquic Argiudoll. Flanagan silt loam is a nearly level, dark colored soil developed in 40 to 60 inches of loess over loam glacial till under prairie vegetation and somewhat poor natural drainage. Before the 1904 season, underground tile lines were installed in the plot borders to provide supplemental drainage. Available moisture holding capacity is about 0.25 inch of water per inch of soil with about 18 milliequivalents/100g of soil of cation exchange capacity in the surface increasing to 25 milliequivalents/100g in the subsoil and the natural soil reaction is acidic with pH about 5.8 to 6.0.

History

The plots were established in 1876 to settle the controversy then raging about whether or not the prairie soils of the area could be depleted. That question was settled by 1904 with corn yields of the continuous plots yielding 32 bu/acre or 78% of the rotation at 41 bu/acre compared to the 2-year rotation at 36 bu/acre or 88%. Interpretations arrived at were:

1. Soils can be exploited and depleted.
2. Soils can be cropped and preserved.

The next soil fertility mile post occurred in 1955 with additions of limestone, nitrogen, phosphorus, and potassium fertilizers to previously unfertilized subplots.

Questions being asked were:

1. Are the changes brought about in the productive capacity of these plots by exploitive cropping of unfertilized subplots only temporary or permanent?
2. Can the low-yielding plots be made to produce yields equal to the highest by adequate chemical fertilizer treatment?
3. If so, can it be done immediately or how long will it take?

Newspaper headlines of the day proclaimed "Fertilizers Will Revive Worn-out Soils." The Morrow Plots' yields show that low yields caused by continuous cropping of non-eroded soils were due to loss of plant food nutrients and not to irreversible changes.

While the increases in crop yields with fertilization were immediate and dramatic, fertilization has not completely offset the effects of past treatment as the MLP + LNPK has consistently produced higher yields than None + LNPK.

Likewise, fertilization did not completely offset the effects of crop rotation. Under each of the different fertilization systems corn yields were higher with the 2- and 3-year crop rotations than with continuous corn. The highest crop yields were obtained with crop rotation and suitable fertilization.

Crop rotation plus appropriate fertilization not only produced the highest crop yields, but also maintained soil N and organic C at the highest levels among the subplots.

Figure 3 shows the organic carbon levels in plots NC which are untreated plots with no known history of any treatment with lime, fertilizer, or manure. It is unfortunate that neither soil analyses nor soil samples can document organic carbon levels at the start of the study nor during the first 28 years. Since 1967, with the change of crop sequence on plot 4NC, the decline in organic carbon of that plot has been more rapid for the new crop sequence than on accompanying plots that are in equilibrium with the crop sequences of long standing.

Present day corn yields, depending on vagaries of the weather, of the untreated plots are in the range of 30 to 50 bu/acre on the continuous corn, 50 to 70 bu/acre on the Corn-Soybeans sequence, and 70-90 bu/acre on the Corn-Oats-Clover sequence. Better treated plots topped 200 bu/acre in 1982 and are respectable in most years.

The Morrow Plots are protected for posterity as they have been designated a Registered National Historic Landmark.

Long-term field research plots such as these document our Agricultural history. They offer hope that with wise management, our soils can feed our population and a challenge to understand the system and do better.

Treatment	**1955 bu/acre**	**1956 bu/acre**
	Plot 3, Continuous Corn	
None	36	29
LNPK	86	113
MLP	79	96
MLP + NPK	98	128
L = 5 tons/acre, N = 200 lbs/acre, P_2O_5 = 150 lbs/acre, K_2O = 100 lbs/acre		
	Plot 4, Corn-Oats	
None	43	
LNPK	97	
MLP	98	
MLP + NPK	107	
L, N, P, K rates as above		
	Plot 5, Corn-Oats-Clover	
None	63	
LNPK	102	
MLP	100	
MLP + NPK	101	
L, P, K rates as above, N = 100 lbs/acre		

Table 1. Corn yields from the Morrow Plots in 1955 and 1956 comparing the effect of rotation, residual soil treatment, and the first and second application of a complete chemical fertilizer treatment.

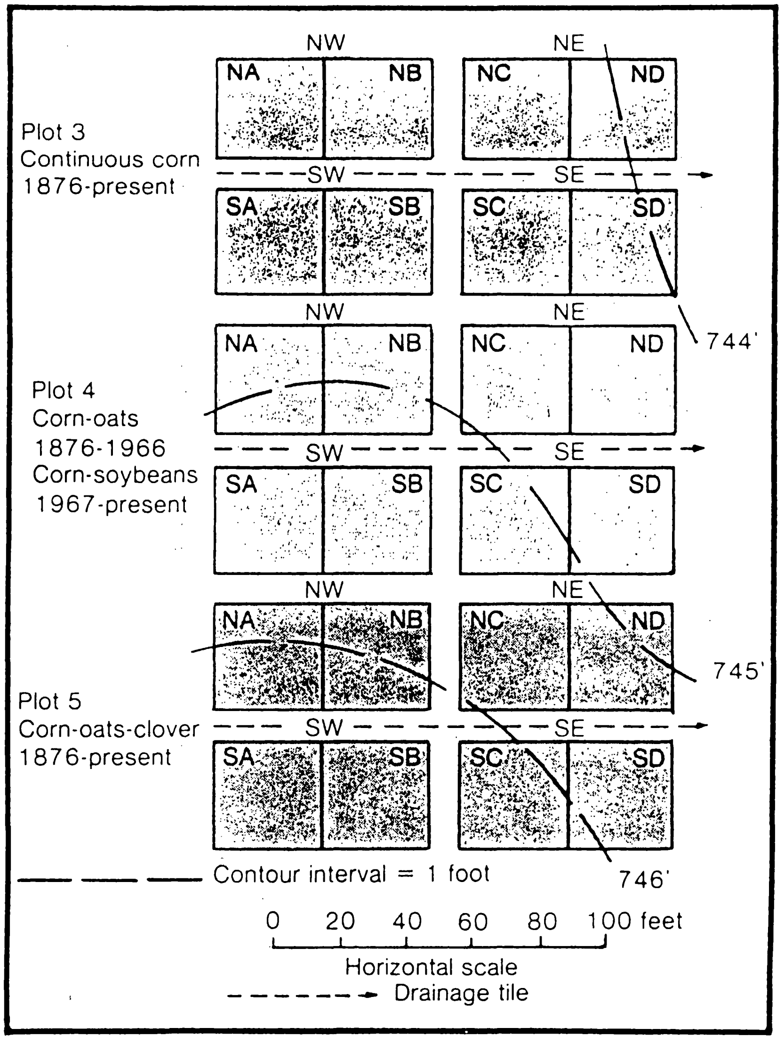
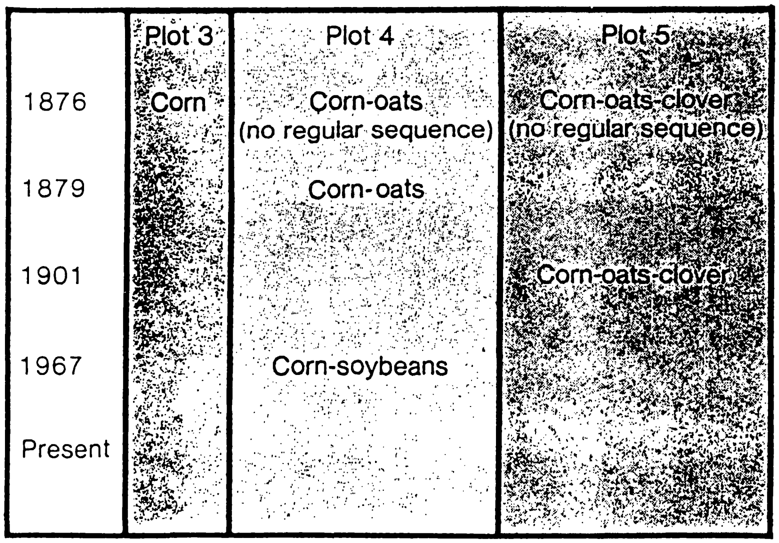


Figure 1. Layout of the Morrow Plots.



	Plot 3	Plot 4	Plot 5
1876	Corn	Corn-oats (no regular sequence)	Corn-oats-clover (no regular sequence)
1879		Corn-oats	
1901			Corn-oats-clover
1967		Corn-soybeans	
Present			

Figure 2. Cropping history of the Morrow Plots.

From: Illinois Agricultural Experiment Station Bulletin 775 (1982)

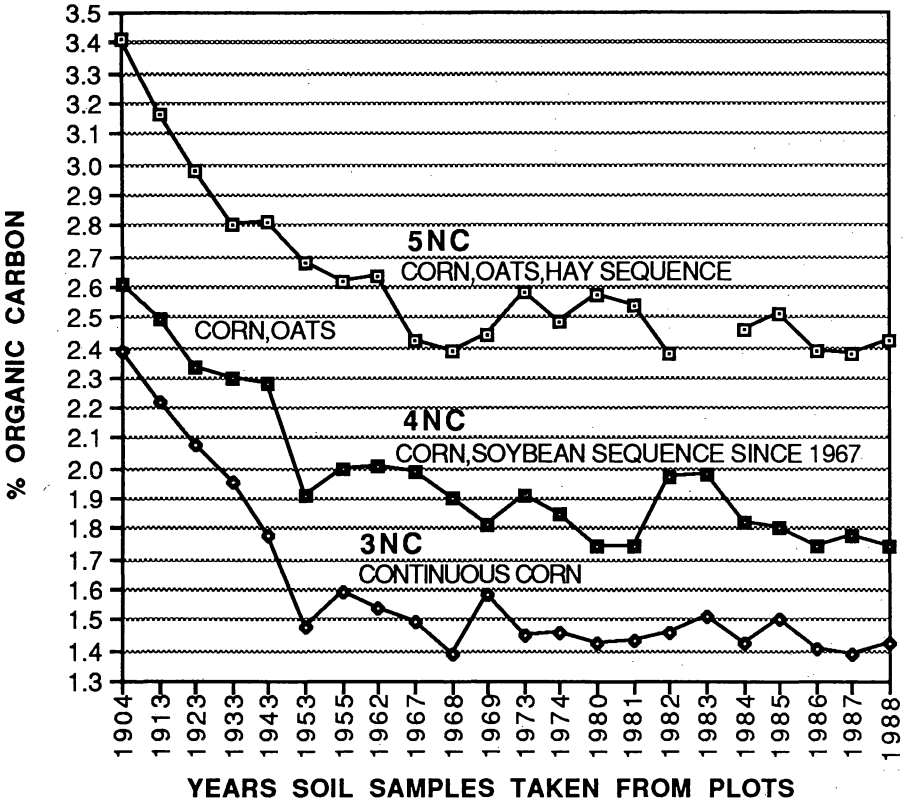


Figure 3. Organic carbon in Morrow Plots soil of plots 3NC, 4NC and 5NC for selected years during 1904 to 1988.

Sanborn Field: An Overview

J. R. Brown and G. W. Wyman

There is no easy way to provide an overview of 100 years in a short document. Upchurch et al. (1985) provided a comprehensive historical perspective to the field. That document took several months of research and writing to condense 97 years into a few pages. Now, for this Centennial document, we need to condense even further yet keep some aspects of depth.

What should be the focus? People? Change at the University? Key findings? The other papers in this document will summarize results so the approach will be to highlight the objectives, present some key historical events, introduce some key people, and outline key changes over the 100 years.

Objectives

A review of the records of Sanborn Field revealed that no one had written clear objectives for the field until Dr. William Upchurch first stated these to the Agronomy Department faculty in 1979. Dr. Ed Runge, then the department chair, had correctly pointed out that objectives were necessary to continue to justify an activity such as Sanborn Field and to guarantee its continuation. Dr. Upchurch compiled these objectives after reviewing the copious notes made by his predecessors. From these notes, the following objectives resulted:

> "1. To maintain Sanborn Field as a research field laboratory for determining long-term effects of crop and soil management upon chemical, physical, and biological properties of soil.
> 2. To display the effects on soil productivity of historical and modern methods of soil management applied to various cropping systems. The effects will be documented by crop yield and composition relative to crop performance in relation to growing conditions, and by measures of chemical, physical and biological soil conditions.
> 3. To maintain a historical field for collecting soil and plant samples systematically to relate to soil and environmental conditions.
> 4. To maintain the vitality of management systems by initiating at appropriate times, practices that have long-range implications relative to soil changes." (Upchurch et al., 1985)

It has become very obvious in the last decade that these objectives while still valid may need revision. The shift in the backgrounds of our students in agriculture from dominantly rural to dominantly urban has demonstrated the great value of Sanborn Field to our undergraduate teaching program. Objective one may need restatement to include reference to teaching. Funding restrictions have limited the sampling and analyses to achieve objectives 2 and 3.

The Deanship

The College of Agriculture was quite small in the 1880's and the Dean tended to directly influence all activities. The personality and training of the Deans from 1888 through 1945 resulted in these gentlemen being directly involved in Sanborn Field and its activities. A brief review of the nature of these Deans will explain the nature of Sanborn Field and why it has survived for 100 years.

Upchurch et al. (1985) and Miller (1961) provided the basis of the following remarks. M. F. Miller came to the University of Missouri in 1904 as a 29 year old member of the recently formed Agronomy Department. He retired as Dean of Agriculture in 1945. His interest in Sanborn Field spanned the longest period of any of the persons who were associated with the field over its first 50 years.

Miller acquired responsibility for the field following several uncertain years. In 1889, having served as Dean for only 7 years, J. W. Sanborn resigned after several stormy encounters with the Board of Curators and the State Department of Agriculture.

E. O. Porter succeeded Sanborn as Dean but had an even shorter tenure. H. J. Waters became Dean in 1895. It was during the Waters reign that the College started to blossom and expand. According to Miller (1961), the great credit is due directly to Dean Waters and it was "his wise judgements and his popularity among people" that led to the success of the College.

When Waters became Dean in 1895, he had delegated the responsibility for Sanborn Field to the manager of the experimental farms. Each of the 39 plots had to be treated as a mini-field and took a great deal of time. At the time M. F. Miller was hired in 1904, the field was almost abandoned. However, Miller kept the plan in place. Thus, for the most of the first 50 years, Miller played a significant role either directly or by influencing those who did direct the operations. F. B. Mumford succeeded Waters as the Dean in 1909 and remained Dean until succeeded by Miller in 1938.

Under the successive leadership of Sanborn, Porter, Waters, Mumford, and Miller, the College evolved from a small group of scientists in 1888 to a large multi-department College set to serve those who returned from World War II. During this evolution, the direction of Sanborn

Field by 1945 had shifted from the College level to a project leader in the Soils Department and remained under the leadership of a soil scientist through 1989.

Key Periods

The history of the field may be divided into several key periods based upon significant changes in management. The other papers in this document will provide greater detail than will be given in this overview. Figure 1 presents the field as it exists in 1989 and is included for reference purposes.

Professor Miller seemed to be the guiding force in the early history of Sanborn Field either directly or indirectly by influencing those who operated the field. As Miller (1961) pointed out, the history of the site prior to the 1888 wheat seeding was not recorded. Miller stated "I have been told that the land on which Sanborn Field was laid out was originally a tract of pasture with scattered elm trees and with buck brush undergrowth....The records aren't clear, but no doubt it was planted to corn for one or more years after which he [Sanborn] laid out these plots...".

Sanborn called the field the "Rotation Field" because he used several crop rotations. On each rotation, he imposed a no treatment plot and at least one manure treatment. In some cases, a chemical fertilizer treatment was also used (Table 1). In 1926, when Sanborn returned to Columbia for the rededication of the Rotation Field as Sanborn Field, he preferred to discuss his problems with Missouri administration rather than answer Professor Miller's questions about the field (Miller, 1961).

The original rotations and treatments selected by Sanborn went unchanged until 1914 (with the exception of plot 29). Several plots within each rotation received 6 tons of manure per acre annually (Table 1). There were also several replications of some of the treatments. The almost complete lack of chemical treatments reflects the limited impact of commercial fertilizer in those days.

Outside events sometimes have unexpected effects. In 1904, a portion of the north side of Sanborn Field, including plot 8, was sacrificed so Bouchelle Avenue could be constructed. The loss of the north border caused the size of each plot to be reduced from one-tenth acre to one-thirteenth acre. All remaining 38 plots were reduced to the same size. The interesting item is that the original per plot treatments were not reduced with the reduction in plot size. For example, the initial 6 tons of manure per acre treatment or 1200 lbs per plot was still applied to 1/13 of an acre making the actual per acre quantity 7.8 tons. Similar calculations should be made for the other manured plots.

In 1914, several significant changes were made in the cropping plan (Tables 2a and 2b). At that time, plot size was further reduced to 1/14 of an acre by widening borders between plots. The quantities of soil amendments including manure on a per plot basis were readjusted to truly reflect the per acre equivalent (Miller and Hudelson, 1921).

These 1914 changes were made in response to increased attention toward commercial fertilizers. Miller and Hudelson (1921) stated "These are very heavy applications, too expensive for practical use in general farming in Missouri, although no greater than are commonly used in trucking, potato growing, cotton farming, or other types of intensive .agriculture." The fertilizer was initially applied by drilling with the seed but interference with germination was noted so the fertilizer was either drilled a few days before the seed or was topdressed after germination.

The initial manure application of 6 t/acre annually was deemed excessive relative to the amount available on the general farm. The changes made in 1914 reduced the amount of manure applied over the course of some rotation cycles. It had been noted that oats yielded less with manure than with fertilizer and the reason was given as lodging due to excessive N in the manure (Miller and Hudelson, 1921).

The addition of a limestone treatment on plot 38 in 1914 was the first liming done on Sanborn Field and predated the accelerated lime program of the 1920s (Miller and Hudelson, 1921). The failure of clover seemed to be the factor that resulted in this change. New phosphorus treatments were added in 1914 following the observations made on wheat heading and maturity between plots 2 and 3 (added P) and untreated plots (Upchurch et al., 1985).

The next change in the management of several plots came in 1928 (Table 3). Smith (1942) listed these changes, as given in Table 3, but did not provide any insight concerning the reasons for the changes. The field records state "It had become apparent that the rotation and soil treatment for some plots were impractical, and were no longer contributing information of much value."

From our vantage point today, one of the two most significant changes made in 1928 was starting the 3 year rotation of corn-soybeans-wheat with sweet clover green manure on plots 31, 32, 33 with P omitted from one plot and K omitted from another. The soybeans were used as forage. The second significant change was splitting N applications on wheat between seeding and spring. These two changes appear to be the first real attempts at managing the fertility for the crop and to document more clearly the role of K in plant nutrition.

The 1928 plan remained unaltered through 1939 when Dr. George E. Smith made his first impact on the field by making several fertility and managerial changes (Table 4). The reasons stated for these changes were impracticality of some in use and duplication of treatments and/or management.

Agriculture had undergone great changes between 1928 and 1939 whether because of, or in spite of, the "Great Depression" remains for the agricultural historians to state. Farming was well on its way toward reliance upon the internal combustion engine for motive power. The Sanborn Field records for 1939 included a statement that a tractor ("new Allis-Chalmers") was first used for a regular operation on the field. The need for animal motive power rapidly declined and along with it manure supplies and the need for oats as feed and of straw for bedding. Hybrid corn had been introduced and its benefits were obvious. The fertilizer industry while in its infancy had already demonstrated the value of fertilizer to crop production.

Upchurch et al. (1985) suggested three concerns formed the theme of the 1940 changes. The availability of P from rock phosphate needed to be clarified. Second, was the question of when P and K should be applied in a rotation. The third was an evaluation of the role of crop residues in nutrient availability. Prior to this, straw and stover had been removed from the field. Also noted was greater reference to the use of the principles of cation exchange in reaching the quantity of soil amendments.

The records made during the 1940-49 period make reference to lack of help, likely as a result of World War II, and of "unusual" weather. This period also encompassed the period from the time George Smith left the Soils Department for military service (1943) and his return to MU after stints in the military and with a commercial food processor. When Dr. Smith returned, he reviewed the management of the field and implemented many major changes starting in 1950 (Table 5).

Smith placed in the Sanborn Field record book the following statement as a preamble to his description of the changes initiated in 1950:

"At the end of sixty years of cropping, it is evident that few of the soil treatments on Sanborn Field are adequate to replace the nutrients removed by cropping. Where some nutrients are present in sufficient quantities, others are low and furnishing the plants an improper balance of nitrogen and minerals. As a result, crop yields and the appearance of the field has declined. "Suggestions" have been made that the area be used as a parking lot or a site for new greenhouses. The increased use of soil tests has greatly increased the use of fertilizers in the state. The availability of cheap nitrogen (ammonium nitrate and anhydrous ammonia) has de-emphasized the importance of animal and green manures in maintaining soil nitrogen. Many of the more progressive farmers are using management systems that are widely different from any of the practices followed on Sanborn Field plots."

The reference to soil testing points out a major activity that was still in its infancy in 1950. Ellis Graham, with the help of C. M. Woodruff, assembled the methods of soil testing that led to the creation of the Missouri County Laboratory Soil Testing Program (Graham 1950). The plots on Sanborn Field provided soil material for the evaluation of these testing methods and gave students experience in testing soils of widely different nutrient levels. These soil samples and this soil resource is still being used for this purpose (Jirapunvanich 1987).

Upchurch et al. (1985) stated that "the primary object of the revised plan of 1950 was to introduce modern approaches to fertilization." "Full treatment" was introduced to describe the optimum application of limestone and fertilizer based upon calibrated soil tests. Starters, while used somewhat prior to 1950, were identified as a good management practice (Table 6).

The Exceptions

The loss of plot 8 to the construction of Bouchelle Avenue lowered the number of plots to 38. The original plan for plots 6 and 7 called for continuous red clover with, and without, manure, respectively, but the red clover failed. In 1909, the plan was changed to continuous cowpeas. In 1928, a 4 year rotation was started on these two plots then in 1940 a special P, K, and lime study on grass was started. Thus, from 1888 through 1949, plots 6 and 7 underwent several changes and have not had the continuity of the remainder of the original 38 plots.

In 1950, continuous corn under full fertility was started on plots 6 and 7 using conventional tillage. In 1962, wheel track planting was introduced on plot 6 with plot 7 remaining conventionally tilled. In 1970, both 6 and 7 were planted no-till into a mowed winter wheat mulch. Irrigation was used on one of the plots and this plan alternated between plots each year through 1979. In 1980, plot 7 was designated to remain no-till but conventional tillage was started on plot 6 with both wheat mulch and irrigation being terminated.

The area in the southwest corner of the field which had not initially been used for plots was brought under experimentation in 1916 after an attempt was made to improve the drainage by tiling. The area was bulk cropped to soybeans for 1 year then put into a 3 year rotation of corn, wheat, and red clover to evaluate several P fertilizers on plots 11 ft. x 100 ft. No differential responses were obtained to any P source so, in 1923, a green manure study using sweet clover was initiated with a corn and wheat rotation. The sweet clover was seeded in the wheat. Significant lodging occurred which was attributed to insufficient potassium.

This area had been divided into 3 plots 66 ft x 100 ft in 1923. In 1930, each of these 3 plots was divided into two with the east 33 ft of each receiving 0 + 48 + 48 (lbs/A) annually. These plots were renumbered in 1940 to become plots 40 through 45. The 1950 plan called for the corn-wheat/sweet clover rotation to continue with all plots receiving full fertility except that 2 would get no Mg, 2 would get Mg, and 2 would get Mg plus micronutrients (Zn, Cu, Fe, Mn).

This plan continued through 1965. In 1966, three populations of corn were used. A corn-soybean-wheat rotation was started in 1967 with corn and soybeans seeded in standing wheat which was mowed. Three of the 6 plots (one in each crop) was irrigated starting in 1967. In 1979, soybeans were seeded following the wheat for grain making the rotation a three year-four crop sequence (corn, soybeans, wheat/soybeans). All plots were seeded to wheat after fall harvest. The wheat on the full season corn and soybeans plots was killed at seeding of the corn or soybeans with herbicides. In recent years, it has become necessary to mow the wheat before seeding full season soybeans to enhance the effectiveness of the herbicides.

People - the Last 50 Years

The earlier discussion of people involved in Sanborn Field focused upon Deans. The most recent 50 years of the field found the College of Agriculture administrators less involved in Sanborn Field because of the increased size of the College. A project leader in soil science is now assigned responsibility for the field with operating funds coming from the Agronomy Department allocation.

When M. F. Miller became dean, George Smith was given the responsibility for the field. Smith was responsible for the changes made in 1940 and in 1950, and for the summary of the first 50 years of Sanborn Field (Smith 1942). From 1943 through 1949, Smith spent some time in the military service and with the Campbell Soup Company. During the absence of G. E. Smith, N. C. Smith (no relation) kept the field operating.

Also, when M. F. Miller became dean in 1938, Dr. William Albrecht started a decisive period as Chairman of the Department of Soils. Dr. Albrecht had great interest in soil-plant relationships. He correctly pointed out after a review of Sanborn Field data that if Ca was adequate, plants could grow quite well on acid soils. Dr. Albrecht focused considerable attention toward nitrogen and the role of the microbial population of the soil. It was Dr. Albrecht who sent Dr. Benjamin Duggar samples from several sites including some from Sanborn Field. Dr. Duggar, then with Lederle Laboratories, isolated the organism responsible for aureomycin from soil obtained on plot 23 (untreated continuous timothy). (This activity led Lederle Laboratories to significantly support this Centennial Celebration.) The variable N levels on the various Sanborn Field plots provided Dr. Hans Jenny some of the numbers used in developing his concepts of the Factors of Soil Formation (Jenny, 1941).

George Smith, in the 1960s, recognized the real estate value of Sanborn Field. In concert with President Elmer Ellis, Dean Elmer Kiehl,and N. A. (Bud) McDonald of the Missouri Limestone Producers Association, the National Park Service was petitioned to name Sanborn Field a Registered National Historic Landmark. The ceremony marking this designation was held in 1965.

C. M. Woodruff, who was assigned responsibility for activities on Sanborn Field from 1967 through 1976, was involved in field activities for a much longer period of time than these 10 crop years. In fact, Dr. Woodruff recalls helping on Sanborn Field as a student in the early 1930s. During the 1960s and 1970s plots 40 through 45, along with plots 6 and 7, were Woodruff's special interest. These plots provided data for Dr. Woodruff's ideas on irrigating claypan soils (Woodruff, 1968), corn populations-yield relationships, and reduced tillage. Students of Dr. Woodruff's during these two decades well remember his discourses on these subjects. The current N recommendations used in Missouri for corn are based, in part, upon Woodruff's work on Sanborn Field.

William Upchurch acquired responsibility for the field in 1977 and retired in December 1984. Dr. Upchurch had spent a career as a mineralogist, on service for the University in India and as a key person in teaching soil chemistry and the beginning soils laboratory. A great deal of Dr. Upchurch's last five years with the University was spent organizing Sanborn Field records, in scraping for support, in actual field work, and in putting the field on a sound foundation by leading the Sanborn Field Committee. J. R. Brown acquired responsibility for Sanborn Field in January 1985 upon Dr. Upchurch's retirement.

Summary

This brief overview of the history of Sanborn Field was included to provide background for the papers to follow. There are many people not mentioned who have contributed to the rich heritage of Sanborn Field. We salute all those persons — scientists, administrators, friends, secretaries, research specialists, farm workers, students, etc.

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Table 1. The original Rotation Field plan.

Rotation*	Treatment		
	None	Manure	Chemicals
		Plot Number	
Corn (C)	17	18	-
Wheat (Wh)	9 (29)**	5, 10, 21, 24, 30, 36	2
Timothy (T)	23	22	-
Clover (Cl)	7	6	-
Oats (O)	16	15	-
Wh-Red Cl.	33	31, 32	-
C-Wh-Red Cl.	27	25, 26, 28	-
C-O-Wh-Red Cl.	39	34, 35, 37, 38	-
C-O-Wh-RC-T-T	13	(1), 8, 11, 12, 14, 19, 20	3, (4)

*Abreviations will be used in succeeding tables.
**Plot 1 - 7 tons manure annually,
Plot 4 - 1/2 chemicals for a full crop + 3 tons manure, and
Plot 29 - No treatment until 1907 then 6 tons manure per acre annually.

Table 2a. The Rotation Field plan as modified in 1914.

Rotation	None	Manure	Starter	Chemicals	Manure + Chemicals
	Plot Number				
Corn	17	18	-	-	-
Wheat	9, 24	5, 10	36	2, 21, 29, 30	-
Timothy	23	22	-	-	-
Cowpeas	7	6	-	-	-
Oats	16	15	-	-	-
Wheat-Clover	33	31, 32	-	-	-
C-Wh-Cl	27, 28	25, 26	-	-	-
C-O-Wh-Cl	35, 39	34	-	37, 38	-
C-O-Wh-Cl-T-T	13	1, 20	-	3	4, 11, 12, 14, 19

Table 2b. Details of the chemical and manure treatments used on the Rotation Field plan initiated in 1914.

Treatment	Quantity	Plots
Manure	6 t/acre annually	1, 10, 15, 18, 20, 22, 25, 31, 34
	3 t/acre annually	5, 6
	6 t/acre before wheat	32
	9 t/acre before corn	26
	8 t/acre before corn 5 t/acre before wh, 2nd timothy	4, 11, 12, 14, 19
Chemicals	"for 40 bu wheat"	2
	200 lbs acid phosphate/acre/yr	21
	10-0-0 $(NH_4)_2SO_4$	29
	10-0-0 $(NaNO_3)$	30
	4-15-6	36
	9-30-12 to corn and 6-20-8 to wheat	37, 38
	Lime 2 t/acre/4 yr	38
	Rock Phosphate 1000 lbs corn	1, 11
	"for a full crop"*	3
	"1/2 for a full crop"*	4
	200 lbs/acre steamed bonemeal corn, wheat	12
	0-48-0/A as acid phosphate to corn, wheat	14

* For each crop in the 6-year rotation.

Table 3. Description of changes in plot management on Sanborn Field made in 1928.

Rotation	Unchanged from 1914 (Plot numbers)	Changes made in 1928	
		Plot	Change
Corn	17, 18	None	
Wheat	5, 9, 10, 21, 24	2	all P and K at seeding; 1/3 N at seeding and 2/3 N in spring
		29	10-0-0 fall and 10-0-0 spring as $(NH_4)_2SO4$
		30	10-0-0 fall and 10-0-0 spring as $NaNO_3$
		36	8-24-8 annually
Timothy	22, 23	None	
Oats	15, 16	None	
C-SB-Wh/Sw.Cl.*			replaced wheat clover rotation, all plots limed when needed
		31	0-50-60/acre annually
		32	0-50-0/acre annually
		33	0-0-60/acre annually
C-Wh-Cl	25, 27	26	lime as needed, 0-32-0/acre on C & Wh
		28	lime as needed 8-24-8/acre on C & Wh
C-O-Wh-Cl	34, 35, 39	6, 7	18-36-18/acre on C & Wh, 16-0-0/acre on C, and 0-30-0/acre on O
		37, 38	8-24-8/acre on C & Wh
		38	limestone as needed
C-O-Wh-Cl-T-T	1, 11, 12, 13, 14, 19, 20	3	for full crop** with 1/3 N at seeding andremainder in spring
		4	1/2 chemicals for full crop** split as on 3. Manure reduced to 4 t/acre on C and 2 1/2 t/acre on Wh, 2nd Timothy

*Sw. Cl. is sweet clover.

**Full crop was defined on a per acre basis as 86 bu. corn, 40 bu. wheat, 60 bu. oats, and 3 tons for clover and timothy.

Table 4. Description of changes in plot management on Sanborn Field initiated for the 1940 crop season.

Rotation	Plots†	Changes
C-Wh-Cl/Ls*	25, 26, 27, 28	Red clover - Lespedeza mix.
	25	5t manure/acre before corn
C-O-Wh-Cl/Ls	34, 35, 37, 38	No change except forage mixture
	36	8-24-8/acre annually, corn stalks, wheat straw, clover/Ls removed
	39	8-24-8/acre annually, return stalks and straw, plow under 2nd clover crop
	4	0-30-15/acre Wh North 1/2: 0-25-12/acre on Corn South 1/2: 0-25-12/acre on Clover
C-O-Wh-Cl-T-T		Seed lespedeza if clover fails
	1	Lime, 1000 lbs/A Rock P on corn North 1/2: 0-30-0/A with corn, wheat.
	3	Add lime to previous plan
	11	Delete manure on timothy from 1914 plan
	12	Lime, 0-30-0/acre on C, Wh
	14	Delete manure on timothy, 0-30-0/acre on C, Wh
	19	Delete manure on timothy
	20	Lime, manure @ 8 T/acre corn, 5 T/acre wheat
C-Wh/SwCl.	21	Lime equivalent to exchangeable H 0-40-0/acre C & Wh East 1/2: KCl = 2/3 exchangeable H each 8 yrs, micronutrients on plowsole; West: 1/2 micronutrients on surface
	24	Lime to pH 5.5 - 6.0 0-40-0/acre C & Wh East 1/2: 0-0-60/acre C & Wh West 1/2: 0-0-60/acre Wh
Wh/Lespedeza (1 yr)	15, 16, 29, 30	0-38-0/acre annually East 1/2: lime; West 1/2: no lime

† Unchanged Plots: 2, 5, 9, 10, 13, 17, 18, 22, 23, 31, 32, 33; Plots 6 and 7 were placed in a special P study in split plots and no records appear in the regular files from 1940 through 1949.

* Ls = Lespedeza

Table 5. Summary of plot treatments included in the Sanborn Field plan initiated in 1950.

	Changes		
Rotation	Plots	Treatment	Plots Unchanged
Corn	6, 7	See Table 6	17, 18
Wheat	2	Full Treatment†	5, 9, 10
Timothy	30	Full Treatment†	22, 23
Red Clover	12	Full Treatment†	
Alfalfa	24	Full Treatment†	
Alfalfa-Bromegrass	21	Full Treatment†	
C-Wh-Red Clover	1, 3, 4	Each crop each year Full Treatment†	
C-SB-Wh(red clover)	31	Full Treatment† (33 lbs N/acre plowed down for wheat, no other N on wheat)	
	32	Same as 31 but no K applied	
	33	Same as 31 but no P applied	
C-Wh-Red Clover	25	6 t/acre manure annually 100 lbs N/acre plowed down - C 33 lbs N/acre top dressed - Wh	27
	26	Full Treatment†	
	28	8+24+8 on C and Wh lime, P and K per soil test	
C-O/LS-Wh/LS	15, 16, 29	72+24+24 C 20+20+20 O, Wh lespedeza hay E 1/2 lime, W 1/2 no lime (each crop each year)	
C-O-Wh-Red Clover	36	Full Treatment† dolomitic lime	34, 35, 37, 38
	39	Full Treatment† calcitic lime	
	11	Manure: 8 T/acre on C, 5 T/acre on Wh Lime + K based on soil tests 1000 lbs rock phosphate/acre each 8th year 100 lbs N/A on C East 1/2 starter: 6+24+24 on C, 20+20+20 on Wh, West 1/2 no starter	
	14	Same as 11 except 0-40-0/acre on C, Wh, Oats - in lieu of rock phosphate	
C-O-Wh-Red Cl-T-T	20	Full Treatment†	13, 19

† See Table 6.

Table 6. Full Treatment as Initiated in 1950 on Sanborn Field.†

Crop	Treatment
General	pH, P, K, Ca, and Mg maintained at sufficiency levels based upon soil tests and prevailing corrective treatments
Corn	6-24-24 starter 100 lbs N/acre plowed down 33 lbs N/acre sidedressed
Wheat, Oats	Annual top-dressing to replace P and K relative to removal. Nitrogen as needed.
Forages	Annual replacement of P and K removals by topdressing 66 lbs N/acre/yr timothy

†Upchurch et al. (1985).

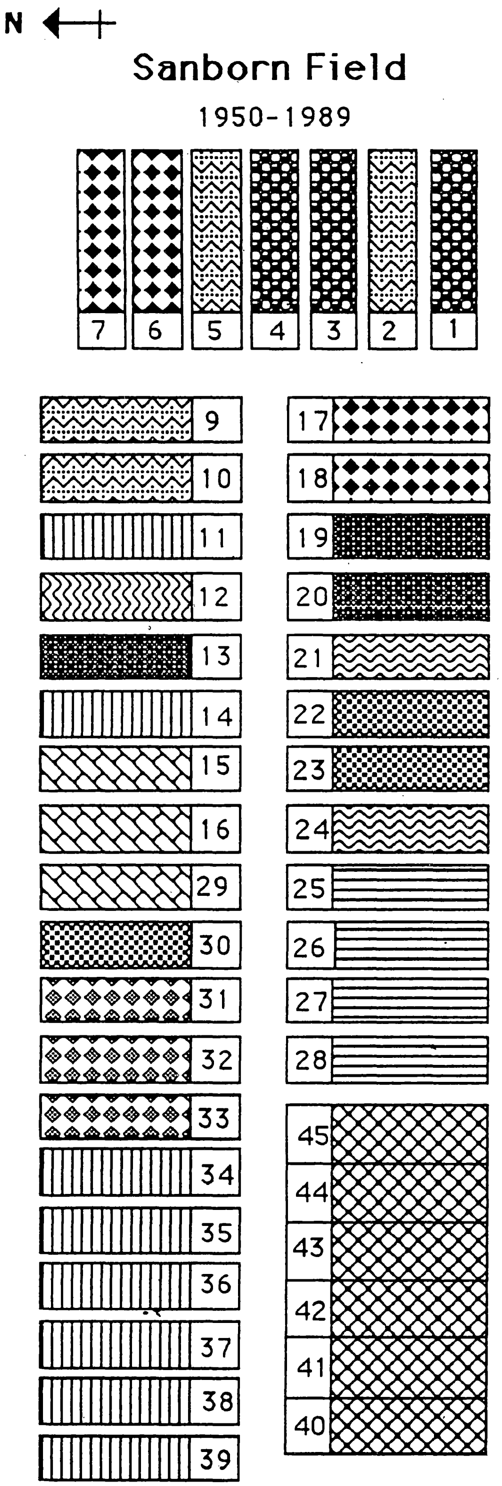

Figure 1. Plot arrangement and treatment plan used from 1950 through 1989 on Sanborn Field.

Continuous Cropping

≋ ALFALFA
plot 21 alfalfa-bromegrass, full treatment
24 pure alfalfa, full treatment

◆ CORN
plot 6 conv. tillage, full treatment
7 no-till, full treatment
17 no treatment
18 6 T. manure/A

⋙ RED CLOVER
plot 12 full treatment

▒ TIMOTHY
plot 22 6T. manure/.A
23 no treatment
30 full treatment

≈ WHEAT
plot 2 full treatment
5 3T. manure/A
9 no treatment
10 6T. manure/A

Rotations

▩ 3 yr. Rot. C-W-RC
plots 1, 3, and 4 full treatment

▧ 3 yr. Rot. C-O/L-W/L
plots 15, 16, 29
East 1/2 of plot limed, West 1/2 not limed

◈ 3 yr. Rot. C-SB-W(rc plowed down)
plot 31 full treatment
32 full treatment-K
33 full treatment-P

▤ 3 yr.Rot. C-W-RC

plot 25 6T.manure annually + 100 lbs N on corn
and 33 lbs N topdressed on wheat
26 full treatment •
27 no treatment
28 8-24-8 on corn and wheat

▦ 3 yr Rot. C-SB-W/SB full treatment
plots 40, 41, 42 irrigated
43, 44, 45 non-irrigated

▥ 4 yr. Rot. C-O-W-RC (various treatments)
plots 11, 14, 34, 35, 36, 37, 38, 39

■ 6 yr. Rot. C-O-W-RC-T-T
plot 13 no treatment
19 6 T.manure/A on corn and wheat only
20 full treatment

Figure 1. Plot arrangements and treatment plan used from 1950 through 1989 on Sanborn Field.

Lessons in Soil Organic Matter from Sanborn Field

George H. Wagner

The value of soil organic matter has been long recognized. From earliest times, its level in soil was used as a general indicator of soil productivity. Maintaining or increasing the level was the goal of many early research projects. When J. W. Sanborn established the plots that bear his name, interest in rotations and the practice of manuring were part of a management philosophy which sought to find methods for increasing soil organic matter (SOM) and the nitrogen contained therein in order to increase yields (Upchurch et al., 1985). Soils research at Missouri in the early years of this century, however, did not achieve practical success in this matter. After some 35 years of accumulating data on Sanborn and other experimental fields, nearly all plots showed nitrogen losses and the philosophy shifted to a consideration of the turnover of SOM and toward nitrogen turnover in relation to productivity of the soil (Wagner and Smith, 1960).

Level of Soil Organic Matter

A major advancement in understanding the level of organic matter in a soil was that which came from the thinking of Hans Jenny, while he was a member of the Missouri soils faculty. The evidence gathered by Jenny (1933) demonstrated that cultivation decreased the soil's productivity. His well known curve showed a loss of soil nitrogen of 35% from the virgin prairie soil during 60 years of cultivation. The data from Sanborn Field showed that this decline did not continue indefinitely, but the level tended toward a new equilibrium where it was again stabilized in accord with the cropping system and soil management being practiced.

A number of years later C. M. Woodruff added to our understanding of the dynamics of SOM. He explored the use of higher mathematics for defining progressive changes in soil nitrogen. Using a first-order differential equation, he was able to solve for the current level of nitrogen in soil. His approach allowed determining the average annual delivery of nitrogen from the soil to the crop as a function of the amount of nitrogen in the soil and the kind of crop grown (Woodruff, 1950). The plots of Sanborn Field had provided Woodruff with data on soil nitrogen level over time. Out of that research came the Missouri soil test assessment of available soil nitrogen calculated from a measurement of SOM.

More than 25 years ago, my interests became focused on SOM as I heeded the advise of respected mentors. At that time, SOM research in the North Central Region was being boosted by a regional research effort. With other specialists focusing on nitrogen, I felt the need to work with carbon and was attracted by the possibility of using ^{14}C (with encouragement from E. R. Graham). The carbon radioisotope with its long half-life and the prospects it offered for discriminating among the various components of SOM opened numerous research opportunities when coupled with the unique resource we have in Sanborn Field.

Microbial Contributions to Soil Organic Matter

Initially, my work was oriented toward laboratory studies to better define the newly formed SOM arising from microbial activity. Soils from several long-term plots on Sanborn Field provided the unique resource for these studies (Chahal and Wagner, 1965; Mutatkar and Wagner, 1967; Wagner and Muzorewa, 1977). Inter-plot comparisons yielded practical up-to-date conclusions in this work because G. E. Smith in 1950 had foresight to add to the management scheme of Sanborn Field, plots of continuous corn which were fertilized according to soil test. By the mid 1960's, these plots had 15 years of history under this management. A practical query of soil scientists then was whether or not continuous corn, liberally fertilized, would eventually result in deterioration of SOM either qualitatively or quantitatively and whether some deterioration in soil structure might occur. On Sanborn Field, the experiment was already in place and no adverse physical problems of the soil were observed.

In 1968, H. M. Hurst, a scholar from England, joined me in the studies using ^{14}C. Building on his background knowledge of melanins in certain fungal cell walls, we demonstrated that this melanic wall material was very resistant to biodegradation and thus an important contributor to the recalcitrant SOM pool (Hurst and Wagner, 1969).

An Australian colleague, J. M. Oades, also helped to make SOM studies on Sanborn Field an international venture during a sabbatical year he spent here. This effort focused on the carbohydrate component of the soil and we were able to show humification of easily decomposable substrates through microbial synthesis (Oades and Wagner, 1971). When subsequently evaluating the distribution of monosaccharides in soil polysaccharide, distinctive patterns were found that set apart prairie soils from those developed under forest vegetation (Folsom et al., 1974).

Equilibrium Levels and Management

Some looking back occurred when 75 years of management history had lapsed on Sanborn Field. I once again recognized the value of building upon the concepts of Jenny and Woodruff which dealt with levels of SOM that were found after long-term cultivation. With the 75 year sampling of the plots, some special analyses for total soil carbon were made (Wagner, 1981). The then current analytical procedures were used with the new samples and also applied to historical samples that had been accumulated and stored since 1915. This approach to applying the same analytical procedure to different-time samples provided additional precision over the alternative of looking at reported historical data collected at different times and comparing that with current analyses. The results with carbon, which contrasted to the earlier approach that measured organic nitrogen, further confirmed the concept that indeed an equilibrium level of SOM develops in 30 to 40 years and this level is defined by each particular management system. A distinctly lower level of SOM under no-treatment corn relative to no-treatment wheat was confirmed by the carbon data. The greater degree of cultivation under corn to accelerate mineralization was presumed to be responsible for this difference. A new conclusion was that management involving the annual addition of 6 T/acre of manure yielded a soil carbon level of one-half a percentage point higher than for the same management system without manure.

Evaluating the initial and rapid loss of organic matter when a virgin soil is first cultivated has been handicapped by the non-existence of bench mark data or of a zero-time soil sample collected from Sanborn Field. A reference point which has been used is that of a sample collected in 1915 from the bluegrass sod border around the plots. It contained only 1.6% carbon. This reference seemed inadequate for several reasons, but has been used in the past as the best available. After some 25 years of reflecting on this, I can offer some alternate thinking built upon accumulated experiences with Sanborn Field. This thinking was used to replot the data reported earlier and that is included here as Fig. 1. Today, I believe that the virgin soil contained nearly 4% soil organic carbon or a level similar to that which exists in Tucker Prairie, a native virgin prairie about 30 km east of here on a similar soil. The level of SOM ascribed to that prairie and to Sanborn Field before it was cultivated, depends upon a judgement concerning the discarding of roots, stems and coarse litter which are not considered to be soil material. This differentiation is done through sieving when a sample is prepared for analysis. Under native prairie, a large quantity of very fine vegetative residue is part of any sample collected from the field. Some clearly distinguishable plant components grade through a continuum of progressively finer material until one reaches the end product, humus. Very fine litter that has undergone some processing towards humification is, in my opinion, part of the soil. This vegetative litter, which different analysts may arbitrarily include or discard, is a fraction that is rapidly lost under cultivation. Cultivated soils, by contrast, contain plant debris present as relatively large fragments and are more uniformly handled by different analysts who decide through sieving what is to be included as soil for an analysis.

Humification of Residues and Respiratory Loss of Carbon

For the past 10 years our focus on Sanborn Field has been that of studying humification of crop residues. G. A. Buyanovsky, a soil ecologist and recent emigrant from the Soviet Union, has been part of this effort which has coupled our respective approaches to advancing knowledge in this area. Experiments on small subplots of Sanborn Field have involved crops of corn, wheat, and soybean labeled with ^{14}C in order to study humification of the crop residues. Preliminary pilot studies have been completed in each case and a number of the results are pertinent to this report and will be cited in the discussion that follows. In the case of a very detailed study on soybeans, the experimental phase has just been completed and analysis, interpretation, and reporting of the results will follow next year.

As we began the project, it became apparent that data on the quantities of crop residues available for humification were incomplete. For Sanborn Field, data on aboveground vegetative residues had been collected through much of the history of the field, but no estimates were available of annual plant biomass produced beneath the soil surface. A study, therefore, was designed to fill this void (Buyanovsky and Wagner, 1986). Data collected on grain yields were supplemented with measurements of the vegetative above-ground and below-ground residues during several years for wheat, soybean, and corn. Root biomass was determined to be 40-50% of the total residue.

Complementary to plant residue carbon which is humified, is that which is liberated as $C0_2$ by soil respiration. Soil respiration is a process that includes the activity of plant roots and the decomposing action of soil heterotrophs. In detailing this respiration in our ^{14}C experiments, we have demonstrated annual cycles of carbon dioxide level in soil air under the different crops (Buyanovsky and Wagner, 1983). In the wheat plots, we found that CO_2 concentration in soil air may reach 6-8% during periods of intensive decomposition of wheat residues. In contrast, the highest CO_2 concentrations under corn and soybean were observed during periods of intensive plant growth.

Detailed analysis of the evolution of CO_2 from soil in the wheat ecosystem has allowed us to develop a stochastic model using the factors of temperature and moisture to characterize respiration (Buyanovsky et al, 1986). The best approach among several examined was that which split the annual cycle into two periods, one extending from late October until the following June when both plants and soil organisms contribute to respiration. The period includes a season of winter dormancy with little or no activity. During the more temperate portion of the period, it is assumed that plant root respiratory activity predominates. A contrasting period from late June through early October is that when CO_2 arises essentially from the activity of decomposers.

The individual contributors to the production of CO_2 such as living roots, decomposing plant residues, and mineralizing soil organic matter remain indistinguishable in classical studies of soil respiration. In our work, we have used the ^{14}C label to attempt to differentiate among the contributing processes. We employed a labeling scheme also designed to allow partitioning between carbon of root and straw origin and to separate the flow of carbon between the processes of respiration and humification. To accomplish the partitioning, the above-ground residues from the unlabeled plot immediately after harvest were transferred to one of the plots with labeled plants from which straw had been removed. This allowed the study of decomposition dynamics of labeled roots in the presence of unlabeled straw. The labeled straw was placed on the plot with unlabeled roots so that CO_2 evolved therefrom could be distinguished from that of unlabeled roots.

In the experiment involving cultivation of winter wheat, we observed a rapid decomposition of the after-harvest residues and this is shown by a histogram (Fig. 2) that reports the relative significance of each component contributing to CO_2 evolution (Wagner and Buyanovsky, 1987). Release of CO_2 from the residues during the first fall represented 50% of the carbon. During the first two years, over 80% of the root and straw carbon was mineralized.

Subsequently the rate slowed markedly and by 5 years, the carbon remaining in the soil approximated 10% of the original label. The mineralization rate for the labeled carbon that remained had adjusted to a rate that was not significantly different from that for the total SOM pool. From other data we were able to estimate the mineralization of SOM so that partitioning was complete among the contributing components. Variability among years is apparent from this diagram and, as mentioned earlier, this is attributed to differences in abiotic factors of temperature and moisture.

In the wheat experiment, the contribution of plant root activity to soil respiration was estimated by difference and judged to exercise its greatest contribution to total respiration during May. In the just-completed study of soybeans, the respiration by the plant roots was determined using short-term ^{14}C activity changes (Wagner and Buyanovsky, 1989). In this case, root respiration during July with plants at V6 maturity stage, was found to be 65% of total soil respiration.

Natural Abundance of ^{13}C Showing Long Residence Time of Carbon

A few years ago, a new tool that was yielding interesting data for geochemists studying long-term carbon cycling appeared to have potential for studying soil organic matter turnover. This approach uses differences in natural abundance of ^{13}C and has now been demonstrated to have adaptability to the study of soil carbon dynamics in long-term experiments. The unique resource we have in Sanborn Field invited use of this approach to examine the assumed long residence time of some fractions of soil organic matter. A group in France was already equipped with mass-spectrometers and preparation facilities to carry out the analyses for such a study. With a sabbatical opportunity ahead of me, I gathered my sample and spent 1986 working on this project in cooperation with J. Balesdent at the Soils Station in Versailles and A. Mariotti, head of the Biogeochemistry Laboratory of the University of Paris.

Natural abundance of ^{13}C in soil organic matter can be used to study carbon turnover in long-term field experiments because of the characteristic fractionation of $^{13}C/^{12}C$ during photosynthesis of different groups of plants. Significant contrasts between C-3 and C-4 plants exist with regard to degree of discrimination against the heavy isotope. As a result C-3 plants such as wheat, timothy, and forest vegetation display a $\delta^{13}C$ of about -27‰ whereas C-4 grasses have values of about - 12‰. When a virgin soil whose organic matter bears the $\delta^{13}C$ level of the native vegetation is brought under cultivation of a crop possessing a contrasting metabolic pathway, the progressive turnover of soil organic carbon can be monitored through the change in the $\delta^{13}C$. This $\delta^{13}C$ progressively approaches that of the cultivated vegetation now feeding the process of humification.

Using the long-term research plots of Sanborn Field established in 1888, we have employed this method to examine soil organic matter over time during continuous cultivation of select crops (Balesdent et al., 1988). Incremental changes in soil carbon level and in origin were determined using historical soil samples collected periodically over the course of the nearly 100 years of history for the field.

The present report extends some of the results reported in the paper cited above, by including measurements of soil volume (see report by Anderson, this publication) to allow interpretation on a unit area basis. Such a consideration further allows evaluation of quantitative inputs of crop residues as they relate to the level of carbon in the soil.

The rapid decline in level of soil organic matter that occurred when the prairie soil was brought under cultivation has already been discussed. Also previously reported was the fact that after about 40 years of continuous management, a new equilibrium is attained, the level of which depends upon the kind of crop and the management practiced. Building upon this understanding of the dynamics of soil organic matter, we have used the ^{13}C natural abundance technique to differentiate between two sources of origin when examining organic carbon level of the soil. The two distinguishable contributors are that of virgin prairie and that of the cultivated crop. A large part of the virgin prairie carbon was demonstrated to be easily decomposable, showing a half-life of 10-15 years. Never-the-less, virgin prairie carbon also included a pool of very stable organic matter and this amounts to more than one-half of the current level of carbon existing in these plots. This stable carbon was determined to have a turnover time of about one thousand years. After accumulating over a time period of 30 to 40 years, the carbon originating from the cultivated crop was determined to have achieved equilibrium level. Present day turnover of carbon in these cultivated soils including the humification of residues and mineralization to release CO_2, primarily involves this crop-origin pool. Using 1915 soil samples essentially depleted of the easily decomposable soil organic matter of prairie origin, we have measured the distribution of the total organic soil carbon with regard to the two sources of origin and compared the values with those found in 1986. The results, as amount of soil organic carbon relative to a unit area are reported in Table 1.

When evaluating samples collected in 1915 for the wheat plot, the amount of organic carbon of prairie origin was about 2.5x that attributed to crop origin at the 0-10 cm depth and 3x that at the 10-20 cm depth. A similar relationship under timothy showed prairie carbon to be nearly 3x that of crop carbon at 0-10 cm and more than 4x at the 10-20 cm depth. Loss of prairie carbon under the timothy crop was less than for wheat, presumably because no annual cultivation occurred under timothy.

When manure was added annually to timothy, this additional substrate resulted in a more than doubling of the quantity of carbon attributed to the new inputs by the end of the first 27 years. In the top 10 cm, this quantity was nearly equal to the quantity of carbon of prairie origin.

In 1986 under wheat, the crop carbon had significantly increased and prairie carbon had declined. The result was that after nearly 100 years the two origin-pools had become approximately equal for both sampling increments. Under timothy, however, even though crop carbon had increased at 0-10 cm, it remained less than prairie carbon and the much greater contrast at 10-20 cm continued to exist. For manure added to timothy at 0-10 cm, the two pools continued to remain about the same as was observed in 1915, however, by 1986 there was additional new input of carbon at the depth of 10-20 cm.

Changes in the wheat plot during the course of its history, including four intermediate observation points between 1915 and 1986, are reported in Table 2. In this presentation, all data are for a combined 0-20 cm depth. A significant drop in prairie carbon from 1915 to 1928 occurred. After 1928, which was 40 years into the experiment, further change in this prairie carbon pool was determined to be very slight. Regression analysis including all points indicated a turnover time greater than 800 years for the prairie carbon. The variability of the data reflect the composite variation attributable to both sampling and the methodology.

The soil organic carbon of crop origin was determined to be relatively stable through the period 1915 to 1962 and the variation among the different dates of sampling is characteristic of that noted above. By 1975, there appears to have been a real increase in crop carbon. This increase has been attributed to a change in management adopted in 1950. At that time, the annual fertilizer treatment was upgraded, but more importantly, the wheat straw was added back to the soil each year. Previous to 1950 the straw was removed and the annual amendment consisted only of roots and stubble. This change in residue management approximately doubled the annual carbon input. Carbon additions attributable to the new management continued to be evident at the 1986 sampling. The later date represents 36 years under this increased level of input and it is expected that a new equilibrium level is approaching.

It has been estimated that mineralization from the stable soil organic matter under wheat would be no more than 2% per year. From a pool of 2300 g of C/m^2 to a depth of 20 cm this would release up to 46 g of C/yr. Annual replacement from stubble and roots totaling 185 g of C/m^2 is expected to contribute to soil carbon at a net humification rate of about 20% or 37 g of $C/m^2/yr$. These assumptions correspond to the observed net losses from 1928 to 1950.

After 1950, annual input was increased by approximately 190 g additional $C/m^2/year$ from the straw. Assuming the same humification index of 20%, this would contribute an additional 38 g of $C/m^2/year$. The total annual input now exceeded net mineralization loss by about 30 $g/m^2/year$. The annual net input would be expected to result in an accumulation of crop-origin carbon, which stood at a low of 350 g/m^2 in 1950, and then has been increasing over time to the point at which a new equilibrium level is attained. By 1986, the level had risen to 846 g/m^2 and this may be the new equilibrium level, but further sampling in the future will be needed to confirm this.

During the past 100 years, Sanborn Field has provided a unique resource for research in soil science. This report documents some of the efforts that have been particularly productive in furthering our understanding of soil organic matter. Techniques for conducting most of the studies reported here were not even available during the first half-century of existance of the field. Without a doubt, numerous additional scientific approaches to the study of soil science will be developed in the future and many of these will find maximum utility when applied to the special plots with their long cropping and management histories that are available on this campus in Sanborn Field.

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Table 1. Distribution of soil carbon as to origin after 27 and 98 years of cultivation of under three different management systems on Sanborn Field.

		1915		1986	
Crop and Management	Sample Depth	Crop Origin	Prairie Origin	Crop Origin	Prairie Origin
	cm	gC/m^2			
Wheat, fertilized	0-10	426	1061	784	800
	10-20	361	1080	974	864
Timothy	0-10	424	1220	720	1202
	10-20	259	1196	305	1220
Timothy, manure	0-10	1390	1427	1280	1487
	10-20	564	1183	817	1244

Table 2. Changes over time in soil carbon under fertilized wheat plots on Sanborn Field.

		Soil Carbon	
Year	$\delta^{13}C$*	Crop Origin	Prairie Origin
		gC/kg soil	
1915	-20.9	3.1	8.4
1928	-21.5	3.5	6.7
1938	-21.1	2.7	6.5
1962	-20.9	2.7	6.9
1975	-21.9	3.9	6.1
1986	-22.9	6.5	6.4

*Prairie soil $\delta^{13}C$ = 18.6 ‰

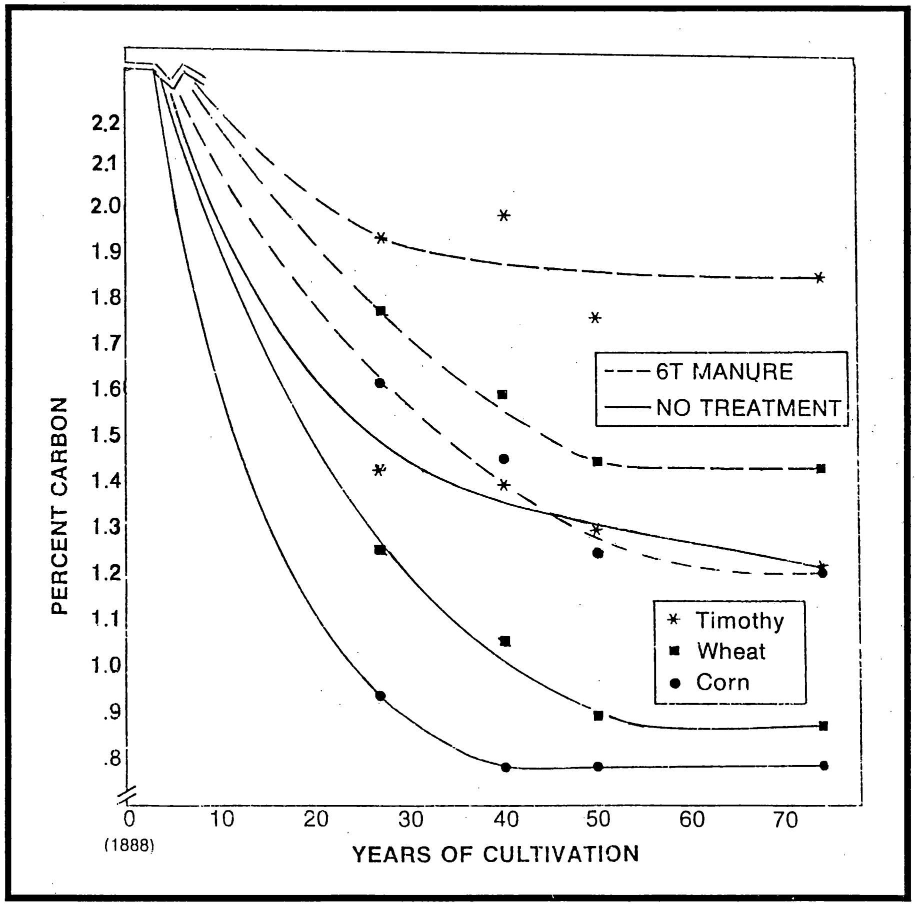

Fig. 1. The organic carbon content of Sanborn Field soils after 75 years of cultivation under different management systems (from Wagner, 1981).

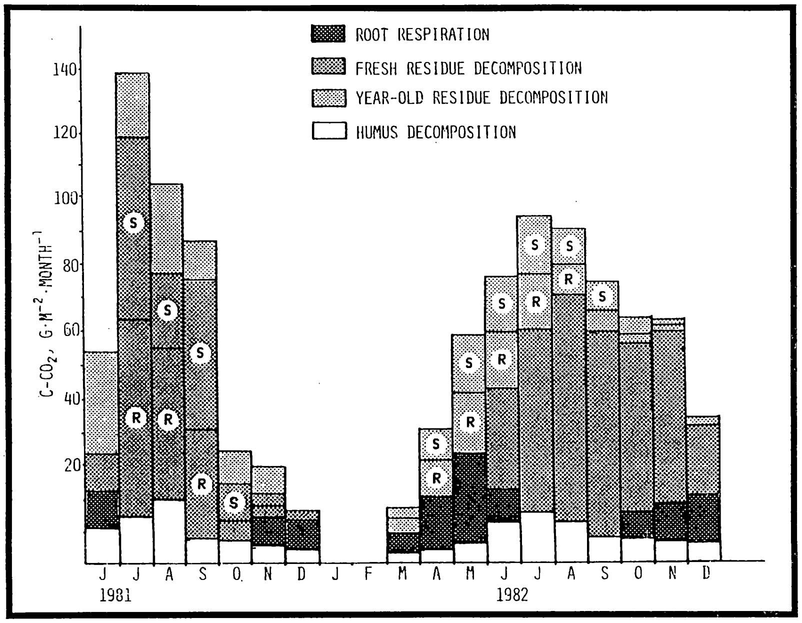

Fig. 2. Total soil respiration by monthly interval and the relative contribution of various components during two years cultivation of winter wheat [S - straw, R - root].

Soil Physical Properties After 100 Years of Continuous Soil and Crop Management

S.H. Anderson and C.J. Gantzer

Introduction

Some concern has arisen over both the economical and environmental sustainability of intensive row-crop agriculture in the U.S. during the past few years (Stinner and House, 1989). The profitability of intensive row-crop systems has declined during the past decade due to a decrease in commodity prices and an increase in machinery, fuel, fertilizer, and pesticide costs (Stinner and House, 1989). Environmental concerns over water contamination (Baker, 1985; Hallberg, 1986) have created a need to improve current row-crop management techniques. Practices used in row-crop agriculture over the past few decades have tended to maximize crop yields by using large amounts of energy intensive inputs of fertilizers and pesticides. However, there is a need in row-crop agriculture to move toward more efficient use of resources. This type of management may use less fertilizers and pesticides to obtain economically sustainable yields.

The Amish have utilized this type of agriculture to maximize production while minimizing input costs (Jackson, 1988). The Amish have used rotations with legumes and annual additions of animal manure to replace additions of inorganic fertilizers. The profitability of such low-input management systems is perhaps better with current commodity prices and input costs than the high-input technology systems (Stinner and House, 1989). With the current world demand for commodities and the personal need for making a living, a choice for the individual land manager is between farming larger areas with intensive methods, or farming smaller areas and reducing input costs of production by using rotations or animal manure to replace harvested nutrients. Each approach has risks. Farming larger areas means a larger financial investment which has the potential for greater loss in the event of a crop failure. The choice of reducing input costs of production translates into more labor since more time and more difficult management are usually required compared to conventional agriculture.

Although different types of sustainable agriculture systems have been suggested such as use of rotations and conservation tillage, little work has been published which quantifies how a system may alter soil physical properties or tilth and thus influence the potential environmental impacts of management. A desired environmental effect of improved management may be to reduce storm water runoff and soil erosion through increased water infiltration. Incorporation of animal manure into the soil is often thought to have beneficial effects on soil physical properties which directly influence infiltration rates. Manure incorporation has been shown to increase soil aggregation (Elson, 1943; Woodruff, 1939), aggregate stability (Woodruff, 1939; Davies and Payne, 1988), infiltration (Cross and Fischbach, 1973; Woodruff, 1939; Jackson, 1988), and water-holding capacity (Hafez, 1974; Gregory, 1988). Manure incorporation has also been shown to decrease bulk density (Khaleel et al., 1981; Jackson, 1988) and to increase a soil's resistance to compaction (Gaultney et al., 1982). One reason for the improvement in soil tilth is an increase in biological activity because of additions of manure (Converse et al., 1976; Davies and Payne, 1988).

Although some studies have quantified the effects of annual additions of manure on tilth, most have only examined the effects of manuring for a short time. Researchers at Rothamsted, England (Davies and Payne, 1988) and Sanborn Field at the University of Missouri-Columbia (Woodruff, 1939; Balesdent et al., 1988; Upchurch et al., 1985) have maintained experimental field plots which may be used to evaluate the effects of annual additions of manure for long time periods (100 years). Although Sanborn Field has been maintained under continuous cropping, it has had limited characterization of soil physical properties during its 100 year history. The objective of this study was to evaluate the effects of 100 years of soil fertility management for continuous cropping systems of wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), timothy (*Phleum pratense* L.), and a three-year corn-wheat-red clover (*Trifolium pratense* L.) rotation on soil tilth, an indicator of possible environmental consequences of changing soil fertility management. The soil physical properties studied were soil bulk density, saturated hydraulic conductivity, soil water retention and pore-size distribution.

Materials and Methods

Sanborn Field is located on the University of Missouri-Columbia campus. The individual Sanborn Field plots have been under various continuous soil and crop management practices since 1888. The soil within the study area is a Mexico silt loam (fine, montmorillonitic, mesic Udollic Ochraqualf) which is representative of most of the gently rolling, more erodible soils of the Midwest claypan area, an area estimated to be about 4 million hectares in size within Missouri, Illinois, and Kansas (Jamison et al., 1968). The following rotations were selected for study: 1) continuous wheat, 2) continuous corn, 3) continuous timothy, and 4) corn-wheat-red clover rotation. The soil fertility management treatments used in the study were: annual fertilization with inorganic fertilizers according to the Missouri soil test recommendations (Buchholz, 1983), annual addition of 13.5 t ha^{-1} of barnyard manure, and no fertility added (unfertilized). The soil and crop management history of the selected plots used in the study are described in Table 1. Details of the management history of all plots are described by other researchers (Upchurch et al.,1985). Plots used in this study were selected from those which had been managed with constant treatment with only minor alterations since 1888. Initially, all plots had plant residues removed each year. However, this practice has been discontinued recently. Since the 1970's, only continuous corn plots have had residues removed. Normal tillage for the plots is fall plowing. The following cultures were selected to compare the effects of annual fertilization or manuring with unfertilized treatments: 1) continuous wheat (Plots 2, 9, 10), 2) continuous corn (Plots 6, 17, 18), 3) continuous timothy (Plots 22, 23, 30), and 4) a three-year corn-wheat-red clover rotation (Plots 25, 26, 27). The corn-wheat-red clover rotation will be referred to as the three-year rotation. The rotation plots were planted to wheat in the fall of 1988. Changes from the original soil and crop management during the 100 year history are presented in Table 1.

The soil textural data of the surface horizon for each plot are presented in Table 2. These data were obtained by using the pipette technique (Gee and Bauder, 1986) on soil material taken for the 100-year characterization of the plots of Sanborn Field (Hammer and Brown, 1989). The most notable feature in the data is that the plots with the Corn Treatment are much higher in clay content compared to the other plots. This was due primarily to soil erosion of topsoil and subsequent mixing of higher clay content material from the subsoil with the remaining topsoil (Gantzer et al., 1989).

On 16 August 1988, six 76-mm-diameter by 76-mm-long undisturbed soil cores at the 25 to 100 mm soil depth were removed using a Uhland sampler from the three plots under wheat cultivation. Other plots were not sampled at this time since they had been recently tilled. Six samples were removed from each of the three plots. On 14 March 1989, four undisturbed soil cores were removed from the 25 to 100 mm soil depth in each of the 12 selected plots. The samples taken in the three plots which were also sampled during 1988 were removed approximately 0.3 m from the prior sampling location. Sample locations were located at least 3 m away from prior soil sampling.

The soil cores, which were housed in aluminum rings, were taken using the core sampling method (Blake and Hartge, 1986). The cores were trimmed and transported to the laboratory. The soil-water characteristic was determined for each core using pressure cells for soil water potentials of 0.0, -0.4, -1.0, -2.5, -5.0, -10.0, -15.0, -20.0, -25.0, -30.0, and -40.0 kPa (Klute, 1986). After weighing cores subsequent to removal from pressure cells, they were slowly resaturated from the bottom over 48 hours and saturated hydraulic conductivity was measured using a constant head permeameter (Klute and Dirksen, 1986). Soil cores were oven-dried and weighed to allow calculation of bulk density subsequent to measurement of saturated hydraulic conductivity. Pore-size distribution was estimated from the water retention data (Danielson and Sutherland, 1986). The equivalent pore radius of the smallest, drained pore neck is estimated from the following relation:

$$\mathbf{r = -2\,\sigma \cos\Theta / (\rho\, g\, h)} \qquad [1]$$

where r is the equivalent pore radius, σ is the surface tension of water, θ is the contact angle, ρ is the density of water, g is the gravitational acceleration, and h is the soil water pressure head.

The pore-size classes (Luxmoore, 1981) were used to classify the pore sizes into three classes: > 500 µm radius are macropores, 5-500 µm radius are mesopores, and < 5 µm radius are micropores. The mesopores were further classified (Sekera, 1951; Hartge, 1978) into coarse mesopores (25-500 µm radius) and fine mesopores (5-25 µm radius).

Results and Discussion

Bulk Density

The means and coefficients of variation [CV, CV = (standard deviation)/mean x 100%] for bulk density measured on cores removed in 1989 are given in Figure 1 and Table 3. The bulk density varied from 1.13 g cm^{-3} in the Fertilized and Manured Corn Plots to 1.45 g cm^{-3} in the Unfertilized Wheat Plot. The CV for the plots were all less than 10% which is expected for bulk density measurements (Warrick and Nielsen, 1980). The means (and CV values) of bulk density for the samples taken in 1988 from the Wheat Plots are 1.32 (3.0%), 1.28 (4.5%), and 1.25 (3.8%) g cm^{-3} for the Unfertilized, Fertilized and Manured Treatments, respectively. Bulk densities were higher in the summer (1988) compared to the spring (1989) except for the Unfertilized Plot. Higher bulk densities in the summer were attributed to lower soil water content (9% by volume) and subsequent shrinking of the clay. The lowest bulk densities for each cropping treatment were found in the Manured Treatment which was expected since annual additions of manure will increase soil organic matter and improve soil structure. The highest bulk densities for each cropping treatment were found in the Unfertilized Treatment except in the Timothy Plots.

Only two contrasts could be made using individual cropping treatments for replication. The "Fertilized vs. Others" (Others included Manured and Unfertilized) contrast was not significant at the 0.10 level for bulk density while the "Manured vs. Unfertilized" contrast was significant at the 0.10 level (Table 4). The effect of 100 years of annual applications of manure resulted in a significant decrease of an average of 0.06 g cm^{-3} in bulk density. (This average used the 1988 Wheat results in place of the 1989 results since the 1989 Unfertilized Wheat Plot had a relatively high bulk density.) Although differences in bulk density were found between treatments, the differences were probably not restrictive to root growth. The lower bulk densities in the Manured Treatments were due to higher concentrations of organic matter. The higher organic matter content indicates that slightly better soil tilth may occur since organic matter creates conditions favoring better soil structure and less potential soil crusting.

Saturated Hydraulic Conductivity

Saturated hydraulic conductivity means are given in Figure 2 and Table 3. The hydraulic conductivity varied from 0.001 m hr^{-1} in the Unfertilized Wheat Plot to 1.089 m hr^{-1} in the Manured Corn Plot. The CV of the conductivity for the plots varied from 32 to 125% which are similar to values obtained by other researchers (Warrick and Nielsen, 1980). The means (and CV values) for saturated hydraulic conductivity for the samples taken in 1988 from the Wheat Plots are 0.021 (43.7%), 0.288 (117.8%), and 0.436 (59.8%) m hr^{-1} for the Unfertilized, Fertilized, and Manured Treatments, respectively. The highest hydraulic conductivity values were present in the Manured Plots for all cropping treatments and the lowest hydraulic conductivity values were present in the Unfertilized Plots except for the Timothy Treatment. The "Fertilized vs. Others" contrast was not significant at the 0.10 level for hydraulic conductivity while the "Manured vs. Unfertilized" contrast was significant at the 0.01 level (Table 4). Although small differences existed in bulk density between Manured and Unfertilized Plots, large differences (up to 3 orders of magnitude) in hydraulic conductivity were present.

Annual additions of manure for 100 years resulted in an average increase in saturated hydraulic conductivity of one order of magnitude. (This average used the 1988 Wheat results in place of the 1989 results since the 1989 Unfertilized Wheat Plot had such an extremely low value.) The effect of annual additions of manure on hydraulic conductivity is attributed to changes in soil structure created by biological activity. Figure 3 illustrates the large correlation ($r=0.95$) between the log-transformed conductivity and the log-transformed number of pores > 1 mm in diameter. Pores were counted in the soil cores immediately after saturated hydraulic conductivity was determined. These pores were probably created by earthworms (*Lumbricus* sp.) since qualitative estimates of earthworm populations encountered during core sampling in the plots were correlated with the number of pores > 1 mm in diameter measured in the cores. Since saturated hydraulic conductivity was higher in Manured Plots, infiltration will be higher during many periods of the year for these treatments. Implications are that greater infiltration, less runoff, less soil erosion, but greater movement of nutrients through the soil profile will occur in plots having higher saturated conductivities.

Water Retention

Water retention curves influenced by soil and crop management are illustrated in Figure 4a-e. Except for the Corn Treatments, the Manured Plots have the highest water contents at saturation. This is attributed to the slightly lower bulk densities and higher organic matter levels which were present in the Manured Plots. The "Fertilized vs. Others" contrast was not significant at the 0.10 level for any part of the curve. However, the "Manured vs. Unfertilized" contrast was significant at the 0.10 level for water contents at saturation and at -0.4 kPa. This may be important since use of manure can improve the water holding capacity of the soil. However, our data showed no significant increase in water holding capacity of the surface soil due to annual additions of manure over 100 years.

Pore-Size Distribution

The pore-size distributions as affected by soil management and cropping system are illustrated in Figure 5a-e. In general, the relative volume of larger pores appears to be greater and the relative volume of smaller pores appears to be lower in the Manured Plots compared to the Unfertilized Plots with the exception of the large pores in the Corn and Rotation Treatments. The "Fertilized vs. Others" contrast was not significant at the 0.10 level for any of the volume fractions of pores while the "Manured vs. Unfertilized" contrast was significant at the 0.10 level for the volume fraction of pores from 5 to 6 μm in radius. This suggests that the Unfertilized Plots had a slightly greater volume of small pores in the 5 to 6 μm radius size compared to the Manured Plots.

The relative proportions of pores divided into macro-, coarse meso-, fine meso-, and micropores as influenced by soil management and cropping system are illustrated in Figure 6a-e. In general, there appears to be a 20% greater proportion of macro- and coarse mesopores in the Manured Plots relative to the Unfertilized Plots. This effect is most striking in the Wheat Treatment in 1989. The "Fertilized vs. Others" contrast was not significant at the 0.10 level for any of the pore-size classes. However, the "Manured vs. Unfertilized" contrast was significant at the 0.10 level for the fine mesopores with the Unfertilized Plots having a greater proportion of fine mesopores than the Manured Plots. Although there appears to be a greater volume of large pores in some of the Manured Plots compared to the Unfertilized Plots, the effect was not consistent across all cropping treatments.

The primary benefit of the increase in coarse mesopores (25-500 µm radius) and the decrease in fine mesopores (5-25 µm) is a potential improvement in soil aeration, resulting in an improved medium for root growth and proliferation. Thus, the use of manure can improve the soil pore-size distribution of the soil by increasing the percentage of larger pores compared to unfertilized soil. However, no great differences in pore-size distribution occur when inorganic fertilizers are added compared to manure for the soil used in this study.

Implications for Sustainable Agriculture

Soil physical properties are an indicator of the environmental impact of soil and crop management systems. This study indicates that the best soil fertility management in terms of enhancing soil physical properties is annual additions of manure and the worst is the unfertilized treatment. Eventhough use of inorganic fertilizers did not add as much organic matter to the soil, this treatment was not significantly different from that of manuring for the soil properties monitored. Research at Rothamsted, England found that 70 annual additions of manure at rates similar to those in this experiment had no measurable effect on soil tilth assessed by determining soil aggregate stability (Davies and Payne, 1988). The one soil property which was significantly affected by annual additions of manure was saturated hydraulic conductivity. The reason for higher hydraulic conductivity in the manured plots is that more earthworms were present because of more organic matter for the worms to consume. One possible drawback to higher saturated hydraulic conductivity at the surface is the possibility of enhanced leaching of plant nutrients to groundwater. Groundwater quality for this type of soil (claypan) will probably not be significantly impacted since the high clay content of the subsoil impedes deep leaching of nutrients (McGinty, 1989). Denitrification is also enhanced during the winter and spring months in these soils because they are somewhat poorly or poorly drained.

There were no significant differences in soil physical properties measured between the continuous corn, continuous wheat, continuous timothy or the three-year corn-wheat-red clover rotation treatments. Even with erosion and an increase in clay percent which were apparent for the corn and wheat plots (Gantzer et al., 1989), the surface soil can apparently maintain good tilth for corn and wheat since the silt loam texture is a very easily managed material.

Summary

This study was conducted to evaluate the effects of 100 years of continuous soil and crop management on soil physical properties of Sanborn Field at the University of Missouri. Undisturbed soil cores were removed from selected plots of Sanborn Field and evaluated for bulk density, saturated hydraulic conductivity, water retention curves and pore-size distributions. The results of this study indicated that annual additions of manure for 100 years significantly decreased bulk density by an average of 0.06 g cm^{-3}. Saturated hydraulic conductivity was significantly increased by an average of one order of magnitude with annual additions of manure for 100 years. Annual additions of manure also altered the pore-size distributions, significantly reducing the volume fraction of fine mesopores (5-25 µm radius) and generally increasing the volume fraction of coarse mesopores (25-500 µm radius) as compared to the unfertilized treatments. Because the annual additions of manure significantly increased saturated hydraulic conductivity, the treatment may also increase infiltration and thus reduce storm water runoff and soil erosion. Use of manure will improve the physical condition of the soil which may significantly reduce erosion if sufficient soil cover is maintained during severe storm events. Since the use of manure may increase infiltration, it may also adversely impact groundwater quality. Further work needs to be done to evaluate the potential impacts of sustainable agriculture systems on water quality.

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Table 1. Cropping and management history of Sanborn Field plots selected for the study.

Plot no.	Culture	Years	Soil Treatment
2	Wheat	1888-1949	Chemicals to replace harvest
		1950-1988	Fertilized by soil test
9	Wheat	1888-1988	Unfertilized
10	Wheat	1888-1988	Manured, 13.5 t ha^{-1}
6	Red clover	1888-1913	Manured, 13.5 t ha^{-1}
	Cowpeas	1914-1927	Manured, 6.7 t ha^{-1}
	4-yr Rotation	1928-1939	Fertilized
	C-3 grasses	1940-1949	Fertilized
	Corn	1950-1988	Fertilized by soil test
17	Corn	1888-1988	Unfertilized
18	Corn	1888-1988	Manured, 13.5 t ha^{-1}
22	Timothy	1888-1988	Manured, 13.5 t ha^{-1}
23	Timothy	1888-1988	Unfertilized
30	Wheat	1888-1913	Manured, 13.5 t ha^{-1}
	Wheat	1914-1927	Nitrogen, 11 kg ha^{-1}
	Wheat	1928-1939	Nitrogen, 23 kg ha^{-1}
	Wheat/lespedeza	1940-1949	Limed by soil test; Phosphorus,19 kg ha^{-1}
	Timothy	1950-1988	Fertilized by soil test
25	3-yr Rotation	1888-1939	Manured, 13.5 t ha^{-1}
		1940-1949	Manured, 11.2 t ha^{-1} before corn only
		1950-1988	Manured, 13.5 t ha^{-1}; Nitrogen, 112 kg ha^{-1} before corn and 37 kg ha^{-1} before wheat
26	3-yr Rotation	1888-1913	Manured, 13.5 t ha^{-1}
		1914-1927	Manured, 20.2 t ha^{-1} before corn only
		1928-1949	Limed by soil test; Phosphorus 16 kg ha^{-1} before corn and wheat only
		1950-1988	Fertilized by soil test
27	3-yr Rotation	1888-1988	Unfertilized

Table 2. Average percent silt and clay content for the surface horizon of selected plots of Sanborn Field.

Crop and Soil Management	Plot no.	Silt Content	Clay Content
		%	%
Wheat, Unfertilized	9	72.0	21.8
Wheat, Fertilized	2	59.6	26.6
Wheat, Manured	10	73.5	20.5
Corn, Unfertilized	17	66.7	26.7
Corn, Fertilized	6	68.1	21.5
Corn, Manured	18	62.5	30.0
Timothy, Unfertilized	23	76.9	16.7
Timothy, Fertilized	30	70.9	19.9
Timothy, Manured	22	76.9	16.7
Rotation, Unfertilized	27	80.0	14.8
Rotation, Fertilized	26	76.3	16.1
Rotation, Manured	25	75.3	17.1

Table 3. The means, $\overline{X}$, and coefficients of variation, CV, for bulk density and saturated hydraulic conductivity measured in 1989 in selected plots from Sanborn Field.

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Crop and Soil Management	Bulk Density		Saturated Hydraulic Conductivity	
	$\overline{X}$	C V	$\overline{X}$	C V
	g cm^{-3}	%	m hr^{-1}	%
Wheat, Unfertilized	1.45	3.0	0.001	104.3
Wheat, Fertilized	1.25	9.6	0.303	125.5
Wheat, Manured	1.15	1.8	0.750	52.2
Corn, Unfertilized	1.20	8.1	0.058	67.0
Corn, Fertilized	1.13	2.6	0.119	75.3
Corn, Manured	1.13	4.5	1.089	53.2
Timothy, Unfertilized	1.24	1.8	0.262	69.5
Timothy, Fertilized	1.34	2.5	0.188	82.2
Timothy, Manured	1.18	0.5	1.037	56.3
Rotation, Unfertilized	1.32	1.4	0.004	31.7
Rotation, Fertilized	1.28	2.5	0.005	38.6
Rotation, Manured	1.27	1.7	0.058	73.8

Table 4. Significance levels for single degree of freedom contrasts for physical properties measured in 1989 in selected plots of Sanborn Field.

Physical Property	Effect+	Significance Level
Bulk Density	Fertilized vs. Others	N S
	Manured vs. Unfertilized	0.10
Hydraulic Conductivity	Fertilized vs. Others	N S
	Manured vs. Unfertilized	0.01
Water Content (0 kPa)	Fertilized vs. Others	N S
	Manured vs. Unfertilized	0.10
Water Content (-0.4 kPa)	Fertilized vs. Others	N S
	Manured vs. Unfertilized	0.05
Volume Fraction of Pores (5 to 6 µm radius)	Fertilized vs. Others	N S
	Manured vs. Unfertilized	0.10
Fine Mesopore Fraction (5 to 25 µm radius)	Fertilized vs. Others	N S
	Manured vs. Unfertilized	0.10

+Only those effects significant at the 0.10 level are illustrated.
NS means not significant at the 0.10 level.

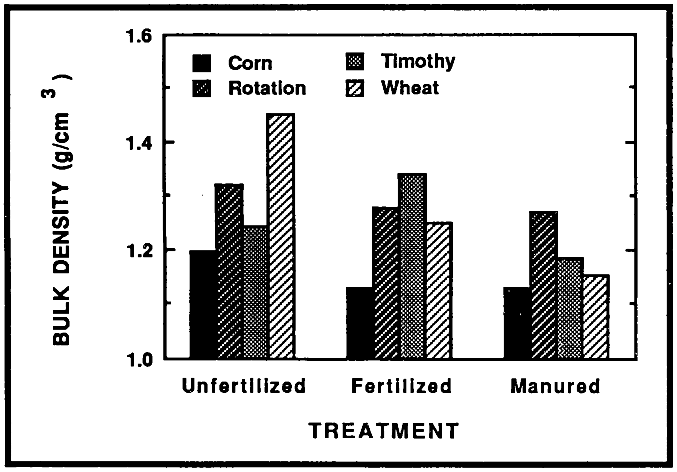

Figure 1. Mean bulk density as affected by soil and crop management treatments measured in soil cores taken in 1989 from Sanborn Field.

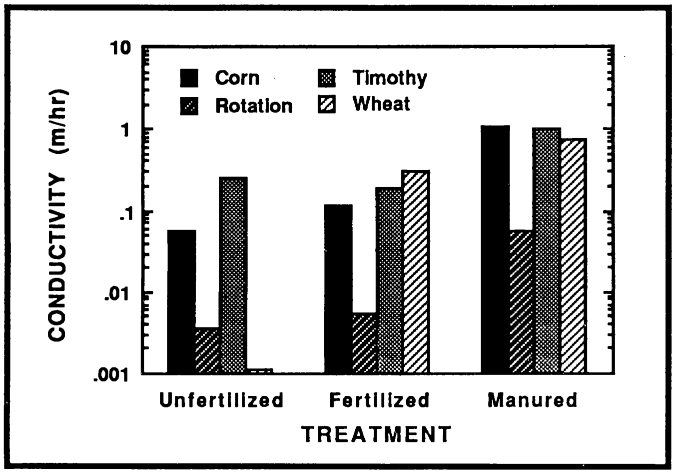

Figure 2. Mean saturated hydraulic conductivity as affected by soil and crop management treatments measured in soil cores taken in 1989 from Sanborn Field.

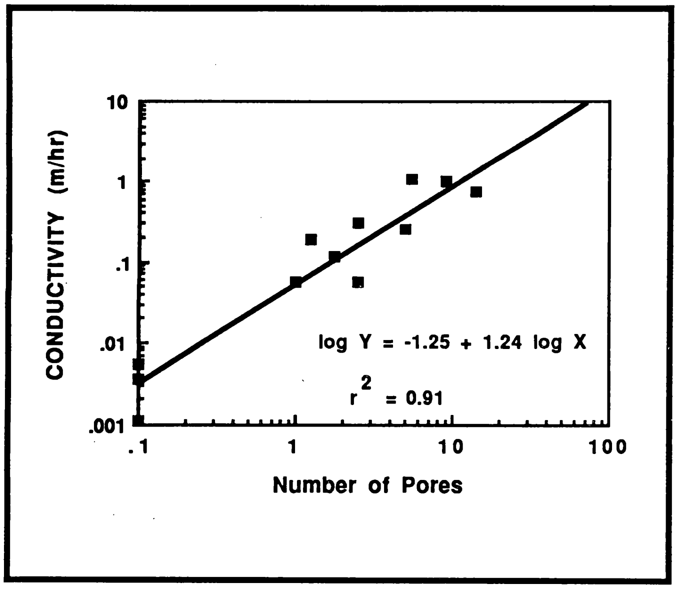

Figure 3. Mean saturated hydraulic conductivity as a function of the mean number of pores > 1mm in diameter measured in soil cores taken in 1989 from Sanborn Field.

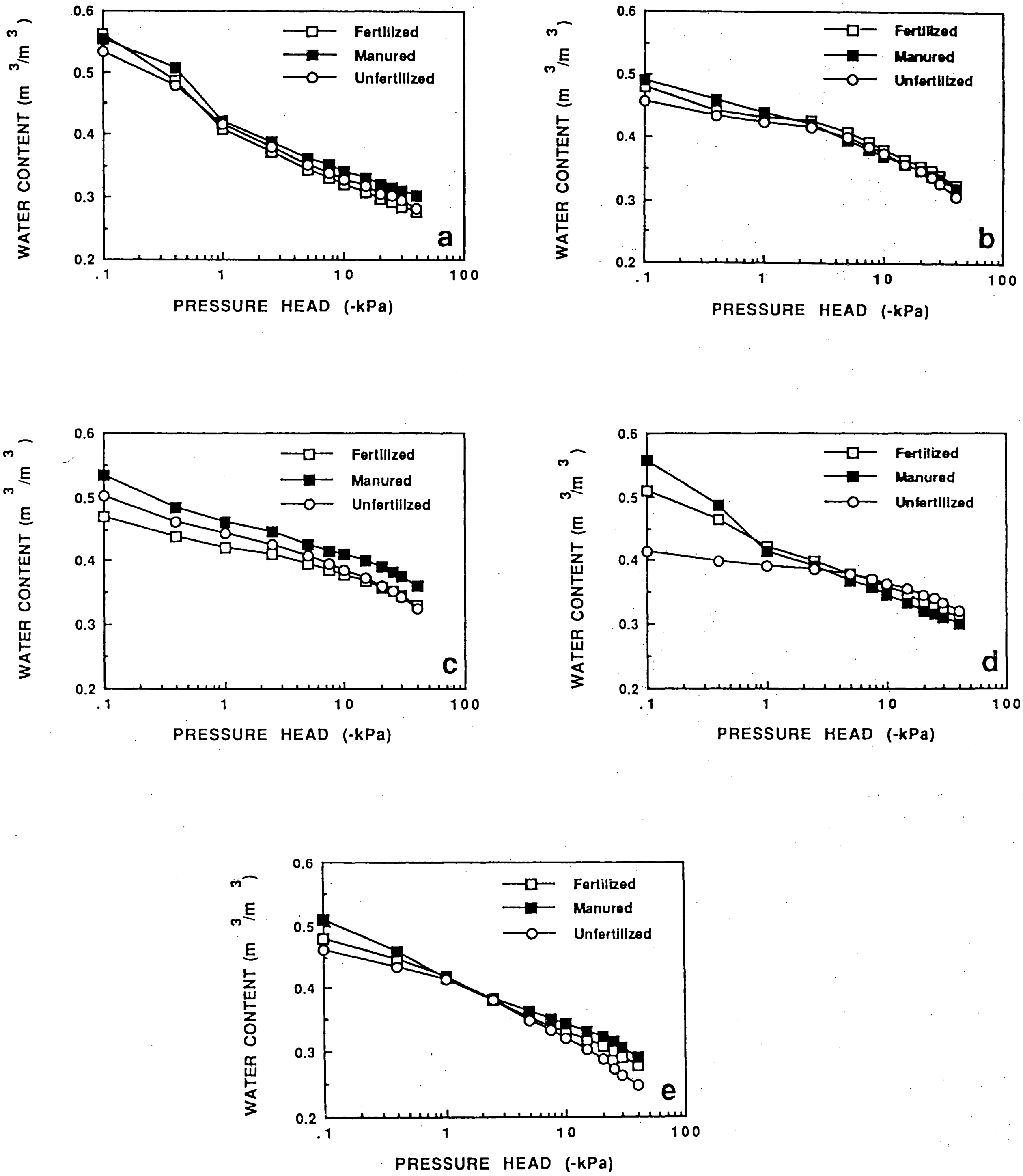

Figure 4. Water retention curves as affected by soil and crop management treatments measured in soil cores taken from Sanborn Field from the following selected plots: (a) continuous corn, (b) corn-wheat-red clover rotation, (c) continuous timothy, (d) continuous wheat, and (e) continuous wheat. Curves in (a) through (d) were measured in 1989 and in (e) in 1988.

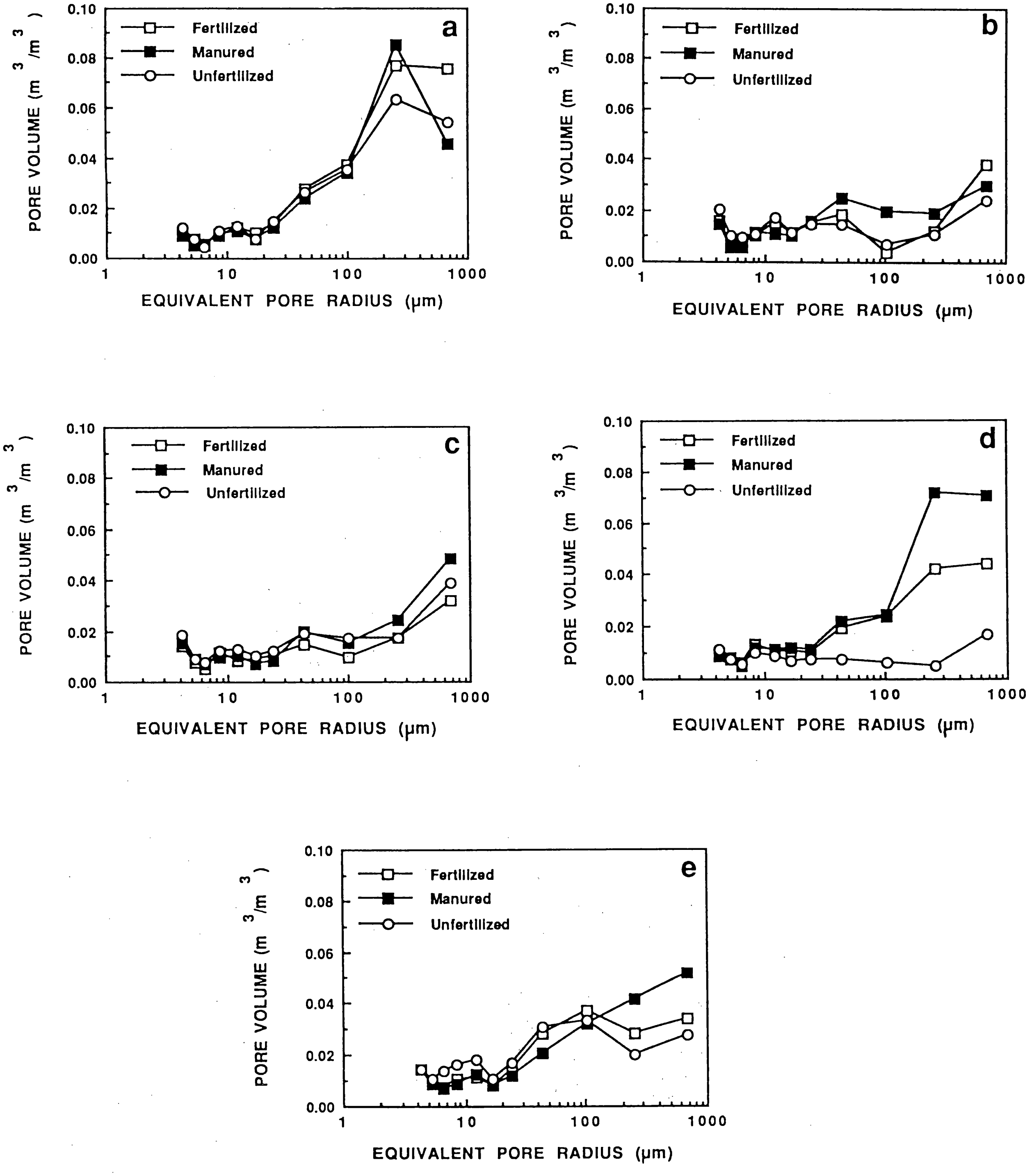

Figure 5. Pore-size distributions as affected by soil and crop management treatments measured in soil cores taken from Sanborn Field from the following selected plots: (a) continuous corn, (b) corn-wheat-red clover rotation, (c) continuous timothy, (d) continuous wheat, and (e) continuous wheat. Distributions in (a) through (d) were measured in 1989 and (e) in 1988.

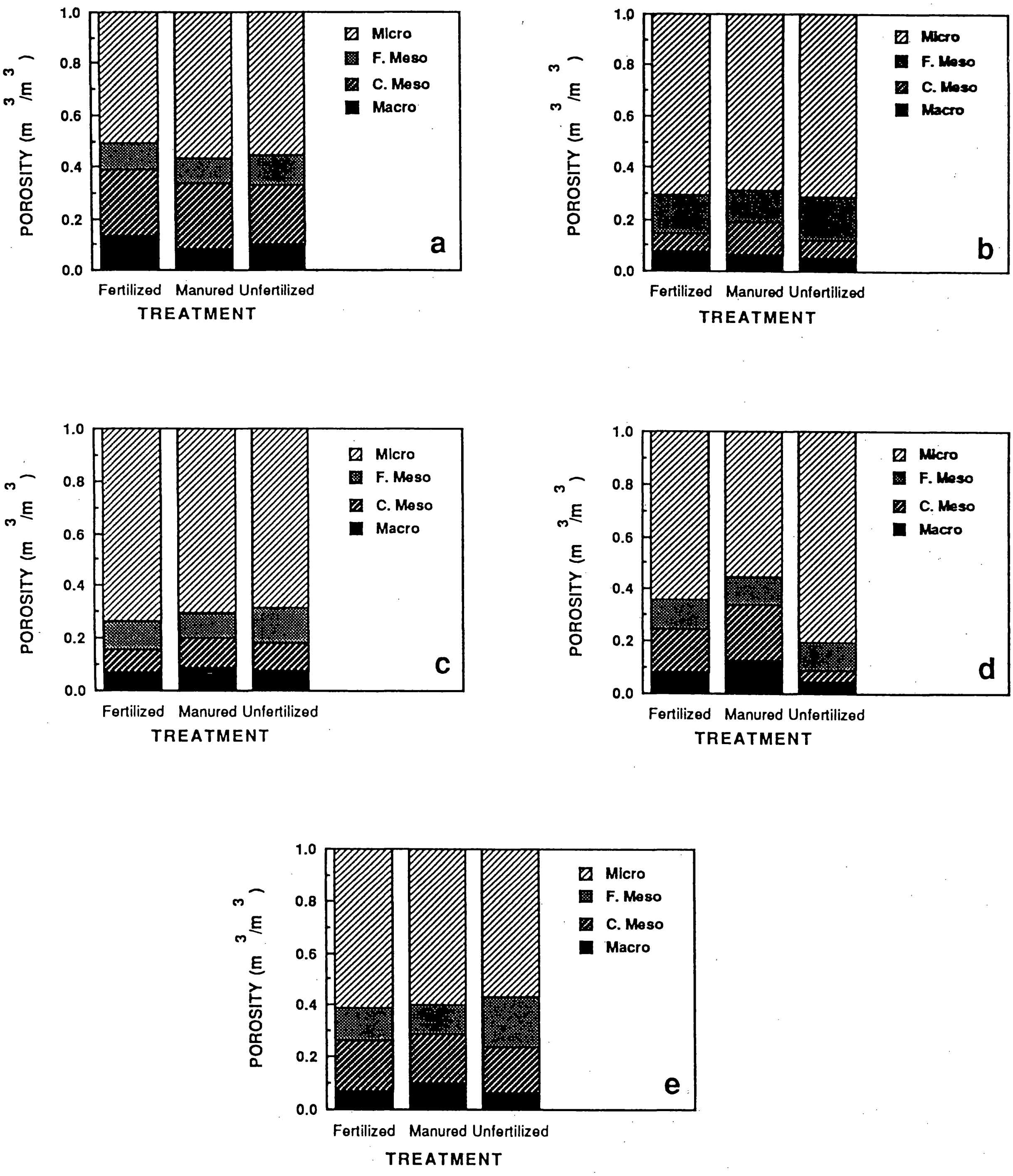

Figure 6. Porosity distributions as affected by soil and crop management treatments measured in soil cores taken from Sanborn Field from the following selected plots: (a) continuous corn, (b) corn-wheat-red clover rotation, (c) continuous timothy, (d) continuous wheat, and (e) continuous wheat. Distributions in (a) through (d) were measured in 1989 and (e) in 1988. Porosity distributions were obtained by the following pore-size classifications: micropores, < 5 μm; fine mesopores, 5-25 μm; coarse mesopores, 25-500 μm; and macropores, > 500 μm in radius.

Estimating Soil Erosion After 100 Years Of Cropping On Sanborn Field

C. J. Gantzer, S. H. Anderson and A. L. Thompson

Introduction

In early 1915, R. W. McClure and M. F. Miller began pioneering studies of soil erosion at the University of Missouri-Columbia (UMC), studies which confirmed that soil erosion removed more plant nutrients from the field than did the crops (Woodruff, 1987). In 1917, F. L. Duley expanded these studies by installing one of the first permanent sets of soil erosion plots in the world. The Erosion Plots were used to document that agriculture accelerates soil erosion and to improve soil conservation practices. Sanborn Field, established in 1888, the oldest agricultural experiment field west of the Mississippi also provides an excellent opportunity to document how long-time crop rotations, and soil management influence soil erosion. The Erosion Plots plots have been jointly designated with Sanborn Field as a Registered National Historical Landmark (Woodruff, 1987).

The Erosion Plots are located on a gentle 3.7% slope. Data collected during the period from 1918 to 1931 on these 28 m long plots showed annual erosion of 94 t/ha from uncropped cultivated fallow land, 45 t/ha from continuous corn land, 7 t/ha from a corn-wheat-clover rotation, and only 0.7 t/ha of erosion from land growing bluegrass sod (Woodruff, 1987). These results showed that crops which maintain a large amount of protective plant canopy or residue cover clearly have the smallest amount of soil erosion. This concept is now recognized as universally true and explains why soil erosion has occurred at Sanborn Field (Miller and Krusekopf,1932; and Bennett, 1939). Although it was not the intent of Dean Sanborn to study soil erosion within the Field, dramatic differences in topsoil depth among plots cropped to continuous corn, or a rotation of corn-oats-wheat-clover-timothy-timothy, or continuous timothy, are so large that documenting these differences for the 100th anniversary of the Field, should as a useful soil conservation lesson.

Because of the layout of Sanborn Field and the oversight of not measuring soil erosion over the last 100 years, it is not possible to determine exactly how or why the plots are in their current state. Several confounded processes have contributed to producing the current conditions including soil erosion from both wind and water, soil movement associated with tillage and the movement of machinery on and off the plots, and naturally occurring differences in topsoil thickness among plots before cultivation. It is clear however that real differences are related to soil and crop management, and documenting the current state of the plots can be helpful in showing how much soil remains after 100 years of cropping.

Objectives

Toward this end, we present an analysis of topsoil remaining after 100 years of continuous cropping in plots planted to continuous corn, to continuous timothy, and to a 6-year rotation cropped sequentially to corn, oats, wheat, clover, timothy, and timothy. We then compare the remaining topsoil in plots with predicted soil erosion by using the Universal Soil Loss Equation (USLE) as the basis of the calculation. Finally, we will attempt to persuade the readers that development of a sustainable system of crop production which reduces soil erosion is essential to conserving soil productivity.

Materials and Methods

Sanborn Field consists mainly of a Mexico silt loam soil (fine, mont., mesic Udollic Ochraqualf), commonly called a claypan soil because of the large amount of clay-sized particles increasing abruptly in the subsoil. Our current understanding of soil variation within Sanborn Field confirms that there are at least two soils within the field. The east end of the field (plots 1-7) grade to a Lindley loam soil (fine-loamy, mixed, mesic, Typic Hapludalf) (Krusekopf and Scrivner, 1962). The southwest corner of the field (plots 40-45) has been modified by movement into and deposition of eroded soil from upslope (Personal Communication, J. R. Brown, 1989). To reduce making comparisons between areas which are confounded by such differences, we chose a small area located near the summit divide for comparison of differences associated with crop management. No erosion prevention was practiced for row crops on the field until the 1970's. Initially, all plots had plant residues removed each year, but this practice was discontinued. Since 1950 to 1960 only the continuous corn plots have had residues removed. Normal tillage for these plots is fall plowing. "In most of the plots the surface soil has been modified by erosion frequent cultivation and is reduced in thickness" (Krusekopf, and Scrivner, 1962).

For this study seven plots, including plots 13, 17, 18, 19, 20, 22, and 23 (see Fig. 1, and Brown and Wyman, 1989; this publication) were chosen as experimental units. Crop treatments included continuous corn, continuous timothy, and a 6-year rotation cropped sequentially to corn, oats, wheat, clover, timothy, timothy. Soil management included unmanured (unfertilized), manured (application of six tons of barnyard manure per acre annually, or 13.4 t/ha/yr) and one fertilized treatment on the 6-year rotation plot with fertilization based on soil test recommendations. A full history of Sanborn Field can be found in Smith (1942), Upchurch et al. (1985) and Brown and Wyman (1989).

Our data collected from the central sampling locations within plots indicate that variability of topsoil thickness and clay content from the center part of the plots is small (Figs. 2-4). To accommodate the lack of knowledge about the original topsoil thickness or clay content, we assumed that in our selected subset of plots, topsoil thickness and clay content were uniform, and that soil has not been lost or added in the timothy plots since cultivation. While these assumptions may not be completely correct, study of soil erosion at Sanborn Field is nearly impossible without making them.

Plots are within about 60 m of each other and were selected to reduce soil variability. Soil samples were collected for analysis of depth to Bt horizon (topsoil depth) and clay content of the Ap or plow layer by R. D. Hammer for the centennial study with a truck mounted hydraulically driven probe. Historical samples collected for the 75th anniversary of Sanborn Field by C. L. Scrivner were also analyzed for topsoil depth (Personal Communication, Prof. C. L. Scrivner, 1988).

All plots were evaluated for topsoil depth at four centrally located sampling positions at least 3.4 m from a width border and 7.9 m from a length-wise border (Fig.1). Plots 17, 18, 22, and 23 were evaluated for clay content of the Ap horizon using samples collected from these cores. Plots 13, 19 and 20 were evaluated for clay-sized particles in the Ap only at location F.

Depth to the Bt horizon was measured using standard procedures for site and pedon description (Soil Survey Staff, 1975). Particle-size analysis was determined using the pipette method (Gee and Bauder, 1985). Percent slope was determined in duplicate along the four margins of each plot.

Since the construction of the first erosion plots, our understanding of the factors influencing soil erosion from cultivated land has improved considerably. Over the last 30 years the development and improvement of the Universal Soil Erosion Loss Equation (USLE) has been a powerful guide in developing conservation management systems (Wischmeier and Smith, 1978). This tool has been shown to be a good predictor of the long term average annual soil erosion. Using a rainfall and runoff factor (R-factor), and cover and management factor (C-factor) developed for Missouri conditions, we estimated the amount of soil erosion expected from the selected plots within Sanborn Field (Steichen, 1979).

Results and Discussion

Comparison of mean topsoil thickness between plots in continuous corn with and without manure (plot 18 vs. 17), and in continuous timothy with and without manure (plot 22 vs. 23) were investigated using unpaired t-tests. Mean values of these data are presented in Table 1. The test between corn plots was significant at the 5% probability level, while the test between timothy plots was not significant at the 20% level. These results suggest that a soil management related effect in the corn plots, or other factor such as difference in land slope or naturally occurring variation in topsoil caused somewhat less topsoil in the unfertilized vs. manured continuous corn plot. These results may in part be explained by the lower organic matter content in the unfertilized corn plot, which could make it more difficult to till as deeply. In fact, topsoil thickness is really less than the thickness of the plow layer in corn plots, since subsoil clay has been incorporated with topsoil. It may also be that soil aggregates from the unfertilized plot were less stable and were thus more prone to erosion. Comparison of mean clay content for corn plots was not significant at the 10% level. Graphical comparison of clay profile data show only a slight difference between these plots (Fig. 2). Graphical comparison of plots 13, 19, and 20 from the 6-year rotation showed similar soil profiles, and standard deviations calculated from these plots were similar to those from 17 and 18, and 22 and 23 (Fig. 3, Table 1). Plots for the continuous timothy show similar variation between cores (Fig. 4).

Although small differences between plots within the same crop treatment did exist for the corn plots, we assumed soil treatments caused only minor differences in the amount of topsoil, and thus replicate plots for testing topsoil depth and clay content of the plow layer were simulated by pooling plots from the unfertilized, manured, and fertilized soil management treatments for continuous corn, the 6-year rotation, and continuous timothy. Pooling created replicate plots within crop management treatments. A completely randomized one-way analysis of variance (ANOVA) was used to quantify the probability of differences related to cropping history (Table 2) for 1961 and 1988 observations. Single degree of freedom contrasts comparing the continuous corn vs. the 6-year rotation and continuous timothy plots, and the 6-yr rotation vs. the continuous timothy plots were partitioned from the total as separate tests.

Results presented in Table 2 and Fig. 5 show that topsoil depth was significantly less for the continuous corn vs. the rotation and timothy plots for both the 75th and 100th year sampling dates, although differences were much stronger for the 100th year samples. The contrast between the rotation vs. the timothy cropping was also highly significant showing that rotation plots had less topsoil than the timothy plots. Analysis of the amount of clay in the plow layer indicated that the corn plots were significantly greater than either the rotation or timothy plots, and that there was no difference between the rotation vs. timothy plots. This later result suggests that mixing of clay subsoil within the plow layer has primarily occurred in corn plots.

Average Rate Of Soil Erosion

Using topsoil depth data from the 75th sampling, we estimated the average erosion rate from the plots. Assuming that soil was neither lost nor added to from the timothy plots, we took the difference in topsoil depth between the rotation and the timothy plots and calculated that 12.4 cm of soil was lost from the rotation plots in 74 years. This equals 16.8 cm/100 yr or about 21 t/ha/yr of soil erosion in the rotation plots. Similar calculations were performed for the difference between the topsoil depth in the timothy minus the corn plots. Since discussions with C. M. Woodruff indicated that subsoil was observed to have been mixed in the plow layer of the corn plots as early as 1948 (Personal Communications, 1988), we calculated about 22 cm of soil was lost from the corn plots in 60 years. This equals an average rate of about 38 cm/ha/100 yr for an average annual soil loss of 50 t/ha/yr. For reference, this amount can be compared with that found in the plow layer. Assuming an acre-furrow slice is equal to 2,241 t/ha, an erosion rate of 22.4 t/ha/yr would completely remove the plow layer in 100 years. Apparently this loss has occurred in continuous corn plots.

Comparison Of Topsoil Dept in the 75th and 100th Year

In addition to the calculation of early erosion, a linear regression of the 100th vs. the 75th year topsoil depth data was conducted to determine how much soil was recently removed from the plots during the last 25 years. Figure 5 presents the plot of topsoil depth collected for the 100th vs. the 75th year of sampling. If no soil had eroded after the 75th year, the regression line would have an intercept of 0.0 and a slope of 1.0. Figure 5 indicates that the fitted intercept is negative, and the slope slightly greater than 1.2. This is unexpected, since soil erosion must have occurred during the last 25 years and would have been expected to produce a slope less that 1.0. We speculate that possible reasons for these results include slightly deeper depth of tillage prior to the 75th vs. the 100th year sampling as well as differences in the characterization of the soil for the two different periods. Results presented in Fig. 5 do not indicate that severe erosion occurred from our selected plots during the last 25 years. This result is strengthened by the fact that during this period, plot management of crop residue changed, and residues were not removed from rotation plots.

USLE Predicted Soil Erosion

Table 3 presents some of the soil properties known to influence soil erosion. For example, the amount of organic matter and clay content is directly related to soil erodibility. Using the USLE nomagraph, we estimated soil erodibility (the K-factor) for each plot. Values ranged from 0.31 to 0.41. The lowest value (or the least erodible soil) is associated with the manured corn plot, and is related to the high clay content, and moderate levels of organic matter of this soil. The highest value (or the most erodible soil) is associated with the 6-year rotation unfertilized plot, and is related to the low clay content (high silt plus very fine clay content) and low organic matter level. LS factors were also calculated for each plot range from 0.11 to 0.21. Data indicate that the LS factors in the two corn plots were very similar. LS factor differences were smaller in other plots. Cover and management factor values had the greatest range in values with a minimum value of 0.01 for the timothy plots and a maximum value of 0.54 for the continuous corn plot, suggesting that soil is as much as 54 times more susceptible to erosion when in corn than when in timothy. It is interesting and important to realize that cover management is about 34 times more variable than soil erodibility and 28 times more variable than slope. In practice, cover management provides the only effective control of potential soil erosion.

The analysis of topsoil depth vs. the USLE predicted soil erosion is presented in Fig. 7. The variables are characterized by a log-linear relationship, and the regression explains 96% of the data's variation. It is surprising that this type of relationship fits so well considering that a linear regression might be expected. It is clear, however, that the data are strongly skewed primarily because of the continuous corn plots. Based on the clay content of continuous corn plots, considerable subsoil has been mixed into the plow layer. Thus, these plots do not in fact have 17 to 21 cm of topsoil, but considerably less. Changing these values to reflect this fact would linearize the data considerably.

Loss Of Soil Productivity

Much interest has centered around how soil erosion can reduce the productive capacity of a soil by permanently altering non-replaceable properties such as bulk density, potentially available water holding capacity or to some extent pH. While our understanding of these relationships is not perfect, Gantzer and McCarty (1987) estimate that reductions in corn yield under high fertility to 60% of that expected in an uneroded soil might be anticipated for a claypan. Analysis of long-term data from Sanborn Field indicate very similar predictions (see Table 4. in Buyanovsky, et. al., 1989; this publication). Erosion nearly always reduces the productive capacity of soils with unfavorable subsoils, such as claypan. If long-term production is to be sustained, it is clear that methods to improve cover management for row-crops is necessary to reduce erosion. Data from Sanborn Field show that even the 6-yr rotation has lost nearly half the topsoil over 100 years. Therefore, continued work is necessary to develop management schemes closer to the ideal (such as that associated with timothy) cover conditions in order to conserve soil productivity.

Summary and Conclusions

Results show that topsoil was significantly less for the continuous corn vs. the 6-yr rotation and timothy plots for both the 75th and 100th year sampling dates. The contrast between the rotation vs. the timothy cropping showed that rotation plots had about 30% of the topsoil in the timothy plots. Analysis of the amount of clay in the plow layer indicated that the corn plots were significantly greater than either the rotation or timothy plots. There was no difference in clay content between the rotation vs. timothy plots. This later result suggests that mixing of clay subsoil within the plow layer has only occurred in corn plots.

Topsoil depth between the rotation and the timothy plots indicated that 12.4 cm of soil was lost from the rotation plots in 75 years. Similar calculations for the difference between the topsoil depth in the timothy minus the corn plots indicated about 22 cm of soil was lost from the corn plots in 60 years. Our data do not indicate that severe erosion occurred from our selected plots during the last 25 years.

We estimated several USLE factors and found soil erodibility values ranged from 0.31 to 0.41, and the LS factors ranged from 0.11 to 0.21. Cover and Management factor values had the greatest range, with a minimum value of 0.01 for the timothy plots, and a maximum value of 0.54 for the continuous corn plots. This C-factor estimate highlights the fact that cover management provides the most effective control of potential soil erosion for Sanborn Field.

The analysis of topsoil depth vs. the USLE predicted soil erosion was characterized by a log-linear relationship and the regression explains 96% of the data's variation. The data is strongly skewed because we underestimated the amount of topsoil lost in the corn plots since subsoil has been mixed into the plow layer in these plots.

Productivity estimates indicate that 60% reductions in corn yield of that expected in an uneroded soil might be anticipated for a claypan even when managed with high fertility. Thus, if long-term production is to be sustained, methods to improve cover management for row-crops is necessary..

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Table 1. The means, $\overline{X}$, and standard deviations, SD, for topsoil thickness (depth to Bt horizon) and percent clay in the Ap horizon measured in selected plots from Sanborn Field, 1988.

		Topsoil		Clay	
Management	Plot	$\overline{X}$	SD	$\overline{X}$	SD
	#	--------cm--------		-----------%-----------	
Corn Unfertilized	17	17.8	2.3	26.8	2.5
Corn Manured	18	21.3	1.0	30.0	2.4
	Mean	**19.6**	**2.2**	**28.3**	**2.8**
6-Yr Rotation Unfertilized	13	31.0	2.0	14.6	2.0 *
6-Yr Rotation Manured	19	28.5	3.9	18.4	2.0 *
6-Yr Rotation Fertilized	20	33.5	4.7	18.4	2.0 *
	Mean	**31.0**	**4.0**	**16.8**	**2.0**
Timothy Unfertilized	23	45.0	4.9	16.7	0.6
Timothy, Manured	22	43.5	4.6	16.7	0.9
	Mean	**44.3**	**4.4**	**16.7**	**0.7**

Table 2. Significance levels for single degree of freedom contrasts for physical properties in selected plots of Sanborn Field, 1988.

Measurement	Effect	Significance
		(Probability)
1961		
Topsoil	Corn vs. Rotation & Timothy	0.003
Depth	Rotation vs. Timothy . . .	0.016
1988		
Topsoil	Corn vs. Rotation & Timothy	<0.001
Depth	Rotation vs. Timothy . . .	0.001
1988		
Ap Clay %	Corn vs. Rotation & Timothy	0.002
	Rotation vs. Timothy . . .	0.923

Table 3. Soil properties and Universal Soil Loss Equation Factors for selected plots in Sanborn Field, 1988.

Treatment	Plot	Organic Matter	Clay	USLE Factors			
				A	K	LS	C
	#	%		----------- Mg/(ha*yr) -----------			
Corn Unfertilized	17	1.2	26.8	23.0	0.52	0.21	0.54
Corn Manured	18	2.4	30.0	14.3	0.40	0.17	0.54
6-Yr Rotation Unfertilized	13	1.6	14.6	2.7	0.62	0.11	0.10
6-Yr Rotation Manured	19	2.5	18.4	2.5	0.50	0.13	0.10
6-Yr Rotation Fertilized	20	2.2	17.6	2.2	0.52	0.11	0.10
Timothy Unfertilized	23	2.2	16.7	0.4	0.53	0.17	0.01
Timothy Manured	22	3.5	16.7	0.2	0.44	0.11	0.01

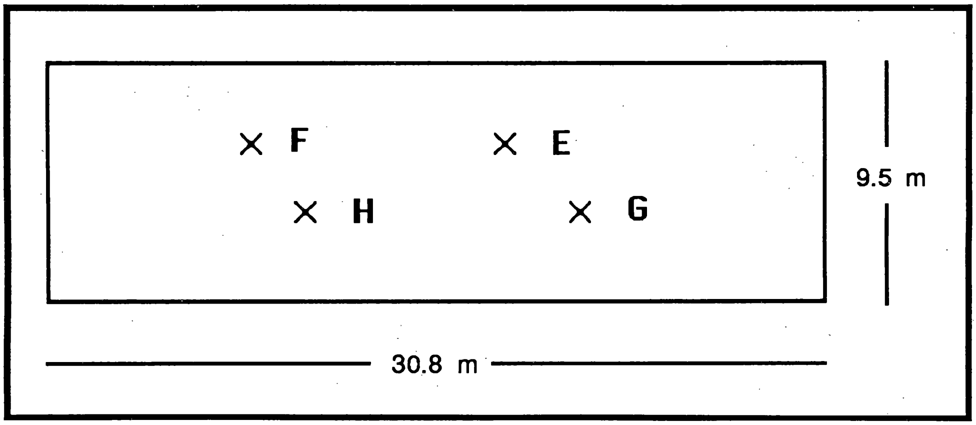
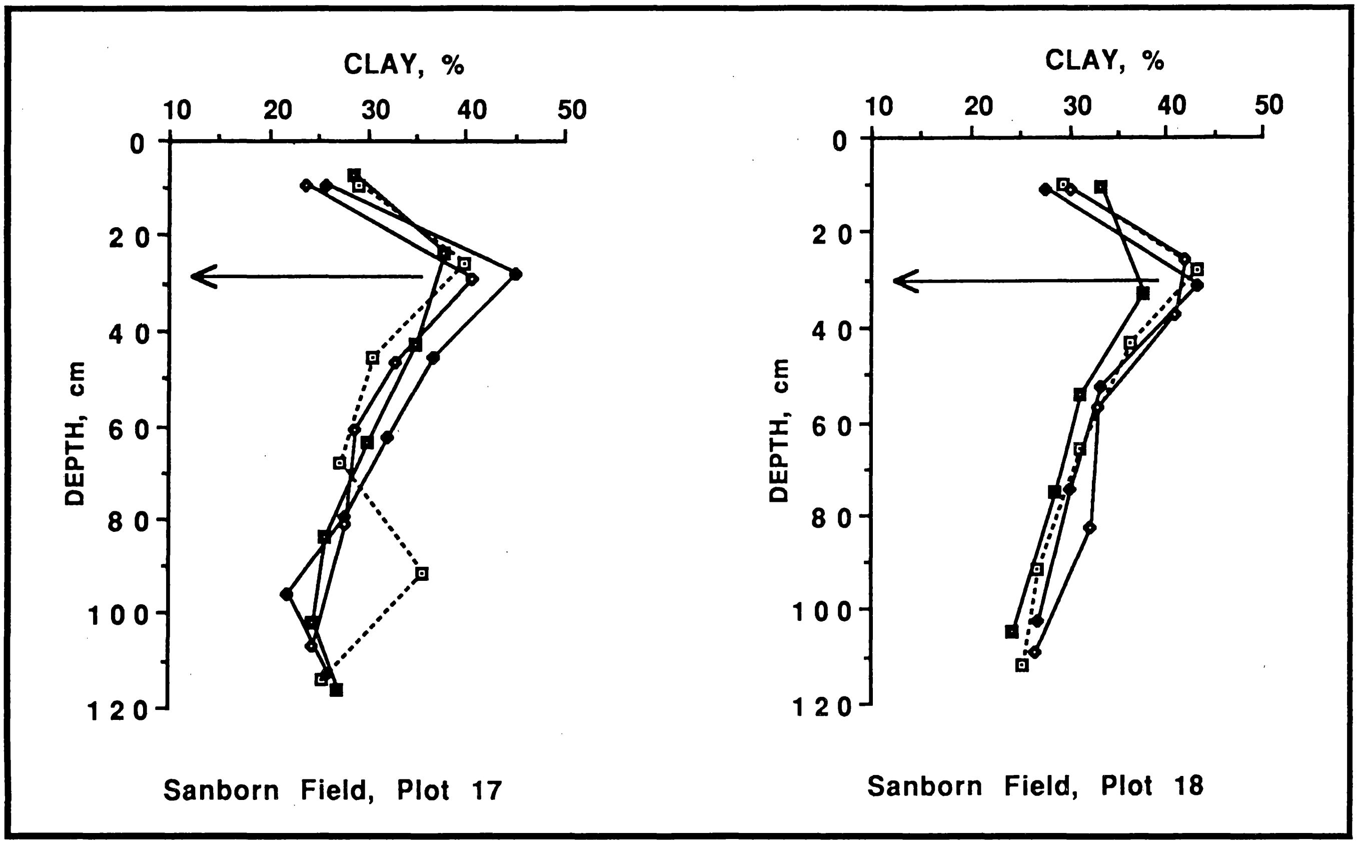


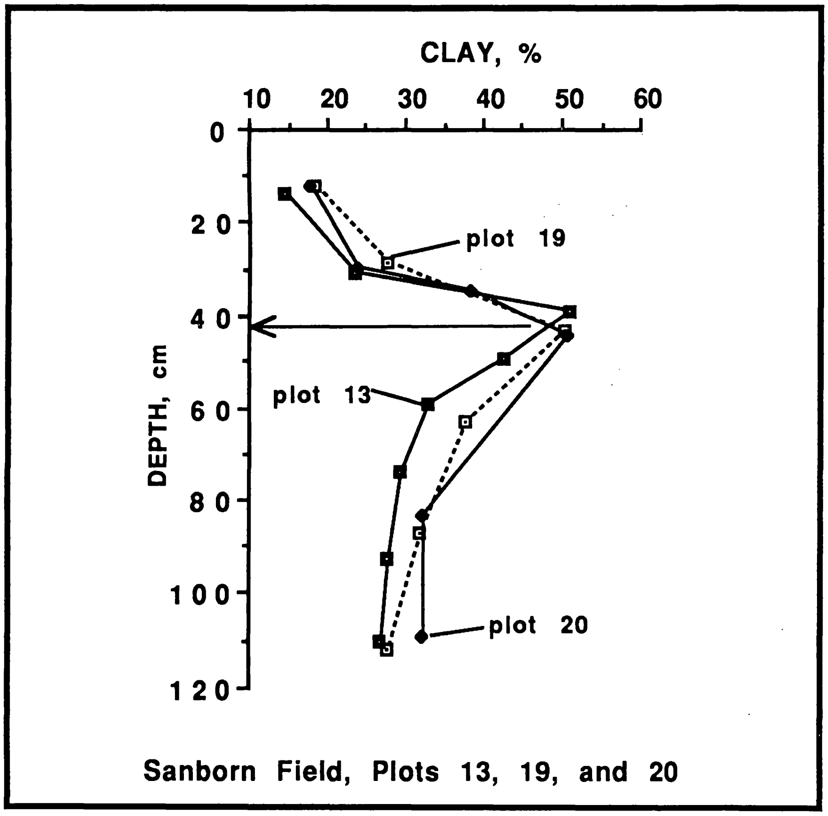
Figure 1. Soil sampling locations for Sanborn Field plots, 1988



Sanborn Field, Plot 17

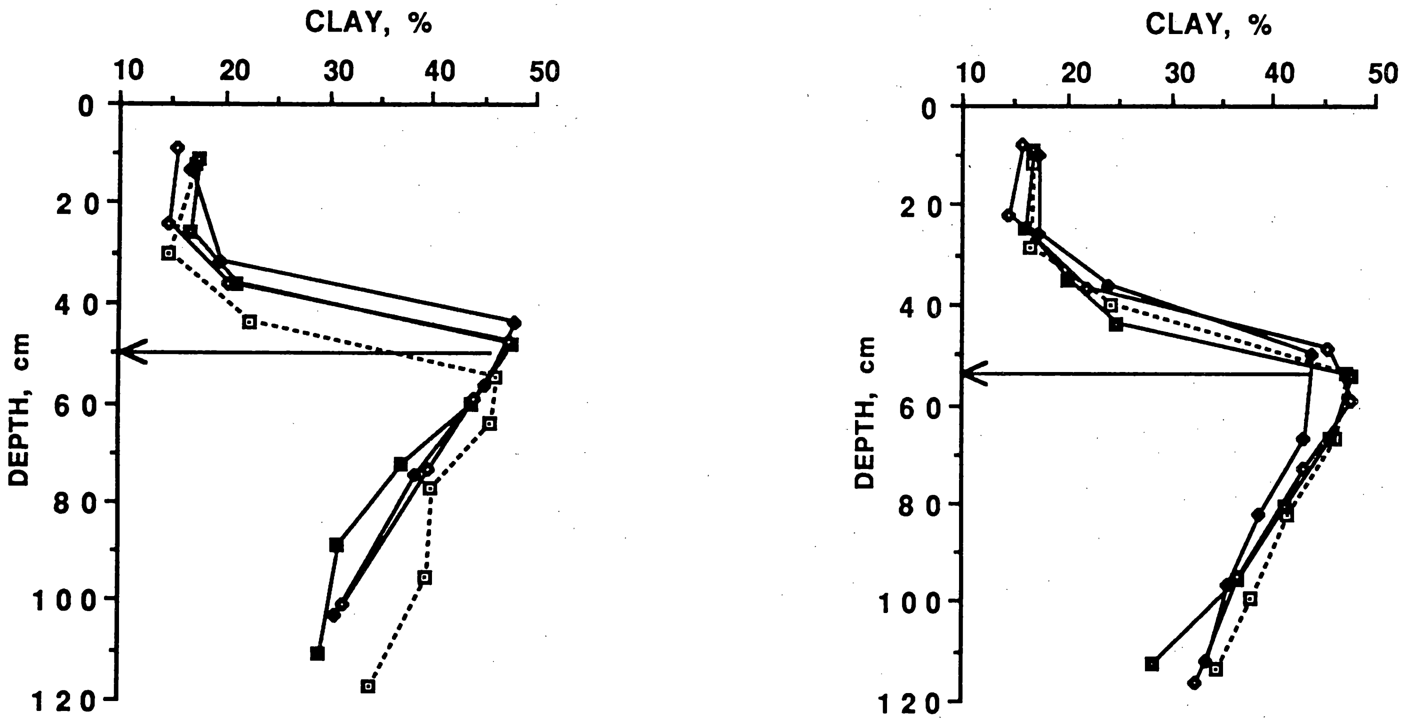
Sanborn Field, Plot 18

Figure 2. Clay profiles of cores from unfertilized and manured continuous cont plots, Sanborn Field, 1988.



Sanborn Field, Plots 13, 19, and 20

Figure 3. Clay profiles of cores from the 6-year rotation plots, Sanborn Field, 1988.



Sanborn Field, Plot 22

Sanborn Field, Plot 23

Figure 4. Clay profiles of cores from manured and unfertilized continuous timothy plots.

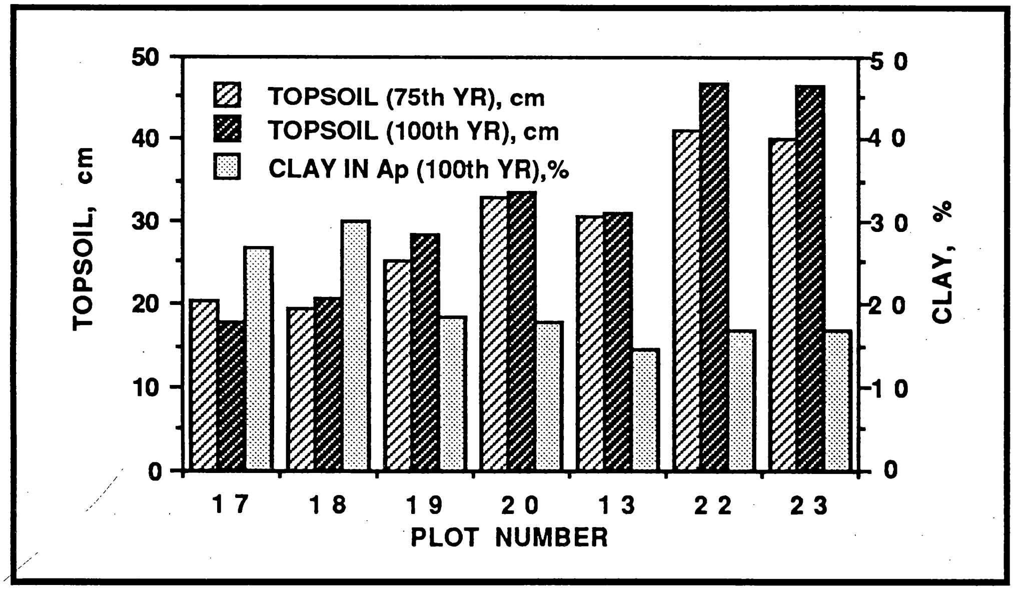


Figure 5. Topsoil depth and the percentage of clay in the plow layer for selected plots from Sanborn Field, 1988.

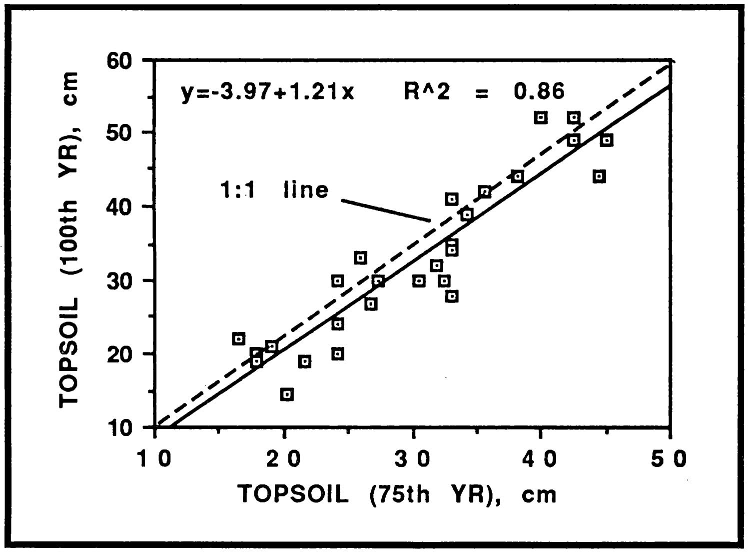


Figure 6. Comparison of topsoil depth based on the 100th vs. the 75th year Sanborn Field samples.

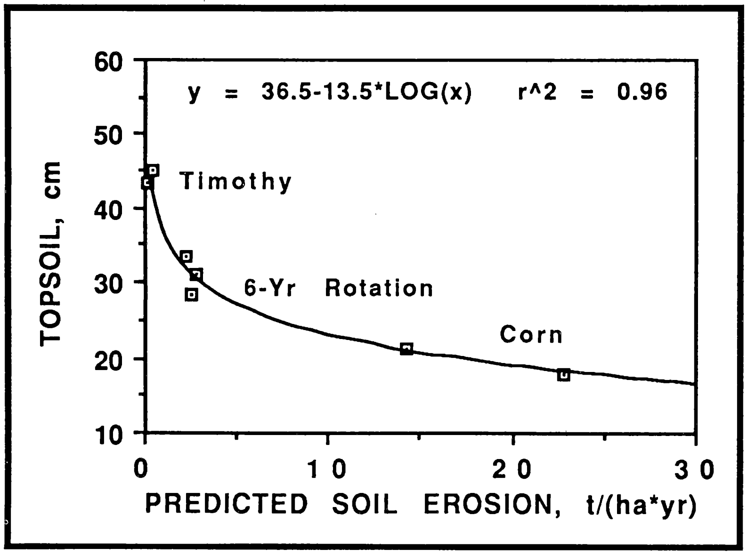


Figure 7. Topsoil thickness vs. the USLE predicted average annual soil erosion for selected plots from Sanborn Field, 1988.

Differences in Subsoil Phosphate in P Fertilized and Unfertilized Mexico Soil

R. W. Blanchar and B. L. Conkling

Unfortunately, as Professor Sanborn began his experimentation in the year 1888, no soil samples were taken from various depths of the research plots currently known as Sanborn Field. Later Kao and Blanchar (1973) measured the phosphorus (P) content with depth in plots which were or were not treated with phosphate during the intervening 82 years and found less inorganic P among the B3 and C1 horizons of the plot not treated with phosphate. Did the fertilizer P move to this depth on the treated plot or did the plants stressed for P in the control plot remove the native soil P from these layers? This question remains unanswered. It is the objective of this paper to examine the data and support the contention that P was removed from the lower depths in the control plot.

Materials and Methods

Description of Soils

Two soil resources, a Mexico silt loam (fine, mesic, montmorillitic, Typic Albaqualf) from Sanborn field and soil from Tucker Prairie mapped as Mexico silt loam, were used for this P distribution comparison. These were nearly level prairie soils with an average slope of 1 to 3%. Tucker Prairie is a native prairie site, approximately 25 miles east of Sanborn Field, that has not been plowed or tilled. It is maintained by the Biological Sciences Division of the University of Missouri as a natural prairie. Using estimates of natural prairie fire frequency, Tucker Prairie is burned regularly and presumably contains the complement of native grasses found on a virgin prairie. For the purposes of the comparisons made in this paper, it was assumed that the current P distribution in Tucker Prairie resembles that of Sanborn field in 1888. In March of 1973 core samples were taken to a depth of 150 cm from Tucker Prairie.

On March 24, 1970 soil profile samples were taken from plots 31 and 33 of Sanborn Field. Plot 31 has received P treatments since 1888 and plot 33, the control plot, received no added P during this period. Rotations which included corn, soybeans, sweet clover, red clover, and wheat have been carried out since 1888 on both plots. From 1888 to 1927 plot 31 received 13,500 kg manure/ha annually. Between 1928 and 1949, a total of 343 kg P/ha was added as 0-20-0. In 1950, 245 kg P/ha as rock phosphate was added. Since 1950, adequate amounts of lime, potash, and rock phosphate have been applied to plot 31 as indicated by Missouri soil tests and residues of crops have been returned to the soil. Every three years, a total of 182 kg ammonium nitrate, 45 kg of 6-24-24, and 91 kg of 10-10-10 fertilizers per ha have been added to plot 31. Plot 33 received the same N, K, and lime treatments as plot 31, but no P was added. Soil samples were obtained by taking a core 320 cm deep with a hydraulically-operated soil sampler. Two undisturbed cores were taken from each plot and each core divided into 13 layers. The soil samples were air dried and crushed to pass through a 2mm screen. All analyses were done in duplicate on samples of each layer of each core.

Soil Analysis

Total P was determined by digesting 1g of soil with 15 mL of 72% $HClO_4$ in a 50 mL digestion tube for 2 to 3 hours (Blanchar et al., 1965). Total P content was estimated by the acid-free vanadate-molybdate method developed by Tandon et al. (1968). Inorganic P was determined by digesting 1g of soil with 10 mL of concentrated HCl for 1 hour and measuring P as described in Method II of Jackson (1958). Organic P was estimated as total P minus inorganic P. Available P was estimated with Bray's 0.1M HCl + 0.03M NH_4F solution as outlined by Graham (1959).

Phosphate ion products were also determined. Five grams of soil were placed in 50 mL centrifuge tubes, 31 mL of either 0.01M $CaCl_2$ + 0.01M HCl or 0.01M $CaCl_2$ + 0.1 M HCl added and the mixture equilibrated at 25° C for 16 days. The solution was analyzed for P (Alexander and Robertson 1970), Al (Lindsay et al. 1959), Fe by orthophenanthroline (Krishna Murti et al. 1966), and pH and Eh measured with glass and button type Pt electrodes, respectively.

Calculation of Ion Activities

The activities of Al, Ca, Fe, and P ion species were computed from their measured total concentrations and the pH and Eh of the equilibrium solutions. Activity coefficients were determined from ionic strength estimated from the molarities of Ca, Cl and H ions using the extended form of the Debye-Huckel equation. Stability constants for the ionic species considered were computed from the standard free energies of formation given by Kao and Blanchar (1973). A pK of 36 was used for the Al6(OH)15+3 as indicated by Richburg and Adams (1970). Computations were carried out by an IBM 360/65 computer.

Results and Discussion

Kao and Blanchar (1973) stated that the total P distribution shown in Fig. 1 for the untreated plot revealed the natural P distribution in the Mexico soil. However, one might also conclude, excluding the immediate surface, that the phosphate treated soil represented the "natural" P distribution in the Mexico soil (Fig. 1). Total, inorganic, and available P measurements indicated similar P distributions within the treated and untreated plots (Fig. 1). The P concentration in the Ap and lower B3 to C2 horizon appeared elevated while a minimum existed in the lower A and upper B2 horizons. This result is in agreement with those of Winters and Simonson (1951), Runge and Riecken (1966), and Vogt (1963). Kao and Blanchar (1973) gave the impression that the higher levels at these depths were due to fertilizer P migration over the years of differential fertilization. This conclusion would not be supported by many observations that added P does not move very far in soil systems (Roscoe, 1960). An alternative explanation may be that the P-stressed plants (plot 33) removed more P from the lower layers than did the P-sufficient (plot 31) plants. Thus, the total P distribution on the phosphated plot may reveal the natural P distribution.

It is assumed that the most common vegetation on the Mexico series soil was a mixed warm and cool season grass prairie. The parent material was 1 to 2 m of loess from the Missouri river system underlain by a glacial outwash described as the Kansan till plain. The loess is primarily fine silt with usually less than 20% clay and very permeable to water flow. The till is usually 30 to 35% smectite type clay and only slowly permeable to water flow. The slopes in this formation are generally in the 1 to 3% range and similar to those found on the Sanborn field plots 31 and 33 and the sample site on Tucker Prairie.

The B2 horizon, often referred to as the claypan in these soils, formed from the loess. It appeared that the loess in the Sanborn field plot extended to about 130 cm as indicated by the increase in sand at that depth (Table 1). The zone of elevated P concentrations extended from about 60 to 140 cm and terminated at the loess/till interface in this system. It is postulated that the boundary between the B and C horizon at 107 cm represents the lower limit of effective root activity as indicated by soil properties. Thus the natural occurrence of elevated P concentrations in this region has been attributed to deposition through a process of root decay and movement of P with water over short distances.

Comparison with a Native Prairie

At the inception of Sanborn field in 1888, a cropping system was introduced which included an annual removal of P by cropping. In the case of plot 31, that P was replaced by fertilization and on plot 33 it was not. The difference in P concentration of these plots shown in Fig. 1 is postulated to be caused by translocation of P in P-stressed plants from the lower layer and failure of P-sufficient plants to translocate P from these layers. A partial verification of this explanation was made by obtaining a Mexico soil sample from a virgin site which resembled the 1888 growing conditions of the prairie which became Sanborn field. The sample from Tucker prairie served this purpose. We assumed for this comparison that the P distributions at Sanborn field and Tucker prairie may have been similar in 1888 and that the Tucker prairie distribution has not been altered by time. The inorganic P concentration of the P-fertilized and unfertilized Mexico soil from Sanborn field and Tucker prairie are shown in Fig. 2. The similarity of the P concentrations in the P-fertilized soil from Sanborn field and the Tucker prairie sample give some support to the hypothesis that 82 years of cropping in Sanborn field reduced the P concentration in the lower B and upper C horizon. Although this is an admittedly weak comparison since the systems are not replicated and exist at some distance from each other, it is one of several facts supporting the hypothesis that P was removed from the control plot's lower horizons.

Estimate of P movement from Soil Chemistry

Solubility of P in the Mexico soil and the pattern of water movement in soil offer another clue as to whether a mechanism for P movement to the subsoil exists which could explain the greater amount of total P found in the P-fertilized plot (Fig. 1). The solution to this problem requires an estimate of P in the soil solution and the solution volume that moves from the surface to the lower B horizon each year.

A model was developed to calculate chemical movement in soil-water systems. The procedure is to calculate the fraction of any given chemical that is in the soil water as a function of depth and then to predict where the water will move in the system. The amount of P in solution was estimated from the ion products and the pH of the various horizons in the Mexico soil. The water movement patterns within the soil-plant system were based upon profile recharge characteristics developed by Scrivner et al. (1973) and used in leaching studies by Baker and Scrivner (1985). The movement of chemicals with the water was calculated by considering the soil as a chromatographic column and applying the basic concepts of plate theory as developed by Martin and Synge and described by Karger et al. (1973). Use of this model provided a method for predicting the P distribution in the soil profile as a function of time.

Several steps were required to apply this theory to a soil-water system. First, the effective depth of a single theoretical plate in the soil system had to be known. The depth of a single plate, estimated at 0.5 cm, was based upon the measurements of breakthrough curves done by Blanchar et al. (1985) on the Tuskeego soil which has properties similar to the Mexico. The theoretical plate height choice will not influence the estimate of the average depth of P movement, it will only influence the width of the P deposition band.

Estimated P Solubility

Second, solubility measurements were made to estimate the fraction of P in solution as a function of soil depth. Phosphate concentration was computed as a function of pH (Table 1) and ion products (Kao and Blanchar, 1973) by assuming that Fe or Ca forms of phosphate controlled the P concentration in the soil solution.

The estimated P solubility as a function of pH in the Mexico soil is shown in Fig. 3. The measured pH of the Mexico soil (Table 1) was used to calculate the P concentration in the soil solution for each horizon. Data presented by Hess and Blanchar (1977) indicated that the soil pH of the Mexico B2 horizon under waterlogged conditions increased from its oxidized value of near 4 to 6.5. This may be the condition when water moves in the profile, however, Hess and Blanchar's data show a 1 to 2 week lag period between waterlogging and increased pH. Under these conditions P becomes more soluble as pH increases, and the values when equilibrium is reached are shown in Figure 3. Estimates of minimum P movement may be associated with pH values of oxidized soil shown on Table 1 and maximum P movement may be associated with the waterlogged soil pH which is assumed to be 6.5. The impact of pH 6.5 will depend upon whether relatively insoluble hydroxy apatite or more soluble octacalcium phosphates control solubility. Plate theory predicts that the mean distance a substance moves in proportion to the movement of the water front is a linear function of the fraction of the substance in solution. Thus the prediction of P movement will be sensitive to the estimated maximum and minimum solubility of P.

Predicted Water and P Movement

Water movement in the Mexico soil was estimated from the annual frequency of dry-moist cycles using the frequency function generated by Scrivner et al. (1973):

Log Frequency = 2.227 - 1.134*(Log Depth in cm)

and is shown in Table 2 with the bulk density and water holding capacity estimates combined in Table 2.

The data in Table 2 and the frequency function were used to generate the estimated pulses of water at each soil depth (Figure 4). The important water movement feature shown in Figure 4 is the high number of leachings of the upper horizons occurring annually, and the low number at the lower depths. It is estimated that 295 water pulses pass the 5 cm depth increment each year, with 216 passing 10 cm, 45 passing 50 cm and 14 increments passing 100 cm. These estimates were made on the basis of recharge and represent a minimum amount of water entering these layers. Good quantitative estimates of water flowing through the Mexico soil do not exist. Order of magnitude estimates of 3 to 5 cm are often used. However, the soil water entering and leaving the zone of elevated P concentration has the same P concentration in the fertilized and unfertilized soil.

The frequency function generated by Baker and Scrivner (1985) suggests that 12.9 cm of water enters the 60 cm zone and 2.9 cm leaves the 140 cm zone. The amounts of P retained in this zone per year, and over 82 years, assuming the absence of plant uptake, are given in Table 3.

The measured solubility of P compounds in the subsoil of P fertilized and unfertilized soil were reported to be similar (Kao and Blanchar, 1973). Since the measured pH of the subsoil of P fertilized and unfertilized soil were not different, the movement of P in these two subsoils would be predicted to be similar regardless of surface P treatment. No basis for predicting greater movement of P in the subsoil of fertilized over unfertilized soil was given by the solubility computations.

In addition, there is no reason to believe that the through-flow component adds or removes P unless the P concentration of the inflowing water is different from the outflow. In our system this would be dependent upon a pH gradient which does not exist. A differential would exist if water which entered the zone provided P for plant uptake and the P was translocated within plants growing in unfertilized soil and not translocated in plants growing in fertilized soil. Thus the difference in P content would be attributed to the failure of plants well supplied with P to translocate P from lower horizons. If this is true, instead of the unfertilized soil representing the distribution of P in 1888 as suggested by Kao and Blanchar (1973), the fertilized soil may more closely represent the original P distribution (Fig. 2). Since the amount of P in the 60 to 140 cm zone of the fertilized soil is 217 kgP/ha, a removal of 2.7 kgP/ha/year by the plant would be required to account for the observed difference in P content.

Average annual removals of 15 to 30 kgP/ha/year by a rotation of corn, soybean, sweet clover, red clover and wheat would appear to be reasonable estimates. Thus, the crop has the potential to remove 2 to 3 kgP/ha/year from the subsoil which is an amount that could account for the difference in P concentrations observed in the subsoil of the treated and untreated P plots.

Summary and Conclusion

Comparative data and estimates of chemical movement in the soil system support the hypothesis that the P concentration in the lower B and upper C horizons in the fertilized plot is higher than in the unfertilized plot because the P was removed by P-stressed plants in the unfertilized plot. Over the 100 years of Sanborn field operation, average crop yields of the P-fertilized plots have been somewhat higher. The contention of Milton Whitney that the total supply of nutrients in soil is inexhaustible and the bitter renunciation of this point by C. G. Hopkins may in part be explained by observing plots 31 and 33 for the next 100 years. Hopkins' contention would be supported if the crop yields on plots 31 and 33 diverge due to mining of the control plot's P reserves. The plots provide one setting where the reversibility of the depletion process may be tested at some future date.

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Table 1. Particle size distribution and pH at various depths in the treated (plot 31) and untreated (plot 33) Mexico soil.

Depth	Plot 31					Plot 33				
	Horizon	pH	Sand	Clay	Silt	Horizon	pH	Sand	Clay	Silt
cm			%					%		
0-23	Ap	6.05	10	22	68	Ap	6.46	10	18	72
23-36	A&B	4.21	4	34	62	A1	6.05	4	20	76
36-43	B2	3.80	4	46	50	A2	5.41	6	22	72
43-61	B2	3.94	4	48	48	A&B	4.65	4	28	68
61-86	B3	4.54	4	40	56	B2	4.00	4	48	48
86-107	C	5.38	4	36	60	B3	4.27	4	44	52
107-137	C	5.68	6	32	62	C	5.00	4	38	58
137-168	C	5.80	16	28	56	C	5.48	10	34	56
168-198	C	5.77	18	30	52	C	5.54	18	34	48
198-229	C	5.70	18	32	50	C	5.50	20	36	44
229-259	C	5.67	20	32	48	C	5.52	20	38	42
259-290	C	5.69	22	36	42	C	5.61	22	38	40
290-320	C	5.74	22	42	36	C	5.78	22	38	40

*Sand refers to the 2.0-0.05 mm size particles, silt 0.05-0.02 mm, and clay <0.002 mm.

Table 2. Bulk density and water holding capacity estimates used to compute water movement.

Depth	Bulk Density	Water Holding Maximum	Capacity Minimum	Recharge Amount
cm	g/cm	% Volume		
0-30	1.25	40	20	20
30-50	1.50	34	27	15
50-100	1.50	43	33	10
100-200	1.55	42	37	5

Table 3. Net addition of P to the 60 to 140cm soil zone due to influx of soil water in the Mexico soil.

Soil pH	Concentration ugP/mL	Annual Addition kgP/ha/year	82 year Addition kgP/ha
Strengite, Hydroxy Apatite or Octacalcium P controls P concentration			
5.20	0.05	0.05	4
5.45	0.10	0.10	8
5.80	0.20	0.20	16
6.00	0.40	0.40	33
Hydroxy Apatite controls P concentration			
6.10	0.20	0.20	6
6.35	0.10	0.10	8
6.60	0.05	0.05	4
Strengite or Octacalcium P controls P concentration			
6.40	0.80	0.80	66
6.65	1.60	1.60	131
7.05	1.60	1.60	131
7.35	0.80	0.80	66

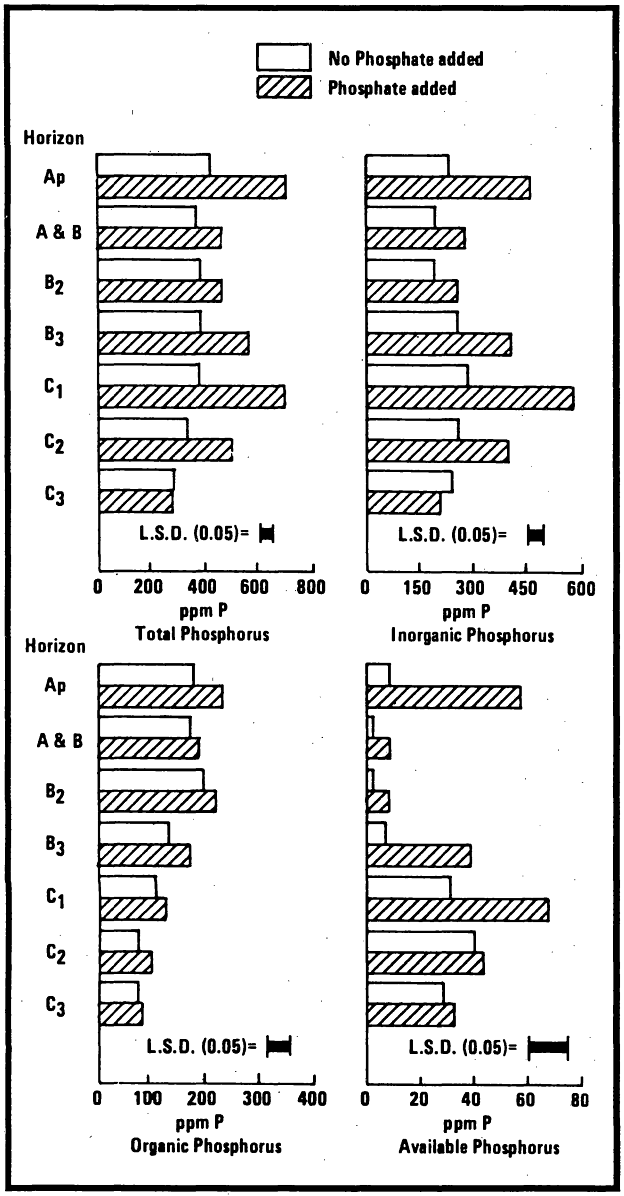

Figure 1.The effect of 82 years of phosphorus fertilization on total, inorganic, organic, and available phosphorus in various horizons of an Albaqualf soil (Kao and Blanchar, 1973).

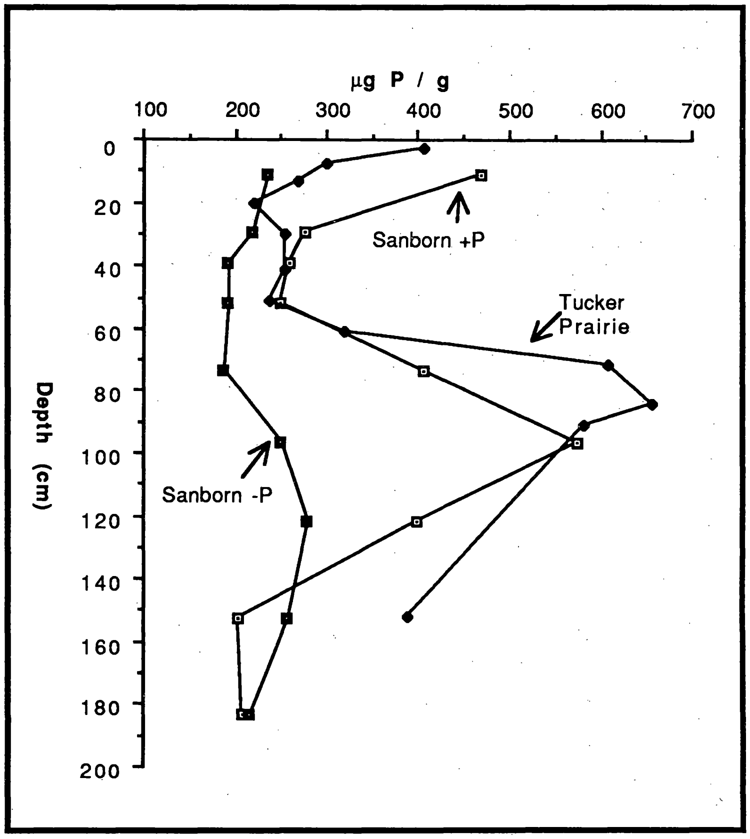

Figure 2.Distribution of inorganic phosphate in Mexico soils from Sanborn Field and Tucker Prairie.

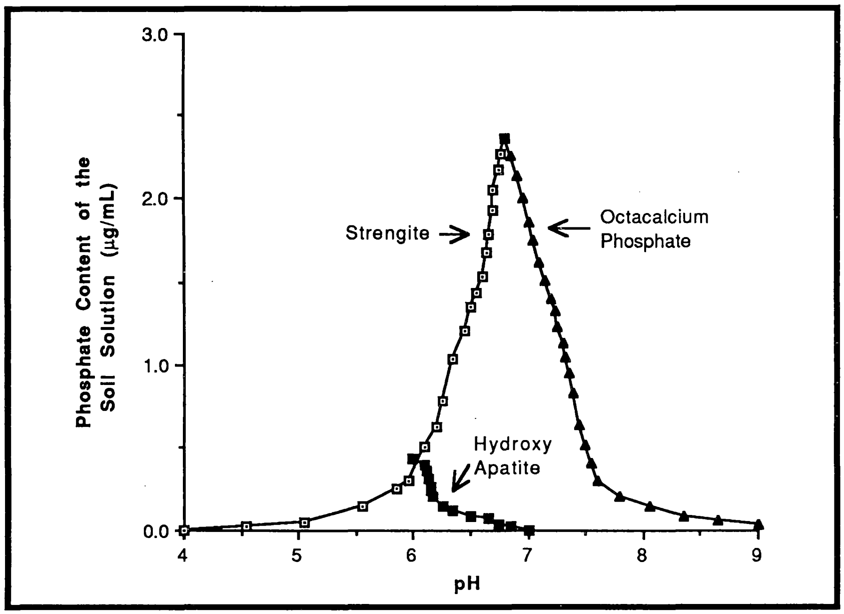

Figure 3.Estimated solubility of phosphate in the Mexico soil.

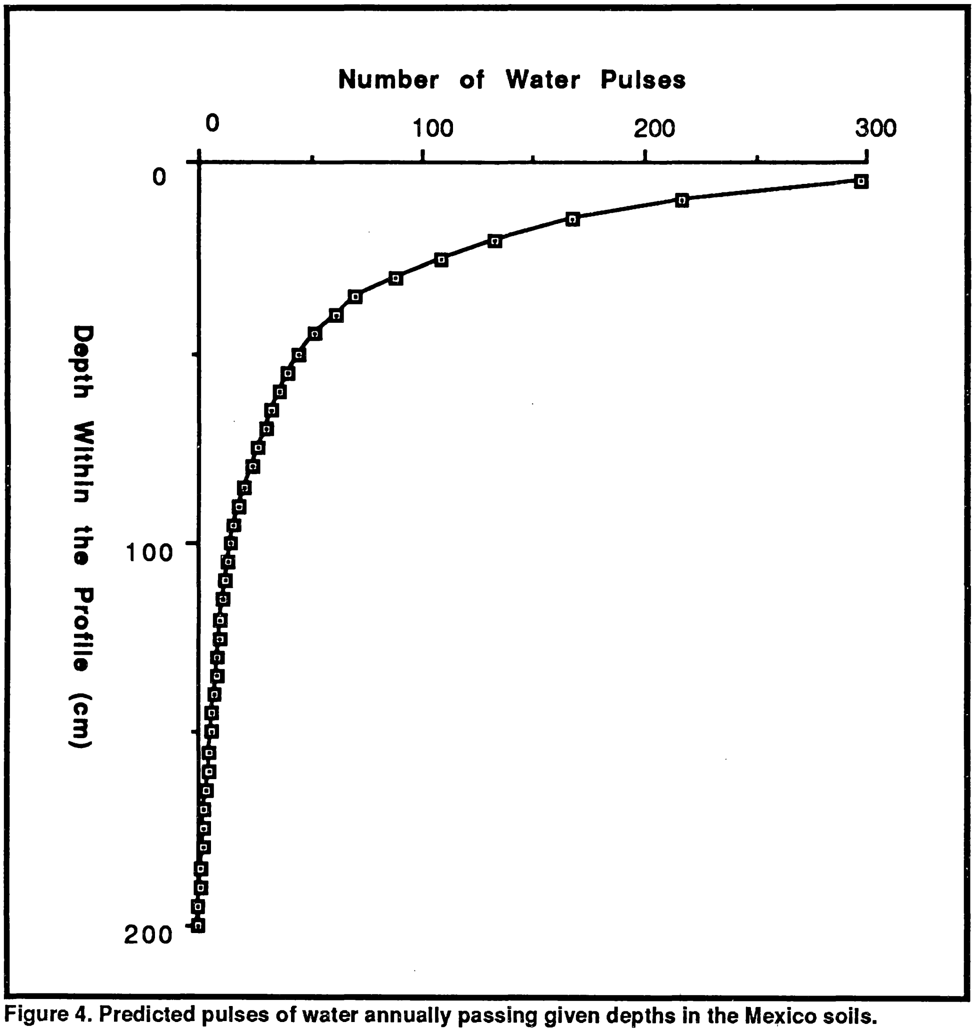

Figure 4. Predicted pulses of water annually passing given depths in the Mexico soils.

One Hundred Years of Sanborn Field: Soil Baseline Data

R. J. Miles and R. D. Hammer

One hundred years of cropping with various combinations of fertilizer, lime, and manure can have a strong influence on soil properties in addition to crop yields and quality. Unfortunately little is known about the long-term influence of management treatments on the important natural resource we call soil. To quote Hans Jenny (1980):

"Soil is a natural resource. On human time scales, its mass is nonrenewable. Today, people are becoming aware of resource limitations and they want to know more about the soil, its behavior, and its fate."

Undoubtedly this concept expressed by Jenny was also in the thoughts of J. W. Sanborn as he established the rotation field to assess the influence of crop rotations and the above-mentioned additions on soil fertility and crop yields.

Little is known about the initial conditions of Sanborn Field, its associated soil properties, and past land use history. The only definitive information noted by M. F. Miller (Upchurch et al., 1985) is that prior to the establishment as an experimental site the field was originally a pasture of scattered elm trees and buck brush. Miller believed the land was cleared and initially farmed in corn for at least one year then laid out into the initial Rotation Field format. There is a paucity of initial baseline soil data, although persistent rumors are told of soil data samples stored during the initial layout of the field. Unfortunately, initial soil samples or data have not been found so that a better understanding of the initial soil resource may be documented.

Factors Influencing the Formation of the Soils of Sanborn Field

Although little information is available on the initial soil properties of Sanborn Field, a better understanding of the original soil resource may be gained through a view of the factors of soil formation as expressed by Jenny (1941). These five factors are: 1.) climate, 2.) biological activity, 3.) parent material, 4.) topography, and 5.) time.

The soils of Sanborn Field are in the claypan land resources area (Upchurch et al., 1985). Climate has been characterized as one of the most influential soil forming factors. The general climatic description for the central area of Missouri has been characterized as humid and temperate. Average annual rainfall is approximately 90 cm (Krusekopf and Scrivner, 1962). The claypan area of Missouri had native vegetation of tall-grass prairie on the flat summits with a transition of prairie to timber on the moderate sideslopes below the summits (Krusekopf and Scrivner, 1962).

The parent materials for the soils of Sanborn Field consist of two possible sources: Kansan age glacial till and loess. Sanborn Field is in the intermediate loess thickness zone (1-2m thick) within Boone County thus making it the dominant parent material. Most of this loess is probably of Peorian Age (Krusekopf and Scrivner, 1962). Parts of the lower soil solum may be directly formed in the Kansan age glacial till or basal mixing of the loess within the till. The slopes on Sanborn Field vary from almost zero up to nearly 7 percent. This range gives rise to a wide diversity of possible water movement patterns.

This above-mentioned set of soil forming factors gives rise to environmental factors which facilitate the downward movement of chemical components and clays within a highly weatherable soil-forming material. Thus, the soils of Sanborn Field possess well-expressed horizons.

Soil properties

Because of the wide spectrum of soil properties, it is nearly impossible to utilize one sampling observation to characterize the "typical" Sanborn Field soil. Therefore, three sampling cores 4F, 13F, and 28F have been chosen to depict the properties of three dominant representative soil areas within Sanborn Field. Plot 4F represents a shoulder-backslope position on a 4 percent slope. Plot 13F is representative of a summit hillslope position with a 0 - 1 percent slope, whereas Plot 28F represents a lower backslope-footslope position on a 2 to 3 percent slope.

Soil Morphology

The morphology and horizon sequence of core 13F (Table 1) is most representative of a typical soil of the Missouri claypan area. The A-E-Bt-Bg horizon sequence is representative of the past Putnam and Mexico soil series designations for Sanborn Field (Krusekopf and Scrivner, 1962; Upchurch et al., 1985). The Ap and E horizons are very silty with the E possessing 2 chroma colors probably indicative of both vertical eluviation of clay and oxides and perching and lateral flow of water above the argillic horizon (Bt). The Bt horizon exhibits a large increase in translocated clay evident from a silty clay texture and the evidence of translocated clay on horizonal and vertical ped surfaces. The lower solum (Bg and BCg horizons) possesses 2 chroma colors and the presence of concretions to reflect anaerobic conditions which could be both relict and contemporary for the landscape position. The Ap and E horizons also contain concretions, which are probably a reflection of the perching of water above the claypan.

The morphology expressed in core 4F (Table 2) is representative of many of the soil properties for Sanborn Field soils on backslope and shoulder positions. A silt loam Ap horizon overlies a well expressed silty clay argillic horizon which is underlain by a series of Bg and BCg horizons. This sequence suggests that either subsurface horizons (AB, BA, or E) were not developed in this soil or cultivation and erosion has worn down to, and incorporated, the subsurface horizons and possibly part of the original Bt horizon. As with core 13F, the expression of clay films in the Bt horizons is reflective of the illuviation of clay in its development. Likewise, the presence of low chroma colors (<2) and of 10YR 3/2 concretions in the Bg and BCg horizons are reflective of restrictive internal drainage during the past and present environments.

The morphological characteristics of core 28F (Table 3) are reflective of many soil properties found in lower, cumulative hillslope positions on the Field. The horizon sequence of Ap, Ep/Ap, EBtp, Bt, Bg is unique relative to the other two representative areas. The subsurface horizons with "p" sub-symbols are representative of the gradual accumulation of erosional sediments from upslope positions over much of the history of the Field. Upon being buried below the depth of tillage, the horizon then develops unique pedogenic characteristics (i.e. Ep developed eluvial characteristics after being tilled and then buried). Subsequently, the depth to the top of the argillic horizon is greater than the other two representative cores due to constructional progresses. Likewise, the depth to gleyed horizons (i.e. Bg) is greater (120 cm) in this plot as a result of the cummulic processes.

The morphological properties of the soil resource of Sanborn Field represent well-expressed pedogenic horizonation, specifically with respect to translocation of clay. The summit area of the field tends to be more like the typical A-E-Bt horizon of the Missouri claypan area. Many of the shoulder, backslope, and footslope areas do not possess typical subsurface horizons (i.e. AB, BA, and E). Because of the lack of initial soil data, it is not known whether these hillslope positions originally contained these soil features. However, it is quite plausible that the cultural practices (i.e. tillage and subsequent erosion) have had a strong influence in changing subsurface horizonation if it was originally present.

Particle Size Distribution

The influence of landscape position, erosion, and parent materials are reflected in the particle size depth distributions of the three plots studied. All of the plots possess a dominant silty matrix which is due to the influence of the parent loess material. Plot 13 (Fig. 1) exhibits silt loam Ap and E horizons, then an abrupt increase in clay to over 50% clay to give silty clay Bt horizons, then decreases to silty clay loam textures in the Bg horizons. Core 4F has a silt loam Ap (Fig. 2) overlying silty clay Bt horizons which grade down to silty clay loam Bg and BCg horizons with depth. However, the BCg horizons contain an increase in sand from the Bg horizons above (from 7 to almost 15 percent) which may be reflective of basal mixing of the loess with the loamy glacial till material. The larger clay content in Ap horizon of plot 4F relative to plot 13F and 28F (Fig. 3) is most likely due to incorporation of the silty clay Bt by tillage and erosion which occurred over the cropping history of plot 4. Upchurch et al. (1985) note that in 1961 the surface soil material deposited by erosion on the east end of plots 1 through 7 was moved back to the west end (upslope) to restore uniformity of topsoil depth. This man-made movement could have helped increase the clay content of the Ap horizon of core 4F.

The particle size depth distribution of core 28F (Fig. 3) is different from that of cores 4F and 13F in that the depth to clay maximum (argillic horizon) is greater. This distribution is a result of the silt loam surface material from plots upslope eroding and being deposited in the footslope position of 28F. As with core 4F, the increased sand content in the BCg horizon at the 90 cm depth may reflect the basal mixing of loess with underlying glacial till.

Chemical Properties

The chemical properties of soils from cores from plots 4, 13, and 30 are presented in Tables 4 through 6. Calcium is the dominant extractable base in all cores, followed in descending order by magnesium, sodium, and then potassium. This ordering is typical of what has been found in other studies on Sanborn Field for plots 6, 7, 17, and 18 (Linder, 1973) and plots 9 and 22 (Agronomy Dept. Files, 1962).

The levels of extractable calcium in the Ap horizons reflect the lime treatments of the plots. Greater extractable calcium levels are found in plots 4 and 28, which are limed, than plot 13 which has not been limed. The extractable magnesium levels in the two surface horizons of plot 4 are slightly greater than the magnesium levels for similar soil depths in plots 13 and 28. This greater magnesium level is probably reflective of the dolomitic lime treatment for plot 4.

The levels of extractable potassium and sodium increased with soil depth. Extractable potassium and sodium showed little correlation with past fertilizer treatments for the three plots.

The neutralizable acidity for each core was greatest in the argillic (Bt) horizon and decreased with depth (Tables 4 through 6). The depth distribution of neutralizable acidity for each core was the opposite of the depth distribution for pH. These depth distribution trends for neutralizable acidity and pH follow those observed trends noted by Linder (1973) and other past researchers on Sanborn

Field (UMC Agronomy Dept. Files, 1962). The greater neutralizeable acidity level of core 4 relative to cores 13 and 28 does not reflect the influence of past liming treatments as observed by Linder (1973) in plots 6, 7, 17, and 18.

The cation exchange capacity (CEC) paralleled the clay depth distribution in that argillic horizons (Bt) in each core contained the largest CEC within the profile. The erosion on plot 4 has increased the clay content in the surface horizon which in turn has increased the CEC of the surface relative to plots 13 and 28.

Soil Mineralogy

Little mineralogy data is available on the soils of Sanborn Field. Semiquantitative estimation of x-ray diffraction analysis of the clay size (Table 7) and silt size components utilizing characteristic peak height for the Bt and Bg horizons from a pit on the south edge of plot 12 is presented. Montmorillonite is the most abundant clay size mineral in both the Bt and Bg horizons. Hydroxy-interlayered montmorillonite and vermiculite are the next most abundant minerals. Moderate amounts of vermiculite and mica exist in both horizons, whereas kaolinite is present in small quantities in the Bt horizon with a slightly greater quantity in the Bg horizon. These data agree with the findings of past research studies of similar soils in Boone County. Aloui (1984) found montmorillonite and illite to be the dominant clay size components in a Putnam soil followed by interlayered mica-like clays then kaolinite in least dominance. Brydon (1954) found montmorillonite (specifically beidellite) to be dominant in the fine clay of a Lindley soil. Illite was next in dominance followed by kaolinite.

The silt mineralogy of the samples from plot 12 were found to be composed primarily of quartz, plagioclase feldspars, and potassium feldspars. Quartz was the dominant mineral in both samples. Greater potassium feldspar contents (two to three times) were found in the Bt horizon in comparison to the Bg horizon. A slightly greater plagioclase feldspar component was found in the Bg than the Bt horizon.

Classification of Soils on Sanborn Field

In an early publication, Miller and Hudelson (1921) classified the soil on Sanborn Field as a Putnam silt loam. They described the "typical" Putnam soil for Sanborn Field to possess a dark, brownish-gray silt loam surface ranging from 23 to 30 cm (9-12 inches) deep with a 10 to 15 cm (4 to 6 inch) gray silty subsurface (probably E horizon) immediately below the surface. They further described the subsoil (probably a Bt horizon) to be a brown heavy clay loam which was very slowly permeable. They recognized that erosion appeared to be greater on plots 1 through 7, 23 through 26, and 29 through 33.

The Boone County soil survey (Krusekopf and Scrivner, 1962) delineates approximately the western two-thirds of Sanborn Field as a Mexico silt loam 1 - 3 percent slopes and the eastern third of the field as a Lindley loam 5 - 8 percent slopes. Current Soil Taxonomic Classification of these two series are fine, montmorillonitic, mesic Udollic Ochraqualf and fine-loamy, mixed, mesic Typic Hapludalf for the Mexico and Lindley series, respectively. The Mexico mapping unit reflects soil development in shallow loess (1-2 m thick) whereas the Lindley soils are developed primarily from loamy Kansan age glacial till with a few centimeters of loess on the surface.

In a recent publication, Upchurch et al. (1985) suggested that the dominant soil series on Sanborn Field was Mexico.

It is difficult to classify the soils on Sanborn Field with only one or two soil taxonomic names because of the great amount of diversity. A wide array of taxonomic classifications (Soil Survey Staff, 1975) can be delineated from the over 130 cores sampled for the Centennial study. The most frequently occurring subgroups on Sanborn Field are: Aeric Ochraqualfs, Udollic Ochraqualfs, Typic Ochraqualfs, and Mollic Albaqualfs. Of these four subgroups, Aeric Ochraqualfs appear to be the most frequently occurring. Many of the sampling cores would be classified as fine, montmorillonitic, mesic at the family classification level.

Summary and Conclusions

The soils of Sanborn Field are diverse! Part of this diversity is a result of the interactive influence of the pedogenic factors. However, original soil baseline data is not available to assess the complete contribution of the pedogenic factors on the contemporary soil properties. Undoubtedly, management practices emplaced on Sanborn Field over the past 100 years have been most influential on the present-day soil characteristics. The additions of fertilizer, lime, and manure have had a large effect on chemical properties as well as crop yields and quality.

However, the effect of water movement in the form of overland flow plus vertical and lateral flow within various hillslope positions as influenced by cultivation have produced preferential erosion and sedimentation within Sanborn Field. Of any hillslope component, stable summits most likely represent the initial soil properties of 100 years ago. Shoulder and backslope positions have enhanced erosion with plow layers immediately above or into the subsoil (Bt) horizons. Footslope positions have accumulated sediment which have eroded from shoulder and backslope positions upslope. It is apparent that this erosion/sedimentation cycle will influence the water holding capacity and water supplying capacity of the soils and subsequently influence crop yields on a large number of the Sanborn Field plots.

Acknowledgements

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Table 1. Morphological properties of core 13F.†

Horizon	Depth cm	Matrix Color	Mottles	Texture Class	Concre-tions	Clay Films‡	Boundary
Ap	0-27	10YR 4/3	F2 10YR 5/2	SiL	F1 10YR 3/2	—	AS
E	27-34	10YR 5/2	F1 10YR 5/4	SiL	C1 10YR 3/2	—	AI
Bt1	34-44	10YR 3/4	C1 7.5YR 5/6	SiC	F2 10YR 3/2	NCVH	CS
Bt2	44-55	10YR 4/4	C1 10YR 5/6	SiC	VF1 10YR 3/2	MPVH	CS
E/Bg1	55-63	10YR 5/2	C2 7.5YR 4/6	SiCL	—	—	AS
Bg2	63-85	2.5YR 5/2	M2 10YR 4/6	SiCL	C3 10YR 3/2	—	GS
Bg3	85-100	2.5YR 5/2	C1 7.5YR 4/6	SiCL	C2 10YR 3/2	—	GS
BCg	100-120	2.5YR 4/2	F1 10YR 4/6	SiL	F2 10YR 3/2	—	—

† Utilizing terminology and abbreviations of Soil Survey Staff, 1981.
Mottles and Concretions: VF = very few (<1%), F = few (0-2%), C = common (2-20%), M = many (20-50%)
1 = faint, 2 = distinct, 3 = predominant
Texture: SiL = Silt Loam; SiCL = Silty Clay Loam, SiC = Silty Clay
Boundary: A = abrupt; C = clear; G = gradual; S = smooth; I = irregular
‡ NCVH = nearly continuous on vertical and horizontal surfaces.\
MPVH = moderately patchy on vertical and horizontal surfaces.

Table 2. Morphological properties of core 4F.†

Horizon	Depth cm	Matrix Color	Mottles	Texture Class	Concre-tions	Clay Films‡	Boundary
Ap	0-21	10YR 4/3	F1 10YR 5/6	SiL	F1 10YR 3/2	—	AS
Bt1	21-35	10YR 4/2	F1 10YR 5/3	SiC	VF1 10YR 3/2	NCVH	CS
Bt2	35-50	10YR 5/3	C2 10YR 5/6	SiC	F1 10YR 3/2	MPVH	CS
Bg1	50-67	2.5YR 4/2	C3 10YR 6/6	SiCL	C2 10YR 3/2	—	CS
Bg2	67-82	2.5YR 5/2	C2 2.5YR 5/6	SiCL	F2 10YR 3/2	—	GS
BCg1	82-98	2.5YR 6/2	C2 10YR 5/8	SiCL	F3 10YR 3/2	—	GS
BCg2	98-120	2.5YR 6/2	M3 2.5YR 6/6	SiCL	VF1 10YR 3/2	—	—

† Utilizing terminology and abbreviations of Soil Survey Staff, 1981.
Mottles and Concretions: VF = very few (<1%), F = few (0-2%), C = common (2-20%), M = many (20-50%)
1 = faint, 2 = distinct, 3 = predominant
Texture: SiL = Silt Loam; SiCL = Silty Clay Loam, SiC = Silty Clay
Boundary: A = abrupt; C = clear; G = gradual; S = smooth; I = irregular
‡ NCVH = nearly continuous on vertical and horizontal surfaces.\
MPVH = moderately patchy on vertical and horizontal surfaces.

Table 3. Morphological properties of core 28F.†

Horizon	Depth cm	Matrix Color	Mottles	Texture Class	Concre-tions	Clay Films‡	Boundary
Ap	0-30	10YR 4/3	————	SiL	VF1 10YR 3/2	—	CI
Ep/Ap	30-44	10YR 5/1	C2 10YR 4/2	SiL	F1 10YR 3/2	—	CI
EBtp	44-52	10YR 4/2	C1 10YR 5/1	SiL	F1 10YR 3/2	—	CI
Bt1	52-76	10YR 4/2	C2 10YR 3/1	SiC	————	CVH	GS
Bt2	76-90	10YR 4/4	F3 10YR 6/3	SiC	F2 10YR 3/2	MPVH	GS
Bg	90-121	10YR 5/2	F2 7.5YR 4/6	SiCL	C1 10YR 3/2	—	GS

† Utilizing terminology and abbreviations of Soil Survey Staff, 1981.

Mottles and Concretions: VF = very few (<1%), F = few (0-2%), C = common (2-20%), M = many (20-50%)
1 = faint, 2 = distinct, 3 = predominant

Texture: SiL = Silt Loam; SiCL = Silty Clay Loam, SiC = Silty Clay

Boundary: A = abrupt; C = clear; G = gradual; S = smooth; I = irregular

‡ NCVH = nearly continuous on vertical and horizontal surfaces.\
MPVH = moderately patchy on vertical and horizontal surfaces.

Table 4. Selected chemical properties of core 13F.

		Extractable Bases							
Horizon	Depth	Ca	Mg	Na	K	Acidity	SUM CEC	pHw	pHs
	cm	cmole c+ • kg-1							
Ap	0-27	5.2	1.0	TR	0.1	8.2	14.5	5.0	4.5
E	27-34	6.6	2.5	0.2	0.1	10.9	20.3	5.2	4.5
Bt1	34-44	13.6	6.7	0.5	0.2	14.9	35.9	5.0	4.5
Bt2	44-55	14.0	7.4	0.8	0.3	12.5	35.0	5.1	4.6
E/Bg1	55-63	13.7	7.6	0.8	0.4	9.1	31.6	5.2	4.8
Bg2	63-85	14.3	8.2	1.2	0.5	8.0	32.2	5.6	5.2
Bg3	85-100	14.0	7.9	1.3	0.5	6.6	30.3	6.1	5.7
BCg	100-120	14.0	7.8	1.5	0.5	6.9	30.7	6.2	5.8

Table 5. Selected chemical properties of core 4F.

		Extractable Bases							
Horizon	Depth cm	Ca	Mg	Na	K	Acidity	SUM CEC	pHw	pHs
		cmole c$^+$ • kg^{-1}							
Ap	0-21	9.3	1.6	TR	0.2	9.3	20.6	5.2	4.6
Bt1	21-35	16.7	5.0	0.1	0.3	13.5	35.6	5.1	4.6
Bt2	35-50	16.9	7.0	0.2	0.4	11.8	36.3	5.2	4.8
Bg1	50-67	15.0	7.3	0.3	0.5	7.7	30.8	5.5	5.0
Bg2	67-82	14.1	6.8	0.5	0.3	5.7	27.4	5.9	5.4
BCg1	82-98	12.9	6.2	0.6	0.3	4.3	24.3	6.4	5.9
BCg2	98-120	12.6	5.9	0.9	0.2	4.3	23.9	6.7	6.2

Table 6. Selected chemical properties of core 28F.

		Extractable Bases							
Horizon	Depth cm	Ca	Mg	Na	K	Acidity	SUM CEC	pHw	pHs
		cmole c$^+$ • kg^{-1}							
Ap	0-30	10.7	0.8	0.0	0.2	4.2	15.9	6.1	5.6
Ep/Ap	30-44	8.5	0.5	0.0	0.1	2.5	11.6	6.6	5.8
EBtp	44-52	10.1	1.3	0.0	0.1	4.9	16.4	6.0	5.2
Bt1	52-76	14.0	4.1	0.1	0.1	11.1	29.4	5.1	4.6
Bt2	76-90	16.1	6.7	0.2	0.2	11.1	34.3	5.0	4.6
Bg	90-121	13.5	6.1	0.2	0.3	5.5	25.6	5.7	5.3

Table 7. Semi-quantitative estimation of clay minerals for selected horizons in plot 12.

Clay Mineral	Bt1 (30-39 cm)†	Bg (83-99 cm)
Montmorillonite	IV	III-IV
Hydroxy-interlayered Montmorillonite	III	III
Hydroxy-interlayered Vermiculite	III	III
Vermiculite	II	II
Mica	I	III

† I = small, II = moderate, III = abundant, IV = dominant

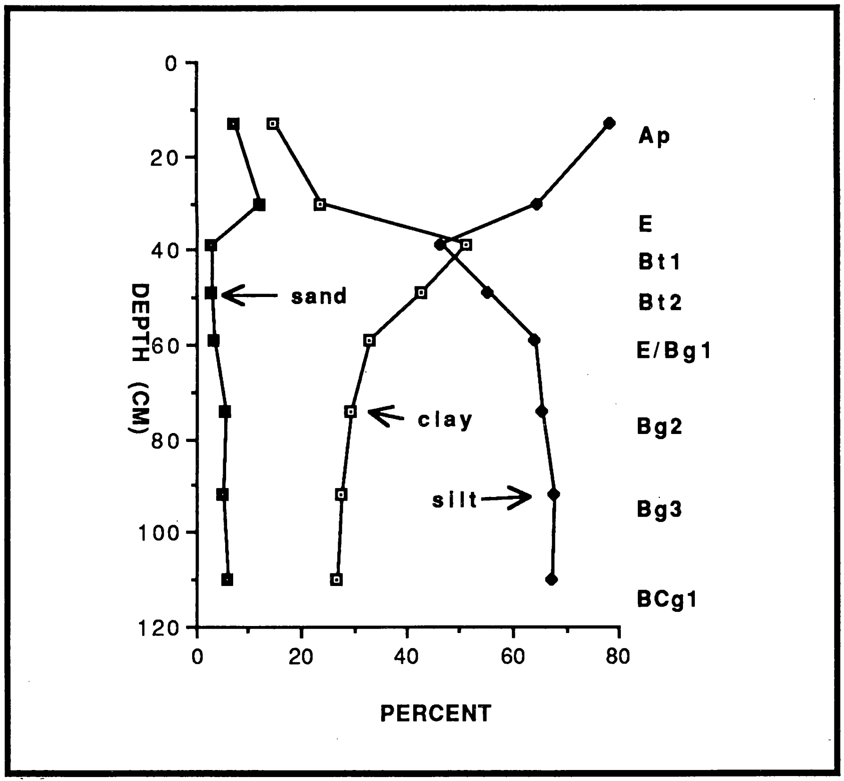

Figure 1. Particle size depth distribution for core 13F.

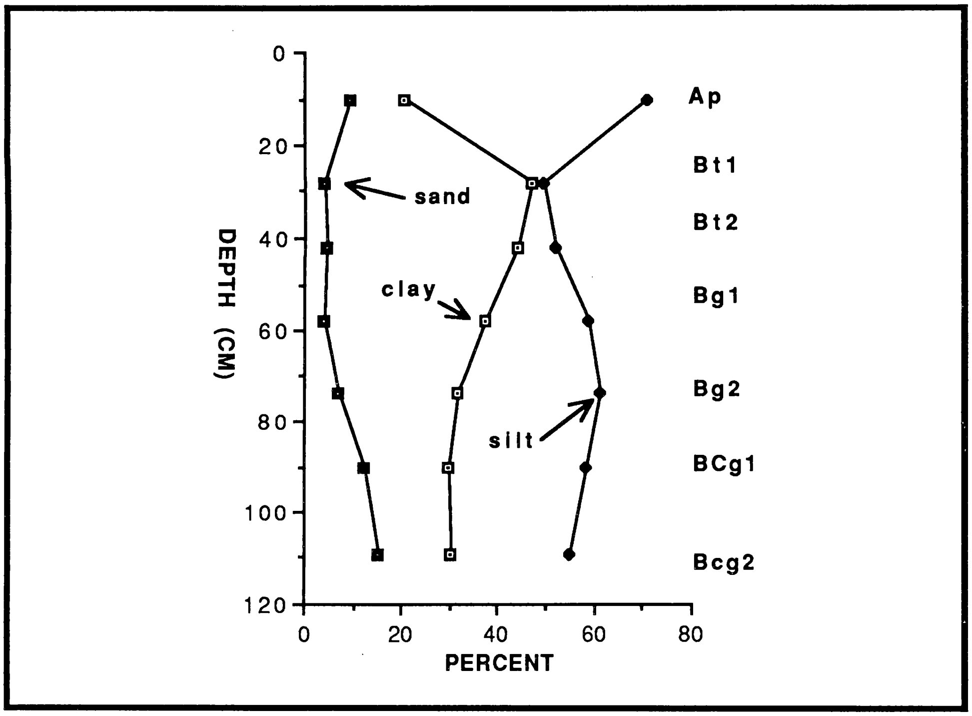

Figure 2. Particle size depth distribution for core 4F.

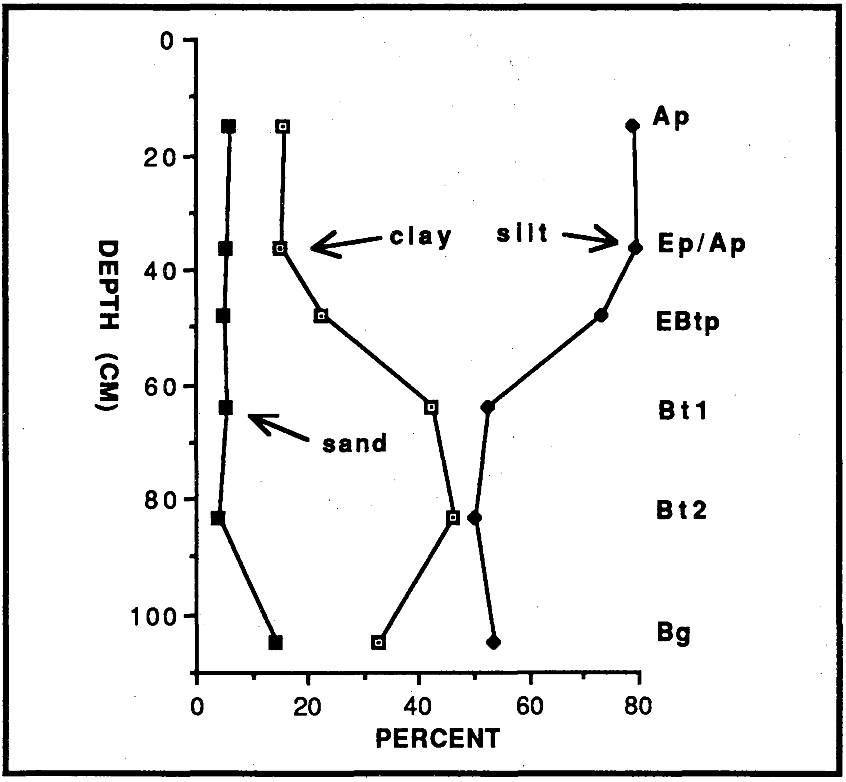

Figure 3. Particle size depth distribution for core 28F.

One Hundred Years of Sanborn Field: Lessons for Future Long-Term Research

R.D. Hammer and J.R. Brown

Introduction

The celebration of 100 years of research on Sanborn Field has provided an opportunity for focus upon the progress made in research in soil and crop science. The progress has been tempered by changing pressures upon the soil resource, changes in technology, increasing awareness of the finite nature of the soil resource, and an awakening of environmental awareness among urban citizens. This Sanborn Field centennial celebration also became an occasion to ponder how scientists might prepare for the next 100 years of challenges and demands upon the soil resource. This paper attempts to view some lessons learned from Sanborn Field and presents an outline which addresses considerations for planning future long-term research.

Sanborn Field Objectives

The stated objectives of the Sanborn Field experiment were "designed to show the value of various rotations; of constant tillage crops on soil fertility; of chemicals fed according to crop analysis to the necessity of rotation; and of various crops unmanured to soil fertility, etc." (Upchurch et al., 1985).

Although not clearly stated, the implication is that the "value of various rotations . . .of constant tillage crops . . . of chemicals fed according to crop analysis . . . and of various crops unmanured . . ." will be assessed through analysis of crop yield. The initial objectives do not contain a clear reference to studies or analysis of the soil. We must assume that J.W. Sanborn knew that the soil would be impacted by various management practices, for the different treatments he proposes imply an awareness that different crop responses could be expected from different treatments.

When one understands how far soil science has progressed in 100 years, one can more fully appreciate why Sanborn might not have anticipated the different questions his successors would have of the experiment than he had envisioned. If this were 1888, when Sanborn Field was founded, it would be:

1. 11 years until the beginning of the first soil survey in the United States (Arnold, 1983).
2. 14 years until publication of King's textbook on soils and the beginning of soil physics (King, 1904).
3. 18 years until publication of Hilgard's text on soil and the beginning of soil chemistry as an organized subdiscipline of soil science. (Hilgard,1906).
4. 33 years until publication of Marbut's guidelines for describing soil profiles (Marbut, 1921).
5. 39 years until Marbut's translation of Glinka's translation of Dokuchaiev's work (Joffe, 1949).
6. 40 years until Bushnell noted the correlation between microrelief and soil properties (Bushnell, 1928).
7. 47 years until Milne published his observations on relationships of drainage to soil properties (Milne, 1935), and until Sir R.A. Fisher published his classical text on experimental design (Fisher, 1935).
8. 53 years until Jenny published the Factors of Soil Formation (Jenny, 1941).
9. 68 years until Ruhe published his observation on relationships between geomorphic surfaces and soil properties (Ruhe, 1956).
10. 71 years until Simonson published his "generalized theory of soil genesis" (Simonson, 1959).
11. 75 years until the current U.S.D.A. Soil Taxonomy was applied in a soil survey.
12. 95 years until Scrivner published his productivity index concept (Kiniry et al., 1983).

After reading this list, one cannot help but hope that current research will be viewed as kindly 100 years hence as we today view Sanborn's farsighted efforts in 1888.

Soil Sampling

Eight soil cores two inches in diameter and 48 inches long were taken from each of 39 plots (1-7, 9-39) using a Giddings hydraulic probe. Two cores were taken from points E, F, G, and H on each plot (Fig. 1). One core was taken at the point, and the second core was taken six inches to the east of the first.

One core from each point was segmented into four inch segments for processing by the soil testing laboratory. The second core was retained for separation by morphological horizons. Four cores from plots 2, 6, 9, 10, 17, 18, 22, 23, 24, 25, 26, 29, and 30 were described, separated by horizons, and characterized in the Univeristy of Missouri Soil Characterization Laboratory. Cores from point "F" from the remaining plots were described and analyzed. The other three cores from the remaining plots were separated by genetic horizons and the samples were retained in glass bottles as "benchmark" samples as part of the permanent Sanborn Field soil sample collection.

Morphological descriptions were as complete as could be taken from two inch cores, and included: horizon thicknesses; size, abundance, and color of mottles; abundance, shape, location and color of concretions; abundance, thickness, and orientation of clay films; structure; and horizon boundary characteristics. Laboratory analyses included: particle size by pipette; pH in 1:1 solutions of water and 0.01M $CaCl_2$; NH_4OAc extractable cations, BaC12-TEA extractable aluminum; cation exchange capacity by sum of bases; percent base saturation; total C; and total N.

Questions Frequently Asked Relative to Sanborn Field

The four questions most frequently asked of scientists who have worked upon Sanborn Field provide a framework for discussion of lessons learned and progress made upon the site.

The discussion may appear overly critical to some readers, but self-evaluation and scrutiny are necessary precursors to personal and professional growth. The four questions are:

1. What does this plot yield?
2. What soil series is it?
3. What has happened here in the past?
4. How has the soil been changed by cultivation over 100 years?

The order in which these questions are given is that normally asked by the casual visitor. The last three will be answered in reverse order because the answer to number four is necessary to answer two and three. Question one will be touched upon, but is discussed by other authors.

Soil Changes Resulting from Management of Sanborn Field

Natural Distribution of Soil Properties

Measuring soil changes resulting from 100 years of continuous cultivation is one of the most valuable and intriguing questions associated with Sanborn Field. Determining the direction and rate of changes of soil chemcial and physical properties to agriculturally important management practices is a necessary requisite to sustained agriculture. Unfortunately, the challenge cannot be completely met on Sanborn Field, for no soil baseline data were collected during the first years of the field's existence. Although one might wonder why no data were collected, the question is tempered by the awareness that descriptive nomenclature and standards for soil morphological features had not been developed in 1888. Even if baseline data were available today, assessing the influence of managment practices on the soil resource would be difficult. Numerous treatments have been imposed upon many of the 39 plots on the site, the plots are small, and they share a portion of a single watershed.

Sanborn Field is a sloping site, so the subsurface movement of water through the system can be expected to redistribute mobile constituents from individual plots, and through erosion and sedimentation, to also redistribute surface sediments. Movement and retention of chemicals through the system will have been heterogeneous, because the soil is a chromatograph which differentially affects the various ionic constituents of the soil solution (Kurtz and Melsted, 1973). Figure 2 is a three-dimensional representation of the current surface of Sanborn Field. The southwest corner of the field lies below the adjacent off-field terrain, indicating either that the field surface has been lowered by erosion since the streets were installed, or more likely, that the streets were built up as the roadbeds were established. Vertical relief on the field is 12.4 feet from the highest point (in plot 12) to the lowest point (the drainage duct in the southwest corner of the field). The slope ranges from nearly level to 7.5 percent. From the convex interfluve summit which dissects the field across plots 12 and 20, the field slopes away to the southwest and to the southeast. The entire field has a slight southerly aspect.

Examination of the soil cores revealed that the Ap horizon of many plots now includes E and Bt horizon materials. Some lower portions of the field have overthickened A horizons, probably due to sediment accumulation from eroded upslope sites. The range in A horizon and Ap horizon thicknesses in the summer of 1988, when most of the cores were pulled, was from a maximum of 19.2 inches (plot 34) to a minimum of 6.4 inches (plot 5). In general, the thinnest A horizons were on the convex shoulder slopes and the thickest were in downslope concavities, which is an expected trend. Soil profiles from west to east across the two rows of plots are in Figure 3, and give a general illustration of the morphological variability within the field.

The key question is "how much of this distribution is natural, and how much has it been affected by cultivation during the past 100 years?" The lack of adequate baseline data renders impossible the finding of an accurate answer. Furthermore, the quantification of soil spatial variability is a challenging task, even under ideal conditions, and is a research topic receiving much interest from pedologists and soil physicists (Nielson and Bouma, 1985). An important consideration in this work is determining the number of samples required to precisely determine the variability of a specific soil property (Wilding and Drees, 1983). Additionally, pedologists are not in complete agreement as to what sampling schemes are best suited for this research, or which statistical procedures are most germane. Some investigators have used "geostatistics" (Campbell, 1978) to quantify the spatial relationship of individual observations, and others have preferred multivariate statistical approaches (Richardson and Bigler, 1984; Rowe and Sheard, 1981). The question is complex, partially because of the natural heterogeneity of soil materials and partially because of the statistical problem of assessing the spatial dependence of specific soil properties in different soil weathering environments.

The three-dimensional surface contour (Fig. 4) of A horizon thicknesses on the convex portion of Sanborn Field (plots 32 and 28 eastward to plots 1 through 7) graphically illustrates the heterogeneity of the A horizon thicknesses. The A horizons in this small area range from 19.2 inches thick (plot 34) to 6.4 inches (plot 5), which is the maximum variability of this soil property encountered in Sanborn Field. In plots 3 and 5 alone, the difference in A horizon thicknesses is four inches.

Soil properties can be expected to vary with geomorphic surfaces across a landscape. Some of the variability will be systematic and predictable, and some will be random. The rates of change and degrees of expression of the properties in question will vary as a function of a number of variables such as site stratigraphy (including depositional environment of the soil parent materials), surface ages, vegetation, shape of geomorphic surfaces within the landscape and climatic history (Daniels et al., 1971).

In the absence of baseline data, one might cautiously attempt to estimate the changes inflicted upon Sanborn Field during the past 100 years by finding similar, uncultivated geomorphic surfaces and parent materials within the climatic region affecting Sanborn Field, and measuring soil properties within that ecosystem for comparison with Sanborn Field. Such an approach must be cautiously interpreted, however. Figure 4 shows the distribution of clay with depth in three soil profiles in an uncultivated Menfro soil (fine-silty, mixed, mexic Typic Hapludalfs) landscape in Schnabel woods, about 10 miles south of Sanborn Field. The soil developed in deep loess near the Missouri River.

The summit profile is a classic forest soil clay distribution, with the eluvial E horizon between 8 and 12 in (20 and 30 cm) overlying the abrupt transition to the illuvial Bt horizon. Maximum clay accumulation is about 28 percent and occurs at a depth of about 20 in (50 cm). The convex shoulder slope is characterized by a shallow, weakly expressed E horizon at about 6 in (15 cm), and the clay maximum, which is equal in clay content to the summit profile, occurs nearer the surface at a depth of about 10 in (25 cm). In the linear backslope position, the maximum clay content is higher and deeper than the summit and shoulder. The slope of the backslope in this ecosystem was about 30 percent, compared to about 7 percent on the backslope of Sanborn Field. Additionally, the relief in the watershed was about 60 feet, compared to about 12 on Sanborn Field. Figure 6 is a graph of clay distribution in three soil profiles representing the summit (plot 12), shoulder (plot 30) , and toeslope (plot 39) of Sanborn Field.

Note that the summit profile does not contain the eluvial E horizon which was evident in the Menfro summit soil profile. The clay maximum in this landscape occurs in the summit profile, rather than in the backslope, and is also nearest the surface in the summit. The shoulder slope of Sanborn Field contains the deepest clay maximum, whereas the shoulder slope in Schnabel woods was contained the shallowest clay maximum.

The total carbon distribution in the virgin Menfro forest soils (Fig. 7A) is the classical carbon distribution of a deciduous forest soil profile—a high surface content, declining rapidly to near zero levels immediately below the surface horizon. The more gradual decline in total soil carbon in the Sanborn Field soils (Fig. 7B), coupled with the greater carbon levels at depth, is more representative of the carbon distribution in cultivated mollisols. The Sanborn Field site was probably under the influence of native prairie vegetation at some time in its developmental history, as the soil classification of Udollic Ochraqualfs would suggest. The Menfro soil at Schnabel woods apparently has not been influenced by prairie.

Are the differences in the clay distributions between these two sites due to man-inflicted influences on Sanborn Field, are they the natural differences one would expect to encounter when comparing soils developed under prairie and forest vegetation, or does the truth lie somewhere between the extremes?

The pronounced differences in relief and slope also render difficult the comparisons between these cultivated and virgin soils. Assessing the impact of cultivation or any other soil management practice is extremely difficult in the absence of a complete set of baseline data. Stone (1975) addressed in detail the problem of separating treatments from soil variability in forest soil managment, and lamented that the "reciprocal influence of forest upon soil and soil upon forest are not easily disentangled. . ."

Induced Differences in Soil Properties

Although the reciprocal influences of treatment upon soil and soil upon treatment are difficult to separate, some long-term practices on Sanborn Field have clearly affected soil properties. The two which were most apparent when the soil cores were being described were the noticeable redistribution of sediments within the field—due to erosion and deposition, and the effects of added organic matter upon soil color and structure.

The Ap horizon had penetrated into the argillic horizon on many plots on the convex shoulder slopes of the field, and the concave portion of the west side of the field contained overthickened A horizons, probably resulting from depositon of sediments eroded from the summit and shoulder.

The surface textures of plots 2, 17, and 18, for example, were silty clay loam. These plots are on the convex southeast-facing portion of the field. Plots 32 and 33 contained silt loam surfaces to a depth of 20 inches. The historical records contain entries describing the use of bladded equipment to relocate surface soil materials on the field to compensate for erosional redistribution. The actual magnitude and extent of surficial erosion on Sanborn Field will never be known.

The influence of organic matter on the soil profiles was quite apparent. The Bt horizon in plot 34 contained strong, fine, subangular blocks coated with a thin film of organic matter (continuous 10YR 3/2 films). The structural aggregates fell from the core like marbles from a sack. In addition to annual additions of manure, plot 34 is in a four year rotation of corn, oats, wheat, and red clover. Plot 34 contained the strongest subsoil structural aggregates noted in the descriptions, so the possiblility that crop rotation acts in conjunction with organic matter additions to enhance structural aggregation cannot be overlooked. The other plots receiving supplemental organic matter also contained strong structural aggregation in the subsoil, but lacked the degree of organic matter coatings on the peds in the Bt horizon that was displayed in the soil from plot 34.

Supplemental organic matter as manure appears to have affected some soil chemical properties. Figure 8 contains the distributions of total carbon and clay within the four soil cores characterized from plots 17 and 18. Plot 18 is continuous corn with annual additions of 6 tons of manure per acre, and plot 17 is continuous corn without manure. Although the argillic horizon in plot 18 seems to have slightly more clay, the patterns of clay distribution within the two plots are essentially the same. Plot 18 contains about twice as much total carbon in the surface horizon as plot 17.

The additions of organic matter apparently affected the levels of Ca, K, and extractable acidity in the soils as well, as levels of the cations are greatest in the surface horizon of the plots receiving organic matter, while the level of extractable acidity has been reduced (Figure 9).

The relationships reported for plots 17 and 18 were also observed on plots 9 and 10 (continuous wheat with no manure and 6 tons per acre per year) and on plots 23 and 22 (continuous timothy with no manure and 6 tons per acre per year).

Soil series on Sanborn Field

The frequently asked question, "what soil series is on Sanborn Field?" is worthy of some discussion. Farmers, soil scientists, and crop scientists all tend to classify soils, because they want to be able to categorize a soil profile when they see one. This is generally done because soils are complex natural bodies, and one could not adequately recall each individual soil he encounters without some form of grouping soils with common features. However, when the practice is carried to research projects and experimental plots, the tendancy may be to assume that since one is familiar by virtue of previous experience with a soil series, that one knows much about that soil. C.F. Marbut once admonished a colleague on a field trip in California to "forget the about the names of the soil types, get the characteristics!" (Joffe, 1949).

Perhaps a better question to ask oneself would be "How does this particular Mexico soil compare to other Mexico soils with which I am familiar?" The old adage that "familiarity breeds contempt" is no less true for agronomists working with certain soil series. One should strive to learn what internal processes are inherent within an experimental plot. An understanding of the pathways and quantities of water and nutrient flux is essential if crop responses to management inputs are to be understood sufficiently that information can be transferred to other soil systems. This concept will be expanded upon in the following section.

Sanborn Field has most recently been mapped as a Mexico soil (fine, montmorillonitic, mesic Udollic Ochraqualfs) (Upchurch et al., 1985). However, the soil cores examined and described for the 100 year celebration were not Mexico soils. The current concept of the Mexico soil is that it lies on the backslopes of broad, flat interfluves of Putnam soils (fine, montmorillonitic, mesic Mollic Albaqualfs), and is characterized by red mottles in the upper solum. Red mottles were not in the soils of Sanborn Field, and the soils of Sanborn Field do not fit neatly into any current soil series in central Missouri.

Yields on Sanborn Field

The question "What is the yield?" is also a proper question to be asked of an agronomist conducting research on crop responses to management practices. Often, however, the important followup questions, "What was the impact upon the soil of this practice, and what are the possible long term ramifications for continued crop productivity?" are not asked. This problem is not recent to the field of soil science. C.F. Marbut (as quoted by Johnston, 1941) once remarked that:

> "The soil has been looked upon by scientific men in America and western Europe largely from one or the other of two points of view. It has been considered either as a medium in which plants grow. . . or merely as a geological formation with slight modification of no great importance. . . The representatives of the first group have confined themselves in their investigations to questions that concern the getting of immediate results in crop yields. Those of the second group have given the subject very little attention. A mere passing notice."

The destructive nature of soil sampling makes it difficult to continuously monitor management practices on field plots. Plots are often small, and would be changed irreversibly by repeated sampling, particularly if investigators attempt to sample the entire rooting volume of the soil profile. Coring often produces a sample too small to provide an adequate data base for applied research.

The problem is further compounded by the spatial heterogeneity of the soil resource. This variability, partly systematic and partly random (unexplained), is treated as entirely random by many investigators; with subsequent impact upon their experimental design and occlusion of their abilities to correlate crop yields to specific soil properties (Daniels and Nelson, 1987). Traditional agricultural plot research has treated soil variability as a random factor to be removed by blocking and replication. This approach has greatly hindered the focus upon internal soil processes which affect plant root growth and crop yield, and has also affected our ability to adequately quantify the nature of soil variability. Wilding and Drees (1983) have pointed out that "many of our current statistical methods come from Snedecor. The major focus of experimental designs was to interpret the significance of main treatment effets (yield or fertility response) with little or no effort to understand the results in terms of soil conditions."

Simonson (1959) provided a simple but elegant conceptual framework upon which to build models and experiments to study the internal processes of a soil system. In this model, the dynamics of a soil system can be reduced to gains, losses, transformations, and translocations. Since Simonson developed the model, many advances have been made in the study of soil processes, particularly in the arena of nutrient flux. Figure 10 is Simonson's model, modified to show deep seepage losses of dissolved substances and to illustrate gains and losses received in lateral water movement through the profile. More attention must be focused upon internal soil processes affecting and resulting from crop growth and management inputs.

When Simonson's model of soil genesis is combined with Scrivner's (Kiniry et al., 1983) Productivity Index for correlating root growth and crop yield to soil properties, the investigator is equipped with an excellent conceptual framework from which to approach the analysis of soil-landscape systems for crop growth and yield. Applications of the Productivity Index concept have been presented in detail elsewhere (Henderson et al., in press; Huddleston, 1984).

Recent research by Daniels and coworkers has focused upon variability in crop yields resulting from soil, stratigraphic, and water-supplying differences inherent within sloping landscapes. Daniels and Nelson (1987) have suggested that thorough correlation of soil properties to crop yields is too complicated an undertaking for scientists from one or two subdisciplines in soil and earth sciences. They suggested that crop scientists, soil scientists, geologists, and statisticians must work closely in interdisciplinary programs to identify and correlate soil-crop interactions responsible for crop yields. More recently, Daniels et al. (1989) reported that crop yields in Piedmont soils varied regardless of erosion class, but that yield reduction directly attributable to erosion is slight. They stated that it is erroneous to assume that yield should be uniform across the natural variability encountered within a soil landscape.

The concept that vegetative biomass production varies with soil and landscape conditions is not new. The foundations of ecological research in North America were laid in investigations of the heterogeneity of distribution and productivity of native forest and grassland plant communities. A plethora of literature addresses the relationships of native plant distribution and growth to to soil, landform, and aspect parameters (Whittaker, 1966; 1967; Carmean, 1975; Ayyad et al., 1964; Weaver and Albertson, 1956; Crockett, 1964; Hopkins, 1951).

Agronomists are learning that the soil, aspect, and geomorphic relationships which affected native plant growth affect agricultural crop productivity. Simmons et al. (1989) demonstrated corn yield differences associated with slope shape and slope position in the Atlantic Coastal Plain. Boudeman (1989) observed yield differences in three forage legumes as a function of landscape position in a Mexico silt loam at the University of Missouri Bradford Research Farm about 10 miles east of Sanborn Field (Fig. 11).

The site was similar in shape to Sanborn Field. Slope did not exceed 7 percent anywhere on the plot. The "summit" could properly have been called a shoulder, because like the summit on Sanborn Field, it was narrow and convex. The total relief in the field was about 12 feet across a linear distance of about 180 feet. Yield varied across the landscape and from year-to-year with respect to specific crops and landscape positions. The spring of 1987 was very wet, and the summer of 1988 was very dry, so differences in yield were related not only to water-holding capacity of the individual soils, but to the water-supplying capacity of various landscape positions.

The point of this discussion is two-fold. First, it demonstrates that some long-held approaches to quantification of crop yield should be re-examined. Fresh approaches will be required if precise quantification of causal mechanisms of crop yield are to be gleaned from field research. Second, the influence of landscape position is a sufficiently important factor in crop yield determination that much care should be exercised when selecting locations for field crop research. When long-term research is planned, site hydrology and stratigraphy should be considered.

What Happened on This Plot?

This question was one frequently asked by scientists analyzing the Sanborn Field data sets. On several occassions, answers were obtained from Dr. C.M. Woodruff, whose experience on Sanborn Field predates the lives of many of the current soils faculty. For example, the Sanborn Field sampling was preceded by an intensive survey of plot 24. Eight soil cores were pulled to assess soil morphological variability. Data analysis of these cores revealed that half of the plot had higher surface levels of K than the other half of the plot (Fig. 12).

No explanation for this difference could be found in the Sanborn Field records, but Dr. C.M. Woodruff recalled that the plot had been split in the early 1940's for an intensive K trial. Half of the plot had been treated with K and the other half had been the control. Residual effects of this treatment remain nearly 50 years later.

Soil cores from plots 2 and 36 contained what were first thought to be pottery shards, until a pit opened in plot 12 revealed a drainage tile running through the center of the plot at a depth of about 30 inches. The tile was made of the same material as the shards from plots 2 and 36. The tile is not mentioned in the Sanborn Field history or chronology, and its discovery came as a complete surprise to the field director. Detailed record-keeping of all treatments or site impacts is a necessity if the results of long-term research are to be interpreted, then transfered to other ecosystems.

Planning Long-Term Research

Lessons from Sanborn Field, perusal of the literature, and discussion with colleagues from other countries and sub-disciplines of the agricultural and earth sciences suggest that several criteria should be considered when planning long-term research. Among them are: considerations of site history; carefully planned, concisely stated research objectives; scientifically and statistically sound experimental design; thorough and precise acquisition of baseline data; careful monitoring and inclusion of climatic data; precise and thorough record-keeping; and imaginative, statistically sound data analysis. These topics will be considered individually.

Site History

Site history should be carefully considered prior to initiation of long-term research, and site selection should not be confirmed until site history and baseline data have been mutually considered. In his excellent treatise, Stone (1975) addressed the problems arising when data are interpreted without adequate consideration of previous management practices upon the site. The pedologist, with cooperation from geomorphologists and geologists, can make important contributions to assessment of previous perturbations upon the soil/landscape system. The previously cited example of a past K application to one half of a research plot is a clear example of how an unrecorded treatment could be identified. Although causal mechansisms for site conditions may not always be determined, the researcher can be alerted to unusual conditions or site heterogeneity and can seek more suitable sites or adapt the experimental design accordingly.

Research Objectives

It may appear ludicrous to emphasize the value of research objectives to a scientific audience discussing long-term research. However, most of us have reviewed research proposals which lacked a clearly stated testable hypothesis supported by objectives which allowed the hypothesis to be examined. Multidisciplinary research requires that all participants understand the overall objectives and are willing to work for the common goal. A sense of team play and team goals, and a willingness to blend one's own ego into the community psyche are important ingredients for success of a project which may take years to conclude. One must resist the temptation to add a new twist to the ongoing project to observe its effects. This philosophy probably runs counter to the basic instincts of the curious scientist pursuing the particular questions which fuel his inner drives.

Sensitive, productive leadership is a rare commodity in all of man's activities, but is an absolute ingredient to keep a long-term, multidisciplinary research team on track. As scientists, we also serve the taxpayers who support our profession, and dollars contributed to support a stated research objective imply an obligation from society to meet the stated objectives.

Experimental Design

Design of long-term experiments will surely be a time-consuming often frustrating undertaking for the participants. Each scientist will bring his perspectives to the planning table, and may resist the urge to "share the pie" with those whose interests seem less germane. Compromise, when necessary, should be by the participants, rather than the project objectives.

Geostatistical and multivariate statistics, by virtue of in the past having been largely inaccesible to the layman, were unknown to most agronomists, who have conveniently labeled these procedures as "new" methods. Powerful high-speed microcomputers have made it possible for every scientist to rapidly conduct statistical analyses impossible on yesterday's mainframe computers. Geostatistical and multivariate analyses now are performed routinely. The opportunity to venture beyond the comfort of ANOVA should be considered at the outset of research planning and design. Project leaders should be urged to consort with statisticians who have specialized in these statistical methodologies, and to involve the statisticians in the research planning and data analysis. Software packages for many of these sophisticated statistical procedures require the user to select from several procedural choices. Often the choices require the user to make decisions based upon experimental design restraints or upon subjective interpretation of previous statistical analyses (Tabachnick and Fidel, 1983). The unitiated should resist the urge to "turn the crank" and should seek informed statistical advice. The proper question to be asked of the statistician when selecting specific statistical procedures or particular software options, is "what procedure will best allow us to test these results?" For example, the tendancy to say "let's kriege these data" should be resisted until a statistician has confirmed that krieging is an analysis necessary to properly interpret the data.

Soil spatial and temporal variability, stratigraphy, geomorphology, and hydrology should be considered and incorporated into the experimental design. Consideration of these factors, as previously suggested, might require considerable investment in site characterization before experimental design can be completed. Powers ((1987) has suggested that we have more knowledge than we apply in experimental design, and that site characterization should focus upon the soil, site, and climatic factors influencing plant-available water. Certainly, financial considerations will greatly limit the resources available for site characterization. Conversely, resources invested to obtain site characteristics likely will pale in comparison to the resources expended during the course of a long-term experiment. One can "pay now" in terms of resources or "pay later" in terms of data not interpretable because of lack of site characterization data or presence of unmeasured factors.

If the experiment requires measurement of the effect of management or cropping systems on crops, soils, and water, the measurement of internal soil processes should be planned in the design phase. Current soil-sampling procedures are often destructive. Experimental plots should be selected and designed to allow soil sampling with minimal detremental affect to the plot. This might simply require that plots be large. As plot size increases, stratigraphic and soil variability factors will become more important (Parks et al,, 1987; Wilding and Drees, 1983).

Precise quantification of inputs and outputs must be made. Our colleagues in forest soil sciences, particularly those who have studied nutrient cycling, have much experience in this domain, and should be consulted when planning measurement of nutrient dynamics or nutrient budget strategies. The pedologist should also be consulted to insure that sampling design considers the processes which have contributed to development of the soil profile.

Sanborn Field is an example of an experiment in which so many treatments were imposed upon a single watershed that it is difficult to separate the effects of the treatments on the individual plots and crops. The soil-water system must be carefully defined, and only one treatment should be applied to the system. Replication of treatments and systems is extemely important when dealing with soils out-of-doors. Watersheds and hillslopes which appear similiar upon superficial examination may differ in important subsoil and hydrologic parameters. Replication should be implemented with care. Effects of small site differences on crop yield might be compounded greatly with time, particularly in perennial crops.

Baseline Data

The systems approach should be used in collecting baseline data. Representative soil and plant tissues should be collected and stored. One should assume that different, more precise analytical techniques will be developed in the future, and that baseline samples will be required to insure that measured differences over time have resulted from managment or processes rather than technological advances.

Soil samples should be collected by pedogenic soil horizons. For example, one could probably not adequately measure the impact over time of acid precipitation on the soil calcium pool if samples were collected by incremental depths in a forested ecostystem (G.S. Henderson, personal communication). One should anticipate that shifts in system inputs will subtley affect the process and pools within the ecosystem, and that ignoring the diagnostic features representative of the processes may occlude subltle shifts in elemental concentrations.

Pedological research suggests that weathering, illuvial/eluvial processes, and root penetration commonly occur at depths below the taxonomic control section of humid-environment soil systems (Miller et al., 1988; Hammer, 1986; Daniels et al., 1987; Boudeman, 1989). Baseline data should include sampling and analysis of as much of the weathering profile as possible. One should consider that succeeding generations of scientists will likely have different perspectives and questions than the experiment planners, and samples should be collected and stored in anticipation of those questions. A rule of thumb could be "when in doubt, sample and save." If budget constraints prohibit complete sample analysis during the baseline data collection phase, samples can be stored for future analysis. Samples of all treatments should also be saved. If fertilizer sources are changed, for example, samples of both fertilizer sources should be retained for possible future analysis.

As previously mentioned, the paucity of information describing past management practices and intentions frequently plagued scientists anlyzing the 100 year samples from Sanborn Field. When scientists visit long-term research plots to sample, observe plots, or discuss management practices, notes should be taken, carefully proofread, and stored for use by succeeding generations of scientists.

Data Analysis

Data should be stored in such a way that they are accessible and can be easily managed. Geographic Information Systems (GIS) technology, which allows storage, manipulation, and analysis of spatial data is ideally suited for database management for long-term research. The GIS technology allows rapid overlaying and spatial interpretation of data in ways not previously possible. The possiblility exists that the "garbage in, garbage out" syndrome can be brought to new levels of frustration by the uninformed, but careful experimental design and planning should reduce this concern. Detailed discussion of the applications and limitations of GIS technology is beyond the scope of this paper, and the interested reader is referred to current reviews and symposia proceedings (Burrough, 1987; American Society for Photogrammetry and Remote Sensing 1986, 1987a, 1987b).

One should assume that new statistical and data analysis techniques will continue to be developed, so raw data should be stored for use by succeeding generations of scientists. If a treatment must be changed or modified as the experiment proceeds, new baseline data should be acquired at the time the treatments are changed. The Sanborn Field files indicate that the source of manure for the plots was changed in the past, but manure samples have not been retained. It is not now possible to separate the effects of manure source on crop yield or elemental content of the treated plots.

Although is is easier said than done, data should be analyzed periodically. Over time, such copious quantities of data can accumulate that even sorting the information can be a formidable task to one not familiar with the history of the project.

Record Keeping

Much of this information has been mentioned previously. We repeat it for emphasis. All treatments and guidelines for analyses should be retained, particularly if the guidelines are in handbooks or manuals of local origin. All notes should be dated and filed carefully. Notes probably should be reviewed by other scientists to ensure their clarity and completeness. Justification for treatments should also be recorded. One should not assume that one's successors will understand why a particular analytical approach or management practice was implemented. Personal judgement probably enters into managment of long-term research more frequently than one might suspect.

The advantages and necessities of long-term research are becoming more obvious to scientists faced with the challenge of managing the soil as a sustainable resource which will be passed to succeeding generations in equal or superior condition to that which we enherited. Certainly, awareness of the importance of the soil as a component of ecosystems is increasing with heightened public concern about water quality, acid deposition, toxic waste disposal, and decreasing availability of suitable landfill sites.

Scientists agree that long-term, multidisciplinary research is necessary to complete assess the impacts of agricultural, forestry or urban management practices upon soil/watershed systems. The "publish or perish," grant-driven environment inherent within government and academic research communities today seems counter to deliberate, precise long-term studies. Who is willing to fund research in which the objectives contain questions which may not be answered for a decade or more? What institution possesses the working environment and reward system willing to financially and professionally reward a team of scientists who don't annually produce a series of refereed papers?

Powers (1987) has suggested that scientists must begin to educate administrators of funding agencies and research organizations as to the future needs and limitations of research if we are to be able to meet the challenges of the future. He has also suggested that as scientists, we must examine our individual research goals and priorities to ensure that we are pursuing relevant and needed subjects.

Sanborn Field has provided many challenges and lessons for those who have studied its history. The efforts of the scientists who have and managed the field and analyzed its data will not have been wasted if the lessons are considered and applied to tomorrow's research challenges.

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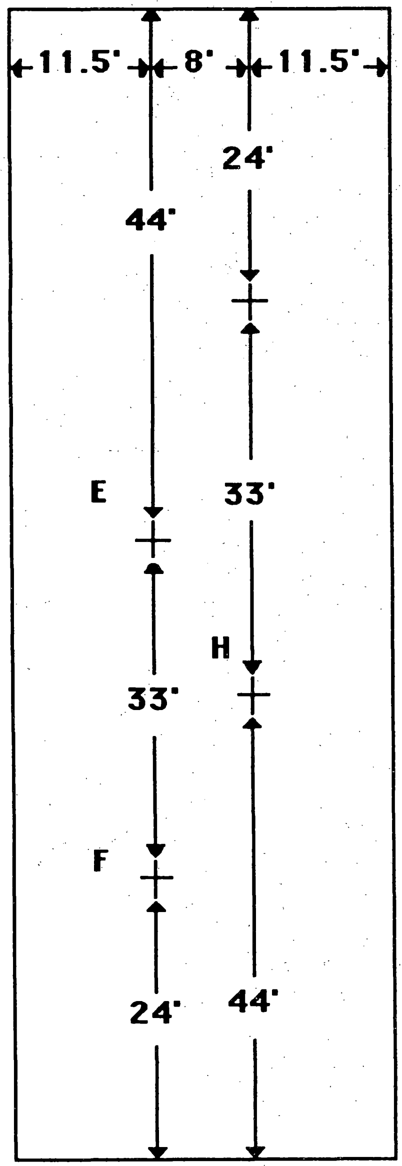
Figure 1. Plot sizes and locations of sampling points for 100th-year soil samples taken from Sanborn Field. Sampling points are designated by letters "E, F, G, and H.



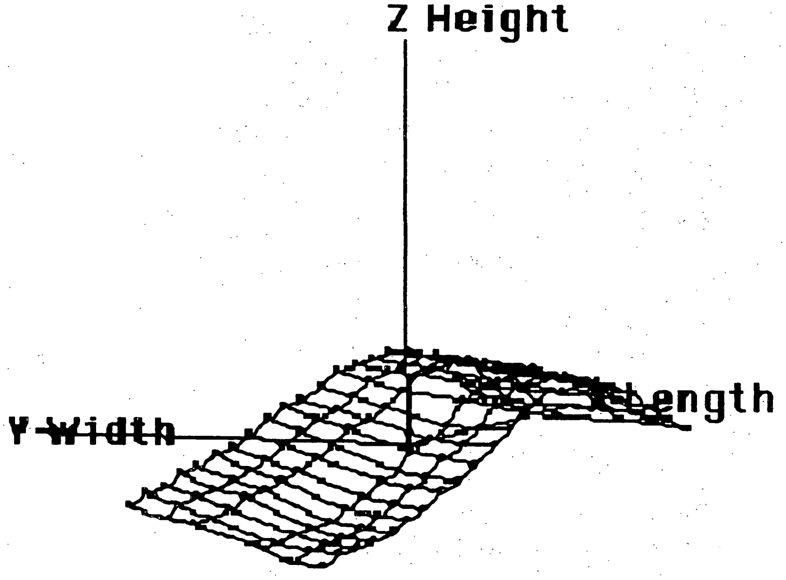


Figure 2. Three-dimensional surface contour of Sanborn Field measured in summer of 1989. The vertical scale is exaggerated by a factor of 10. The view is southwest to northeast.

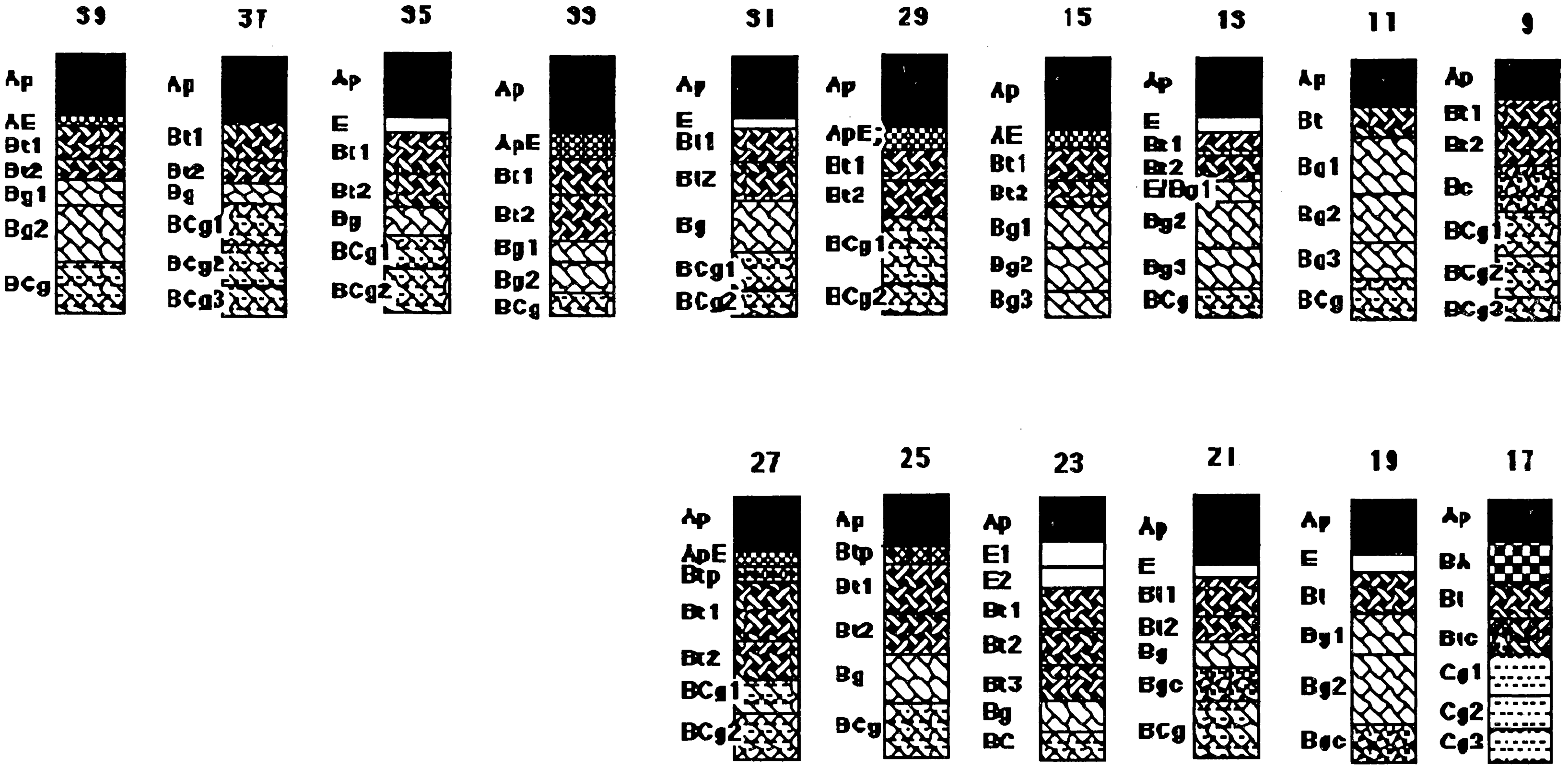


Figure 3. Soil profiles of Sanborn Field plots in a transect from east (top) to west (bottom) across the field.

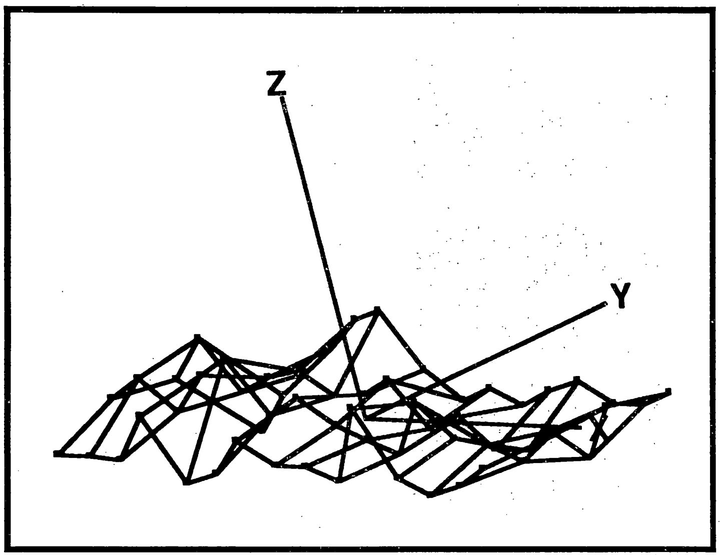


Figure 4. Three-dimensional surface contour of A horizon thicknesses in the convex portion of Sanborn Field (plots 32 and 28 east to plots 1 through 7). The Z axis is A horizon thickness, and the X and Y axes are field length and width, respectively. The plot has been tilted north on the X-Y plane to accentuate the variability.

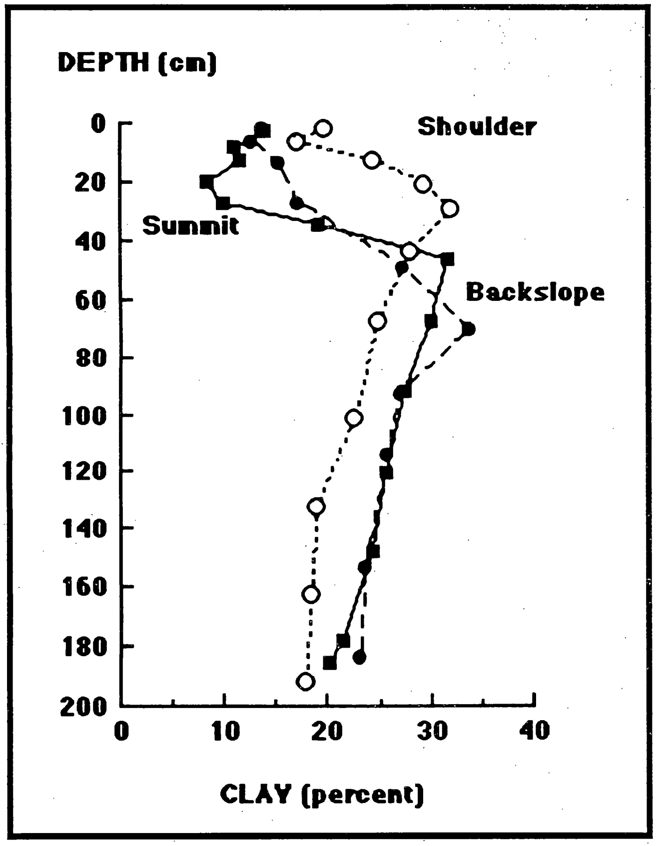


Figure 5. Clay distribution within three soil profiles of an uncultivated Menfro soil near Columbia, MO. The three geomorphic surfaces were on the same hillslope in a mixed mesophytic forest.

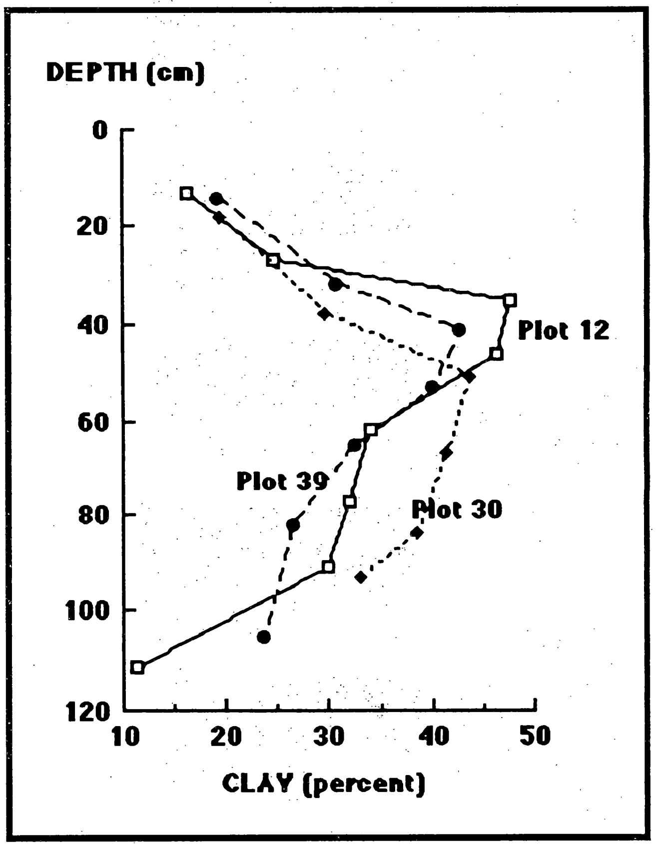


Figure 6. Clay distribution in three soil profiles representing the summit (plot 12), shoulder (plot 30) and toeslope (plot 39) of Sanborn Field.

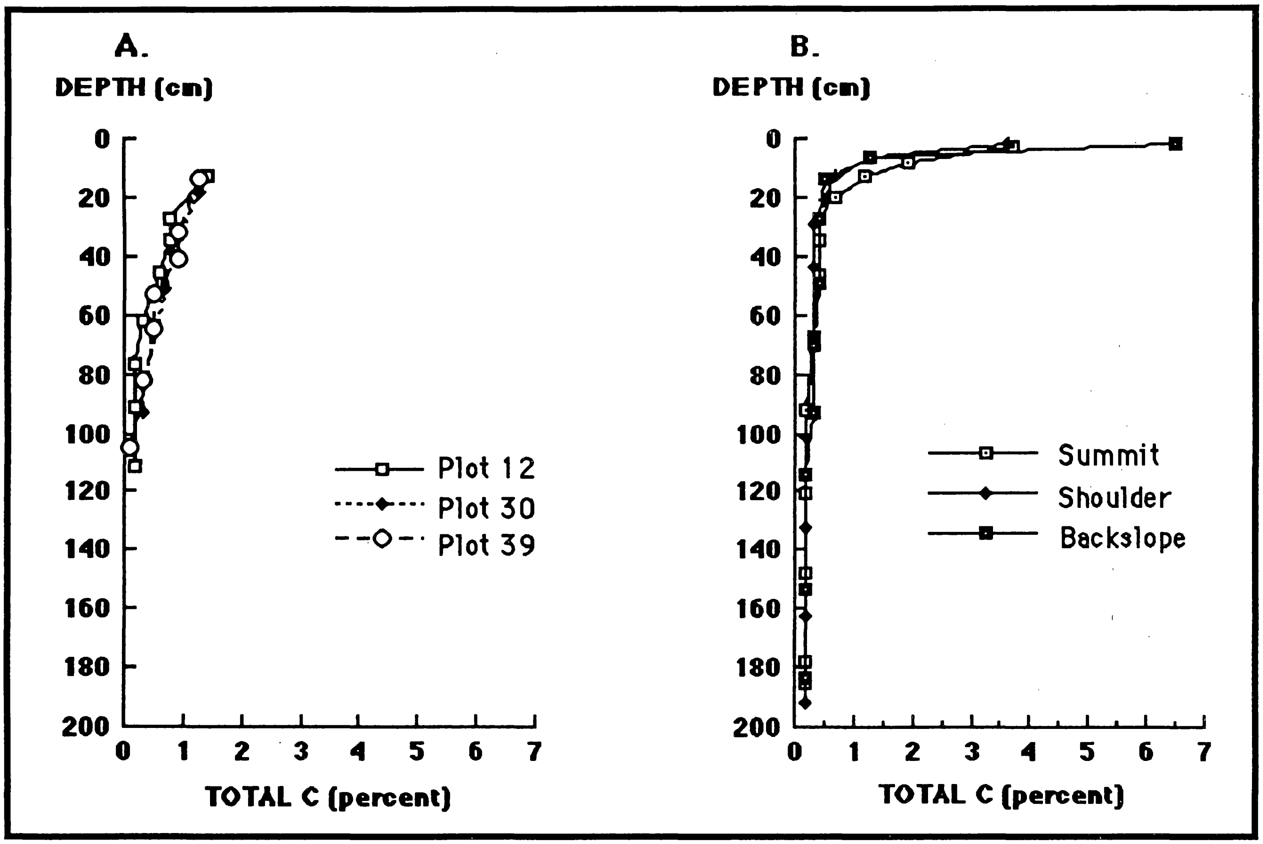


Figure 7. Total carbon distribution in three virgin Menfro soil profiles and in three soil profiles from Sanborn Field.

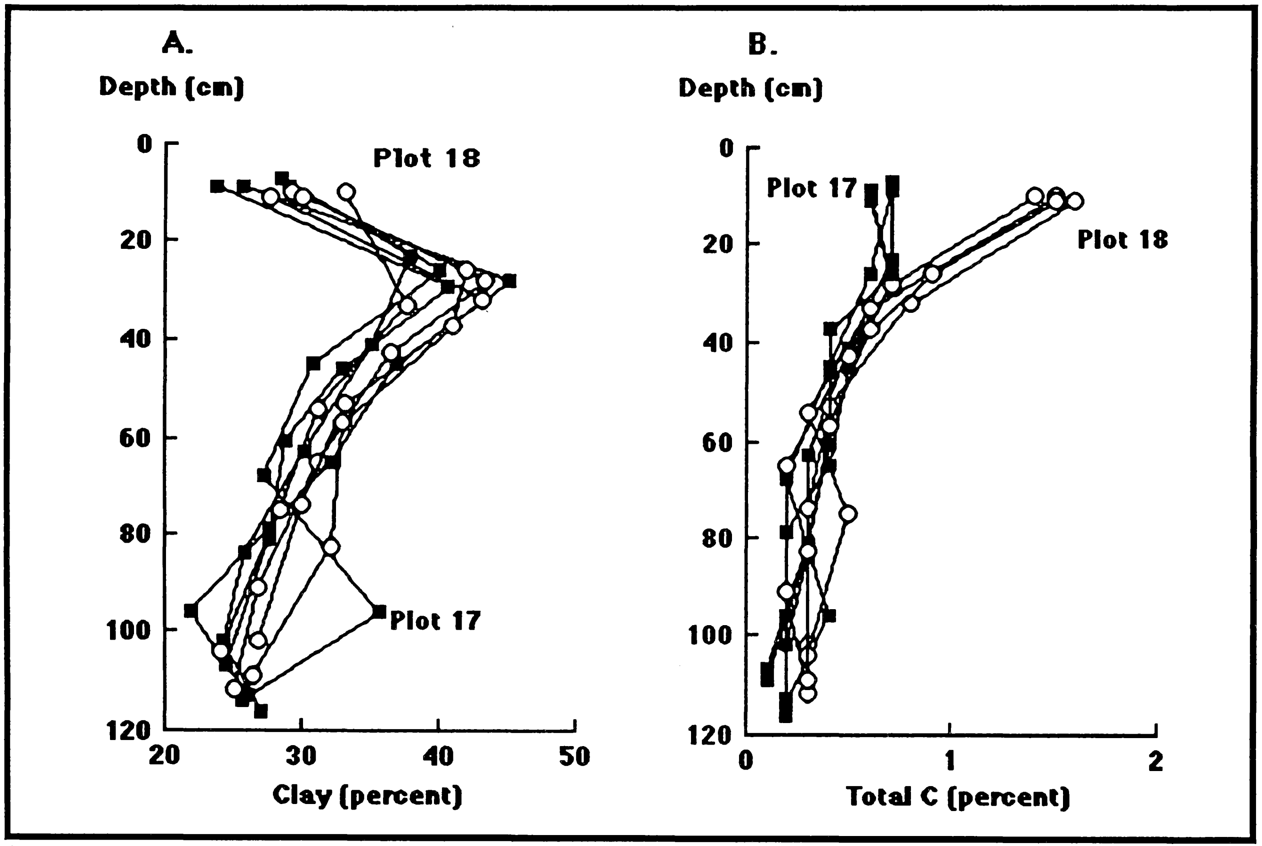


Figure 8. Distribution of total carbon and clay in plots 17 and 18 on Sanborn Field.

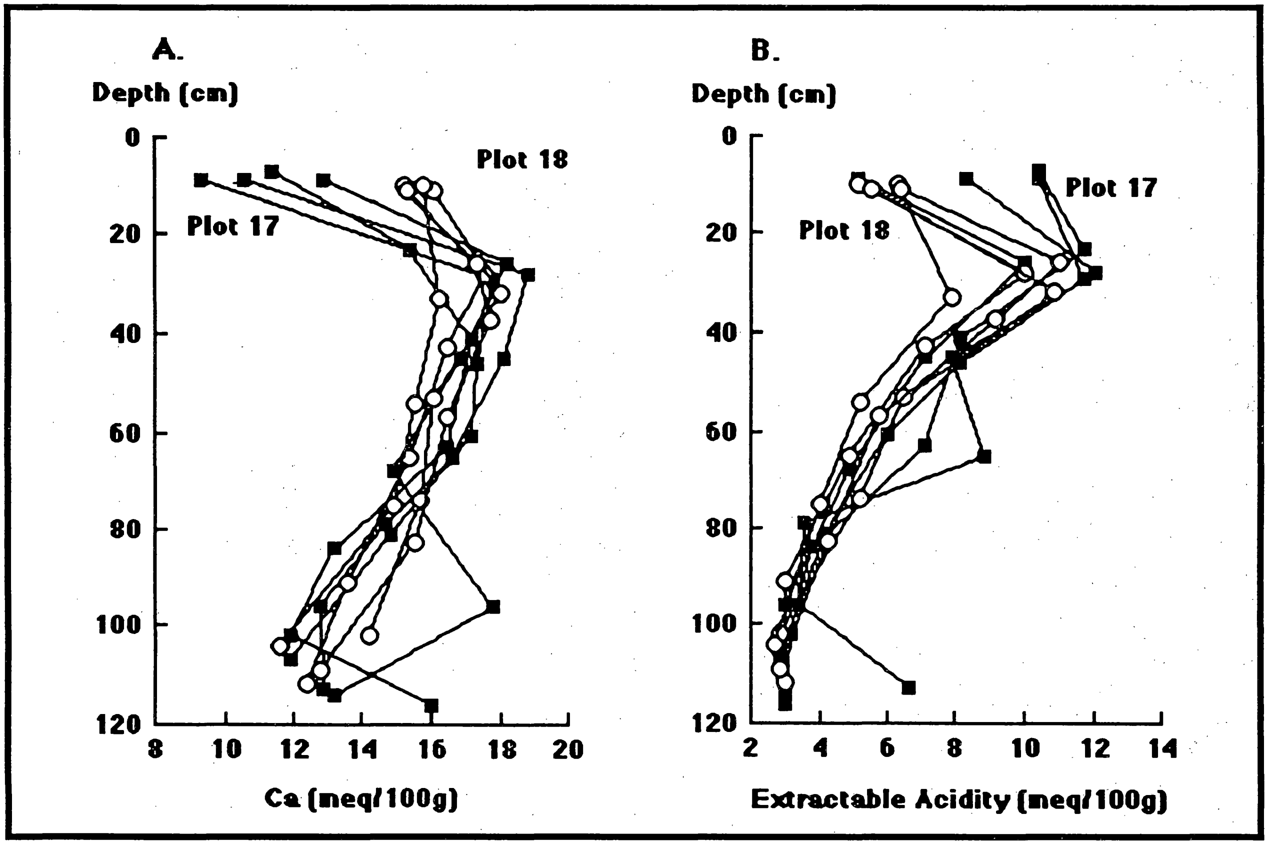


Figure 9. Distribution of calcium and extractable acidity in plots 17 and 18 on Sanborn Field.

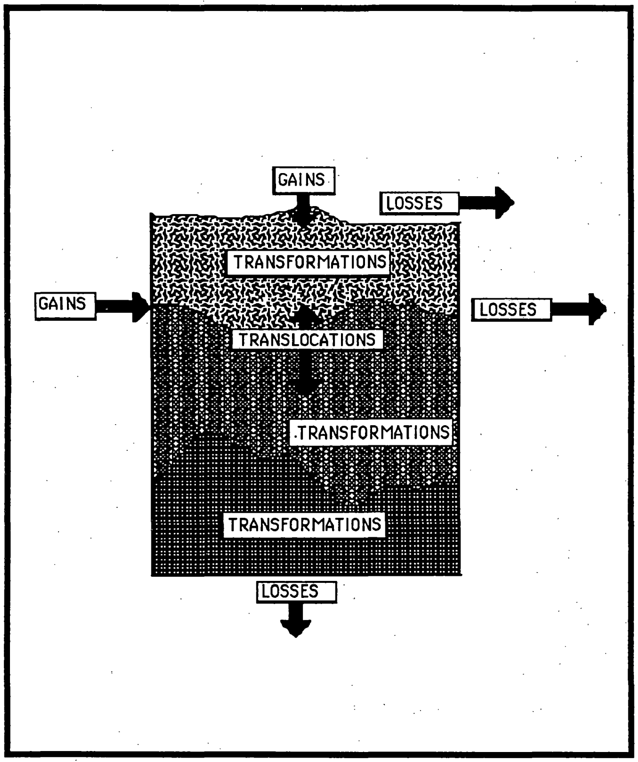


Figure 10. Soil-forming processes acting upon and within a single soil profile (From Simonson, 1959).

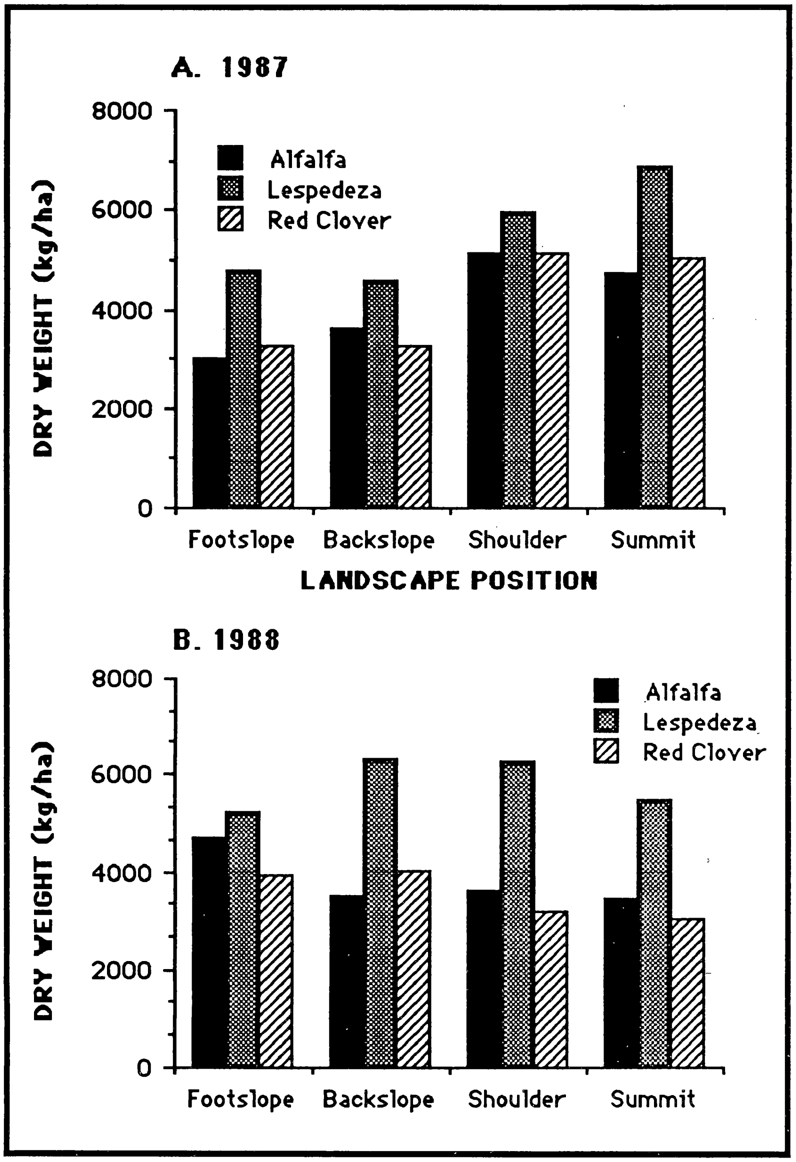


Figure 11. Yield of alfalfa, red clover, and lespedeza as a function of landscape position on a Mexico silt loam (fine, montmorillonitic, mesic Udollic Ochraqualfs) in central Missouri (From Boudeman, 1989).

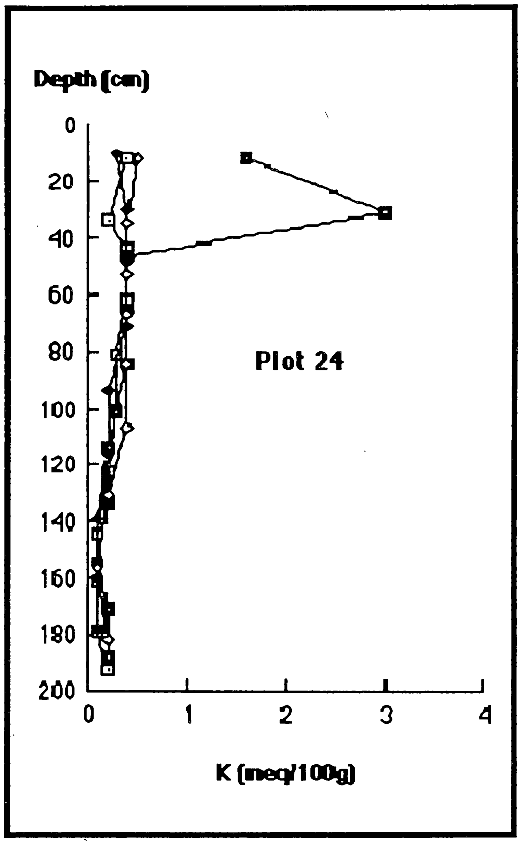


Figure 12. K distribution on Sanborn Field plot 24.

Changes in Plant Nutrients
A Century of Change

J. R. Brown and S. G. Breight

Every 25 years, a special flurry of activity on Sanborn Field occurs. It is similar to the excitation of a calcium ion in a flame. There is a flurry of increased energy followed by an emission and a drop back to base energy level. This paper (analyst) will cause a bundle of knowledge (light) to be emitted to the audience which is reading this article to be enlightened (photomultiplier tubes). My job is to package that knowledge in such a way that it is receivable.

The problem is that the instrument (audience) can be overloaded. We have accumulated so many numbers that we've been unable, as yet, to make meaningful packages from all of the data and yet continue everything else that needs to be done every crop year in field research.

Therefore, three sets of data from selected plots are used in this paper to give an idea of the kind of soil data that have been, and can be, generated from a long-term study. The full set of data will be published later. The three sets of data and the reason each was selected are:

1. A series of soils tests made over the period 1939 to 1988, to demonstrate change with time and the need for consistency of methods.
2. The relative extractability of phosphorus by different extractants from stored soil samples are given to illustrate changes over time and the reason methods should be consistent over time.
3. The distribution of extractable nutrients with depth on selected plots to demonstrate the need to study soils in depth.

Methods

A sketch of the field has been included to illustrate the field arrangement and the cropping sequences. The plot numbers will be used for reference purposes in the text and tables (Figure 1).

Critics of long-term field research discount the value of such studies because things are done better today than "back then". I would argue that had our predecessors not done their best "back then", we would not be doing things "better" today. Thus, let's look at how things have been done and not be too critical because we know more today. Knowledge about soils in 1888 was limited compared to the expanse of such knowledge near the end of the 20th century (Hammer and Brown 1989). One must speculate that Professor Sanborn did not recognize the value of detailed soil samples at the start of a field study but there is disagreement about the existence of soil samples taken in 1888. There are no 1888 samples in the soil storage area today nor are there any analytical data in the files.

The sampling in 1914 was the first recorded systematic sampling of each plot in depth (Figure 2). According to the record, the surface 12" were divided into three 4" increments and 28 samples at the locations as designated in Figure 2 were composited at each depth. The second 12" increment was divided into two sub-sections 12 to 18 and 18 to 24" below the soil surface. There were 16 samples taken at each depth and each depth was composited. The next two samples were taken at 24 to 36 and 36 to 48" in depth. Twelve of the 24 to 36" samples were taken and composited. Eight of the 36 to 48" depth samples were taken and composited. All samples were air dried, crushed to pass a 40 mesh screen, and stored in "sealed" glass jars. They were sent to the station chemist for total analysis but the methods used were not recorded.

The records of the 1928 soil sampling are incomplete. The old chemical analysis records state that the samples were taken in "Fall 1928". The listing of data show three depths of sampling: 0 - 8", 8 - 18", and 18 - 24". The data suggest only a composite sample was taken from each plot for each depth. There is no statement in the records indicating whether the sampling within each plot followed some systematic plan such as that used in 1914 or if a completely random approach was used.

The 1938 sampling was systematically done by Albert Fulkerson and L. B. Stuckey in December. Each plot had 12 sampling stations. The record book contains only a rough sketch of the systematic sampling and no dimensions were given. Samples were taken at 0 to 4, 4 to 8, and 8 to 12" with a 2" tube sampler. A 1 3/4" auger was used to get the 12 to 18" depth, 1 1/2" auger for the 18 to 24", a 1 1/4" auger to get the 24 to 36" depth and a 3/4" auger for the 36 to 48" depth. Apparently the samples within each plot were composited for each depth.

The record books suggest sets of soil samples were taken in both 1949 and 1950 but no sampling plan was recorded. N. C. Smith, on April 6-7, 1949, took samples 0 to 4", 4 to 8", and 8 to 12" from each plot. These samples were air dried to pass through a 40 mesh screen. The records contain "soil test" results from a set of soil samples taken in 1950. As with the 1949 samples, no sampling plan was recorded for the 1950 sampling and these samples were taken to two depths: 0 to 7, and 7 to 14".

The 1949 and the 1950 soil samples have been misplaced or lost. This is indeed unfortunate for at least two reasons. These would have been good indices of the state of the soil at the end of the "animal era" of agriculture and the start of intensive fertilization. Second, these samples could be useful as post-atomic bomb samples.

The next set of samples were taken in 1961 and 1962 to commemorate 75 years of continuous production on Sanborn Field. Two cores were taken within 1 foot of each 12 sampling stations arranged systematically on each plot. A 2" tube was used to get individual samples of the Ap, A1, A2 (E), and 10" of the B2. A 1" tube was used to collect 48" of soil at each sampling station. These 1" cores were divided into increments of 0 to 4, 4 to 8, 8 to 12, 12 to 18, 18 to 24, 24 to 36, and 36 to 48". Each depth increment was composited into a single sample for a given plot.

The 100th year samples were collected by a modification of the 1961-1962 plan. The 1988 sampling stations were slightly offset from the 1961-62 stations. Two cores were collected from only the 4 sampling stations nearest the center on each plot. This decision was based upon a detailed sampling of all 12 sampling stations on plot 24 in May 1987. The soil tests made on soil of the stations near the outer borders of the plot were quite variable. The planning committee decided that the purpose of the sampling was to estimate and/or evaluate changes on the plots due to treatments so the center 4 stations were selected.

One core at each station was divided into 10 cm increments with maximum depths from 120 to 140 cm. These were kept separate, dried, ground, and subjected to the routine Missouri soil tests (Brown and Rodriguez, 1985). Each of the second cores from each location was placed in a semicircular PVC pipe section and wrapped in plastic film to prevent evaporation of water. These cores were later subjected to morphological description and analyses by diagnostic horizons by Dr. David Hammer.

Periodically, after 1949, surface soil samples have been taken. This relatively frequent sampling was done to provide a basis for making the "full treatment" recommendations as described in other papers in this document. In addition, interest in soil testing increased as the practices promoted by Bray (1942) and others were adopted.

Activity on soil testing in Missouri actually started with Miller's publication of a modified Comber's test for acidity and lime requirement (Miller, 1936). Soil testing in Missouri after World War II culminated in the county soil testing lab program using the procedures published by Graham (1950). These procedures included the original Bray "strong" test (BK2) with a 7:1 extractant:soil ratio. Potassium was extracted with a 2:1 $NaNO_3$ solution:soil ratio with the K concentration measured by the sodium cobaltinitrite test. At this time, pH was measured in a 1:1 distilled water:soil suspension.

The Graham test procedures were likely used on soil samples taken from Sanborn Field up through the mid-1960's when the tests were shifted to those standardized for the North Central region (Dahnke, 1980; Brown and Rodriguez, 1983). In the mid-1950's, soil pH measurements started being made in 0.01 M $CaCl_2$ (Graham, 1959).

The work reported herein by Jirapunvanich (1987) utilized selected samples from 1914, 1928, 1939, 1962, and 1980. All samples were tested in duplicate for extractable P using the Bray and Kurtz 1 (BK1), Bray and Kurtz 2 (BK2), and Mehlich 3 (M3) extractants (Dahnke, 1980; Mehlich, 1984).

The Mehlich 3 extractant was developed as an alternative to the old double acid P extractant used in the southeastern U.S. (Mehlich, 1984). The Mehlich 3 has gained popularity as a "universal extractant" since introduction and is used as a single extractant for several extracted plant nutrients because the nutrient concentrations in the extract may be determined by inductively coupled plasma (ICP) spectrometers. Interpretations have been made using simple correlations with extractants such as BK1 and BK2 which had been previously calibrated through extensive field work. The BK1 and BK2 extractants were 0.03 M NH_4F in 0.025 M and 0.1 M HCl, respectively. A 10:1 extractant:soil ratio was used.

The analyses of the 1961-1962 core samples was done using BK1 and 2 for P (Graham, 1959). The 1987-1988 samples were tested by the methods outlined by Brown and Rodriguez (1983).

Results are presented in the same units as the original work. Extractable soil P was reported as pounds P_2O_5 per acre up through December 1982. It is assumed this unit was used to be consistent with the units of P used in the fertilizer trade.

Results and Discussion

The soil test results from 1949 through 1988 will be discussed first to show the effects on soil of the major management shifts made in 1950 and to illustrate test variability. Second, data on extractable P will be presented to show the changes that occurred from 1914 through 1980 using the same extraction methods on all ages of samples (Jirapunvanich, 1987). Third will be a brief demonstration of the profile distribution of test values on soils in 1987-88.

Soil Tests 1949-1960

The interest in soil testing during the middle of the 20th century made the Sanborn Field plots valuable regionally and within the state. Uncounted numbers of samples were taken from the field from 1949 until the mid-1970s to the point that the Sanborn Field Committee now requires a written proposal for each sampling exercise. In this way control of soil removal by man is maintained.

Comparison of results from each of these samplings from 1949 to present is subject to criticism because test methods have changed since 1949. The trends in results found on the different plots may be useful in explaining treatment effects. The soil test data from plots 25 through 28 serve to illustrate the information and misinformation one may glean from such data. Table 1 outlines the treatments and their modification (Upchurch, et al., 1985). Table 2 lists the soil test results on samples from plots 25 through 28. The 1938 samples were tested in 1950.

The extractable phosphorus was determined using the BK2 procedure and reported as pounds P_2O_5/A to be consistent with the method of expression used in Missouri up through December 31, 1982. The 1:7 soil-extractant ratio was used until 1969 when the ratio was shifted to 1:10 to conform to the "recommended" procedure (Dahnke et al., 1980)(The Delta Center lab shifted to 1:10 in 1965, John Garrett, 1989, Personal communication).

When the BK2 was used, the sufficiency level was 150 lbs P_2O_5/acre (Hanson and Brown, 1977). Plots 26 and 28 were designated in 1950 to receive "full treatment" which included holding the BK2 extractable P at 150 lbs P_2O_5/A. Table 2 shows that goal was clearly achieved. Note that in some cases in Table 2 the soil test was expressed as "224+". At the time these tests were made, the testing labs did not dilute the soil extract to obtain a quantitative figure since a test of 224 lbs P_2O_5/acre was well above the soil level where corrective treatments would be used.

Table 2 also shows that between 1955 and 1960 the manure treatment had raised the extractable P_2O_5 from 89 to 277 lbs/acre. We feel this reflects the variation in quality of manure used; this topic will be discussed in the section which compares soil tests for P.

The BK2 extractable P on plot 27, which has been untreated since 1888, showed a gradual decline between 1938 and 1988 although there were some instances of large variation e.g. 1980 vs. 1978 or 1988.

Missouri recommendations suggest that for the corn-wheat-clover rotation and a cation exchange capacity (CEC) of 11 millequivalents per 100 g the sufficiency level of K should be 275 lbs K/acre. The K extractant prior to 1968 was sodium nitrate solution and the concentration of K in the extract was determined by the sodium cobaltinitrite turbidimetric procedure (Graham, 1959). This turbidimetric technique does a marginal job of K extraction and tends to lack precision where temperature is not controlled as was the case when labs were not air conditioned.

The 1980 and 1988 results suggest that more attention should be given the K status of these plots. The increase in extractable K on plot 27 between 1978 and 1988 was unexpected and cannot be explained since the clover hay crop should reduce the K in the soil with time and the 1987 crop had been clover.

These results demonstrate that analyses done at different times on soil from samples provide inconsistent results. Soil samples from long-term studies must be taken periodically and stored. New techniques and/or new environmental concerns will make such samples valuable.

Extractable P

Some of the stored samples were selected to measure P extractability. Three P extractants were selected to evaluate the relative extractability of P on twenty-two of the 44 Sanborn Field plots were used by Jirapunvanich (1987). Details of the results of four of these plots are reported here.

Jirapunvanich (1987) used stored samples from selected Sanborn Field plots differing in P management history. The objective was to determine and compare the relative extractability of P by Mehlich 3, Bray 1, and Bray 2 from the samples from different plots and to evaluate the relationships between the extractants as indexed by extractable P.

The three tests for extractable P were evaluated over time and treatments. In this paper, the results from one rotation series (plots 25, 26, 27, and 28) and one continuously manured plot (plot 5) are used to graphically demonstrate the nature of the results.

The ranking of the three extractants on relative amounts of P extracted was predictable based upon acid concentration and ionic strengths, i.e. BK2 > Mehlich 3 > BK1.

One key observation was that extractable P on soil from all plots tended to decline from 1915 through 1938 (Figures 3, 4, 5, and 6). After 1938, slow decline in P ceased on most plots. It is unfortunate that the 1949-1950 soil samples were lost because sometime between 1938 and 1962, some drastic changes in P application must have occurred.

Extractable P in the 1938 sample from plot 25 was nearly the same with Mehlich 3 and BK2 with BK1 P being less. Between 1962 and 1980, the difference between BK1 and Mehlich 3 remained constant but BK2 extractable P increased much faster than P extracted by the other two extractants. This behavior is expected when soils are treated with rock phosphate but the records do not indicate that plot 25 received rock phosphate. This effect has been observed since World War II and may have been due to a shift in kind of manure used. Sometime around 1950, the source of manure shifted from bedding based material to a more concentrated material collected from concrete floored confinement systems. One explanation is that animals were moved from the campus to the modern facilities at the dairy and beef farms where less bedding, such as straw, was used.

Rock phosphate was applied to plot 26 (Figure 4) in 1950 and is reflected in the 1962 results. Note that only BK2 extractable P increased significantly. Plot 28 also received rock phosphate (Figure 6). Ninety-two years of cropping on plot 27 with no additions made the amount of extractable P so low that the results from the three tests are indistinguishable (Figure 5).

The relationship between the three tests did not always hold as shown in Figures 3 through 6. Plot 5 (Figure 7) has received annual applications of manure and the Mehlich 3 extractable P in recent years tends to parallel that extractable with BK2 rather than BK1.

The data were subjected to linear regression analysis by management groupings as outlined in Table 3. The poorest relationships between tests, as a group, were on samples which had been received no fertilizer. The low quantities of extractable P in these soils would be expected because any variability would be magnified by the low quantities of extractable P.

There was high correlation between all three tests made on soils which had received only processed phosphate or only manure in the earlier years of the study (prior to 1940). These results show that both BK2 and Mehlich 3 extract more soil P than BK1 but the slope of the relationship was near 1 (0.81 to 1.28) which suggests all tests could be intercalibrated on soils that have a history of no rock phosphate application. The intercepts of the regression equations calculated using results from manured plots (group B) were different from those with no rock phosphate (group D) but as with group D, the slopes were near 1 (0.99 to 1.02). This relationship was not true with results from the plots which had been treated with rock phosphate (Group C) but varied with the two extractants being compared.

The source of P had an effect upon the magnitude of difference between each two tests. For soils that had received organic P and soils that had received processed P, the 1:1 relationship between any two tests was close (r2 > .94). There were no such relationships for soils treated with rock phosphate. This likely means that any attempt to use the calibration data for one test as a basis for fertilizer P recommendation from soil test data of a second test would be in serious error on soils which had been treated with rock phosphate.

Based upon this work, it is recommended that if BK1 calibration data are used to interpret Mehlich 3 test results using a regression equation, that the data be separated into three management groups based upon sources of previous P treatments, i.e. organic P, rock P, and processed P. Table 4 was constructed to demonstrate that when a Mehlich 3-BK1 regression equation was calculated using all the data, the intercept differed from those on Table 3 where the data were divided into management groups.

Changes in Plant Nutrients with Depth

The core samples from the various plots provided a resource for trying to evaluate the effects of treatments upon the amount of extractable nutrients with depth. While this may be a valid approach, there are three problems which have been alluded to by other papers in this document. First, there were soil data from samples taken in 1888. Secondly, the soil samples taken since 1914 have not been subjected to a uniform set of soil analytical techniques. Third, the site likely had significant inherent variability so any comparisons between locations on the field are suspect.

In spite of these possible problems, cores were analyzed if for no other reason than to document their change and status in 1988. Bar graphs were selected to present the data to highlight the changes.

The BK II extractable P profiles were surprising. There is strong evidence of a marked lithologic discontinuity between plots 5 and 9 (Figure 8). A view of the plot arrangement (see Figure 1) will show that plot 9 is across the field alley west of plot 5. In that short distance, the extractable P between 50 cm and 120 cm in depth suggests a major difference between these two plots that is unexplained by cropping and past management.

The difference in the BK2 P profile between plots 5 and 9 was not as evident with the BK1 extractant (Figure 9). These two extractants differ only in acid concentration (BK1 = 0.025 M HCl; BK2 = 0.1 M HCl). (Bray 1942) maintained that the BK1 extracted "adsorbed" P while BK2 also extracted "acid soluble" P. The BK2 extractant was used in Illinois and Missouri on soils treated with rock phosphate to measure acid soluble P. The data present from the Jirapunvanich thesis attest to these differences in extractability of P in the surface samples. Therefore, it can be concluded that the subsoil of plot 9 contains much more apatite-like materials than plot 5 because of the greater amount of BK2 extractable P.

In the case of plots 5 and 9, it is unlikely that subsoil P below 50 cm has had much influence on crop yield. The lack of vigor of wheat on plot 9 due to N deficiency would result in a limited root system in wheat. However, this P difference with depth might have importance on those plots with P variable treatments.

Another example of the necessity to determine the nature of the subsoil is illustrated by Figure 9. Treatments on Plots 31, 32, and 33 differ only in the omission of K on 32 and P on 33. The last 7 crops of corn in this rotation have averaged 111, 106, and 111 bu/A on plots 31, 32, and 33, respectively.

Plot 32 was treated with 6 tons manure per acre through 1927 but has received no K since. The distribution of K in the profile explains the lack of marked yield reduction after not receiving any K since 1928. In this case, the green manure clover crop must bring sufficient K to the upper horizons to replenish the K removed by the grain crops. These results illustrate the need for long-term studies to measure soil changes.

Summary

This brief sampling of Sanborn Field data illustrates the kinds of evaluations that may come from long-term research studies. We do not know what advances in evaluation of soils lie ahead, but Sanborn Field history lesson dictates that any new long-term study site that is initiated must be thoroughly sampled with depth before plans are completed and the experiment is initiated. Otherwise, variability of subsoil properties such as evident on plots 5 and

9 may confound or negate findings in crop production.

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Table 1. Management Scheme of Sanborn Field plots in a corn-wheat-clover rotation (1928 through 1988).

Plot Number	Year New Plan Started 1928	 1940	 1950
25 (from 1888)	6T BYM/A/yr† before corn	5T BYM/A core corn + 100 lbs N/A 33 lbs N - wheat	6T BYM/A before
26 as 16% acid phosphate	Lime, 0-38-0	No change	Full treatment
27 (from 1888)	No treatment	No change	No change
28 8-24-8 in corn, wheat‡	Lime	No change soil test, 8-24-8 starter on corn, wheat	Lime, P, K per

† BYM is an abbreviation for barnyard manure.

‡ 8-24-8 ≠ N, $P_2 0_5$ and $K_2 0$ per acre.

Table 2. Soil tests of surface soil samples from plots in a 3 year corn-wheat-clover rotation.

		Plot Numbers and Soil Treatment			
Test and Units	Year	25 manure + N	26 Full	27 None	28 Full, No N
pH	1938	4.8	5.7	5.0	6.3
	49	5.3	6.7	5.1	7.1
	50	5.0	6.5	4.8	6.8
	55	4.6	6.7	4.5	6.4
	60	5.9/5.3†	6.6/6.0	5.1/4.5	6.8/6.4
	62	5.1/4.6	6.8/6.4	5.2/4.6	6.9/6.5
	67	-/4.7	-/6.2	-/4.9	-/6.7
	75	5.4/4.9	5.8/5.4	5.6/5.0	6.3/6.0
	78	-/5.7	-/5.6	-/5.1	-/6.1
	80	5.8/5.5	5.8/5.4	5.7/5.2	6.4/5.9
	88	-/5.6	-/5.0	-/5.1	-/5.6
lbs P_2O_5 per acre	1938	122	123	50	117
	49	90	70	36	94
	50	98	224+	36	224+
	55	89	224+	27	94
	60	277	294	31	156
	62	195	268	43	152
	67	205	236	25	182
	75	212	250+	28	234
	78	334	334	20	254
	80	254	306	46	252
	88	269	324	21	226
lbs K/A	1938	325	172	150	148
	49	128	60	104	62
	50	280+	280+	280+	280+
	55	234	156	202	171
	60	428	253	174	227
	62	400	240	205	158
	67	269	137	106	103
	75	165	332	98	195
	78	350	275	95	230
	80	270	218	131	211
	88	220	246	212	220
OM%	1938	Not Determined			
	49	2.2	2.4	2.0	2.2
	50	2.2	2.1	1.5	1.9
	55	2.6	2.7	2.1	2.3
	60	2.6	2.4	2.1	2.3
	62	2.4	1.9	1.8	2.0
	67	2.4	2.0	2.0	2.4
	75	2.4	2.2	1.5	2.4
	78	3.1	2.5	2.0	2.2
	80	2.5	2.1	1.8	1.6
	88	3.2	2.4	2.0	2.3

†pH values presented with a slash (/) are pH in distilled water on the left and pH in 0.01 M $CaCl_2$ on the right.

Table 3. Relationships among Bray #1, Bray #2, and Mehlich 3 soils tests by management groups.

Management groups†	Regression Equation	r2
A	BK #2 = 1.69 + 1.38 BK #1	0.86*
	Mehlich 3 = -2.17 + 1.73 BK #1	0.59
	Mehlich 3 = -4.68 + 1.27 BK #2	0.71
B	BK #2 = 21.41 + 0.99 BK #1	0.79
	Mehlich 3 = 5.84 + 1.22 BK #1	0.89
	Mehlich 3 = -7.45 + 1.02 BK #2	0.78
C	BK #2 = -41.02 + 4.36 BK #1	0.69
	Mehlich 3 = 2.08 + 1.27 BK #1	0.94
	Mehlich 3 = 23.59 + 0.21 BK #2	0.71
D	BK #2 = 8.04 + 1.28 BK #1	0.98
	Mehlich 3 = 9.17 + 1.05 BK #1	0.94
	Mehlich 3 = 3.02 + 0.81 BK #2	0.94

†A – Plots which received no treatment (9, 17, 23, 27, 33, and 13).

B – Plots which received only manure (5, 10, 18, 22, 19, and 25).
C – Plots which received rock phosphate during 1959-1980 period (1, 2, 4, 11, 20, 26, 28, 31, and 32).
D – Plots which received no rock phosphate (2, 4, 20, 26, 28, 31, and 32 from 1915 to 1938; and plot 14 from 1915 to 1980).
* All r2 were statistically significant at less than the 1% level of probability.

Table 4. The relationships between Mehlich 3 (M3) and Bray and Kurtz #1 (BK1) extractable P across all P treatment groups (Table 3).

Year of sampling	Regression Equation	r2
1915	M3 = -1.84 + 1.37 BK1	0.85
1928	M3 = 7.04 + 1.23 BK1	0.75
1938	M3 = -0.29 + 1.52 BK1	0.94
1962	M3 = 1.80 + 1.33 BK1	0.98
1980	M3 = 2.09 + 1.16 BK1	0.98
1915-1980*	M3 = 4.23 + 1.21 BK1	0.95

+ The r2 for all equations were statistically significant at the 1% level.
* Excluding 1928 samples

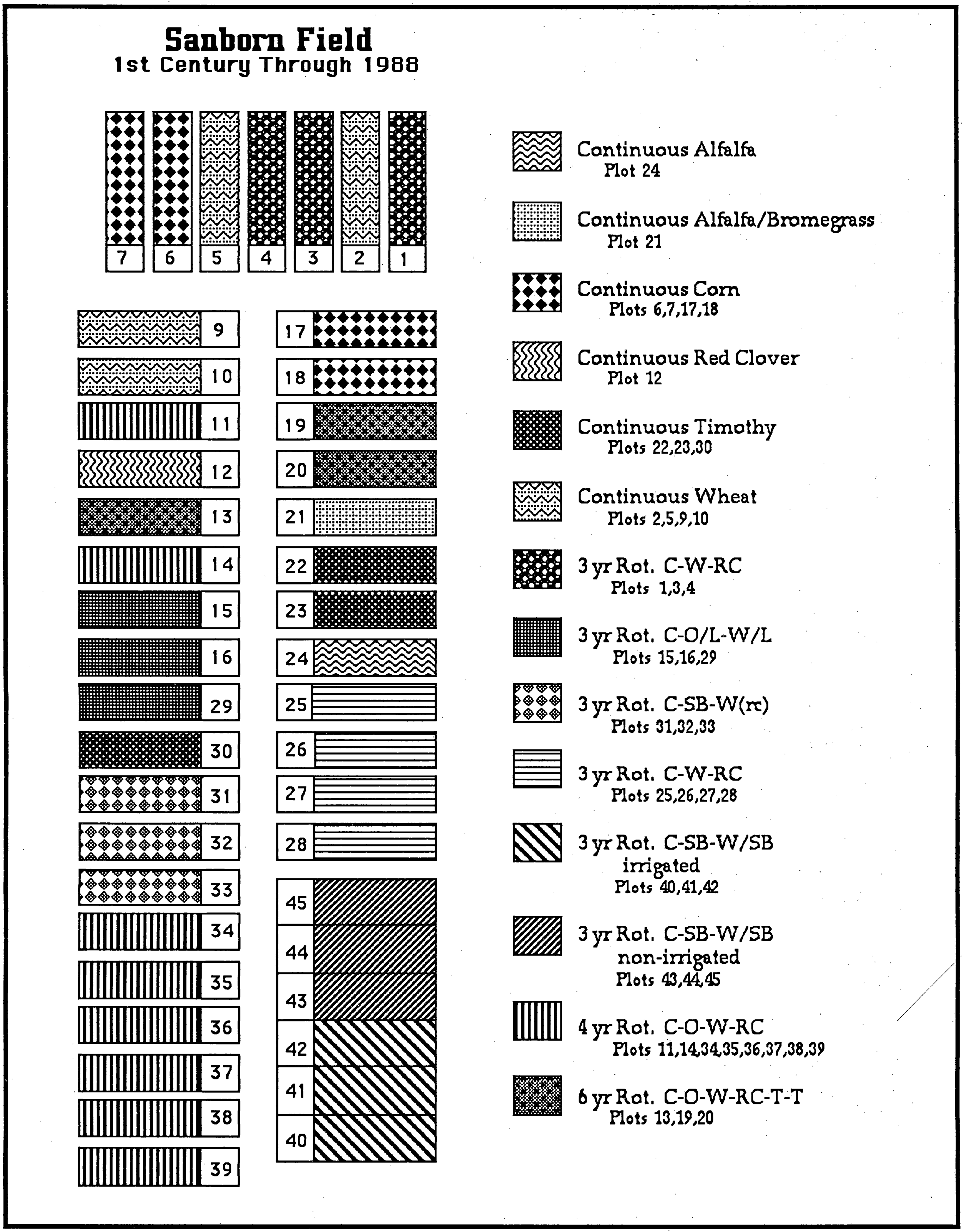

Figure 1. Layout of plots on Sanborn Field.

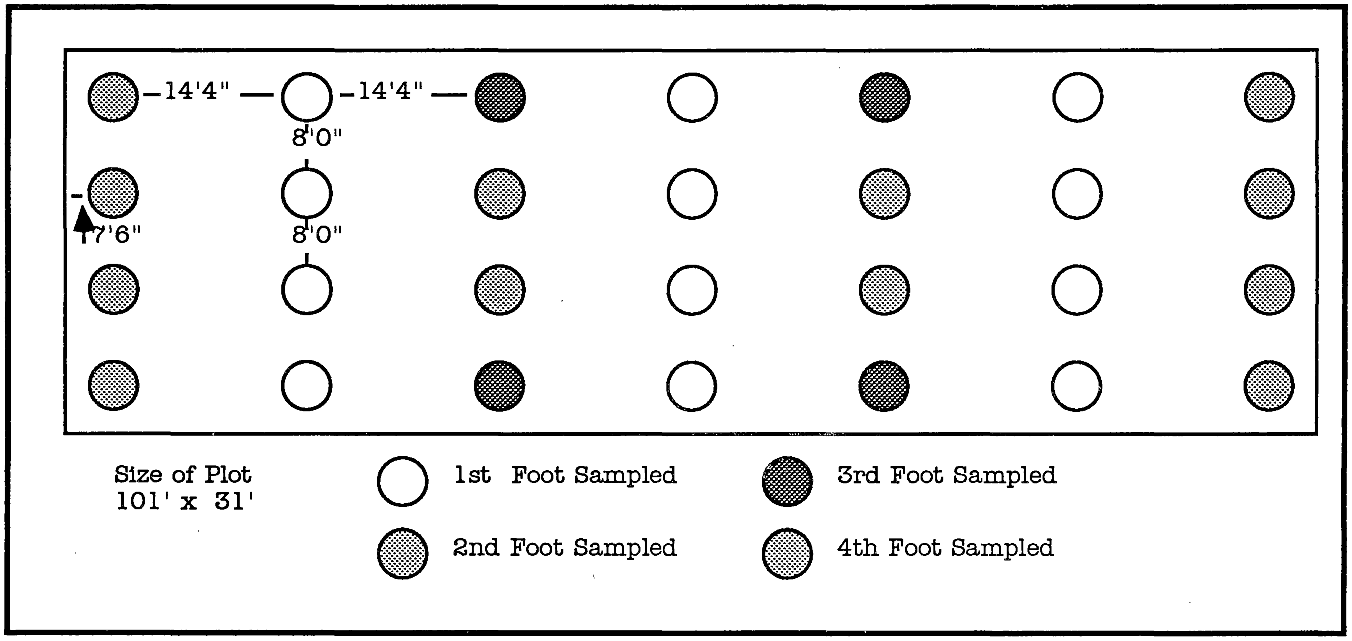

Figure 2. Sanborn Field plot samplings, 1914.

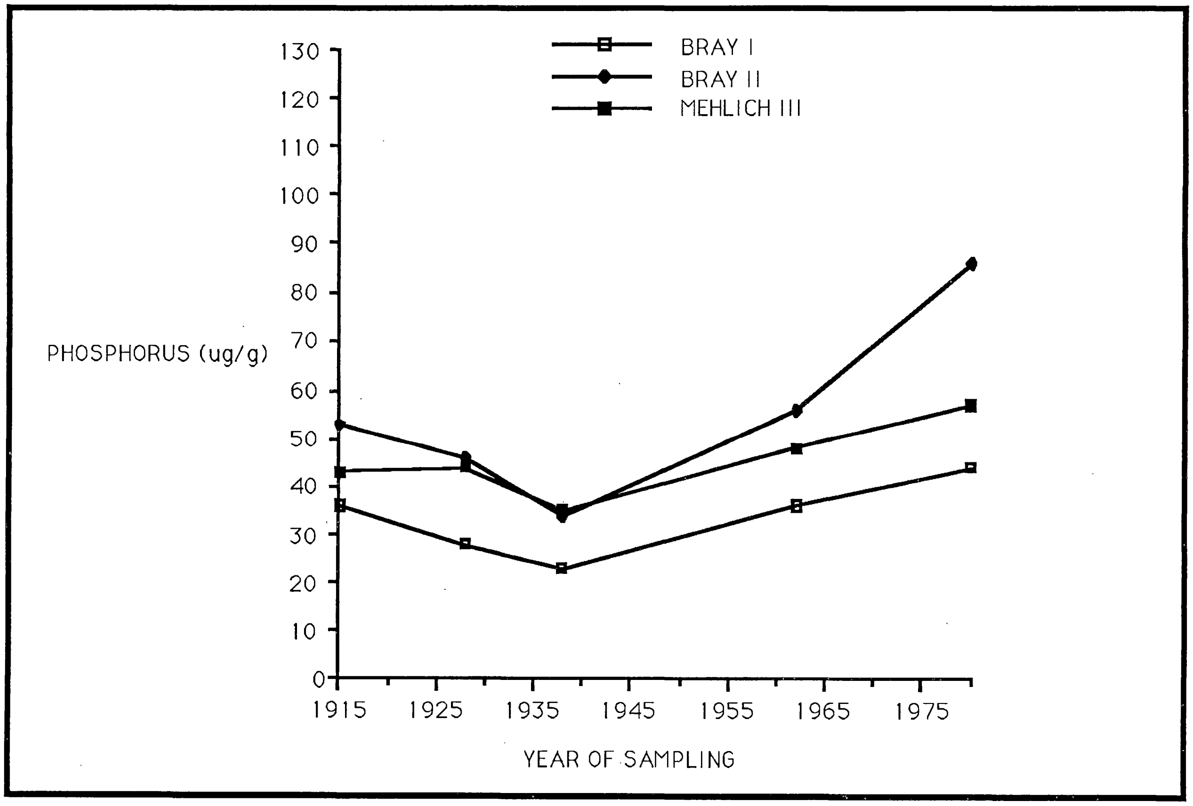

Figure 3. Soil tests on plot 25 (3 yr. rotation).

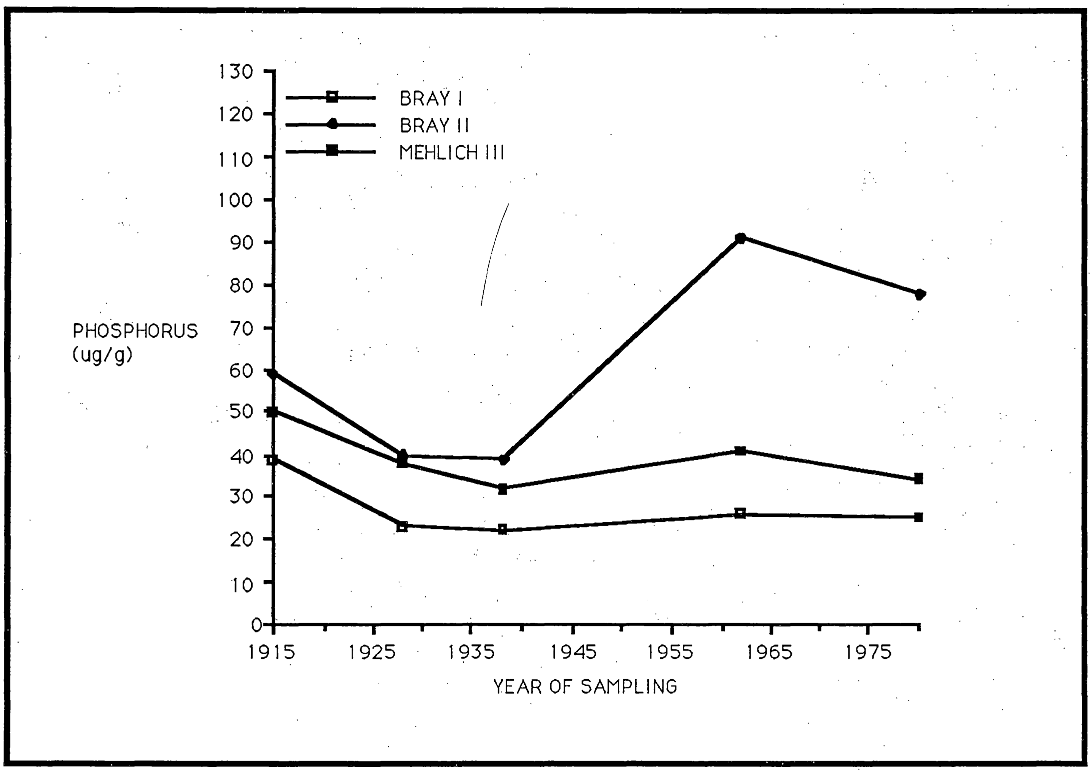

Figure 4. Soil tests on plot 26 (3 yr. rotation).

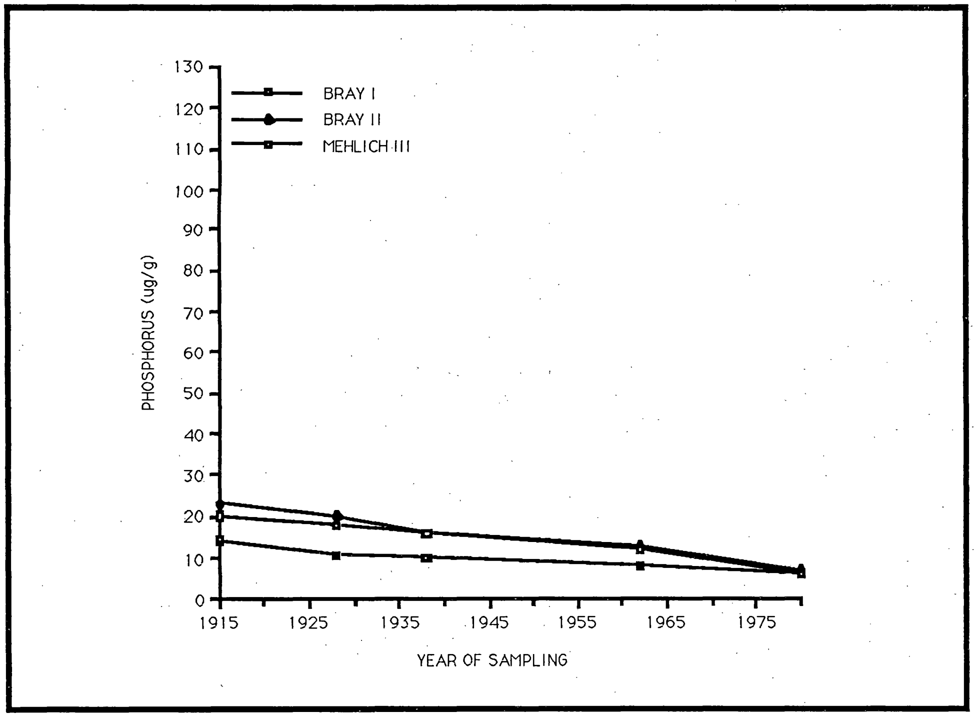

Figure 5. Soil tests on plot 27 (3 yr. rotation).

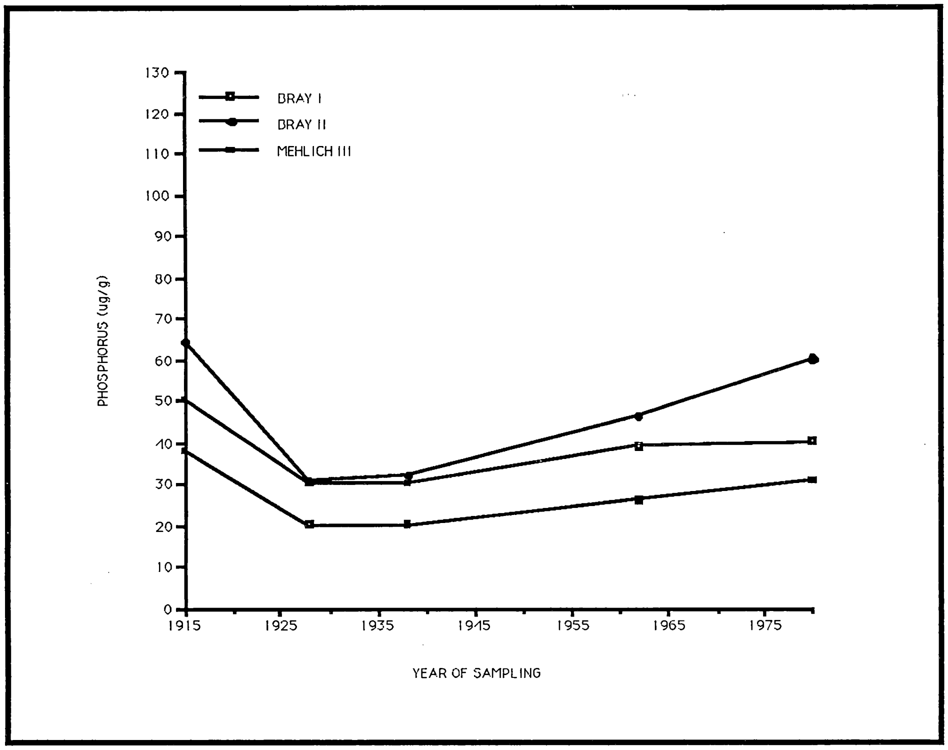

Figure 6. Soil tests on plot 28 (3 yr. rotation).

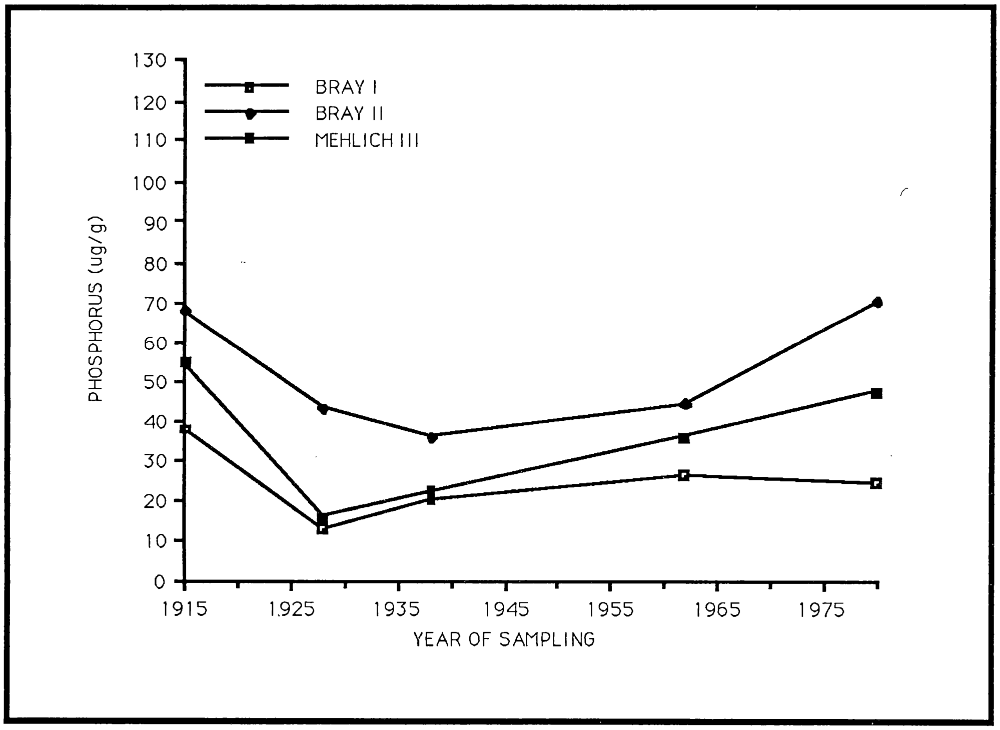

Figure 7. Soil tests on plot 5 (continuous wheat).

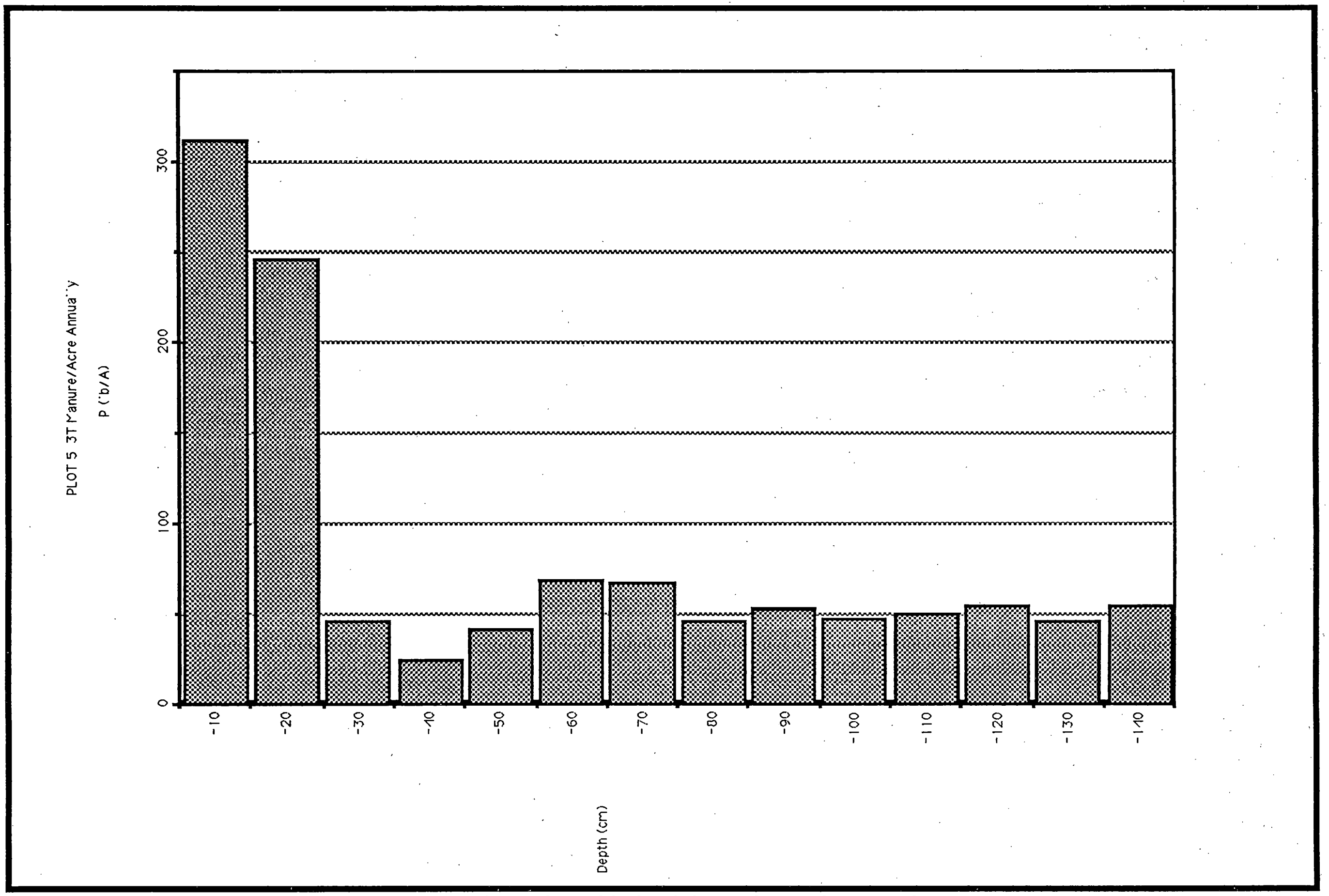

Figure 8. Distribution of Bray and Kurtz extractable soil P with depth Plot 5 in continuous wheat, 1988.

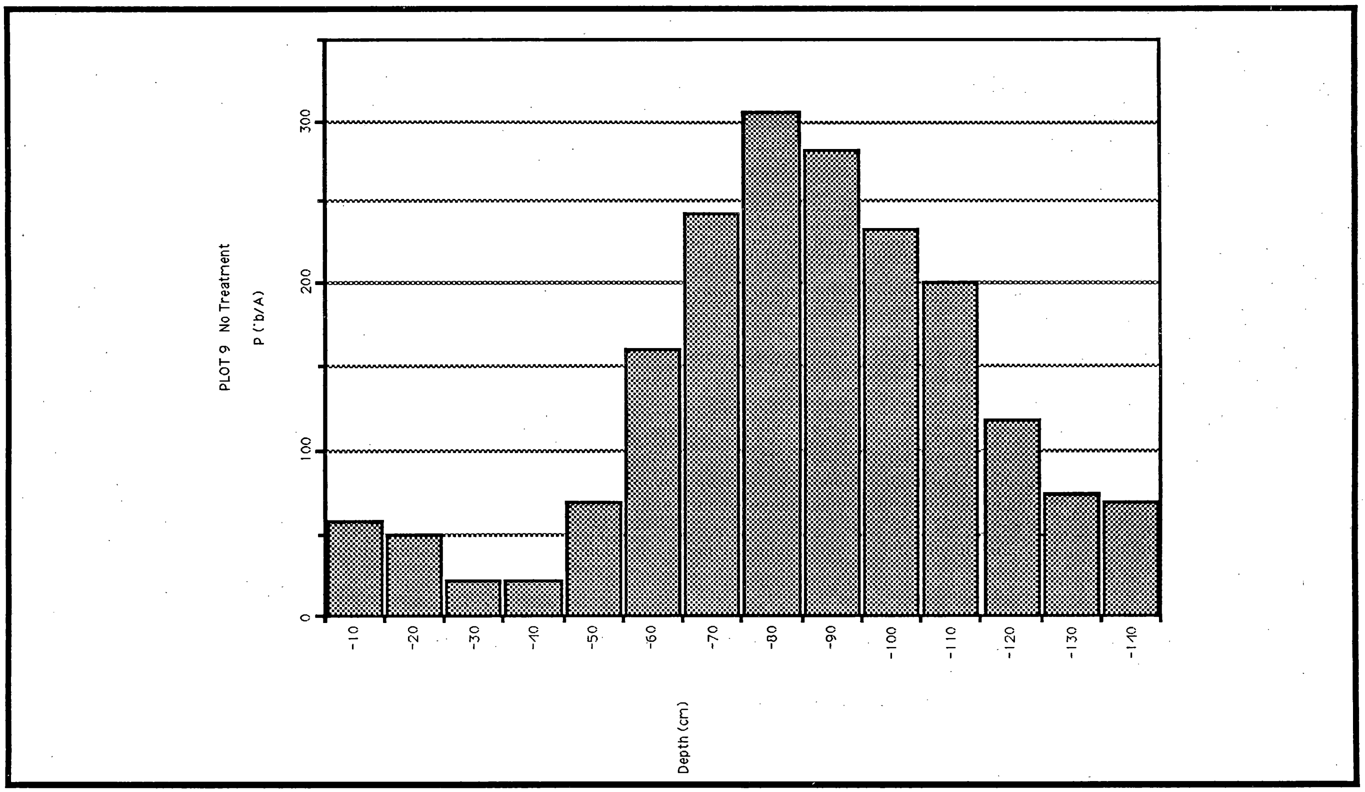

Figure 8. Distribution of Bray and Kurtz extractable soil P with depth Plot 9 in continuous wheat, 1988.

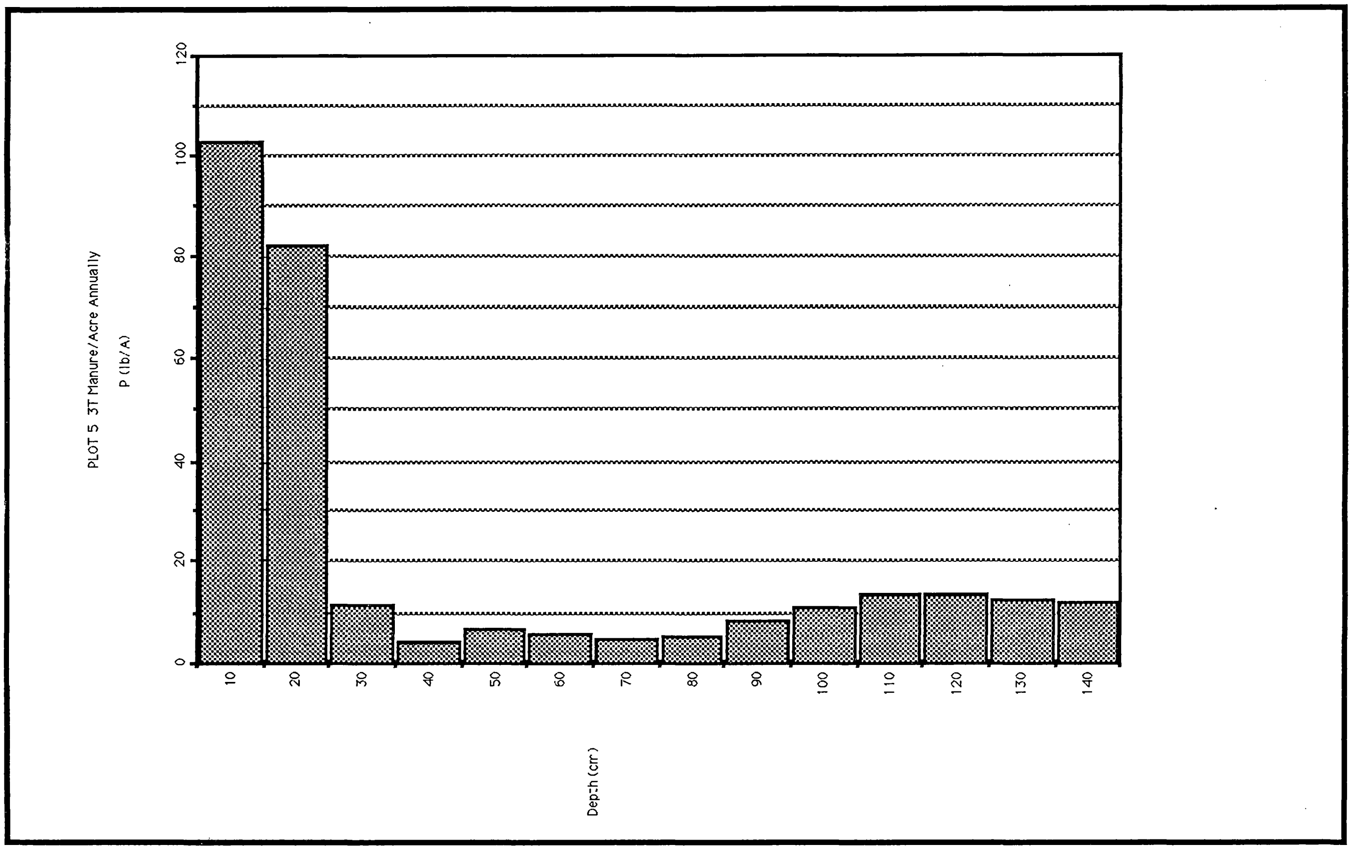

Figure 9. Distribution of Bray and Kurtz extractable soil P with depth Plot 5 in continuous wheat, 1988.

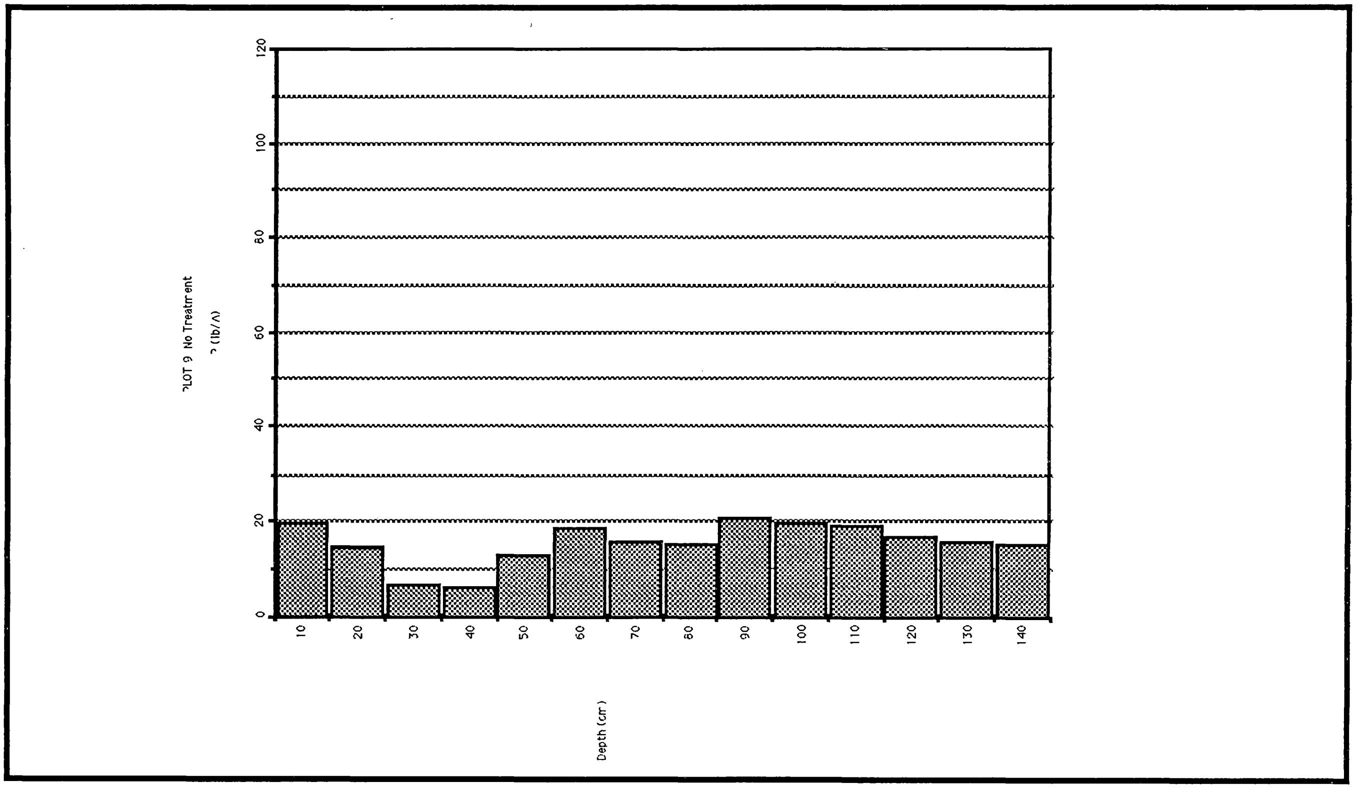

Figure 9. Distribution of Bray and Kurtz extractable soil P with depth Plot 9 in continuous wheat, 1988.

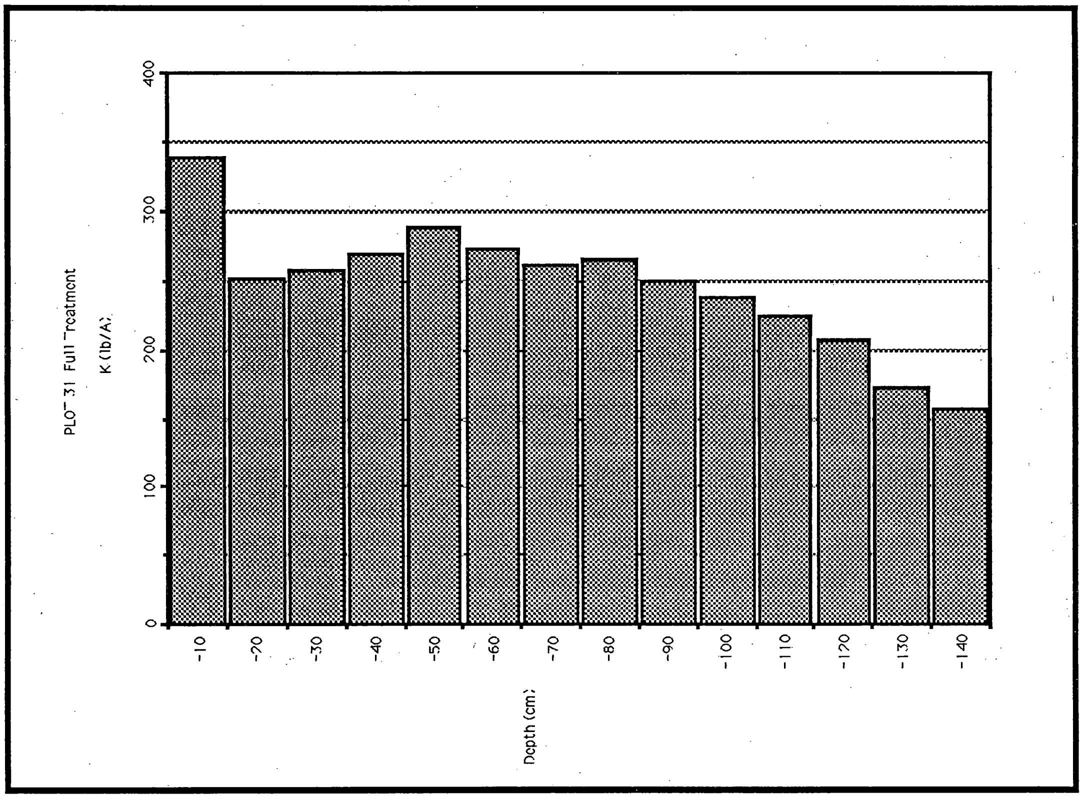

Figure 10. Extractable soil K with depth on plot 31 under a corn-soybean-wheat (clover) rotation, 1981.

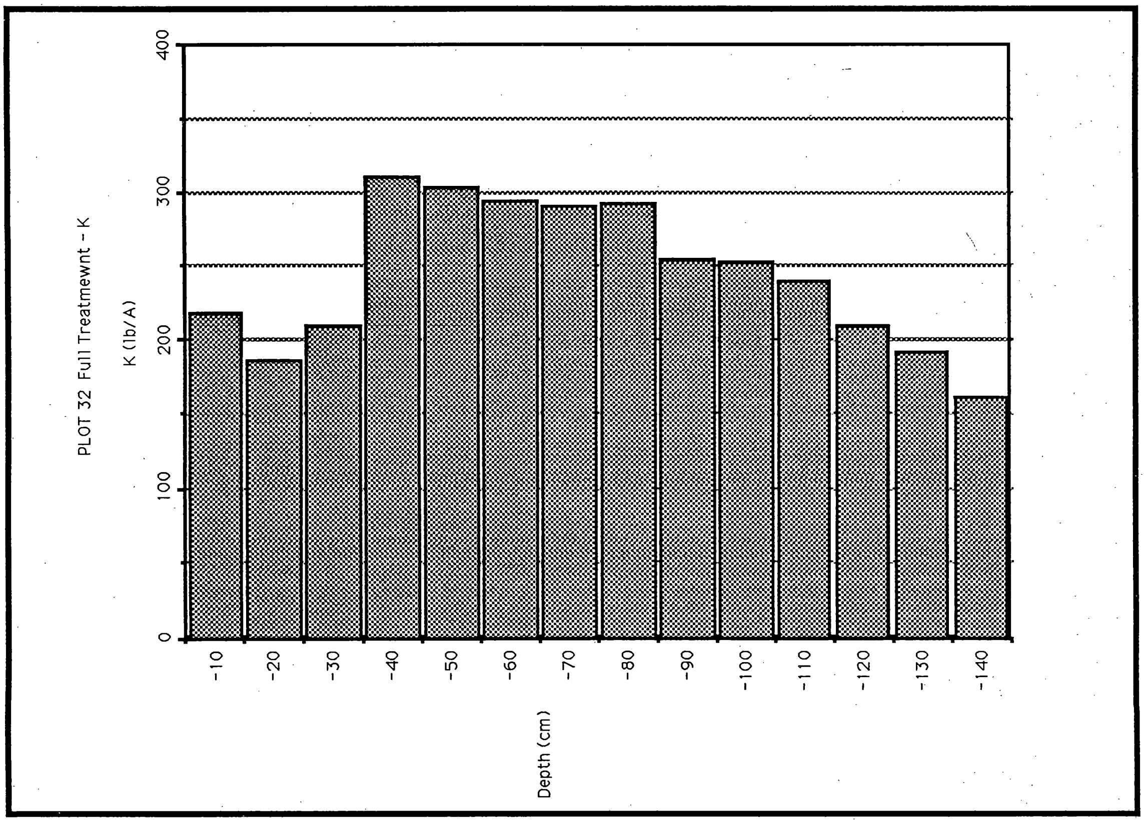

Figure 10. Extractable soil K with depth on plot 32 under a corn-soybean-wheat (clover) rotation, 1981.

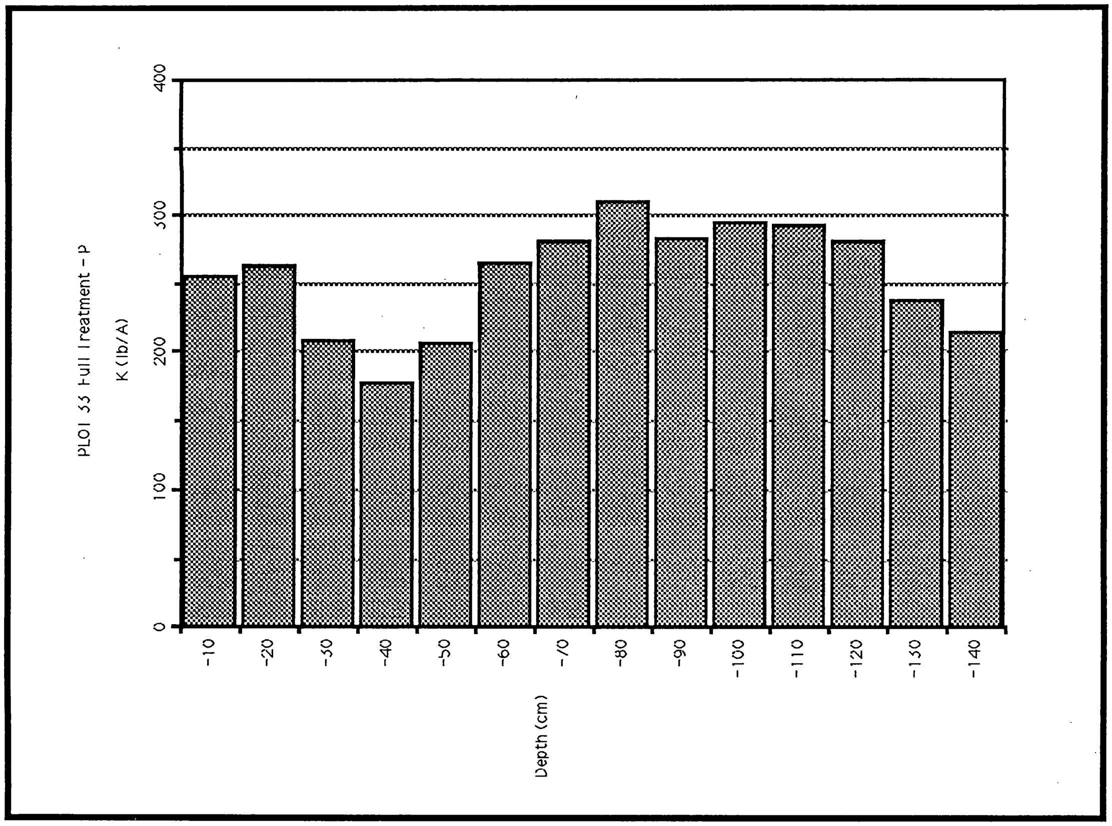

Figure 10. Extractable soil K with depth on plot 33 under a corn-soybean-wheat (clover) rotation, 1981.

100-Year-Old Cropping Systems: Yields and Soil Properties

G. A. Buyanovsky, C. J. Nelson, and S. Breight

One hundred years is a very long period for plot maintenance and data collection from a field experiment. At least four generations of supervisors have been involved during this time, and each has brought about new ideas and new priorities as agriculture as a whole developed. This explains why Sanborn Field has experienced several waves of "new thinking" (Upchurch et al., 1985).

During the 100 years, new technologies of cropping and soil treatments evolved, improved varieties of crops were introduced, and the use of mineral fertilizers changed dramatically. Naturally, the initial design of the field had to be adjusted, to incorporate modern practices which already had found their way to commercial farming, and because some systems were proven to be impractical.

Despite all temptations, several treatments maintained their integrity throughout the first 100 years, and are summarized in this report. Those systems provide us with invaluable data for determining long-term effects of crop and soil management on productivity and properties of the soil. Unfortunately, we know little about the initial soil properties. We assume that the soil of Sanborn Field, which was mapped as Mexico silt loam by Krusecropf and Scrivner (1962), 100 years ago was similar to that found associated with a tallgrass prairie. Thus, as a reference point, we have chosen an area of native grassland known as Tucker prairie. That virgin prairie, located about 15 miles east of Columbia on Putnam-Mexico soil association, has been monitored closely over the past 20 years, and is managed in several ways to maintain a natural condition (Kucera et al., 1967).

Crops and Treatments

The systems which were maintained through 100 years were mainly those with no treatment or with manure application (Table 1). Only one plot with continuous wheat was designed to receive "complete fertilizer for maximum crop" (Miller and Hudelson, 1921). The rate was determined as "annual application of enough sodium nitrate, dissolved bone or acid phosphate, and muriate of potash to replace all of the nitrogen, phosphorus, and potassium removed in a 40 bushel crop of wheat with 2 tons of straw." In accord with plant composition data of Morrison (1956), this rate approximated today's "full treatment" for wheat (50-20-20).

Wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), and oats (*Avena sativa* L.) were the major grain crops, and clover (*Trifolium pratense* L.) and timothy (*Phleum pratense* L.) were the main forage components of rotations around 1888. Wheat and corn have been grown continuously and also in seven systems of crop rotation. Timothy has been grown continuously for 100 years with and without manure. Varieties for each crop were selected to represent the highest yielding ones at a given time. Attempts were made to use the same variety for several consecutive years.

Barnyard manure was used as fertilizer. The manure is thought to be from a horse barn for the first 50 years or so. Later, it has been from a dairy barn, being composted during the year. No manure analysis has been made. During the first 50 years, nitrogen was applied as Chile niter (sodium nitrate that occurs naturally) and later (since 1950) as ammonium nitrate (34-0-0). Fertilizer P was applied as crude grade acid phosphate or normal superphosphate (16% and 20% P_2O_5, respectively) for the first several decades. After the mid 1940s, P was applied as superphosphate. Potash was applied in the form of muriate (potassium chloride).

The grain crops were harvested at maturity either by hand or using current farming technology. In normal weather years, wheat was harvested in late June to early July, corn in late September. Forage yields in recent years have been estimated with strips cut with a plot mower. The plot was then cleaned with a tractor mounted mower. Earlier, the forage yields were cut with a field mower, allowed to dry, and the entire plot yield of hay was weighed. Perennial grasses and red clover were normally harvested twice each year.

All plot operations were performed using field-size equipment, with changes throughout the period dictated by the development of agricultural machinery, including the disappearance of the horse and the introduction of the tractor. Currently, all equipment is that usable with a 40 to 50-horsepower tractor (a 2-plow tractor in 1940s jargon). A moldboard plow set for about 8 inches depth has been used for conventional tillage in the fall. Seedbed preparation just prior to planting was performed with two passes of a disk and a pass of a finishing harrow.

The planting of crops was usually done at recommended times with minor adjustments due to weather conditions. Winter wheat was usually planted in the middle of October, corn was planted in late April or early May. All crops were seeded at the recommended seeding rates. Wheat was sown at 90 lbs/acre with 6-inch rows. Corn seeding rates were variable, reflecting the nutrient status and expected yield goal of each plot. The population was 12,000 plants/acre for continuous corn; in rotations, the population was 19,000 plants/acre with manure, and

13,000 plants/acre with no treatment.

Forage crops that followed a small grain crop in rotation were usually frost seeded into the grain crop during early February. Plant vigor and persistence have been problems in continuous timothy with no treatment. Therefore, reseeding of both continuous timothy plots was done in the fall about every 4 to 5 years in a prepared seedbed.

Up to the early 1960s, stover was weighed and removed from plots under systems 1a, 1b, 1c, and 1d (continuous wheat), however, during the last 30 years, this practice has not been used. Stover has been spread uniformly over the plot.

Crop Response

Wheat

Wheat grown continuously for 100 years without fertilizers caused a gradual decrease in soil productivity (Fig. 1). Grain yield for the first 50 years (1888-1938) averaged 10.3 bu/acre (Smith, 1942), but in some years the yield was as high as 20 bu/acre. Yields were significantly lower during the 1940s and 1950s (4 to 5 bu/acre). After the introduction of new varieties in the 1960s, however, yields were higher for a short period, but later decreased again. In general, yields for the first 50-year period were higher than for the last 50 years (10.3 bu/acre vs. 8.6 bu/acre).

Nonfertilized wheat in a 3-year rotation with corn and clover (system 6a) had about 50% higher yields than nonfertilized continuous wheat (Table 2). A four-year rotation (system 10a which includes corn, oats, and a legume) gave a significant increase in wheat yields as compared with other rotations. This was probably due to the different crop sequence: in the 3-year rotation wheat follows corn; in the 4-year rotation it follows oats. Due to the short time period between corn harvest (late September to early October) and wheat planting (late October) there is little chance that soil can restore its water storage and recycle nutrients from residues. This could cause a negative effect on wheat development. In contrast, in the 4-year rotation oats are harvested in July allowing a fallow period during which the soil accumulates water and nutrients. Alternatively, corn may be more efficient in using some nutrients in the non-fertilized soil than oats. Thus, when wheat is planted following corn, it is subjected to a different residual supply of nutrients. Likely, both factors are involved and contribute to the rotation effect. Adding two years of timothy to the rotation (compare system 10a with 11a) decreased wheat yields to about 75% of those in the 4-year rotation.

Application of barnyard manure or chemical fertilizers was very effective in increasing yields of continuously grown wheat (Fig. 1). Manure at 3 t/acre increased average yield for the 100 years to 22 bu/acre, or more than double that of non-fertilized wheat. With 6 t/acre manure, average yield was 25 bu/acre, but the difference between manure rates, using years as reps, was not significant at the $P < 0.05$ level (Table 2). The trend of 5-year moving averages (Fig. 1), nevertheless, consistently indicates a greater yield from the 6 t/acre rate. Much of the increase in yield occurred during the past 30 years, presumably after improved varieties were used that were responsive to inputs. In rotations, manure (systems 6b, 10b, and 11b) significantly increased yields of wheat (up to 45%) over non-fertilized systems (6a, 10a, and 11b).

Mineral fertilizers were not used widely in 1888, and they were applied only in systems 1d and 11c. For more than 60 years, “chemicals for 40 bu/acre of wheat grain” were applied to the plot under system 1d. In 1950, the plot was switched to “full treatment” (53-20-20). It should be noted, however, that during the first 60 years yields never reached 40 bu/acre, and averaged only 19.7 ± 5.7 bu/acre. For the period of 1950-1988, the average yield was close to the initial goal, and in some years it reached 55 to 60 bu/acre, with an average for 40 years of 35 bu/acre. In general, yields of continuously grown wheat with full treatment (system 1d, 53-20-20 applied annually) were similar to yields of system 1c with 6 t/acre manure (Table 2). Fertilized treatments usually had numerically higher yields than manure treatments, but the difference between them for 100 years is not significant. The exception is a 6-year rotation with full treatment (system 11c) where the highest average wheat yield was attained. Under this treatment, corn received 140-24-24, oats/wheat received 60-20-0, timothy received 66-0-0, and clover received P and K per crop removal.

In general, average yields of rotated wheat receiving a manure treatment (system 6b, 10b, and 11b) were about 25% higher ($P < 0.05$) than those of continuous wheat which received the same treatment (system 1c). Sometime between 1915 and 1928, Miller and Duley (cit. Upchurch et al., 1985) observed that manured wheat gave good growth of straw, but the crop ripened unevenly. By contrast, wheat fertilized with mineral fertilizers usually matured more evenly and several days earlier than other treatments. They concluded that the cause of these differences was phosphorus. We found that the harvest index (ratio of grain to total harvested material) for wheat receiving no fertilizer treatment and wheat receiving full treatment for 100 years was 0.42 and 0.36, respectively, and for manured wheat (6 t/acre) it was 0.33 (Fig. 2). This confirmed the earlier observation that yield of straw was better on manured plots. However, after 100 years, the content of available phosphorus, measured by Bray 2 extraction, is higher on the manure-treated than on the full-fertilizer treated plots (Table 3).

Continuous wheat had the best effect on the soil when 6t of manure were applied annually. Under this treatment, the soil pH increased substantially, the organic matter content decreased only to 2.8%, and the soil accumulated available P_2O_5 and K_2O to very high levels (Table 3).

Corn

Several systems involving corn have been maintained since 1888 (Table 1). Non-fertilized, continuous corn had the lowest productivity (Table 4). The decline in yields noted during the whole period continued throughout the second 50 years despite the introduction of new more productive varieties (Fig. 3). The average yield for 1888-1938 was 18.5 bu/acre, and for five consecutive decades since 1938, yields gradually declined to average only 8 to 9 bu/acre during the last 20 years. In contrast, manure application (6 t/acre, system 4b) increased average yield of continuous corn to 33 bu/acre for 1888-1938. Average yield was significantly higher for the last 50 years (41.9 bu/acre), and even more during the last 15 years (67.7 bu/acre).

Corn yield from non-fertilized rotations was 2 to 3 times higher than from non-fertilized continuous corn for the whole period, and the difference was greatest during the last 15 years. Since 1975, corn in rotation yielded 5 to 6 times more than that grown continuously. Productivity of corn in all non-fertilized rotations (3-year rotation - system 6a, 4-year rotation - system 10a, and 6-year rotation - system 11a) was similar for the last 15 years, averaging between 50 and 60 bu/acre. For the first 50 years of the Sanborn Field experiments, productivity of these systems varied between 30 and 40 bu/acre.

Manure application in rotations was not very effective for improving corn yield. For example, in the 4-year rotation (corn-oats-wheat-clover) with 6t manure applied annually the yield during an earlier period (1888-1938) varied from 41 to 47 bu/acre, and was increased for the whole period from 54 to 64 bu/acre. A significant increase was obtained when manure treatment was supplemented with nitrogen (73 bu/acre, system 6b).

One hundred years of continuous non-fertilized corn dramatically changed the soil (Table 3). The soil lost most of its organic matter and nutrients partly as a result of the erosion process. Likely, decreased fertility decreased biomass yields, which in turn offered less soil protection, especially since the stover was also removed. In contrast, application of manure at 3 t/acre, and especially at 6 t/acre maintained pH, organic matter, and built up the P and K test. The lack of response of corn yield to manure application may be more closely associated with soil properties other than fertility status.

Timothy

Timothy was grown continuously (systems 15a and 15b) and in a 6-year rotation (corn-oats-wheat-clover-timothy-timothy, systems 11a, 11b, and 11c). Without fertilizer, timothy grown continuously steadily decreased in productivity (Fig. 4). After high yields in 1891-1895 (1.9 to 2.7 t/acre), yields decreased to nearly half, and for the 100 years, the average was only 1.2 t/acre (Table 5). The stand of non-fertilized continuous timothy deteriorated rather fast, and the plot had to be reseeded almost every 4 to 5 years. Assuming the forage removed contained 0.14% P and 1.59% K (Morrison, 1956), timothy extracted and removed significant amounts of nutrients from the soil during the 100 years (about 120 lbs/acre of P_2O_5 and 1,350 lbs/acre of K_2O), and the content of available phosphorus and potassium in the soil was depleted (Table 3). In 1980, the soil was very low in nutrients (only 8 lbs/acre of P_2O_5 and 105 lbs/acre of K_2O). Due to a well developed root system of timothy, and less tillage disturbance, loss of topsoil and organic matter in the plow layer was considerably less (from assumed 4.2% in native prairie to 2.1%) than with continuous non-fertilized wheat or corn.

Timothy in 6-year rotation without fertilizers (system 11a) gave the same amount of forage as non-fertilized continuous timothy (average for the first 50 years was 1.3 t/acre, and for 100 years was 1.1 t/acre). Since the late 1940s, this system could no longer sustain vigorous timothy. Timothy in the second year was usually choked by weeds, mainly summer annual grasses, which covered nearly all of the plot.

Application of manure (6 t/acre) doubled forage yield in continuous timothy (average for the first 50 years was 2.5 t/acre, for the whole period was 2.3 t/acre). In some years, up to 3.5 t/acre of hay was collected. The effect of manure on hay yield in the 6-year rotation was the same (2.7 t/acre of forage on average).

The soil under manured continuous timothy underwent positive changes (Table 3). Content of organic matter in this plot after 100 years was the highest of all manured treatments on Sanborn Field, although it was lower than in the same soil under native prairie that is predominated by warm season prairie grasses (Buyanovsky et al., 1987). Phosphorus and potassium availabilities were high (446 and 239 lbs/acre, respectively). The effect of manuring on the soil fertility was less visible in the long-term rotation with timothy (system 11b).

Some Ideas and Conclusions

We are already at the beginning of the second century, but unfortunately thorough scientific analysis of the results of the first 100 years has not been completed. Such an analysis will require significant time and effort. Some results, however, are clear and should be emphasized.

The first result is the near complete mineral depletion and loss of soil organic matter, not only under continuous grain crops, but also under continuous timothy when no manure or fertilizer was applied. The content of organic matter under corn and wheat has decreased to one-third to one-fourth that of the native prairie in our geographical area. Continuous timothy does not have such a deleterious effect on soil organic matter, but in no way is it self-supportive or able to maintain organic matter to the same degree as native prairies. This may be due to the less extensive rooting of timothy, its generally lower yield potential, and the fact that the stand deteriorated and had to be reseeded regularly. Tillage kills the roots, mixes the organic matter in the plow layer, and may speed loss of organic carbon.

Adding two years of timothy to a four-year rotation (system 10a and 10b) to make a six-year rotation system (11a and 11b) had little influence on soil properties when plots were nonfertilized (Table 3). When 6 t/acre of manure were applied annually (compare system 10b and 11b), the addition of timothy to the rotation caused an increase in organic matter, but phosphorus, potassium, and pH were lower than for the four-year rotation. This again suggests that two years of timothy in a rotation were not enough to maintain the soil productivity.

One can distinguish plot 9 (continuous wheat) and plot 17 (continuous corn) even in winter by the soil color and texture. Judging from equations describing relationships between the number of years under continuous cultivation and productivity (Fig. 5), we expect further gradual decrease in yields for the second 100 years. Although the practice of residue removal has been abandoned for about 40 years, retaining the residue did not increase yields or soil nutrient accumulation with corn, and for wheat only a short-lived increase in yield was observed when a new, more productive variety was introduced. Then wheat yield returned to the previous low productivity. We have calculated the removal of major nutrients during 100 years (Table 6), and the annual removal rates for these elements for each quarter of the century (Table 7). The amounts of Ca, P, N, and K removed from the soil during 100 years are much higher than the available resources of the soil under native vegetation (Table 3). As the resources of these elements declined, their rate of uptake decreased and the productivity of the soil deteriorated dramatically.

Current plans for the second century of Sanborn Field are to maintain continuous wheat and continuous corn plots, with and without 6 t/acre of manure annually. Likewise, the continuous timothy with and without manure will be continued. These decisions are based largely on the historical significance for the wheat and corn plots, and on the significant nature of plot 23, the source of aureomycin, which is in continuous timothy. In addition, the three-year rotation of corn-wheat-clover (systems 6a and 6b) will be maintained for the next 100 years. That rotation will allow comparisons to be made between corn and wheat grown in rotation with the same species in continuous cropping.

As indicated in Figure 5, we do not predict much change in yield response on the continuous cropping treatments, and probably not much change in soil status in the non-fertilized treatments. There may be continued decrease due to soil erosion. There may be occasional increases in yield due to new varieties, especially if some are developed specifically for low-input agriculture. That variety comparison, however, may include the necessity to "split the plot", a decision that has not been looked at favorably for the first 100 years. The detailed soil analyses, especially assessment of variability within the individual plots, may or may not show that splitting the plot is feasible.

Another long-term implication is the growing awareness of shifts over time in climate, e.g. the increase in CO_2 and associated changes in rainfall patterns and air temperature, and increased emphasis on environmental quality. For the first 100 years, no pesticides were used on Sanborn Field plots in the long-term studies. That policy had to be abandoned in fall, 1988 due to budget constraints, which will limit the use of the cropping systems for certain environmental assessments in the future. Even so, there is a need for documented long-term studies for monitoring and evaluating long-term changes in the environment. The plots being retained for the second century should allow continuation of use of soil-crop ecosystem for environmental monitoring.

Some would argue that continuous non-fertilized farming systems have proven to be impractical, and perhaps there is no reason to keep those systems for the second 100 years. It may be more logical to split those plots in order to determine how long it would take to restore, at least partly, the productivity of exhausted soil by introducing rotations, manure or mineral fertilizers. It would be another way to demonstrate and evaluate the long-term value of cropping systems.

Rotations show less negative effects over the 100 years compared with non-fertilized continuous cropping. In some cases, rotations have the same influence as the annual application of manure or mineral fertilizers. In the current era of overproduction, environmental concerns, and the rising popularity of "organic agriculture", we must consider our historical, current, and future attitudes regarding continuous cropping and the value of simple rotations. On Sanborn Field, yields of wheat from a non-fertilized 3-year rotation (corn-wheat-clover, system 6a) were not different from continuous wheat with full treatment for the last 15 years. Corn, with high requirements for nutrients, does not respond to rotations as well as wheat (corn yields in the same rotation are two times less than that in the full mineral fertilizer system). However, we cannot preclude that under the pressure of environmental concerns some producers in the near future will opt for lower yields of "organically grown" corn and other grain crops. There is growing evidence that the public will be willing to pay higher prices for products that are perceived to be "clean" or "natural".

As for the effect on the soil, rotations reduce the amount of soil erosion, but usually deplete the soil in nutrients, especially phosphorus. This problem, however, can be solved with the application of small amounts of phosphate fertilizer. Perhaps some long-term research efforts should, at least in part, be directed toward determining the lowest rates of fertilizers needed to sustain moderate production and to maintain a quality environment.

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Table 1. Cropping systems that were not altered during 100 years.

System No.	Crops	Fertilizers (N, P_2O_5, K_2O) lbs/acre	Years	Plot No.
1a	continuous wheat	none	1888-1988	9
1b		manure, 3t/acre	1914-1988	5
1c		manure, 6t/acre	1888-1988	10
1d		chem. for 40 bu (50-20-20)	1888-1927	2
		1/3N fall, 2/3 N spring	1928-1949	2
		full treatment (20-20-20 starter 33-0-0 topdressed as needed)	1950-1988	2
4a	continuous corn	none	1888-1988	17
4b		6t manure	1888-1988	18
6a	corn-wheat-sweet or red clover	none	1888-1988	27
6b		6t manure annually, 100-0-0 for corn, 33-0-0 for wheat	1888-1988	25
10a	corn-oats-wheat-red clover	none	1888-1940 1914-1988	39 35
10b		6t manure	1888-1988	11, 14, 34, 36, 37, 38
11a	corn-oats-wheat-red clover-timothy-timothy	none	1888-1988	13
11b		6-7t manure	1888-1988	19
11c		full treatment	1888-1949 1950-1988	3 20
15a	continuous timothy	no treatment	1888-1988	23
15b		6t manure	1888-1988	22

Table 2. Comparison of wheat yields from cropping systems that were not altered during 100 years.

	System	Grain Yield, bu/acre
1a	continuous wheat, nonfertilized	9.8 f*
1b	3t manure	22.2 cd
1c	6t manure	26.7 bc
1d	full treatment	27.7 bc
6a	corn-wheat-clover, nonfertilized	15.0 ef
6b	6t manure	30.0 b
10a	corn-oats-wheat clover, nonfertilized	25.7 bcd
10b	6t manure	30.8 b
11a	corn-oats-wheat-red clover-timothy-timothy, nonfertilized	19.1 de
11b	6t manure	27.8 bc
11c	full treatment	37.7 a

*Means followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

Table 3. Some soil characteristics after 100 years of cultivation (for 0-20 cm layer).

	System		Organic Matter	P_2O_5 (Bray 2)	K_2O	pHs
			%	lbs/acre		
1a	continuous wheat,	nonfertilized	1.4	54	194	4.5
1b		3t manure	2.2	295	629	6.0
1c		6t manure	2.8	532	790	6.1
1d		full treatment	2.2	400	312	5.8
4a	continuous corn,	nonfertilized	1.0	40	247	4.5
4b		6t manure	2.4	558	587	6.2
6a	corn-wheat-clover	nonfertilized	2.0	21	212	5.1
6b		6t manure	3.2	269	220	5.6
10a	corn-oats-wheat-clover	nonfertilized	1.9	33	103	5.0
10b		6t manure	2.4	263	235	5.6
11a	corn-oats-wheat-clover-timothy-timothy	nonfertilized	1.9	24	101	4.6
11b		6t manure	2.9	163	165	5.3
11c		full treatment	2.0	468	232	6.6
15a	continuous timothy	nonfertilized	2.1	25	105	4.8
15b		6t manure	3.4	446	239	6.1
—	Tucker Prairie*		4.2	372	309	6.7

*Tucker Prairie is a mixed-grass prairie that is managed to maintain a vegetation diversity similar to native prairie. Soil is Putnam-Mexico silt loam, similar to that of the original Sanborn Field site.

Table 4. Comparison of corn grain yields from cropping systems that were not altered during 100 years.

	System	Grain Yield, bu/acre
4a	continuous corn, nonfertilized	15.d*
4b	6t manure	41.9c
6a	corn-wheat-clover, nonfertilized	43.6c
6b	6t manure + nitrogen	73.1a
10a	corn-oats-wheat-clover, nonfertilized	54.5bc
10b	6t manure	64.4ab
11a	corn-oats-wheat-red clover-timothy-timothy, nonfertilized	42.9c
11b	6t manure	67.0ab
11c	full treatment	70.0a

*Means followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

Table 5. Comparison of timothy forage yields from cropping systems that were not altered during 100 years.

	System		Forage, tons/acre
11a	corn-oats-wheat-clover-timothy-timothy	nonfertilized	1.24c
11b		6t manure	2.29b
11c		full treatment	2.96a
15a	continuous timothy	nonfertilized	1.11c
15b		6t manure	2.73a

*Means followed by the same letter are not significantly different at the 0.05 level according to Duncan's multiple range test.

Table 6. Estimated amounts of nutrients removed from the soil by continuous cropping during 100 years. Data are from plots that received no fertilizer.*

	System	Grain	Residue/ Hay	Ca	P	N	K
		t/ha		kg/ha			
1a	continuous wheat	53.5	88.2	154	217	1419	1265
4a	continuous corn	92.5	228.0	1250	455	3428	3665
15a	continuous timothy	—	95.7	355	134	1014	1521

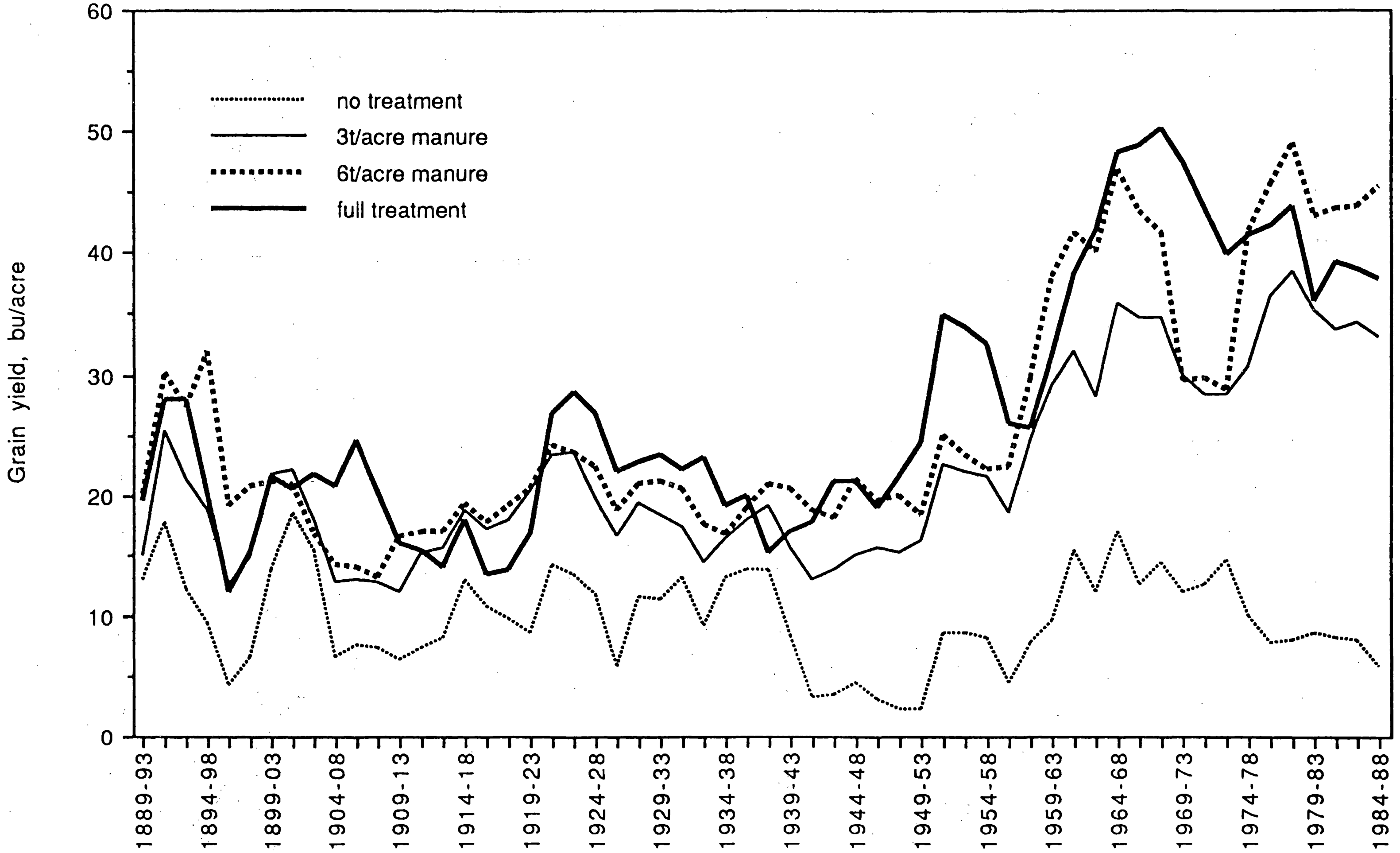
*Removal was calculated from weight of grain and residue, based on data on average composition of grain and feeding stuff from Morrison (1956).

Table 7. Estimated yearly rates of nutrients uptake by continuous non-fertilized crops, kg/ha.

System			Ca	P	N	K
1a	continuous wheat					
	years	0-25	2.2	2.5	17.3	18.0
		25-50	2.8	3.0	20.6	22.1
		50-75*	1.0	1.5	9.7	8.1
		75-100	0.2	1.6	9.2	2.4
4a	continuous corn					
	years	0-25	12.4	5.5	39.0	37.1
		25-50	12.5	4.8	35.7	37.0
		50-75	13.2	4.4	34.3	38.4
		75-100	11.9	3.4	28.2	34.1
15a	continuous timothy					
	years	0-25	3.8	1.5	11.5	17.3
		25-50	3.3	1.3	10.0	15.0
		50-75	3.4	1.4	10.3	15.5
		75-100	2.9	1.2	8.7	13.1

*Significant difference in nutrients uptake by wheat in years 0-50 and 50-100 is due to the change in residue treatment.
During the first period straw was removed with the grain, during the last 40 years, straw was returned to the plot.

Figure 1. Yields of wheat grown continuously with no treatment (system 1a), with 3t/acre manure annually (system 1b), 6t/acre manure annually (system1c), and full treatment (system 1d), as 5-year moving averages.



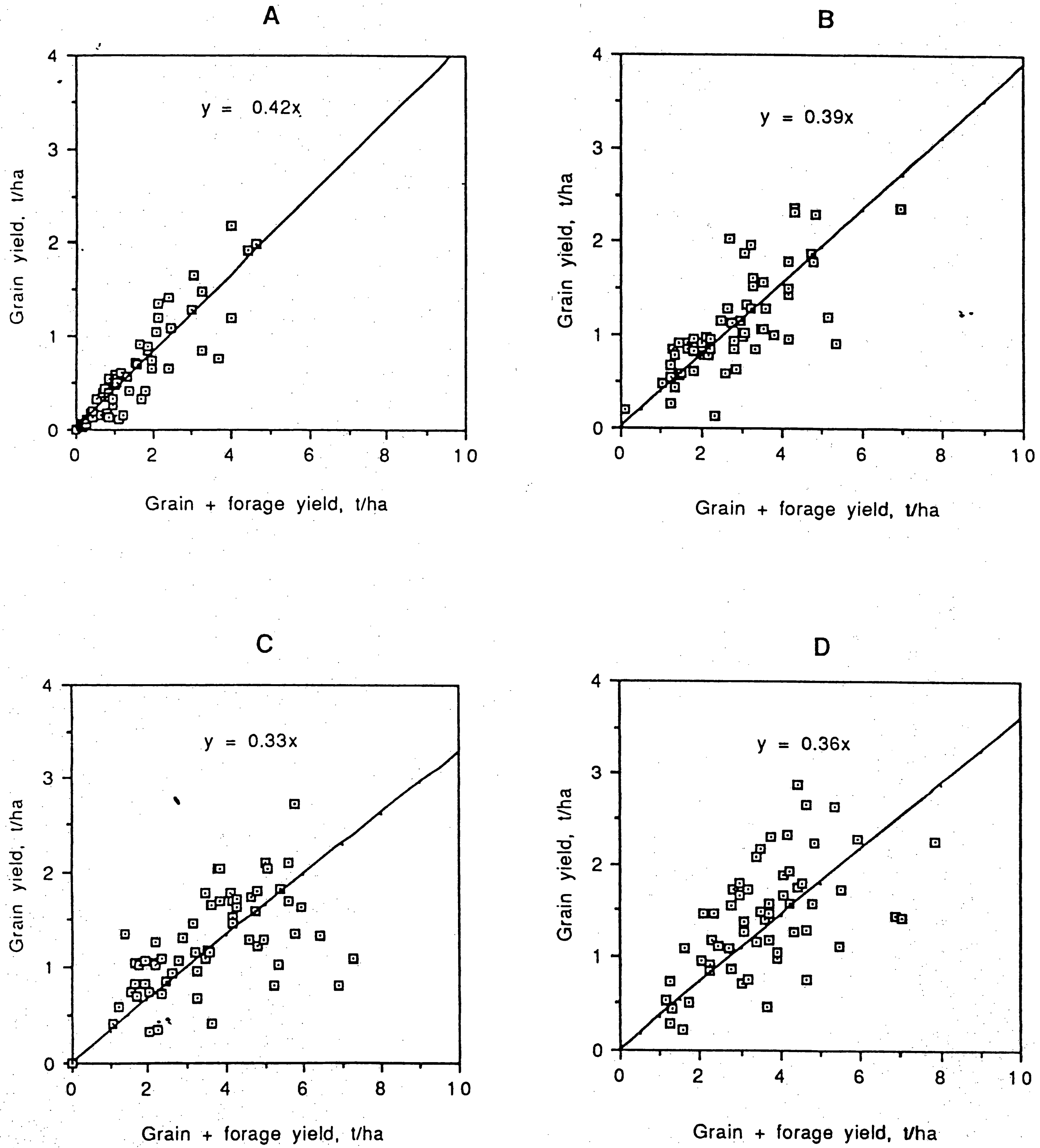


Figure 2. Relationship between wheat grain yield and total harvested biomass: A - no treatment (system 1a), B - 3t/acre manure annually (system 1b), C - 6t/acre manure annually (system 1c), D - full treatment (system 1d).

Figure 3. Yields of corn grown continuously with no treatment (system 4), and with 6t/acre manure annually (system 4b), as 5-year moving averages.

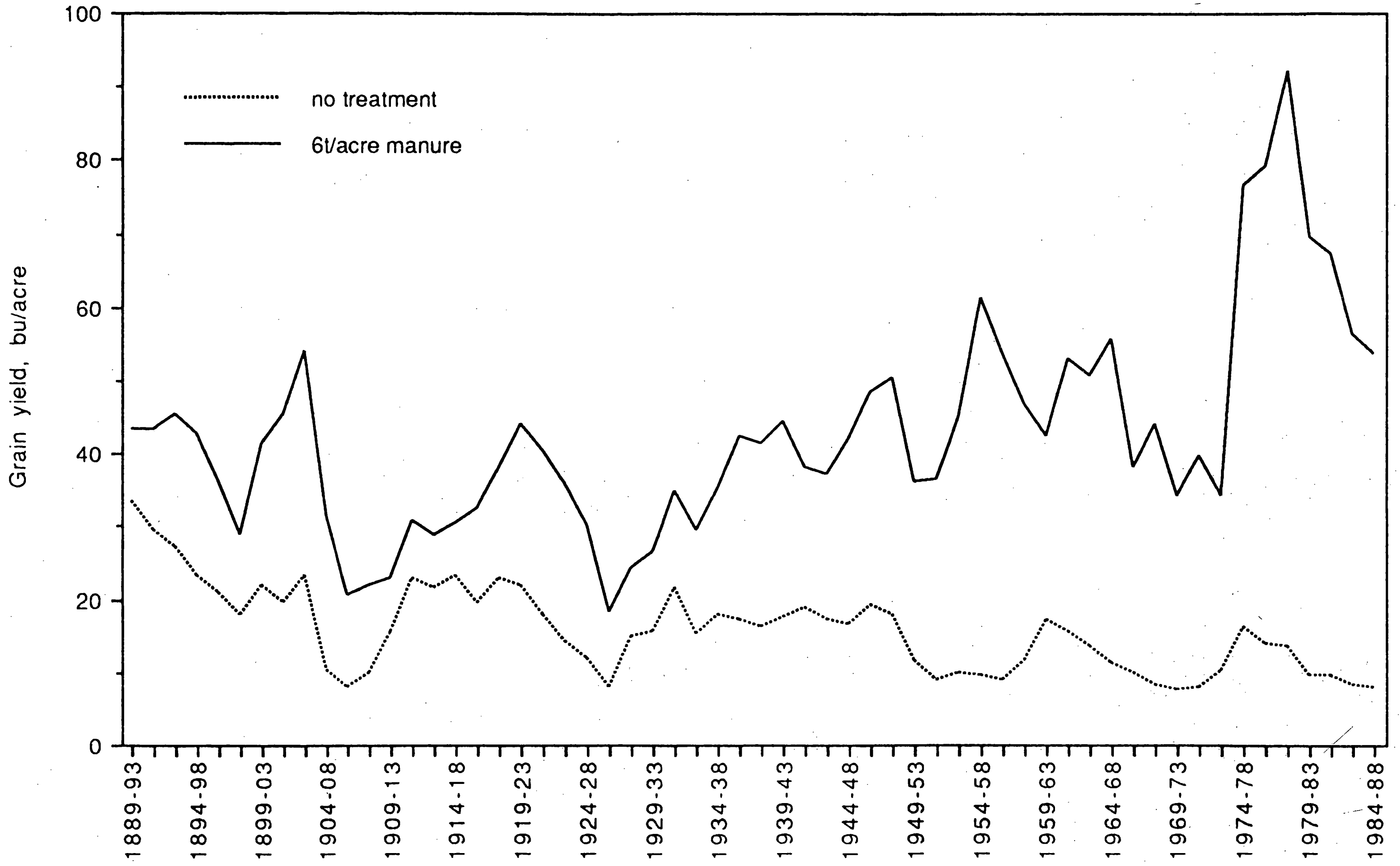
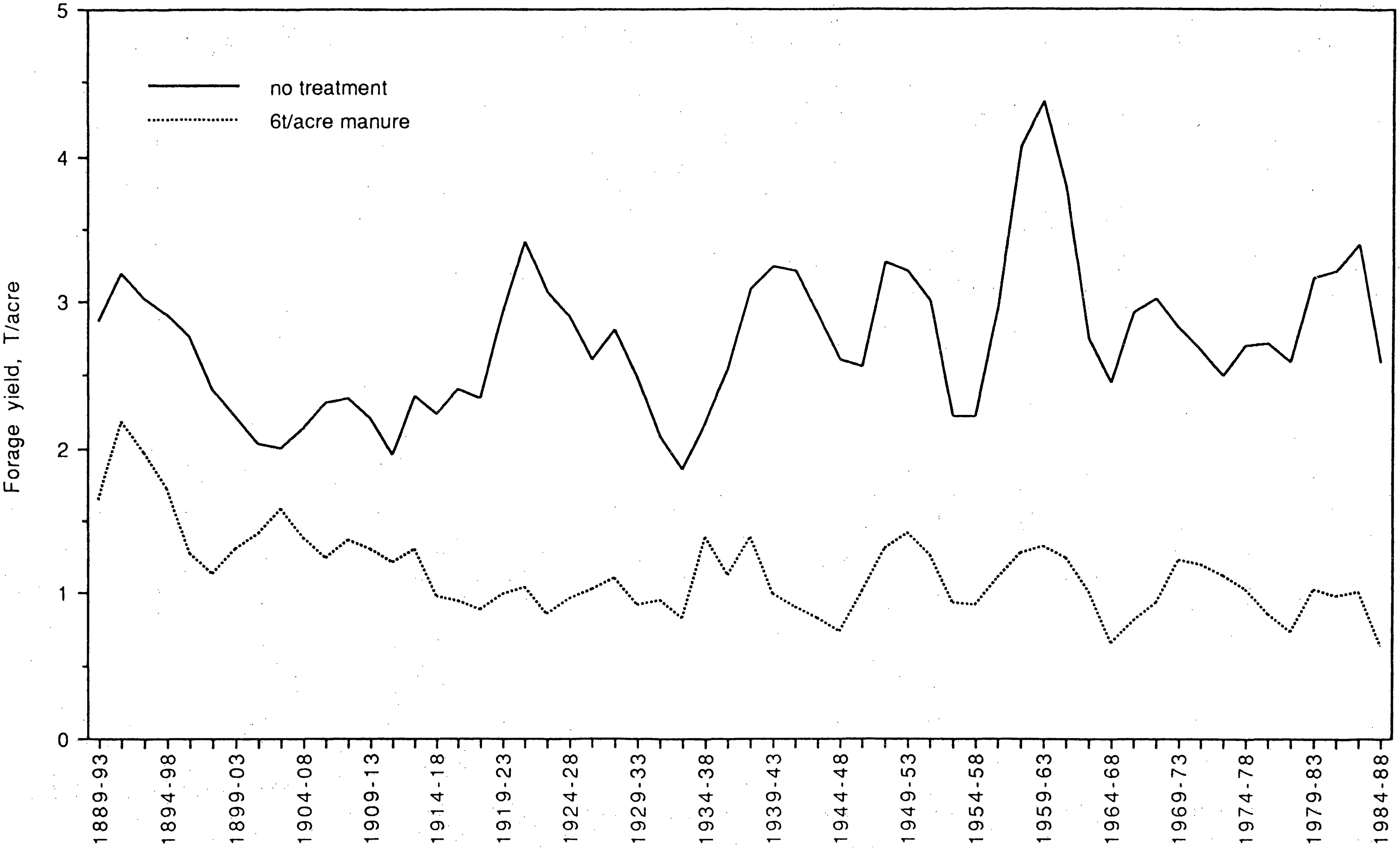


Figure 4. Forage yields of timothy grown continuously with no treatment (system 15a), and 6t/acre manure annually (system 15b), as 5-year moving averages.



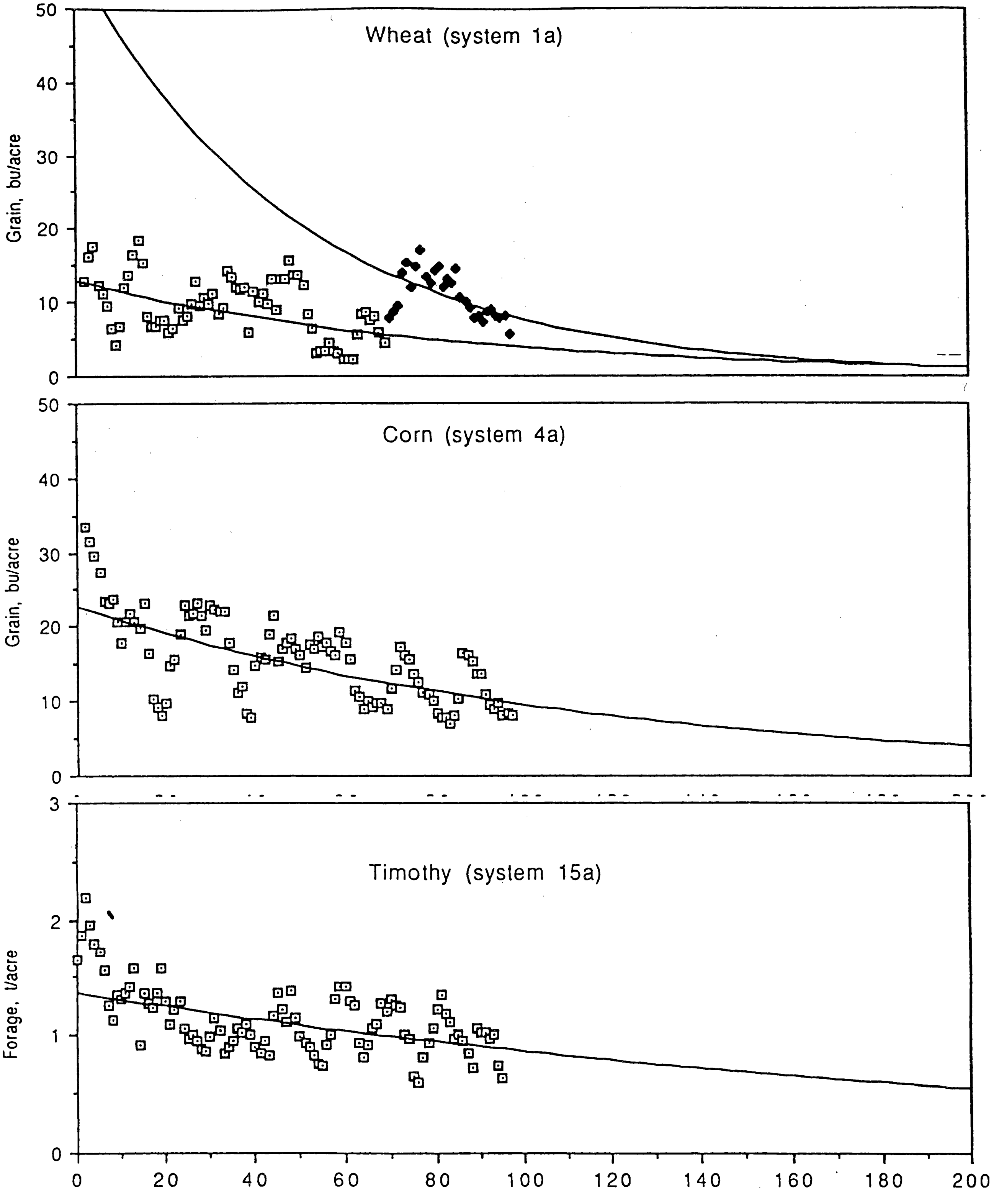


Figure 5. The relationship between yields (as a 5-year moving average) and the number of years in three continuous non-fertilized cropping systems. Data are extrapolated for the second hundred years. Two curves on the graph for wheat (system 1a) are due to changes in the post-harvest residue treatment and the introduction of more productive varieties in the 1960s.

Biographical Sketches

As of 9-5-89

Stephen H. Anderson is Assistant Professor of Soil Physics at the University of Missouri. He received his B.S. in Agronomy from Brigham Young University, and M.S. and Ph.D. degrees from North Carolina State University. He has worked for the past four years in the evaluation of spatial and temporal variability of soil physical properties. His current research effort involves developing techniques for using X-ray computed tomography and magnetic resonance imaging for the evaluation of small scale soil density and water content variations. He is also evaluating the long-term effects of conservation tillage on soil hydraulic properties and chemical transport. He teaches Soil Physics, Advanced Soil Physics, and was the initial coordinator for the interdisciplinary Water Resources Seminar at the University of Missouri.

Robert W. Blanchar is Professor of Soil Chemistry at the University of Missouri. He received his B.A. degree in Chemistry from Macalester College and his M.S. and Ph.D. from the University of Minnesota. He has taught soil chemistry, physical chemistry of soils, and soil testing and interpretation for the past 20 years. His research emphasis has included the measurement of solubility and hydrolysis reactions of phosphate in soil-water systems, oxidation reactions of iron and sulfur compounds in soils, and description of the chemical changes occurring in the rhizosphere. His current research effort is concentrated on electrochemical techniques for studying the rhizosphere with emphasis on microelectrodes.

Steve Breight, a native of Kirkwood, Missouri, earned his B.S. in Agronomy from the University of Missouri-Columbia in 1978. He worked on farms in Cooper County, Missouri for 7 years. In January 1985, he became a Research Specialist on Sanborn Field. He gave up that position in January 1988 to pursue an advanced degree in business. He currently is working part-time organizing Sanborn Field records and data.

James R. Brown, Professor of Agronomy (Soil Science) grew up on a general farm in Edgar County, Illinois. After receiving a B.S. in General Agriculture at the University of Illinois in 1953, he spent 2 years in the military service. He earned an M.S. from the University of Illinois in Soil Management in 1957 after which he was employed as a Teaching Assistant at Iowa State University. After earning the Ph.D. in Soil Fertility from Iowa State in 1963, he joined the faculty at the University of Missouri. He has taught courses in beginning soils, soil microbiology, soil management, undergraduate seminar, and soil fertility and plant nutrition at both the graduate and undergraduate level. He has conducted research in nitrates, micronutrients, cation nutrition, liming, and soil testing. He currently does plant nutrition work in forages. He acquired responsibility for Sanborn Field in 1985.

Gregory A. Buyanovsky, Associate Professor of Agronomy (Soil Ecology/Biology) received his education and academic degrees (Ph.D. and Dr. Bio. Sci.) in the Soviet Union. He worked in Southern Russia and Israel until 1981, when he joined the faculty at the University of Missouri. In work prior to coming to Missouri, Dr. Buyanovsky investigated the influence of biological factors on soil mineral components. The current research is concerned with the fate of carbon accumulated by cultivated plants and not used for food or feed, using ^{14}C as a tracer in field studies.

Bent T. Christensen has been head of the Askov Experiment Station, Denmark since July, 1988. He was born May 9, 1952 and grew up on a farm. He holds degrees from the University of Copenhagen in biology and ecology. His Askov Station research has been on straw decomposition, soil organic matter, and animal manuring.

Barbara L. Conkling has a post-doctoral appointment at the University of Missouri-Columbia. She holds a B.A. in chemistry from Ohio Wesleyan University and the M.S. and Ph.D. in Agronomy from the University of Missouri. Her research activities have included the study of ion diffusion in soils and the study of acid rain effects on the rhizosphere chemistry of growing plants using microelectrode technology. Current research efforts are reclaimed surface-mined soils and flyash scrubber sludge.

Clark J. Gantzer currently is an Associate Professor in the Department of Agronomy. He holds B.S. and M.S. degrees from the University of Minnesota. After completing his Ph.D. in Soil Physics at the University of Minnesota in 1980, he worked at the USDA National Sedimentation Lab in Oxford, MS before joining the faculty at the University of Missouri in 1982. He teaches a course in soil conservation and has taught the undergraduate seminar. His research interests include erosion mechanics, effects and management of cover crops, splash detachment, and soil productivity.

R. David Hammer is an Assistant Professor of Soil Science at the University of Missouri-Columbia. A former jet pilot, he holds the B.S. degree from the U.S. Naval Academy, the M.S. degree from the University of Illinois, and the Ph.D. from the University of Tennessee. He joined the faculty at the University of Missouri in 1986. Dr. Hammer supervises the Soil Characterization Laboratory and teaches Soil Genesis at the University. His research interests include: investigation of patterns and causes of soil spatial and temporal variability; the relationships of soil properties and soil water movement to landscape positions and stratigraphy; surface mine reclamation; and the use of Geographic Information Systems for soil inventory and land use planning.

A. E. Johnston, recently retired from the Headship of the Soils and Crop Production Division of the Agricultural and Food Research Council's Institute of Arable Crops Research at Rothamsted. On his retirement, he was elected to a Lawes Trust Senior Research Fellowship and so hopes to maintain his links with Rothamsted and bring up-to-date the published record of some of the classical and long-term experiments. After studying Agricultural Chemistry at the University College of North Wales Bangor, and doing National Service in the Royal Air Force, Johnny joined the then Chemistry Department at Rothamsted in 1953. His first job was to help soil sample and prepare pH maps of the Chemical Experiments — those experiments started by Lawes and Gilbert in the 1840-1850s — which still continue today. From this lowly beginning began major research interest — the importance of long-term experiments in Agricultural Science; — their value to the farmer and the research scientist.

Randall J. Miles, Associate Professor, is a native of Crawfordsville, Indiana. He received his B.S. and M.S. degrees in Agronomy from Purdue University and his Ph.D. in Soil Science from Texas A&M University. He served on the faculty in the Department of Plant and Soil Science at the University of Tennessee-Knoxville for two years prior to coming to the University of Missouri. He has been a faculty member in the Department of Agronomy at the University of Missouri since 1983. His research is in the area of Pedology with emphasis in soil landscapes and water movement.

Jerry Nelson is Professor of Agronomy, University of Missouri-Columbia. After obtaining B.S. and M.S. degrees from the University of Minnesota, he earned the Ph.D. from the University of Wisconsin. Dr. Nelson has taught Plant Science and Crop Physiology courses. Research activities involve photosynthesis-yield relationships of tall fescue, and legume management for plant persistence. His recent focus has been on leaf growth and carbohydrate metabolism. Year-long sabbatical leaves have been spent in Aberystwyth, U.K. and Zurich, Switzerland.

James A. Robertson is Professor of Soil Science at the University of Alberta and will become chairman of the department on July 3, 1989. Dr. Robertson's undergraduate and M.S. work was done at the University of Manitoba. He earned the Ph.D. degree at Purdue University in soil fertility. He teaches in the area of soil management and soil fertility. His research interests include crop responses to the major plant nutrients and chloride and optimization of the management of Gray Luvisolic soils. He has particular interest in the Breton plots.

Bob G. Volk received his B.S. and M.S. degrees from Ohio State University in Agronomy with emphasis in mineralogy. His Ph.D. was received at Michigan State University in Soil Chemistry. He was employed at the Everglades Experiment Station and the University of Florida researching soil organic matter. In 1984, he was accepted as the chair of the Department of Agronomy at the University of Missouri. Future research will focus on water quality.

George H. Wagner is a Professor of Agronomy, University of Missouri-Columbia. He holds B.S. and M.S. degrees from the University of Nebraska and the Ph.D. from the University of Missouri. Dr. Wagner has taught soil microbiology and biochemistry at the University of Missouri for over thirty years. His major research activities have focused on understanding the annual carbon transfer from crop residues back to the atmospheric pool of CO_2 or into soil organic matter. He and his students have characterized microbiological roles in these processes. Special research endeavors have included appointments with the National Research Council of Canada, the International Atomic Energy Agency, and the Institut National de la Recherche Agronomique of France.

Gary Wyman is a native of Stoddard County, Missouri. After growing up on a diversified grain and fiber farm, he enrolled at the University of Missouri in 1983. After graduating in December 1987 with a B.S. in Agronomy with emphasis in plant breeding and physiology, he became the Research Specialist on Sanborn Field in February 1988.