AN ABSTRACT OF THE THESIS OF

__Robert A. Christ__ for the degree of __Master of Science__ in __Crop and Soil Science__ presented on __June 30, 1992__

Title: Effects of Long-term Residue Management and Nitrogen Fertilization on Availability and Profile Distribution of Nitrogen, Phosphorus, and Sulfur

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Richard P. Dick

A greenhouse pot study was conducted on soils from the Residue Utilization Plots, established in 1931, in Pendleton, OR, to evaluate the ability of various residue management systems to supply nitrogen (N), phosphorus (P), and sulfur (S). Ryegrass (*Lolium Perenne* L.), grown for 120 days in 1 kg of soil, which had been treated at varying rates of inorganic N, P, and S, was harvested and analyzed for total N, P, and S at 30 day intervals. A history of animal manure application (22.4 Mg ha^{-1} 2 yr^{-1}) significantly increased (>50%) the dry matter yield (DMY) of ryegrass when greenhouse applied inorganic N and S was absent or low. Ryegrass DMY response to P was unaffected by the residue history of the soil or the rate of greenhouse applied P. The yield

the residue history of the soil or the rate of greenhouse applied P. The yield advantage of the manure treated soil was overcome by high rates of applied inorganic N and S. The uptake of N, P, and S was significantly greater from the manure treated soil when greenhouse application rates were low. A history of pea vine incorporation (2.4 Mg ha^{-1} 2 yr^{-1}) did not affect DMY or N, P, and S uptake of ryegrass. Although the burning of wheat straw tended to decrease both DMY and nutrient uptake, the decrease was generally not significant at $P<0.05$. Analysis of the soil profile from the long-term plots showed accumulations of $Ca(H_2PO_4)_2$ extractable NO_3 (>12 mg N kg^{-1} soil) and SO_4 (>7 mg S kg^{-1} soil) at lower depths in the manure treated plots. Many of the soil profiles had accumulation of $NaHCO_3$ extractable PO_4 (>80 mg P kg^{-1} soil) at the lower depths. An accumulation of total S near the bottom of many soil profiles is largely in the ester sulfate form. The application of animal manure increased the residual supply of N, P, and S and succeeding crop yields.

Effects of Long-term Residue Management
and Nitrogen Fertilization on
Availability and Profile Distribution of
Nitrogen, Phosphorus, and Sulfur

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Robert A. Christ

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Redacted for Privacy

Head of the Department of Crop and Soil Science

Redacted for Privacy

Dean of the Graduate School

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INTRODUCTION

Soil, water, and air supply the twenty elements that have been identified as essential for plant growth and development. A majority of these elements are considered micronutrients which are needed in plants in relatively small concentrations. Three macronutrients, carbon, hydrogen, and oxygen, are accessible by the plant from the air or water. The remaining six macronutrients, nitrogen, phosphorus, potassium, sulfur, magnesium, and calcium, are needed by plants in relatively high amounts and quite often limit plant growth and development.

Nutrients are made accessible for plants in a variety of ways. Microorganisms convert inert nitrogen (N_2), which is abundant in the atmosphere, to plant available forms. The rate of conversion of N_2 is generally much less than that needed by plants and lack of nitrogen often limits plant growth. Phosphorus (P), which is often in large amounts in the soil matrix and organic matter, can also be limiting. Chemical reactions in the soil form relatively insoluble P compounds, which are unavailable for plant uptake. Sulfur (S) can be made available for plants by natural occurrences such as volcanic depositions or by human activity such as pollution and the application of S-containing pesticides and fertilizers. Until recently, little concern was given to S limitation, but the increased use of

high analysis fertilizers which contain little or no S and the elimination of many S-containing pesticides, along with the decrease in airborne sources of S, have increased the occurrence of S deficiencies in soils around the world.

Nutrients that have been assimilated into a crop can be recycled into the soil to replenish the essential nutrients, either directly with green manures or burning or indirectly through the use of animal manures. Traditionally, soil fertility and crop production have been maintained by the management of crop and animal residues.

The availability and use of low-cost, inorganic "synthetic", nutrient salts, which can be manufactured in plant available forms and applied directly to the soil, has dramatically increased over the past few decades. The shift from crop and animal residue management systems to inorganic fertilizer amendment systems has fueled much discussion of the long-term benefits and hazards of various systems on soil fertility and crop production.

A series of experimental plots at the Columbia Basin Agricultural Research Center in Pendleton, Oregon, provide an opportunity to study the long-term effects of residue management and inorganic N fertilization. In 1931, in the semi-arid region of eastern Oregon, treatments under a wheat-fallow system were established that included wheat straw burning and incorporation of animal manure, legume plant residue, and inorganic N.

Management of the plots has remained virtually unchanged for the last 60 years.

The objectives of this study were to examine the cumulative effects of long-term residue management practices and the application of inorganic N fertilizer: 1) on the plant availability of N, P, and S; and 2) on the soil profile distribution of N, P, and S.

LITERATURE REVIEW

Nitrogen

Nitrogen is an important part of many compounds necessary for plant growth and development. Chlorophyll, the light-gathering pigment of photosynthesis which converts light energy into chemical energy, contains N. Carbohydrates, the end product of this photosynthetic activity, require N for utilization in plants. Nitrogen is also an essential component of amino acids, the building blocks of proteins and enzymes which control the metabolic activity of plants. Nucleotides, the monomers from which the genetic blueprint nucleic acids DNA and RNA are formed, contain N. Nitrogen stimulates root growth and development, enabling other nutrients to become available for plant uptake (Tisdale et al., 1985). It is often the nutrient that governs the yield of crops which receive sufficient quantities of water (Brady, 1984).

Although N may have any oxidation number from -3 to +5, primarily the -3 state of N as nitrate (NO_3^-) and the +5 state of N as ammonium (NH_4^+) are available for plant uptake. The most readily available reservoir of N is found in the diatomic N_2 form which comprises approximately 78 percent of the atmosphere (Mengel and Kirkby, 1987). Atmospheric N_2 can be converted into plant available forms by one of four methods: 1) fixation by microorganisms in a symbiotic association with leguminous and certain non-leguminous plants; 2) fixation by free-living microorganisms; 3) fixation

by atmospheric electrical discharges; and 4) fixation by industrial processes (Tisdale et al., 1985).

Although symbiotic associations occur between many strains of microorganisms and leguminous or non-leguminous host plants, the most important association, agriculturally, is that of *Rhizobium* with legumes (Mengel and Kirkby, 1987). Unable to fix N independently, the *Rhizobium* microorganism and legume, when combined, can synthesize the protein leghemoglobin which serves as an "oxygen buffer" controlling the O_2 concentration in the root nodule and facilitating N fixation. This symbiotic association can provide most of the N required for growth and productivity of the host plant (Vidor, 1982). The use of legumes, in a rotation or as a winter cover crop, can reduce or eliminate the need for N fertilizers (Goldstein and Young, 1987; Dabney et al., 1987; and Neely et al., 1987) Although N fixation varies with the bacterial strain, host plant species, environment, and soil management factors, the amount of N fixed is generally under 100-200 kg N ha^{-1}. Rates as high as 600 kg N ha^{-1} have been recorded in clover in New Zealand (Cooke, 1982).

A variety of free-living N fixers, including *Azotobacter, Cyanobacteria, Clostridium, Azospirillum, and Anabaena* among others, can form either mutualistic associations with plants or inhabit the rhizosphere of plants while supplying N to the host plant. The amount of N fixed by some of free-living microorganisms is much less than that fixed by symbiotic

microorganisms. Rates of 0.5-2.5 kg N ha^{-1} yr^{-1} for *Azotobacter* are

common (Burns and Hardy, 1975). Although N fixation by free-living

microorganisms is currently of little importance in agriculture, research

being conducted in this area may affect their N fixing capabilities.

The mineralization of N in soil organic matter to plant available forms

is a three step process: aminization, ammonification, and nitrification

(Tisdale et al., 1985). Aminization involves the decomposition of proteins to

amines and amino acids:

$$proteins \rightarrow R\text{-}NH_2 + CO_2 + energy$$
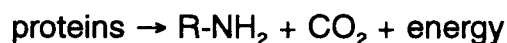
In the ammonification process the amines and amino acids are transformed

to ammonium:

$$R\text{-}NH_2 + H_2O \rightarrow NH_3 + R\text{-}OH + energy$$
$$\searrow + H_2O$$
$$\rightarrow NH_4^+ + OH^-$$
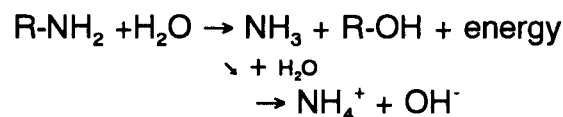
Nitrification further converts the ammonium into nitrate:

$$2NH_4^+ + 3O_2 \rightarrow 2NO_3^- + 2H_2O + 4H^+.$$

Nitrogen from industrial waste and natural occurrences (such as

electrical discharges and NH_3 escaping from the soil) can be found in the

atmosphere in the forms of NH_3, NO_3^- and NO_2. This N can then be

combined with rainfall and returned to the soil. Except near some industrial

plants and animal feed lots where N rates can become quite high, this

source of N is generally not significant in agricultural crop production (Tisdale et al., 1985; Stewart et al., 1967).

Traditionally, animal manures and legumes, in crop rotations or as cover crops, provided N for cropping systems. With the advent of inexpensive N and increased crop yield potential, a dramatic increase in the use of synthetic inorganic N occurred. Although much of the increase in crop yields during the last 50 years has been attributed to the increased availability and use of inorganic fertilizers, there is growing evidence that synthetic chemical fertilizer use has contributed to environmental pollution of groundwater, soil acidification, and is associated with depletion of soil organic matter (Legg and Meisinger, 1982; Rasmussen et al., 1980; Jenkinson and Johnson, 1977).

Phosphorus

Phosphorus is required in all plants because of the phosphate compounds' ability to store and transfer energy. The high-energy pyrophosphate bonds of adenosine di- and triphosphate (ADP and ATP) power almost every energy-requiring process in plants. Phosphorus is also important in structural and reproductive components (DNA and RNA) of plants. Phosphorus has been identified to increase root growth, resistance to diseases, and early maturity.

Like N, P may have any oxidation number from -3 to +5, however, only the +5 state of P in PO_4^{-3} is available for plant uptake. Depending on

the pH of the soil, phosphate is generally absorbed by the plant in either

the $H_2PO_4^-$ form or the HPO_4^{2-} form. Unlike N, a large reservoir of P is

located in the soil complex and can be made available by either weathering

or desorption. Another major reserve of P is associated with the soil

organic matter and can become available by mineralization. The enzyme

phosphatase, which is produced by both microorganisms and the roots of

higher plants, cleaves inorganic phosphate from organic matter. Microbial

activity and the resulting mineralization of P is controlled by temperature,

moisture, and the pH of the soil. Phosphorus in the soil complex is located

in one of three pools: 1) soil solution P which is a readily available form but

only a small fraction of the total; 2) labile P, a somewhat larger fraction,

which can be readily released into the soil solution; and 3) non-labile P

which is a large majority of the P but is only slowly available to the labile

fraction (Mengel and Kirkby, 1987). The amount of P available for plant

uptake is dependent on the adsorption/desorption characteristics of the soil,

the pH of the soil and the mineralization of organic matter. Walker and

Adams (1958) suggested that the P content of the soil parent material

ultimately controls the maintenance of organic matter and the N and S

content of the soil. Evidence for this was shown by Thompson et al. (1954)

who found that when virgin soils were cropped, decreases in organic P

were less than the decreases in N and S.

Reservoirs of P are located throughout the world and can be mined and applied to soils that have been depleted due to intensive cropping or soil chemistry. However, it is estimated that these reserves could be depleted as early as 60 years. Phosphorus is a major limitation for continued high yields as it is deficient in many soils. It has the lowest rate of recovery among macronutrients due to sorption reactions.

Sulfur

Sulfur is required by plants for the synthesis of the amino acids, cysteine and methionine, the building blocks of proteins. The ability of two S atoms to bond (disulfide bond) is an important feature of proteins and polypeptide chains. Sulfur is also an important part of many vitamins and coenzymes and is required for the activation of some enzymes (Coleman, 1966).

Sulfur is a reactive element with stable valence states from -2 to +6. Sulfur is taken up by plants in the +6 state as SO_4^{-2}. The largest reservoirs of S occur in the soil complex and sea water. Other sources of S include industrial pollution, volcanic activity, and organic matter. Sulfur is also located in large reserves, can be mined and applied to the soil. Sulfur in soils occurs both as organic and inorganic S, with as much as 95% found in the organic form (Tabatabai, 1982). The conversion of organic and inorganic forms of S to plant available SO_4 is largely carried out by microorganisms. The rate of conversion is generally dependent on the

population size of the microorganisms, the form of S to be converted, and the environmental conditions such as temperature and moisture.

Before the use of high-analysis fertilizers, sufficient quantities of S were inadvertently supplied along with N,P, and K fertilizers or from pesticides.

Conventional and Alternative Agricultural systems

Conventional agricultural systems may include a variety of practices which are currently considered to be the norm or standard of modern agricultural crop production. Conventional systems can include all or some of the following techniques: manufactured "synthetic" chemical fertilizer use to supply nutrients in plant available forms; herbicide and pesticide use for the control of plant and animal pests; deep moldboard plowing for weed control and seedbed preparation; and continuous monocropping for pathogenic control and economic profitability.

Alternative or sustainable agricultural systems, which seek to incorporate natural biological processes, include any of a variety of techniques to maintain and improve soil fertility and crop production. The growing of green manures and legumes, either as a winter cover crop or in rotation, and the incorporation of animal manures are used to replace the need for inorganic fertilizers. Crop rotation is used for soil fertility and soil conservation. Minimum or no-till techniques seek to decrease soil disturbance and energy consumption. Integrated Pest Management (IPM)

and Bio-control methods are used to decrease or eliminate the need for herbicides and pesticides. New crop management systems, such as shorter rotations with legumes, straw removal, and straw composting, are being developed to eliminate the practice of field burning.

Few farming operations are completely conventional or alternative agricultural systems. Most farmers incorporate a variety of techniques into their operations and could be considered to be at some point on a continuum between completely conventional and completely alternative.

Effects of Alternative Agricultural systems

The incorporation of a legume or green manure into a crop rotation can supply N for subsequent crops, increase organic matter, and improve soil physical properties (Bruulsema and Christie, 1987; Gakale and Clegg, 1987; McVay et al. 1989; Reddy et al. 1986). Unlike animal manure N, which can undergo considerable decomposition and alteration prior to its incorporation, a green manure generally begins decomposition when it is incorporated into the soil. The quantity of N fixed biologically each year can vary depending on the legume species and cultivar, soil type and texture, temperature, available water, soil drainage, and crop harvest management (Power, 1987).

The addition of animal manure to the soil can increase organic matter content, total C and N, microbial populations, enzyme activities, moisture retention, pH buffering capacity and crop yields (Dick et al., 1988;

Sommerfeldt et al., 1988; Cope et al., 1958; Bishop et al., 1964; and Tisdale et al., 1985). Animal manure is an important source of N for crop production in alternative agricultural systems. Although most animal manure is returned to the land, poor storage and application practices often result in losses of N so high that only a fraction of the original nutrients are available for plant uptake (U.S. Department of Agriculture, 1978).

Highest yields and greatest N recovery are obtained only when the mineralization of animal manures and legumes is concurrent with crop requirements (Heck, 1931).

The burning of crop residue has long been used to facilitate residue removal, prepare seedbed, control weeds, and enhance nutrient availability (Biederbeck et al., 1980). Studies have shown, however, that wheat straw burning decreases soil organic matter, potentially available N, and microbial activity (Shipley and Regier, 1977; Rasmussen et al., 1980; Unger et al., 1973). Although the burning of wheat straw may increase yields of succeeding crops in the short term, it appears to have little effect on long-term yields (Biederbeck et al., 1980; Hooker et al., 1982).

The management system can have a major impact on nutrient conservation. For example, a study of N fixation of soybeans in the Midwest found that net N gain or loss ranged from +20 lbs. acre^{-1} to -70 lbs acre^{-1} depending on the management system used (Heichel, 1987).

Sustainable agricultural systems require that mineralization of organic matter nutrients be tightly coupled to crop uptake. Management of organic and inorganic amendments can have a significant effect on levels of organic matter. Larson et al. (1972) determined that more than 6 Mg ha^{-1}yr^{-1} of cornstalk (dry matter) were needed to prevent the loss of organic matter but much more was needed to maintain total P concentrations. When farmyard manure was added to the soil annually, over a 20-year period from 1852-1871, and then discontinued, after 100 years the manure treated soil still retained more organic C and N than unamended soils (Jenkinson and Rayner, 1977).

In order to understand the long-term implications of alternative and conventional agricultural systems, studies must be conducted to determine the effects of these systems on nutrient availability. Because soil properties change slowly, the cumulative effects of agricultural management practices on nutrient dynamics can best be studied on long-term field experiments (Yates, 1949).

CHAPTER 1

EFFECTS OF LONG-TERM RESIDUE MANAGEMENT

AND NITROGEN FERTILIZATION ON

AVAILABILITY AND PROFILE DISTRIBUTION

OF NITROGEN

ABSTRACT

Concerns about groundwater pollution, government regulations and rising prices of commercial fertilizers along with current interests in alternative agricultural systems have renewed interest in the use of animal manures, green manures and legumes in crop rotations. A long-term residue utilization experiment under a winter wheat-fallow system in the semi-arid region of eastern Oregon provided an opportunity to study the cumulative effects of long-term residue management and N fertilization. Established in 1931, Residue Utilization Plot (RUP) treatments included wheat straw burning, or incorporation of animal manure, legume plant residue, or inorganic N. To evaluate the plant availability of N, a greenhouse pot study was conducted on RUP soils collected from the 0-20 cm depth. Ryegrass (*Lolium perenne* L.), grown for 120 days in 1 kg of soil, which had been treated at rates of 0, 80, 160, or 320 mg N kg^{-1} soil, was harvested and analyzed for total N at 30 day intervals. At the 0 N rate, ryegrass dry matter yield (DMY) and N uptake from the manure treated RUP soil were >50% higher than the other residue treatments. Burning of wheat straw did not significantly influence DMY, although yields from the burn plots tended to be lower. Potentially mineralizable N was significantly greater in the manure and pea vine amended soils compared to those receiving inorganic N. Analysis of the soil profile from the long-term plots showed that previously declining levels of total N in plots receiving no

fertilization or inorganic N fertilization may have stabilized at current levels. Large accumulations of extractable nitrate (>12 mg-N kg^{-1} soil) in the lower portion of the manure treated soil suggest a potential for nitrate groundwater contamination.

INTRODUCTION

Before the introduction of low-cost inorganic "commercial" fertilizers, agricultural production depended heavily on the use of animal manures and crop rotations, with legumes or green manures to sustain yields and maintain soil fertility (Bruulsema and Christie, 1987; Hesterman et al., 1986). Increasing concern about groundwater pollution, government regulations and rising prices for inorganic fertilizers have renewed interest in the use of legumes, green manures, and animal manures (Gakale and Clegg, 1987; Heichel and Barnes, 1984; Sarrantonio and Scott, 1988).

The addition of animal manure to the soil can increase organic matter, total C and N, microbial populations, enzyme activities, moisture retention, pH buffering capacity and crop yields (Dick et al., 1988; Sommerfeldt et al., 1988; Cope et al., 1958; Bishop et al., 1964; Tisdale et al., 1985). However, highest yields and greatest N recovery are obtained only when the mineralization of N from animal manures and legumes is concurrent with crop requirements (Heck, 1931). If environmental conditions are unfavorable or the application of animal manures is not

managed properly, the N mineralized can be a source of potential pollution to the soil and groundwater (McCalla, 1974; Xie and MacKenzie, 1986) or lost from the system through NH_3 volatilization, denitrification and nitrate leaching (Thompson et al., 1987).

The incorporation of a legume or green manure into a crop rotation can supply N for subsequent crops, increase organic matter, and alter soil physical properties (Bruulsema and Christie, 1987; Gakale and Clegg, 1987; McVay et al., 1989; Reddy et al., 1986). Unlike animal manure N, which can undergo considerable decomposition and alteration prior to its incorporation, a green manure and legume generally begins decomposition when it is incorporated into the soil. The quantity of N fixed biologically by legumes each year can vary depending on legume species and cultivar, soil type and texture, temperature, available water, and crop harvest management (Power, 1987). Depending on environmental conditions, a large portion of the green manure or legume N can be immobilized in soil-organic pools and then slowly become available to subsequent crops (Ladd and Amato, 1986).

The burning of crop residue following harvest has long been recognized to facilitate straw disposal, seedbed preparation, pathogen and weed control (Biederbeck et al., 1980). Studies have shown that straw burning decreases soil organic matter, potentially available N, and microbial activity, and it may increase yields of succeeding crops in the short term (Shipley

and Regier, 1977; Rasmussen et al., 1980; Unger et al. 1973). Straw

burning appears to have little effect on long-term yields (Biederbeck et al.,

1980; Hooker et al., 1982).

Because soil properties change slowly, the cumulative effects of

agricultural management practices on nutrient dynamics can best be

studied on long-term field experiments (Yates, 1949). A series of

experimental plots at the Columbia Basin Agricultural Research Center in

Pendleton, Oregon, provided an opportunity to study the long-term effects

of agricultural practices on soil properties and processes. In the semi-arid

region of eastern Oregon, under a winter wheat-fallow system, treatments

were established in 1931 that included: straw incorporated (N_0); spring burn

of straw (N_0SB); fall burn of straw (N_0FB); straw plus 45 kg N ha^{-1} 2 yr^{-1}

(N_{45}); spring burn plus 45 kg N ha^{-1} 2 yr^{-1} ($N_{45}SB$); straw plus 90 kg N ha^{-1} 2

yr^{-1} (N_{90}); spring burn plus 90 kg N ha^{-1} 2 yr^{-1} ($N_{90}SB$); straw plus 2.24 Mg

pea vine ha^{-1} 2 yr^{-1} (PV); and straw plus 22.4 Mg strawy beef manure ha^{-1}

2 yr^{-1} (M) (Table 1.1). Except for a single application of 56 kg $CaSO_4$-S ha^{-1}

in 1967, the soils received no other fertilization. The management of the

plots has remained virtually unchanged for the last 60 years.

The objectives of this study were 1) to examine the cumulative

effects of long-term residue management and N fertilization on the plant

availability of N, and 2) to examine the soil profile distribution of N fractions.

Table 1.1. History of Residue Utilization Plots from 1931 to 1989.
Pendleton Agricultural Research Center, Oregon (adapted from Rasmussen
et al. 1989).

Residue Treatment	Description of Residue Management†	N applied per crop
		kg ha^{-1} 2 yr^{-1}
N$_0$	Straw incorporated into the soil	0
N$_0$FB	Wheat straw burned in the fall	0
N$_0$SB	Wheat straw burned in the spring	0
N$_{45}$	Straw incorporated into the soil	45(34)§
N$_{45}$SB	Wheat straw burned in the spring‡	45(0)§
N$_{90}$	Straw incorporated into the soil	90(34)§
N$_{90}$SB	Wheat straw burned in the spring‡	90(0)§
PV	Straw plus 2.24 Mg ha^{-1} 2yr^{-1} of pea vines incorporated into soil	34(40)¶
M	Straw plus 22.4 Mg ha^{-1} 2yr^{-1} strawy manure incorporated into soil	111#

† All treatments moldboard plowed 20 cm deep in late March or early April of the fallow year. Pea vines and manure applied 1-3 days prior to plowing.

‡ Initiated in 1979, straw incorporated from 1931-1978.

§ Nitrogen rates changed in 1967, number in parentheses is for 1931-1966.

¶ Pea vine input changed in 1950, prior to 1950 pea vines included pea seed, number in parentheses, after 1950 pea vines included only vines and pods, N input based on chemical analysis from 1976-1987.

Strawy manure N input based on chemical analysis from 1976-1987.

MATERIALS AND METHODS

Greenhouse Experiment

Six treatments from the Residue Utilization Experiment Plots (Table 1) were selected for a greenhouse study (N_0, N_{90}, N_0SB, $N_{90}SB$, PV, M). The soils were collected in November 1988, from the 0 to 20 cm depth, passed through a 15 mm screen, and stored field-moist in sealed bags at $4°C$. One kg (oven-dry basis) of soil was put into plastic non-draining pots (14 x 9 cm) and uniformily amended with NH_4NO_3 at rates of 80, 160, or 320 mg N kg^{-1} soil. Because these soils do not respond to K (P. E. Rasmussen, personal communication), only supplemental amounts of P and S were added at the rate of 80 mg P kg^{-1} soil as $Ca(H_2PO_4)_2 \cdot H_2O$ and 40 mg S kg^{-1} soil as $CaSO_4 \cdot 2H_2O$. An unfertilized control treatment was included for each soil treatment.

Ryegrass (*Lolium perenne* L.) was used as the indicator plant. One g of seed was planted in each pot. The soils were maintained at gravimetric water content of 30% by daily watering with deionized water to replace the amount lost during the previous 24 hours, as determined by weighing 10 randomly selected pots. Three times weekly all pots were weighed and adjusted to the preselected weight. Lighting in the greenhouse was maintained for 15 hour days and daily temperature ranged from 20 to 25°C.

The ryegrass plants were cut at a height of 1 cm from the soil surface every 30 days for a total of four cuttings. After each cutting, the plant material was dried at 65°C, weighed, ground to pass a 0.37 mm sieve, and analyzed for total N. All pre- and post-experiment soil samples were analyzed for extractable NH_4, NO_3, and pH. Pre-experiment soils were also analyzed for total C and N.

The design of the experiment was a 6 x 4 randomized-complete-block factorial with six residue treated soils, four N rates, and four replications. The repeated cuttings were considered to be a split plot in time. SAS software program with the general linear models and ANOVA subprogram was used to perform ANOVA procedures (SAS Institute, 1985).

Nitrogen mineralization (Nmin) was determined from the uptake of N from the four cuttings of ryegrass. The equation used to calculate Nmin as proposed by Stanford and Smith (1972) was:

$$Nmin = Nmin_0[1-exp(-kt)]$$

where $Nmin_0$ is the potentially mineralizable N, t is time, and k is the rate constant.

Soil profile

The Residue Utilization Plots are located on a Walla Walla silt loam soil (coarse-silty, mixed, mesic Typic Haploxerolls). The area is slightly sloping with each treatment being replicated on the upper and lower slope areas. All nine of the long-term residue plots were subsampled in August

1988, at 0-15 cm, 15-30 cm, and at 30 cm increments to the basalt bedrock. Each plot sample was the result of 8-12 composite samples. The depth to bedrock varied with landscape position; the upper position was sampled to 210 cm and the lower position was sampled to 120 cm. Soil samples were dried and passed through a 2 mm sieve prior to analysis for extractable NO_3 and NH_4. Soil samples were ground to pass a 0.149 mm sieve for total C and N analysis.

Analytical procedures

Total soil N was determined by Kjeldahl digestion, followed by NaOH distillation, and measured by titration with 25 mM H_2SO_4 in boric acid indicator (Bremner, 1970). Available NO_3 was extracted with 16 mM $Ca(H_2PO_4)_2$ and measured on an ion chromatograph (Dionex Corp., Sunnyvale CA.) (Dick and Tabatabai, 1979). Available NH_4 was extracted with 2 M KCl and measured colorimetrically on an autoanalyzer (Alpkem, Clackamas, OR).

Total organic C was determined by combustion and infrared detection on a carbon analyzer (Dohrmann, Santa Clara, CA). Soil pH was measured using a glass electrode on a pH meter (soil:water ratio 1:2).

RESULTS AND DISCUSSION

Greenhouse Experiment

Plant Growth Response

At the control N rate, ryegrass dry matter yield (DMY) from the manure treated soil was significantly higher for each of the four cuttings (Fig. 1.1). When compared to the inorganic N and PV soil treatments, ryegrass DMY from the manure treated soil was 40% greater at the 30 day cutting, increasing to 54% at the 120 day cutting. Increasing the rate of inorganic N applied in the greenhouse decreased the DMY response of the manure treated soil over the other soil treatments (Table 1.2). Only at the highest rate (320 mg N kg^{-1}) was there no increase in yield from the manure treated soil over the other treatments.

Long-term yields from the Residue Utilization Plots have indicated that the strawy manure (22.4 Mg ha^{-1} 2 yr^{-1}) increased wheat yields 5% over 90 kg N ha^{-1} 2 yr^{-1} and 30% over 2.24 Mg ha^{-1} 2 yr^{-1} of pea vine (Rasmussen et al., 1989). The results from the greenhouse study indicate that a yield advantage on soil treated with manure can be overcome by adequate N, P, and S applications. This suggests that there are no other nutrient deficiencies nor are there any intrinsic or unknown effects from manure applications that increases crop yields.

Table 1.2. Effect of greenhouse N application rate on cumulative dry matter yield of ryegrass on soils from the Residue Utilization Plots.

Residue	N application rate (mg kg^{-1} soil)						
Treatment	0		80		160		320	
	--------------------g pot^{-1}--------------------							
N$_0$	1.28	b	2.84	bc	4.70	bc	7.72	a
N$_0$SB	1.17	b	2.60	c	4.54	c	7.55	a
N$_{90}$	1.24	b	2.98	b	4.75	bc	7.42	a
N$_{90}$SB	1.31	b	2.99	b	4.80	bc	7.64	a
PV	1.38	b	2.96	b	4.65	bc	7.64	a
M	1.96	a	3.41	a	5.10	a	7.96	a

Means within a column followed by the same letter are not significantly different at P=0.05 LSD level.

Table 1.3. Soil chemical analysis of soil from Residue Utilization Experiment Plots prior to greenhouse experiment.

Residue	Total	Total	NH$_4$	NO$_3$	C:N	pH
Treatment	C	N			Ratio	
	g kg^{-1}	---------mg kg^{-1}----------				
N$_0$	9.80 d	827 c	3.1 b	10.7 e	11.85	6.36 d
N$_0$SB	9.98 d	854 c	2.5 e	12.8 d	11.69	6.77 b
N$_{90}$	10.55 c	818 d	2.7 d	14.8 b	12.90	5.90 f
N$_{90}$SB	10.76 c	806 d	2.9 c	12.9 d	13.35	6.01 e
PV	11.49 b	922 b	2.9 c	13.9 c	12.46	6.56 c
M	14.00 a	1214 a	3.4 a	28.1 a	11.53	6.89 a

Means within a column followed by the same letter are not significantly different at P=0.05 LSD level.
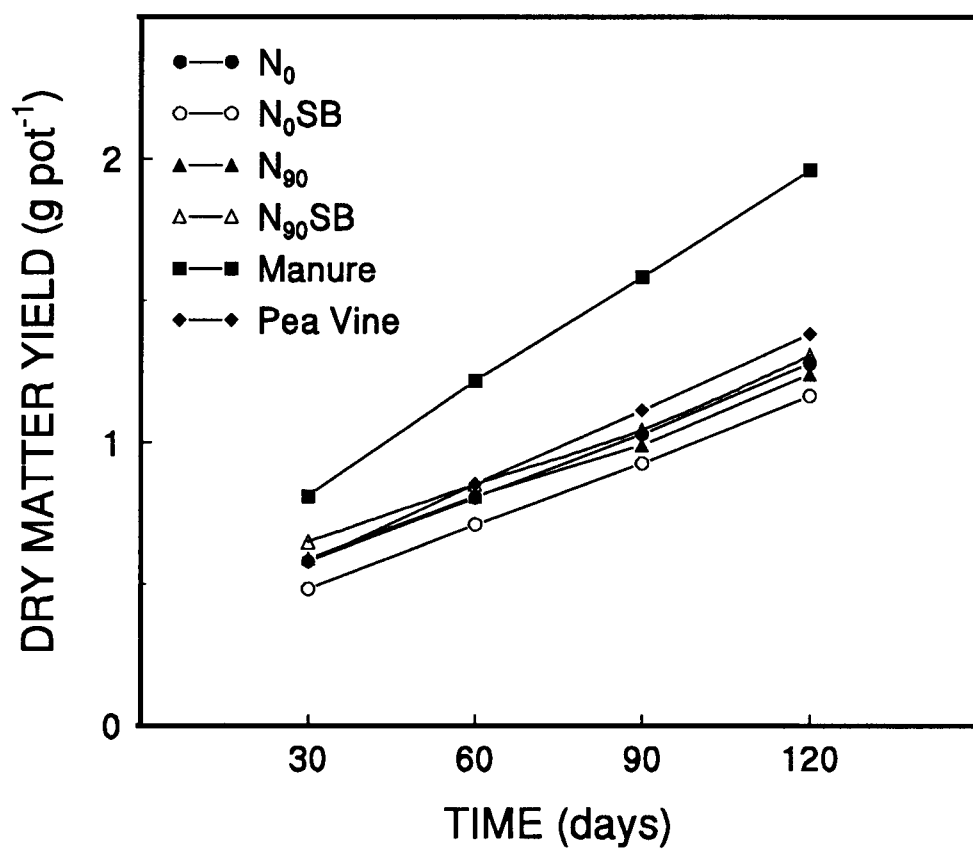
Fig. 1.1. Cumulative ryegrass dry matter yield in the absence of a greenhouse N application on soils from the Residue Utilization Experiment Plots.

Other studies have also shown that manure can have long-term impacts on crop yields. Cope et al. (1958), showed that corn yields from soils amended with manure at a rate of 11.2 Mg ha^{-1} yr^{-1} consistently outyielded 52 kg inorganic N ha^{-1} yr^{-1} by 9% and an annual input of 7 Mg ha^{-1} yr^{-1} of vetch green manure by 28%. Jenkinson and Johnson (1977) found that the application of 35 Mg ha^{-1} yr^{-1} of animal manure for 19 years at the Rothamsted Experiment Station increased residual N and crop yields for 123 years after the treatment was terminated.

In the absence of N amendments in the greenhouse, DMY of ryegrass from the pea vine treated soil was not significantly different from the control soils or the soils receiving inorganic N (Table 1.2). An explanation for the poor yield results from the pea vine treated soil could be that since 1950 the pea seed has been removed from the vine prior to incorporation. Chemical analysis estimated that prior to 1950, N input from the pea vines averaged 40 kg N ha^{-1} 2 yr^{-1}. After 1950, N input from the pea vines decreased to 34 kg N ha^{-1} 2 yr^{-1} (Table 1.1). Heichel (1987) determined that after the harvest of soybean seed, the soybean vine contributed little to total soil N. Additionally, the input of only 34 kg N ha^{-1} 2 yr^{-1} from 2.24 Mg pea vine ha^{-1} 2 yr^{-1} (Table 1.1) is considerably less than the 70-200 kg N ha^{-1} yr^{-1} some studies have shown is necessary to maintain fertility levels and sustain crop yields (Hargrove, 1986; and Hesterman et al., 1986).

Ryegrass DMY from the N_0SB treated soil tended to be lower than all other treatments at all rates of applied inorganic N. Although the decrease was not significant at the greenhouse N rate of 320 mg N kg^{-1} soil, it was significantly lower than all treatments at 80 mg N kg^{-1} soil and significantly lower than the M treatment at 0, 80, and 160 mg N kg^{-1} soil (Table 1.2). This trend was consistent with results from Hooker et al. (1982) and Biederbeck et al. (1980) who found a trend of reduced crop yields after long-term annual burning of crop residue. Biederbeck et al. (1980) estimated that burning of a wheat crop residue caused volatile N losses of 27%. Chemical analysis prior to our greenhouse experiment showed the N_0 treatment had lower total N values (827 mg N kg^{-1}) than the N_0SB treatment (854 mg N kg^{-1}) (Table 1.3), but N_0 had greater cumulative DMY than N_0SB. This suggested that burning crop residues, in the absence of inorganic N applications, caused greater accumulation of N in pools that were resistant to mineralization.

At the control rate, ryegrass N uptake was similar to DMY in that it was significantly higher for the manure treated soil than the other treatments (Table 1.4). Ryegrass N uptake in the manure treated soil was 53% greater at the 30 day cutting, increasing to 61% greater at the 120 day cutting (Fig. 1.2). Although the manure treated soils consistently had higher N uptake in the presence of N greenhouse applications (80, 160, or

320 mg-N kg^{-1}), there was no significant difference in N uptake for any of these soil treatments (Table 1.4).

There was no long-term field treatment effect on ryegrass N concentration at the individual rates of greenhouse applied N (data not shown). As the rate of greenhouse applied N increased, N concentration of ryegrass increased from 1.89% (N_0 at 0 mg N kg^{-1}soil) to 3.74% (N_{90} at 320 mg N kg^{-1} soil).

Table 1.4. Effect of greenhouse N application rates on cumulative N uptake of ryegrass on soils from the Residue Utilization Plots.

Residue	N application rate (mg kg^{-1} soil)			
Treatment	0	80	160	320
	----------------------mg pot^{-1}----------------------			
N_0	24.2 b	85.8 a	160.5 a	271.2 a
N_0SB	22.9 b	81.0 a	149.7 a	263.8 a
N_{90}	25.1 b	95.7 a	157.8 a	277.1 a
N_{90}SB	24.8 b	92.3 a	160.9 a	270.3 a
PV	27.0 b	99.0 a	157.2 a	259.8 a
M	40.0 a	102.3 a	167.4 a	280.8 a

Means within a column followed by the same letter are not significantly different at P=0.05 LSD level.
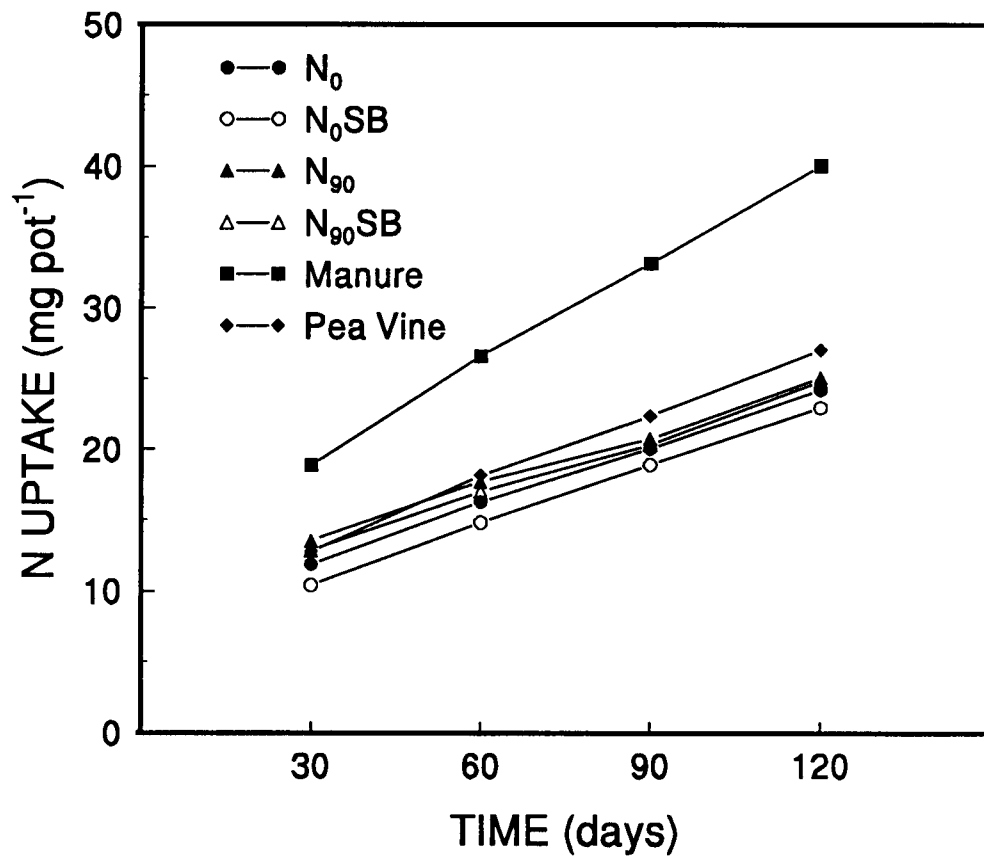
Fig. 1.2. Cumulative ryegrass N uptake in the absence of a greenhouse N application on soils from the Residue Utilization Experiment Plots.

N Mineralization Potential

Nitrogen mineralization potentials ($Nmin_0$) and rate constants were calculated from the N uptake of ryegrass, using the exponential equation proposed by Stanford and Smith (1972) (Table 1.5). Potentially mineralizable N ranged from 25.93 mg N kg^{-1} (N_{90}) to 46.2 mg N kg^{-1} (M). The greater uptake of N from the manure treated soil (Fig. 1.2) appears to be a result of having a larger available N pool (i.e. $Nmin_0$) and not from a greater rate of N mineralization as shown by k values which are not significantly different from the control soils.

Mineralization rates tended to be inversely related to mineralization potentials, ranging from 0.01529 mg N kg^{-1} d^{-1} (M) to 0.02111 mg N kg^{-1} d^{-1} (N_{90}). The soils receiving the high rates of inorganic N (N_{90} and $N_{90}SB$) had the highest rate of mineralization (k), but the lowest amount of potentially mineralizable N ($Nmin_0$). Rojas (1986) reported similar results, using 13 Iowa soils and ryegrass in a greenhouse experiment. This may indicate that although total mineralizable N is lower in soils that received long-term inorganic N, the form in which it is found is much more readily available. Nitrogen mineralization for all treatments was not rapid enough to meet crop needs for the duration of the 120 day experiment.

A coefficient of simple determination (r) was used to evaluate the relationship between soil chemical parameters and mineralization potentials (Table 1.6). Mineralization potential ($Nmin_0$) was significantly correlated to

total C and N and initial extractable NO_3. The mineralization rate constant (k) was significantly negatively correlated to the pH of the soil.

Table 1.5. Nitrogen mineralization potential ($Nmin_0$) and rate constant (k) calculated from the exponential equation of Stanford and Smith (1972) from N uptake of ryegrass.

Residue Treatment	$Nmin_0$		k		R^2
	--mg N kg^{-1}--		--mg N kg^{-1} day^{-1}--		
N_0	26.9	bc	0.0167	ab	.95
N_0SB	27.6	bc	0.0174	ab	.97
N_{90}	25.9	c	0.0211	a	.92
$N_{90}SB$	26.4	bc	0.0188	ab	.93
PV	30.9	b	0.0156	b	.96
M	46.2	a	0.0152	b	.96

Means within a column followed by the same letter are not significantly different at P=0.05 LSD level.

Table 1.6. Coefficient of simple determination (r)† between various pre-experiment N fractions and mineralization constants from greenhouse experiment for Residue Utilization Plot soils.

	Total N	NH$_4$	NO$_3$	pH	C:N Ratio	Nmin$_0$	k
Total C	.95 ‡	.72	.95 ‡	.49	-.28	.95 ‡	-.19
Total N		.72	.95 ‡	.70	-.57	.99 ‡	-.41
Ext. NH$_4$			.67	.30	-.31	.75	-.06
Ext. NO$_3$				.51	-.40	.96 ‡	-.18
pH					-.87 ‡	.68	-.93 ‡
C:N Ratio						-.55	.78
Nmin$_0$							-.39

† n = 6.

‡ significant to p=0.05.

Greenhouse Soils

Results of soil chemical analysis on the Residue Utilization

Experiment Plots prior to the greenhouse experiment are presented in

Table 1.3. Total C ranged from 9.8 g kg^{-1} (N$_0$) to 14.00 g kg^{-1} (M). This is

consistent with the increased biomass that had been added with the 22.4

Mg manure ha^{-1} 2 yr^{-1} plus the incorporation of the wheat straw.

Pre-experiment levels of total N ranged from 806 mg kg^{-1} (N$_{90}$SB) to

1214 mg kg^{-1} (M). Decreased levels of total N in the plots receiving 90

kg-N ha^{-1} 2 yr^{-1} could be due the result of increased N uptake from the

increased yields of these plots (Rasmussen et al., 1989).

Although total C and N were higher in the M treated soil, the C:N

ratio was highest in the treatments receiving high rates of inorganic

fertilizer.

Pre-experiment levels of exchangeable NH$_4$-N were not significantly

different for any of the residue treatments. Xie and MacKenzie (1986)

found that within 60 days of application most of the manure applied NH$_4$-N

had been either converted to NO$_3$-N, volatilized, or immobilized. Since the

soils were collected in November 1988, 18 months after the manure and

pea vine incorporation and 12 months after N fertilizer application, it would

be expected that NH$_4$-N levels would be low and not significantly different.

Increased NH$_4$-N levels following the greenhouse experiment were most

likely due to the increased mineralization from the optimal environmental

conditions of the greenhouse and the high demand for N by the ryegrass plants which prohibited significant nitrification (Table 1.7).

Prior to the greenhouse experiment, the manure treated soil had significantly higher levels of NO_3-N than the other treatments. The increased level is probably due to the higher total N levels of manure treated soil and N mineralization since the previous wheat crop harvest in July 1988. Following the greenhouse experiment, there was no significant treatment effect at the individual rates of applied N; however, there was significantly less NO_3-N at the highest rate of applied N for all the treatments (Table 1.7). At the highest rate of applied N (320 mg), plant growth was significantly greater and sustained longer. Since NO_3 is taken up preferentially over NH_4 (Mengel and Kirkby, 1987) this could explain the decreased amount of NO_3 remaining in the soil.

Pre-experiment soil pH levels ranged from 6.89 (M) to 5.90 (N_{90}). The pH levels were higher for the burn plots compared to the straw incorporated plots at the same N rate. These results vary from Biederbeck et al. (1980) who found no effect of burning on the level of pH.

Upon termination of the greenhouse experiment, for treatments receiving no N, pH increased for all the treatments with the manure treated soil showing the largest increase. As the rate of applied N increased, the pH level decreased for all treatments. The smallest decrease occurred in

the manure treated soil, which could be due to the increased buffering

capacity of that soil (Tisdale et al., 1985).

Table 1.7. Results of soil chemical analysis on Residue Utilization Plot soils following greenhouse experiment.

Residue Treatment	Greenhouse N rate	NH_4	NO_3	pH
	-----------------mg N kg^{-1} soil------------------			
N_0	0	4.8	2.4	6.58
	80	6.0	3.1	6.21
	160	6.2	2.2	6.08
	320	6.0	0.4	5.92
N_0SB	0	4.9	2.1	6.90
	80	6.8	2.4	6.55
	160	6.7	3.7	6.36
	320	5.5	0.5	6.28
N_{90}	0	5.0	1.5	6.14
	80	5.8	2.4	5.85
	160	6.9	3.1	5.73
	320	6.1	0.3	5.65
$N_{90}SB$	0	5.4	1.8	6.23
	80	8.3	4.7	6.03
	160	6.9	2.1	5.85
	320	5.6	0.4	5.66
PV	0	5.2	1.8	6.72
	80	6.6	4.3	6.35
	160	6.4	1.3	6.22
	320	5.7	0.3	6.17
M	0	4.7	2.5	7.24
	80	6.7	3.2	6.94
	160	6.3	1.3	6.75
	320	6.3	0.8	6.63

Soil Profile

Due to the difference in profile depth, the results were divided into upper slope position (deeper profile) and lower slope position (shallower profile) (Fig. 1.3-1.6).

In the upper 75 cm of the soil profiles, as depth increased, the concentration of total C decreased (Fig. 1.3). This is consistent with results from Havlin et al. (1990). Below 75 cm, all plots had some accumulation of total C and many plots from the lower slope showed large accumulation of total C. Since both lower and upper slope profiles were sampled to bedrock, it appeared that the leaching of organic compounds resulted in the accumulation of total C which was more concentrated in the lower slope (shallower) profile.

Total N decreased throughout the entire profile (Fig. 1.4). Because of the varying trend of C and N concentrations with depth, the C to N ratio of 10:1 in the upper portion of the profile increased to as high as 200:1 in the lower portion of the profile.

Research by Rasmussen et al. (1980) indicated that since the experiment was initiated in 1931, total N in the 0 to 15 cm depth had increased only in the manure residue treatment. Conversely, plots receiving no fertilization or inorganic N fertilization had shown distinctly linear declines in total N. Previously declining N levels may have stabilized because current levels are equal to or somewhat higher than 1976 levels.

This is consistent with an 18 year study conducted in Alabama, Cope et al.(1958) showed that total N increased with annual manure applications of 11.2 Mg ha^{-1} and stabilized with either 58.2 kg N ha^{-1} yr^{-1} as $NaNO_3$ or an annual winter cover crop of vetch with annual biomass equal to 7 Mg ha^{-1}.

Extractable NH_4 concentrations in both the upper and lower landscape positions generally decreased or remained constant with increased depth (Fig. 1.5). Any N mineralized to NH_4 would either be converted to NO_3, taken up by plants as NH_4, or held by cation exchange which would limit movement to the subsoil.

Extractable NO_3 concentrations were generally under 3 mg N kg^{-1} in both the upper and lower landscape position (Fig. 1.6). This was due to the low N status of these soils. The notable exception was in the 90-150 cm portion of the manure treated plot from the lower landscape position which had NO_3 concentrations of >12 mg N kg^{-1}. This provided evidence that mineralization was converting significant amounts of manure-N to NO_3 and mineralization exceeded crop requirements and immobilization rates. This could be due to manure application rates that were too large or the mineralization of the manure did not coincide with succeeding crop needs. Long-term N budgets on these plots (Dick et al., 1988) showed that biennial net N inputs from the manure treatment were 29 kg N ha^{-1} yr^{-1}, which was significantly higher than the pea vine and N rate treatments which had net N inputs of < 8 kg N ha^{-1} yr^{-1}. The greenhouse study also confirmed that

the manure treated soil had greater potential to mineralize N. The differential accumulation of NO_3 in the upper and lower slope positions for the manure plots may be due to the depth to bedrock in relation to water movement. Rainfall and water storage data for these plots showed that the lower slope had water in excess of storage capacity during every fallow year since 1931. During this time the average water in excess of storage capacity was equal to 13.5 cm. The upper slope (deeper) had water in excess of storage capacity only 52% of the fallow years, with average water excess of 2.4 cm (P. E. Rasmussen, personal communication).
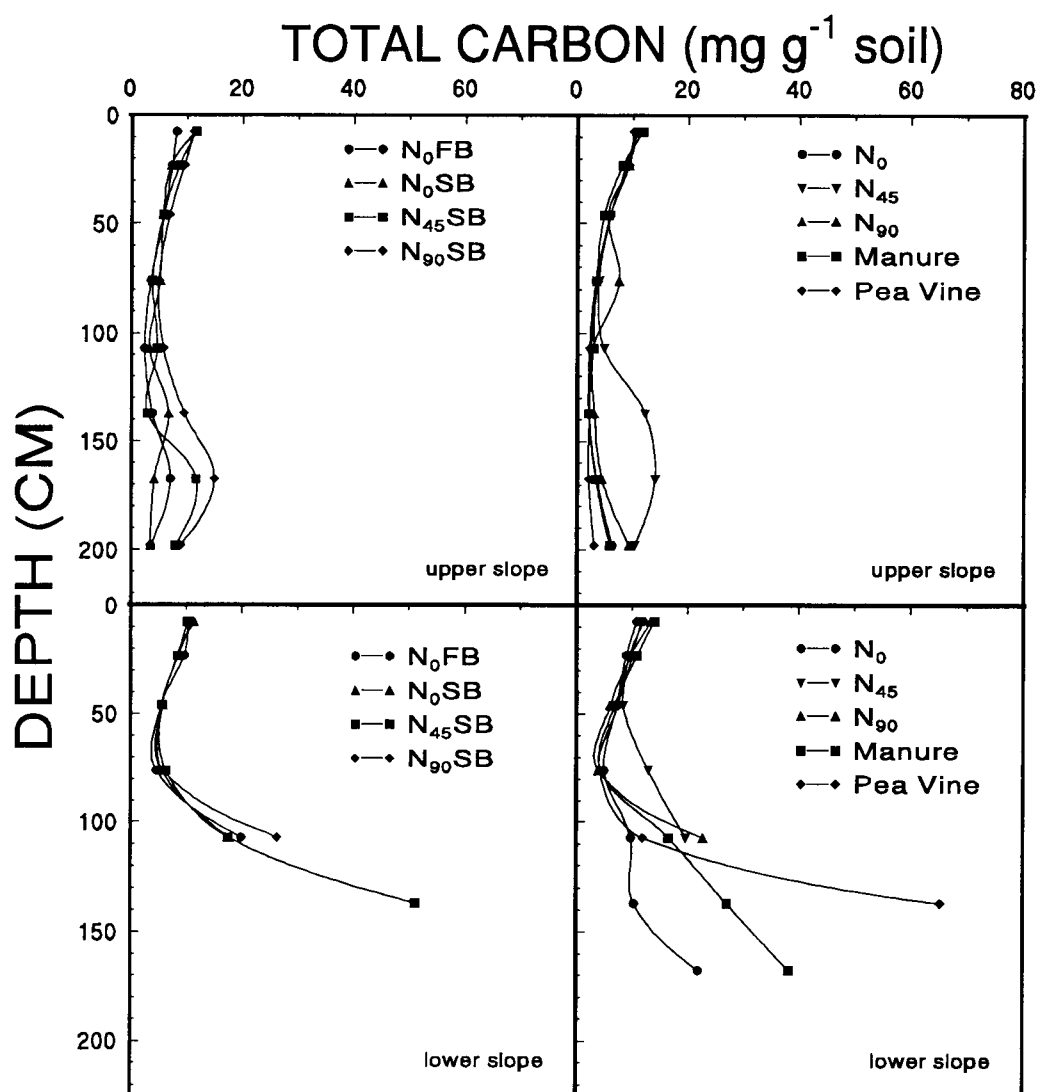
Fig. 1.3. Soil profile distribution of total carbon from the upper (deeper) and the lower (shallower) slopes from the Residue Utilization Plots.
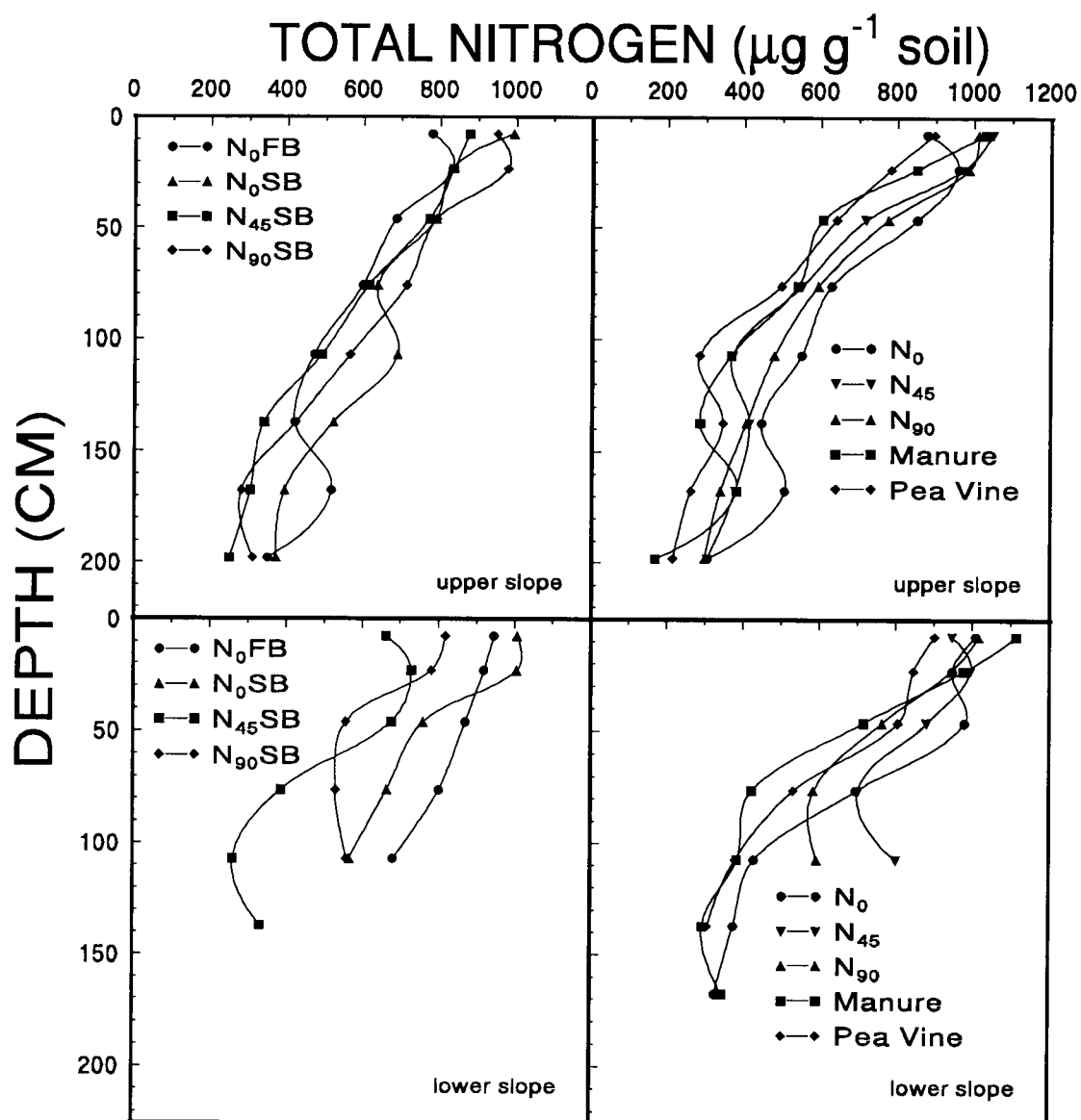
Fig. 1.4. Soil profile distribution of total nitrogen from the upper (deeper) and the lower (shallower) slopes from the Residue Utilization Plots.
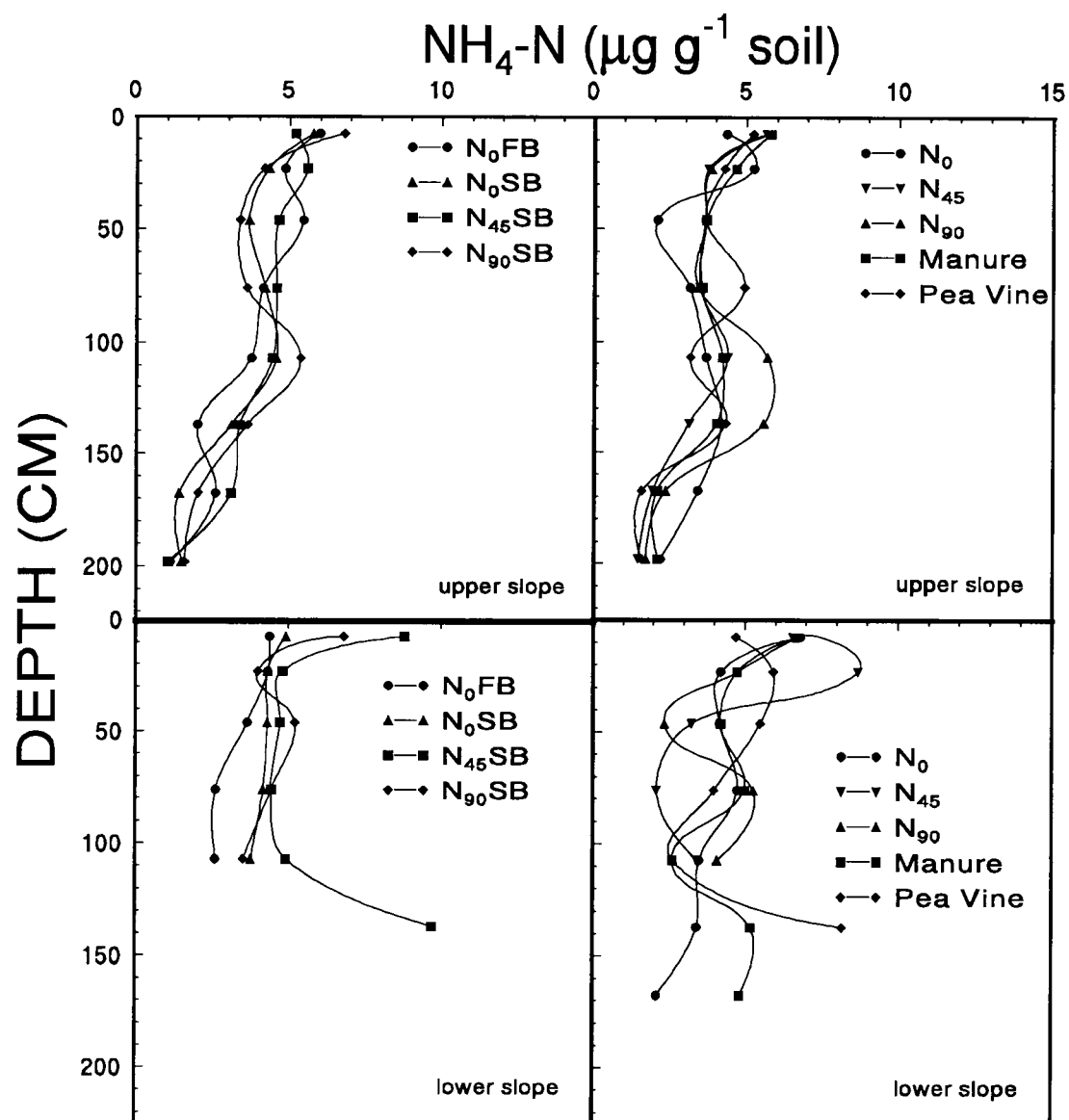
Fig. 1.5. Soil profile distribution of extractable NH_4 from the upper (deeper) and the lower (shallower) slopes from the Residue Utilization Plots.
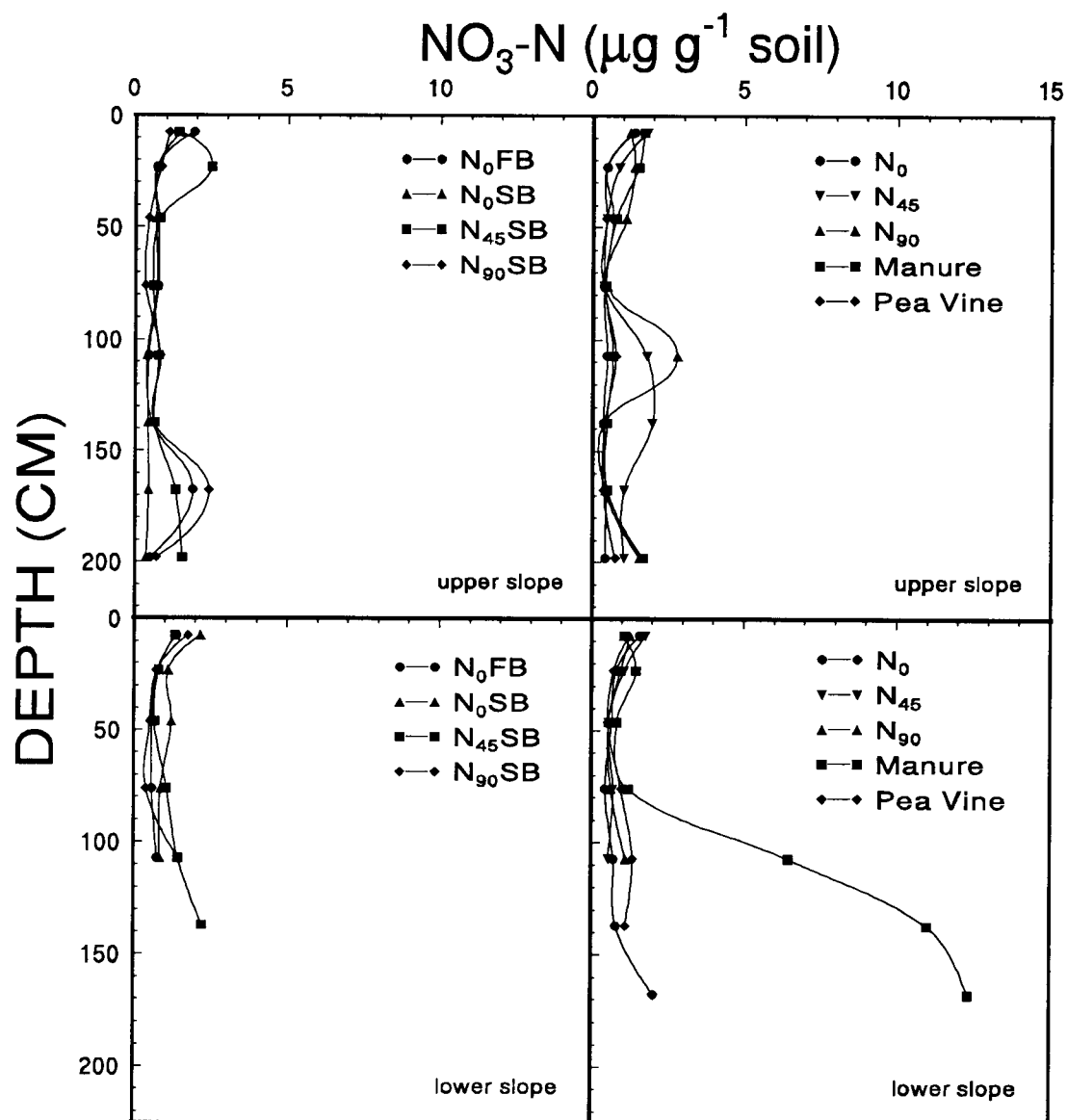
Fig. 1.6. Soil profile distribution of extractable NO_3 from the upper (deeper) and the lower (shallower) slopes from the Residue Utilization Plots.

CONCLUSIONS

The application of animal manure to the soil increased ryegrass dry matter yield and N uptake when compared to soils that received pea vine or inorganic N treatments. However, under greenhouse conditions, additional N on manure treated soil was needed to maximize biomass productivity. Although greenhouse yields of ryegrass tended to be somewhat lower from soils where crop residue was burned, the results indicated that the decreased yields were generally not significant. Calculated N mineralization potential showed that the greater amount of N produced by manure treated soil was due to a larger potential N mineralization pool and not due to greater rates of mineralization. Conversely, plots receiving inorganic N had higher rates of N mineralization indicating that long-term applications of inorganic N results in accumulation of N which is more labile. Previously declining levels of total N in treatments receiving no N fertilization or inorganic N fertilization may have stabilized at current levels. Although the application rate of 22.4 Mg animal manure ha^{-1} 2 yr^{-1} provided significantly more residual N for subsequent crop yields and has maintained soil fertility, it may also be a potential source of nitrate groundwater pollution in a semi-arid wheat-fallow cropping environment.

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CHAPTER 2

EFFECTS OF LONG-TERM RESIDUE MANAGEMENT

AND NITROGEN FERTILIZATION ON

AVAILABILITY AND PROFILE DISTRIBUTION

OF PHOSPHORUS

ABSTRACT

The long-term effects of inorganic fertilization and residue management on the availability and soil profile movement of P are not well understood. A long-term residue utilization experiment under a winter wheat-fallow system in the semi-arid region of eastern Oregon provided an opportunity to study the cumulative effects of long-term residue management and N fertilization on plant availability of P. Established in 1931, treatments included wheat straw burning, or incorporation of manure, legume plant residue, or inorganic N. To evaluate the plant availability of P, a greenhouse pot study was conducted on soils collected from the 0-20 cm depth. Ryegrass (*Lolium perenne* L.), grown for 120 days in 1 kg of soil, which had been treated at rates of 0, 20, 40, or 80 mg P kg^{-1} soil, was harvested and analyzed for total P at 30 day intervals. Ryegrass dry matter yield (DMY) was unaffected by the residue management or N fertilization history of the plots and the rate of greenhouse applied P. However, there was a significant effect of P rate on P uptake for each residue of N treatment. The uptake of P from the manure treated soil was significantly greater than all other treatments at all four P rates. A history of burning of wheat straw did not significantly influence greenhouse DMY or P uptake. Analysis of the soil profile from the long-term plots showed that even with no P fertilization over the past 60 years, concentrations of total and available forms of P remained sufficient to maximize yields. Most plots

showed increased concentrations of total P, extractable PO_4, and inorganic

P with increased depth. Significant concentrations of extractable PO_4

appear to be accumulating in the lower portion of many of the residue plots.

Although P does not appear to currently be limiting plant growth, depletion

of the upper portion of the profile indicates that P could become a limiting

nutrient in the future.

INTRODUCTION

Although P has long been recognized to be an essential nutrient for

plant development and is often exceeded only by nitrogen as the limiting

nutrient in crop production (Hunter et. al, 1961), few experiments have been

conducted on the long-term effects of various fertilization and residue

management practices on the availability and movement of P in the soil

profile. Soil properties change slowly and the cumulative effects of

agricultural management practices on nutrient dynamics can best be

studied on long-term field experiments (Yates, 1949).

Because C and N are added through biological mineralization and S

is available from the atmosphere and mineralization of the parent material

of the soil, it has been suggested that the P content of the parent material

ultimately controls the maintenance of organic matter and the N and S

content of the soil (Walker and Adams, 1958). Research by Thompson et.

al (1954) showed that when virgin soils were cropped, decreases in organic P were lower than the decreases in N and S.

The application of manure while increasing crop production has also been shown to increase the availability, persistence, and movement of P in the soil (Abbott and Tucker, 1973; Campbell et. al, 1986; Hannapel et. al, 1964; and Meek et. al, 1982). Abbott and Tucker (1973) found that within 5 years of the application of manure, a 35% increase in P uptake in alfalfa was obtained.

The management of crop residues has also been a common technique used for improving crop production, maintaining organic matter and available P in the soil. Larson et. al (1972) determined that 8 Mg ha^{-1} yr^{-1} of cornstalk (dry matter) were needed to prevent loss of organic matter but much more was needed to maintain total P. Singh and Jones (1976) determined that net immobilization of P occurred when residues containing less than 0.3% total P were incorporated into the soil. Nuttall et. al (1986) found that while the burning of straw residue did significantly increase the $NaHCO_3$ soluble P, the resulting unprotected soil during the fall and winter was vulnerable to increased erosion.

A series of experimental plots at the Columbia Basin Agricultural Research Center in Pendleton, Oregon, provided an opportunity to study the long-term effects of agricultural practices on soil properties and processes. In the semi-arid region of eastern Oregon, under a winter

wheat-fallow system, treatments were established in 1931 that included:

straw incorporated (N_0); spring burn of straw (N_0SB); fall burn of straw

(N_0FB); straw plus 45 kg N ha^{-1} 2 yr^{-1} (N_{45}); spring burn plus 45 kg N ha^{-1} 2

yr^{-1} ($N_{45}SB$); straw plus 90 kg N ha^{-1} 2 yr^{-1} (N_{90}); spring burn plus 90 kg N

ha^{-1} 2 yr^{-1} ($N_{90}SB$); straw plus 2.24 Mg pea vine ha^{-1} 2 yr^{-1} (PV); and straw

plus 22.4 Mg strawy beef manure ha^{-1} 2 yr^{-1} (M) (Table 2.1). Except for a

single application of 56 kg $CaSO_4$-S ha^{-1} in 1967, the soils received no

other fertilization. The management of the plots has remained virtually

unchanged for the last 60 years.

The objectives of this study were 1) to examine the cumulative

effects of long-term residue management and N fertilization on the plant

availability of P, and 2) to examine the soil profile distribution of P fractions.

Table 2.1. History of Residue Utilization Plots from 1931 to 1989.
Pendleton Agricultural Research Center, Oregon (adapted from Rasmussen et al. 1989).

Residue Treatment	Description of Residue Management†	N applied per crop	P applied per crop
		\-\-kg ha^{-1} 2 yr^{-1}\-\-	
N$_0$	Straw incorporated into the soil	0	0
N$_0$FB	Wheat straw burned in the fall	0	0
N$_0$SB	Wheat straw burned in the spring	0	0
N$_{45}$	Straw incorporated into the soil	45(34)§	0
N$_{45}$SB	Wheat straw burned in the spring‡	45(0)§	0
N$_{90}$	Straw incorporated into the soil	90(34)§	0
N$_{90}$SB	Wheat straw burned in the spring‡	90(0)§	0
PV	Straw plus 2.24 Mg ha^{-1} 2yr^{-1} of pea vines incorporated into soil	34(40)¶#	3.4#
M	Straw plus 22.4 Mg ha^{-1} 2yr^{-1} strawy manure incorporated into soil	111#	30#

† All treatments moldboard plowed 20 cm deep in late March or early April of the fallow year. Pea vines and manure applied 1-3 days prior to plowing.

‡ Initiated in 1979, straw incorporated from 1931-1978.

§ Nitrogen rates changed in 1967, number in parentheses is for 1931-1966.

¶ Pea vine input changed in 1950, prior to 1950 pea vines included pea seed, number in parentheses, after 1950 pea vines included only vines and pods, N input based on chemical analysis from 1976-1987.

Strawy manure and pea vine N and P input based on chemical analysis from 1976-1987.

MATERIALS AND METHODS

Greenhouse Experiment

Six treatments from the Residue Utilization Experiment Plots

(Table 2.1) were selected for a greenhouse study (N_0, N_0SB, N_{90}, $N_{90}SB$,

PV, M). The soils were collected in November 1988, from the 0 to 20-cm

depth, passed through a 15-mm screen, and stored field-moist in sealed

bags at 4°C. One kg (oven-dry basis) of soil was put into plastic non-

draining pots (14 x 9 cm) and amended with $Ca(H_2PO_4)_2 \cdot H_2O$ at rates of 0,

20, 40 or 80 mg P kg^{-1} soil. Because these soils do not respond to K, (P.E.

Rasmussen, personal communication), only supplemental amounts of N

and S were added at the rate of 320 mg N kg^{-1} soil as NH_4NO_3 and 40 mg

S kg^{-1} soil as $CaSO_4 \cdot 2H_2O$. A control treatment was included for each soil

treatment.

Ryegrass (*Lolium perenne* L.) was used as the indicator plant. One

g of seed was planted in each pot. The soils were maintained at

gravimetric water content of 30% by daily watering with deionized water to

replace the amount lost during the previous 24 hours, as determined by

weighing 10 randomly selected pots. Three times weekly all pots were

weighed and adjusted to the preselected weight. Lighting in the

greenhouse was maintained for 15 hour days and daily temperature ranged

from 20 to 25°C.

The ryegrass plants were cut at a height of 1 cm from the soil surface every 30 days for a total of four cuttings. After each cutting, the plant material was dried at 65°C, weighed, ground to pass a 0.37 mm sieve, and analyzed for total P. All pre- and post-experiment soil samples were analyzed for $NaHCO_3$ extractable PO_4 and pH. Pre-experiment soils were also analyzed for total C and P.

The design of the experiment was a 6 x 4 randomized-complete-block factorial with six residue treated soils, four P rates, and four replications. The repeated cuttings were considered to be a split plot in time. SAS software program with the general linear models and ANOVA subprogram was used to perform ANOVA procedures (SAS Institute, 1985).

Soil profile

The Residue Utilization Plots are on a Walla Walla silt loam soil (coarse-silty, mixed, mesic Typic Haploxerolls). The area is slightly sloping with each treatment being replicated on the upper and lower slope areas. For profile analyses, each of the nine long-term residue plots were subsampled in August 1988, from 0-15 cm, 15-30 cm, and at 30 cm increments to the basalt bedrock. Each plot sample was the result of 8-12 composite samples. The depth to bedrock varied with landscape position; the upper slope position was sampled to 210 cm and the lower slope position was sampled to 120 cm. Soil samples were dried and passed through a 2-mm sieve prior to analysis for extractable PO_4 and inorganic P

fractions. Soil samples were ground to pass a 0.149 mm sieve for total C and P analysis.

Analytical procedures

Total plant P was determined by a modified alkaline oxidation procedure (Dick and Tabatabai, 1977) where a portion of the digested sample was removed for sulfur analysis prior to phosphorus analysis (Appendix 8). Total soil P was determined by alkaline oxidation procedure (Dick and Tabatabai, 1977). Available PO_4 was extracted with 0.5 *M* $NaHCO_3$ (Olsen et al. 1982). Inorganic P was extracted with 0.5 *M* H_2SO_4 (Saunders and Williams, 1955). Organic P was determined by difference:

total P - inorganic P = organic P

Total organic C was determined by combustion and infrared detection on a carbon analyzer (Dohrmann, Santa Clara, CA). Soil pH was measured using a glass electrode on a pH meter (soil:water ratio 1:2).

RESULTS AND DISCUSSION

Greenhouse Experiment

Plant growth response

Although ryegrass DMY from the manure treated soil tended to be somewhat greater than from other treatments at all four rates of greenhouse applied P, the difference was not significant at P=0.05 (Table 2.2). Burning of wheat straw residue appeared to have had no effect on DMY; N_0SB was significantly lower than all other treatments only at the 0 mg P kg^{-1} rate. Greenhouse ryegrass yield results indicate that even with no addition of P for 60 years, available P in all the residue management and N fertilization treated soils was sufficient to maximize DMY when subjected to the optimal growing conditions of the greenhouse.

Ryegrass P concentration was significantly affected by P rate and residue treatment (data not shown). The concentration of P in the ryegrass from the manure treatment was higher than all other treatments at all four rates of applied P. Additionally, ryegrass P concentration increased with increasing rate of applied P.

Uptake of P by ryegrass was also significantly affected by rate of applied P (data not shown) and residue treatment (Table 2.3). Increasing the rate of applied P increased the P uptake for all the treatments. Additionally, P uptake from the manure treated soil was significantly greater than all other residue treatments at the four rates of applied P. At the 0

rate of applied P, uptake of P from the manure treated soil was 43% higher

than other treatments (Fig.2.1) and was 11% higher than the other

treatments at 80 mg P kg^{-1}. This compares favorably with findings by

Abbott and Tucker (1973) that within 5 years of the application of manure, a

35% increase in P uptake in alfalfa was obtained over the control.

Although, the burning of wheat straw residue appeared to have little effect

on DMY; P uptake tended to be depressed by burning in the $N_{90}SB$ soil but

was generally not significantly lower than no burn soils.

Table 2.2. Effect of greenhouse P application rate on cumulative dry matter
yield of ryegrass on soils from the Residue Utilization Plots.

Residue	P application rate (mg kg^{-1} soil)			
Treatment	0	20	40	80
	--------------------------------g pot^{-1}--------------------------			
N_0	7.65 a	7.54 a	7.25 b	7.72 a
N_0SB	7.07 b	7.30 a	7.12 b	7.55 a
N_{90}	7.46 a	7.58 a	7.47 ab	7.42 a
$N_{90}SB$	7.62 a	7.47 a	7.43 ab	7.64 a
PV	7.68 a	7.49 a	7.65 ab	7.64 a
M	7.83 a	7.67 a	7.72 a	7.96 a

Means within a column followed by the same letter are not significantly
different at P=0.05 LSD level.

Table 2.3. Effect of greenhouse P application rate on cumulative P uptake of ryegrass on soils from the Residue Utilization Plots.

Residue Treatment	P application rate (mg kg^{-1} soil)							
	0		20		40		80	
	--------------------------------mg pot^{-1}--------------------------							
N_0	17.3	b	21.9	bc	26.5	bc	32.6	b
N_0SB	18.8	b	24.9	b	27.5	b	33.1	b
N_{90}	18.3	b	21.7	c	24.9	cd	31.5	bc
$N_{90}SB$	15.2	b	21.9	bc	23.7	d	30.0	c
PV	17.6	b	22.8	bc	26.8	bc	32.4	b
M	26.9	a	30.9	a	32.8	a	36.9	a

Means within a column followed by the same letter are not significantly different at P=0.05 LSD level.
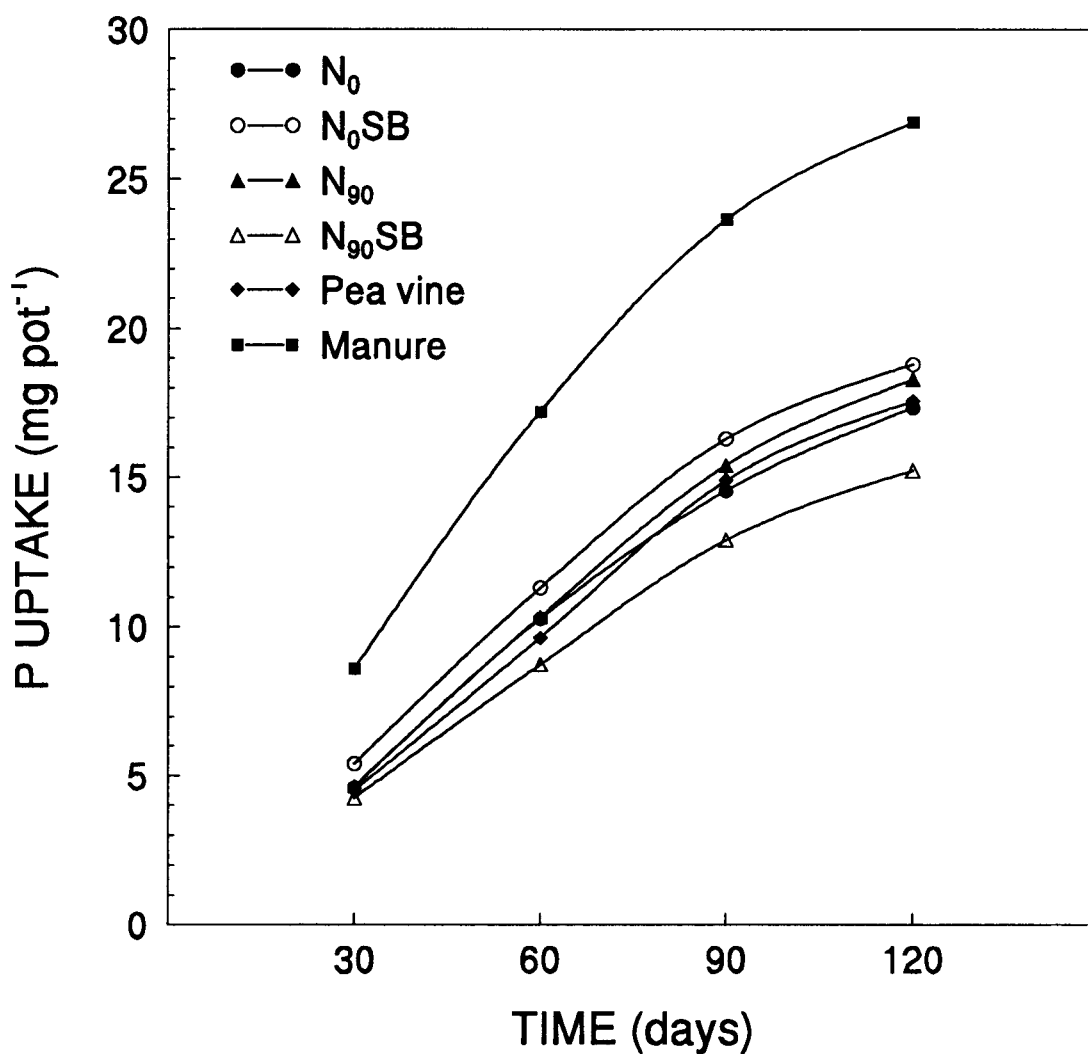
Fig. 2.1. Cumulative ryegrass P uptake in the absence of a greenhouse P application on soils from the Residue Utilization Experiment Plots.

Field History and Greenhouse P Amendments Effects on Soil P

Total P in the soils prior to the greenhouse experiment ranged from 649 mg P kg^{-1} ($N_{90}SB$) to 802 (M) (Table 2.4). Estimates of gross P inputs over the last 60 years show that the manure has added an average of 30 kg P ha^{-1} $crop^{-1}$ and the pea vine has added an average of 3.4 kg P ha^{-1} $crop^{-1}$ (Table 2.1). The addition of P from the 22.4 Mg animal manure ha^{-1} $crop^{-1}$ would account for the increased concentrations of total P found in the manure treated soil. In a survey on the long-term effects of manure application to soil P, Haas et. al (1961) showed that total P decreased an average of 8% when virgin soils were cropped without the addition of animal manures but increased an average of 14% with the addition of as little as 5.6 Mg ha^{-1} of animal manure. The peavine treated soil did not show a corresponding increase in total P concentration. This could be due to the relatively small quantity of 2.24 Mg of peavine ha^{-1} that has been added each cropping year. Larson et. al (1972) determined that 6 Mg ha^{-1} yr^{-1} of cornstalk (dry matter) were needed to prevent decreases in organic matter and total P content. Normally, high $C:P_O$ (Organic) ratios (>200) are associated with soils "deficient" in P, whereas soils well supplied with available P or on which there is no yield response to added P have $C:P_O$ ratios which are generally <100 (Barrow, 1961). Analysis of these soils prior to the greenhouse experiment showed $C:P_O$ ratios of 43 (N_O) to 68 (M)

(Table 2.4) which indicated that there is potential to mineralize organic P, even after 60 years without inorganic P fertilization.

Although there were significant differences in the concentrations of NaHCO₃ extractable PO₄ in the soils prior to the greenhouse experiment (Table 2.4), it appeared that even the lowest level of 18 mg P kg⁻¹ in the $N_{90}SB$ soil was sufficient to maximize DMY of ryegrass. Addition of inorganic P resulted in luxury consumption of P by ryegrass. The manure treated soil had almost twice the amount of NaHCO₃ extractable P for plant uptake than the other soil treatments which was not reflected in DMY but was reflected in the increased P uptake by ryegrass.

Table 2.4. Results of soil chemical analysis from Residue Utilization Plot soils (0-20 cm depth) prior to the greenhouse experiment.

Residue Treatment	Total C	Total N	Total P	PO_4†	P_o‡	$C:P_O$	pH
	g kg⁻¹	----------mg kg⁻¹----------					
N_0	9.80 d	827 c	744 b	27 c	230	43	6.36
N_0SB	9.98 d	854 c	754 b	35 b	211	47	6.77
N_{90}	10.55 c	818 d	715 c	21 d	227	46	5.90
$N_{90}SB$	10.76 c	806 d	649 d	18 e	176	61	6.01
PV	11.49 b	922 b	725 c	27 c	209	55	6.56
M	14.00 a	1214 a	802 a	56 a	206	68	6.89

Means within a column followed by the same letter are not significantly different at P=0.05 LSD level.
† Extracted with 0.5 M NaHCO₃ solution
‡ Organic Phosphorus

Analysis of the soils following the greenhouse experiment showed that all treatments had higher concentrations of extractable PO_4 remaining in the soil at the highest rate of applied P when compared to the lower three rates (Table 2.5). The increased concentration of PO_4 in the soil following the greenhouse experiment indicates that with the addition of <80 mg P kg^{-1} soil these soils were maximizing P uptake.

Table 2.5. Results of soil chemical analysis on Residue Utilization Plot soils following greenhouse experiment.

Residue	P application rate (mg kg^{-1} soil)							
Treatment	0		20		40		80	
	-------------------------mg PO_4-P kg^{-1} soil-------------------------							
N_0	17.7	b	20.6	b	19.9	c	50.6	b
N_0SB	21.1	b	26.6	b	23.0	b	58.2	b
N_{90}	18.0	b	20.3	b	17.4	c	44.5	c
$N_{90}SB$	15.9	c	19.1	c	18.3	c	45.6	c
PV	19.7	b	23.5	b	21.7	b	57.2	b
M	36.4	a	44.4	a	40.0	a	85.0	a

Means within a column followed by the same letter are not significantly different at P=0.05 LSD level.

Soil Profile

Total P levels throughout the soil profile ranged from 500-1000 mg P kg^{-1} soil (Fig. 2.2). With the exception of the manure treated soil on the lower slope position, the general trend was increased total P concentration with increased depth. A possible explanation for this trend may be that over the last 60 years the P removed in crop yield has depleted P from the upper portion of the profile, thereby decreasing the native concentration of P from the upper portion of the profile. Both the manure and pea vine plots showed elevated concentrations of total P in the upper portion of the profile when compared to the other treatments. Considering that the incorporation of manure and pea vine over the last 60 years has added an average of 30 and 3.4 kg P ha^{-1} 2yr^{-1} respectively, it is consistent that total P concentrations would be higher in these plots.

The extremely high total P content in the N_{45}SB plot of the lower slope was an anomaly which was also higher in all P fractions. This treatment is at the extreme end of the residue plots and is possibly being influenced by a change in soil type.

Although extractable PO_4 is usually considered to be quite immobile, the profile of these soils showed medium to large accumulations of $NaHCO_3$ extractable PO_4 (Fig. 2.3). The manure treated soil had large accumulations >55 μg P g^{-1} soil of extractable PO_4 in the upper portion of the profile of both the upper and lower slopes positions. All other soil

treatments had a trend of decreased concentrations of PO_4 with increased depth in the upper 100 cm of the soil profiles. Many of the treatments reversed this trend in the lower portion of the profile, with increased concentrations of PO_4 with increased depth.

The concentration of inorganic P in the soil profile generally ranged from 400-600 µg P g^{-1} soil (Fig. 2.4). The concentration of inorganic P increased with increased depth which may indicate that P requirements for plant uptake were being furnished from the upper portion of the profile. At the top of the profile the manure treated soil had higher concentrations of inorganic P while treatments receiving highest additions of inorganic N had somewhat lower concentrations of inorganic P.

The concentration of organic P in the soil profiles varied dramatically but was generally under 300 µg P g^{-1} soil (Fig. 2.5). The manure treated soil had generally high levels of organic P in the upper portion of the profile which would be expected from the contributions of P over the last 60 years.
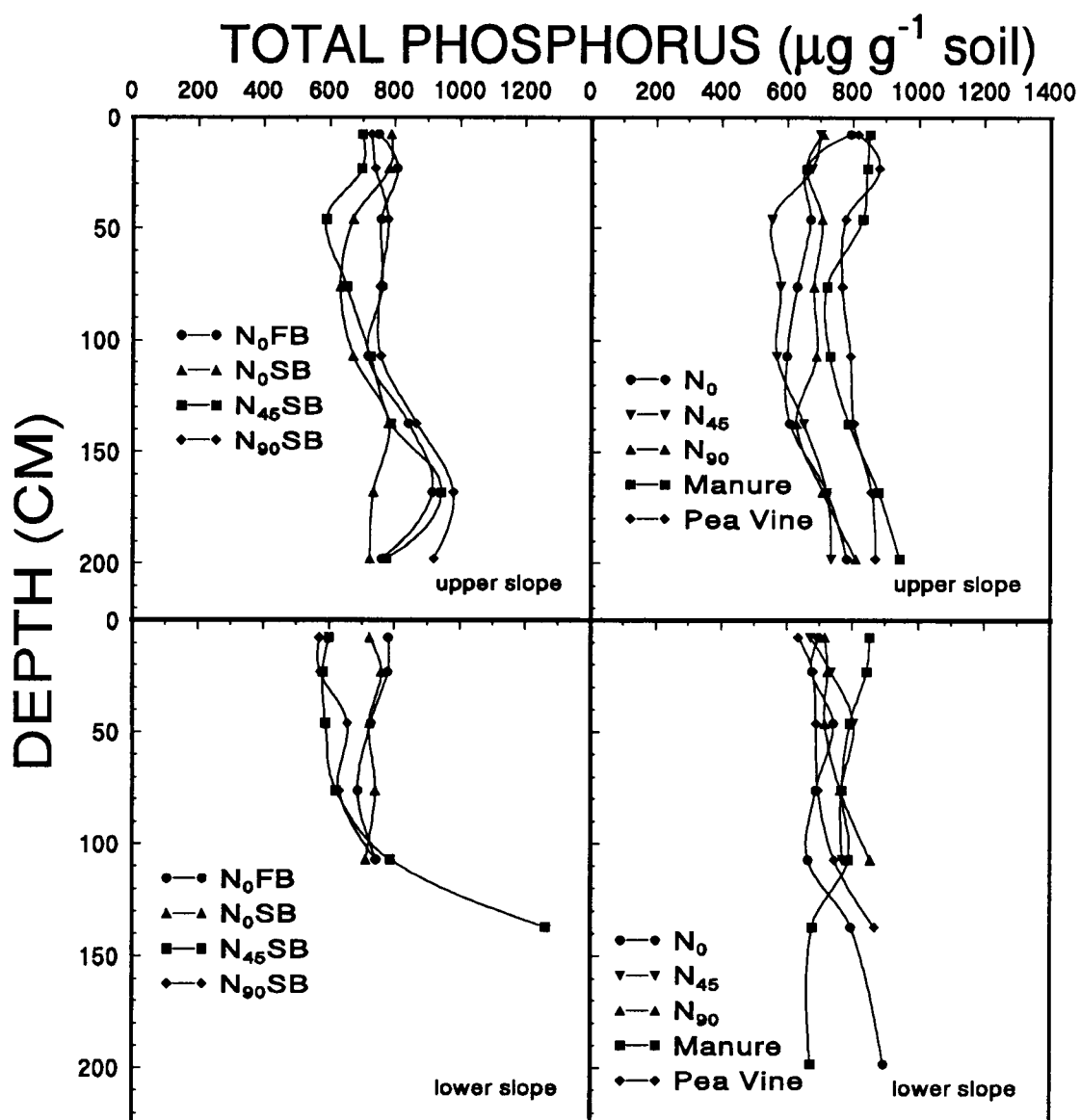
Fig. 2.2. Soil profile distribution of total P from the upper (deeper) and the lower (shallower) slopes from the Residue Utilization Plots.
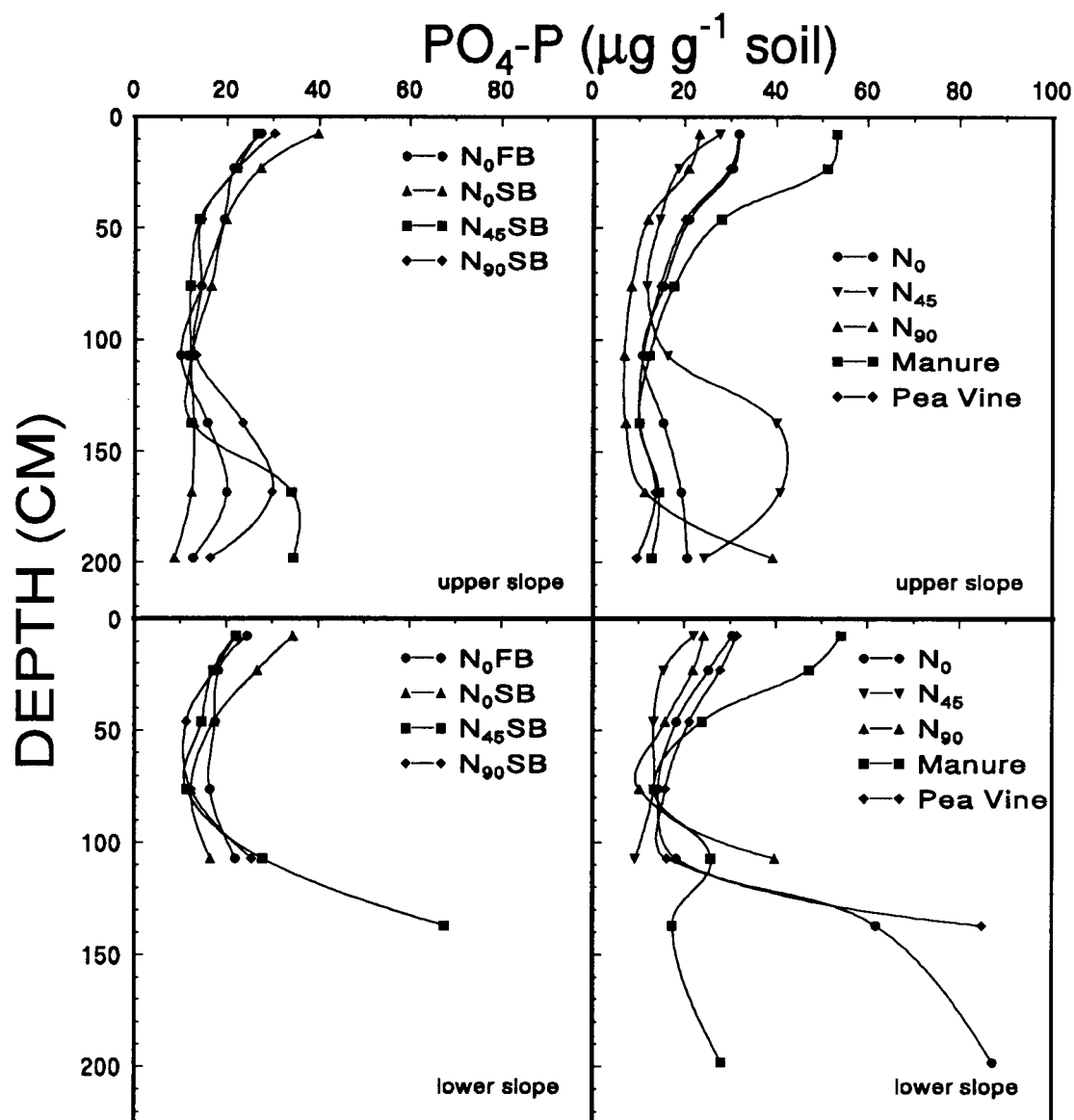
Fig. 2.3. Soil profile distribution of $NaHCO_3$ extractable PO_4 from the upper (deeper) and the lower (shallower) slopes from the Residue Utilization Plots.
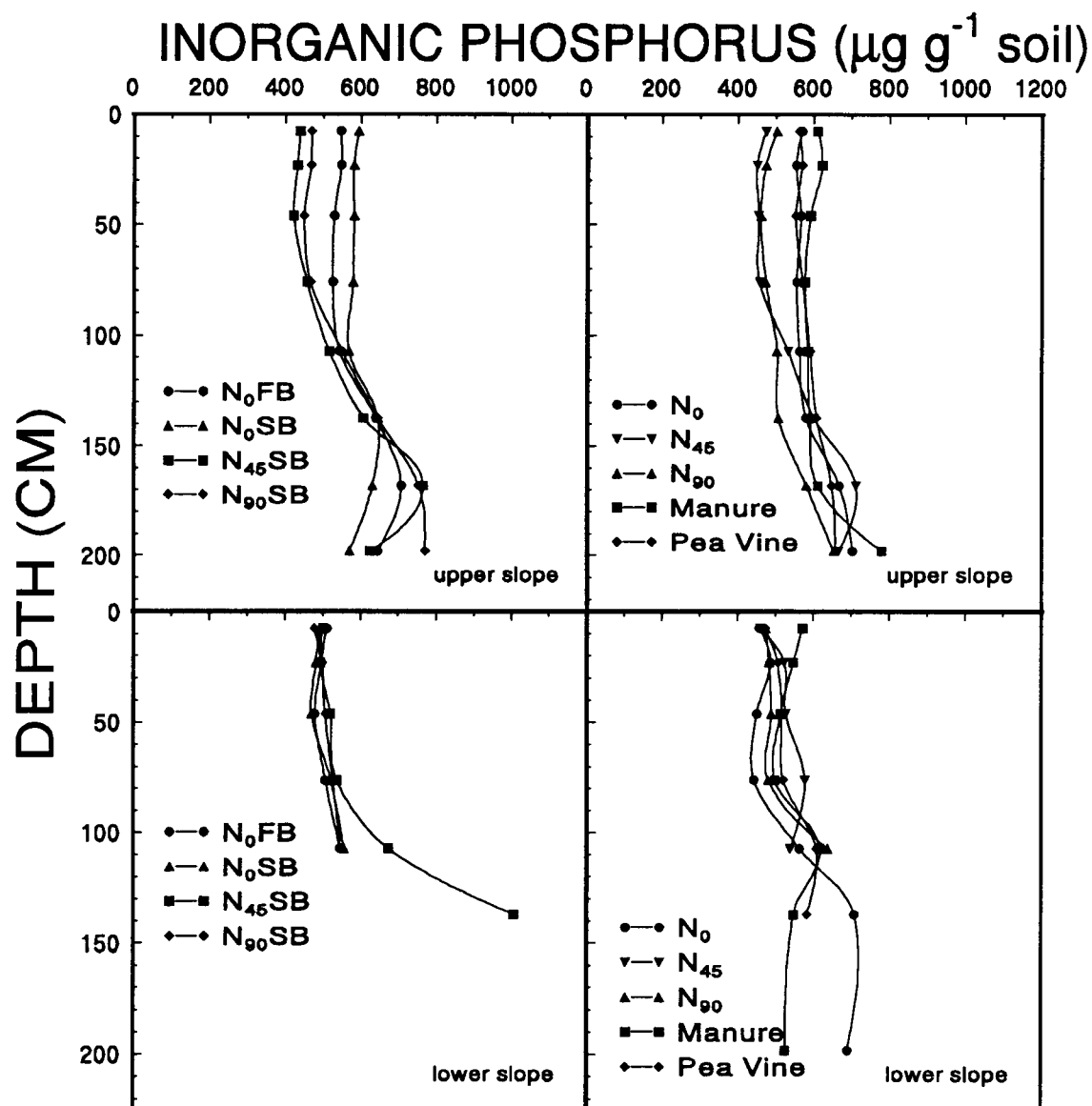
Fig. 2.4. Soil profile distribution of inorganic P from the upper (deeper) and the lower (shallower) slopes from the Residue Utilization Plots.
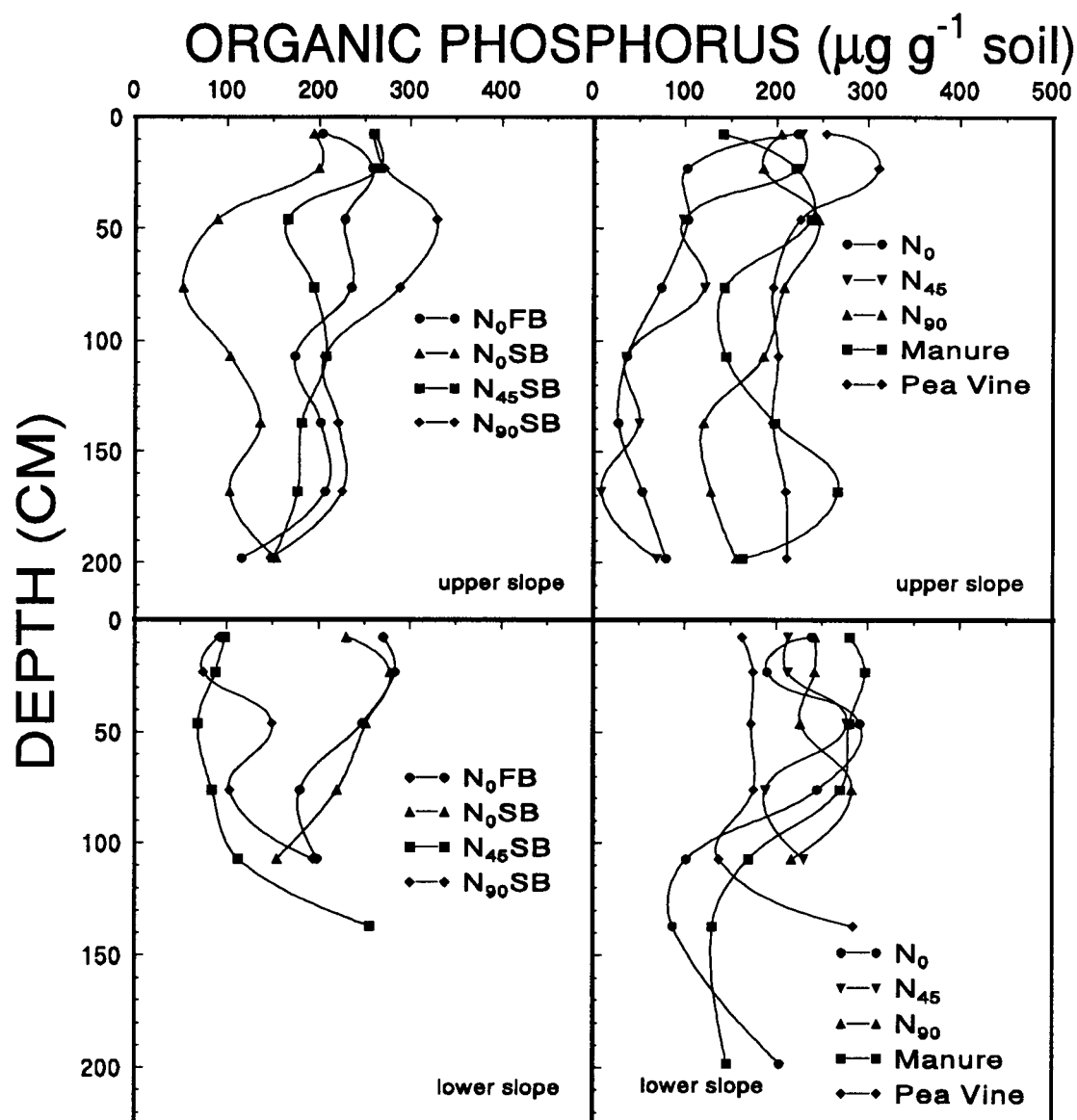
Fig. 2.5. Soil profile distribution of organic P from the upper (deeper) and the lower (shallower) slopes from the Residue Utilization Plots.

CONCLUSIONS

Ryegrass dry matter yield (DMY) in the greenhouse was unaffected by residue management or N fertilization history or the rate of greenhouse applied P. Even though no inorganic P fertilizer had been added to these soils for the last 60 years, it appeared that a sufficient quantity of available P still remained in the soil to maximize DMY of ryegrass. However, when inorganic P was added to these soils, additional P was taken up by the ryegrass in the form of luxury consumption. Uptake of P from the manure treated soil was significantly greater than the other treatments at all four P rates, indicating that the addition of organic residues can be used to meet plant requirements to maximize yields if soil P is limited. Burning of wheat straw did not significantly influence DMY or P uptake. The manure treated soil had almost twice the amount of available P for plant uptake than the other soil treatments which was not reflected in DMY but was reflected in the increased P uptake by ryegrass.

Analysis of the soil profile from the long-term plots showed that in spite of no P fertilization over the past 60 years, concentrations of total and available forms of P remained high. Most plots showed increased concentrations of total P, extractable PO_4, and inorganic P with increased depth. Significant concentrations of extractable PO_4 appeared to be accumulating in the lower portion of many of the residue plots. The addition of animal manures improved the long-term availability of P which

suggests that manure additions can increase P availability in soils that are deficient in P. Because of the relatively low rate of pea vine residue incorporated into the long-term plots (2.2 Mg ha^{-1} 2 yr^{-1}), soil from this treatment had no significant influence on DMY.

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CHAPTER 3

EFFECTS OF LONG-TERM RESIDUE MANAGEMENT

AND NITROGEN FERTILIZATION ON

AVAILABILITY AND PROFILE DISTRIBUTION

OF SULFUR

ABSTRACT

Renewed interest in sustainable agricultural systems and concerns about groundwater pollution have prompted closer examination into the effects of long-term applications of animal manures, green manures and legumes on soil properties and productivity. A long-term residue utilization experiment under a winter wheat-fallow system in the semi-arid region of eastern Oregon provided an opportunity to study the cumulative effects of long-term residue management and N fertilization on plant availability and soil profile distribution of S. Established in 1931, treatments included wheat straw burning, or incorporation of manure, legume plant residue, or inorganic N. To evaluate the plant availability of S, a greenhouse pot study was conducted on soils collected from the 0-20 cm depth. Ryegrass (*Lolium perenne* L.), grown for 120 days in 1 kg of soil, which had been treated at rates of 0, 10, 20, or 40, mg S kg^{-1} soil, was harvested and analyzed for total S at 30 day intervals. Ryegrass dry matter yield (DMY) and S uptake from the manure treated soil were >50% higher than other residue treatments when no inorganic S was added. All residue treatments required addition of S to maximize yields. A history of field burning did not influence DMY or S uptake. Analysis of the soil profile from the long-term plots showed accumulations of total S in the subsoil of several treatments. Additionally, the manure treated soil had significantly higher concentrations of total S in the upper 15 cm of the profile. Further investigation

determined that C-bonded S tended to accumulate near the surface with concentrations >25 mg S kg^{-1} soil in the manure treated soil, while ester sulfate tended to accumulate at the bottom of the profile with concentrations >400 mg S kg^{-1} soil.

INTRODUCTION

Although sulfur (S) has long been recognized to be an essential nutrient for plant growth, little attention was given to the need to maintain adequate S reserves in the soil. Before the use of high-analysis fertilizers, sufficient S was inadvertently supplied along with N, P, and K fertilizers or was available from S-containing pesticides or from pollution in the atmosphere. Sustainable agriculture systems, which seek to decrease the use of inorganic fertilizers and chemical pesticides, require that mineralization of organic matter nutrients be tightly coupled to crop uptake.

Sulfur in soils occurs both as organic and inorganic S, with as much as 95% found in the organic form (Tabatabai, 1982). Mineralization of organic S, a biochemical process, is necessary to supply ample quantities of plant available S. Although soil organic matter is an important source of plant available S, many studies have shown that total S decreases with cultivation in the absence of organic inputs other than crop residues (Jensen, 1963; McLachlan and DeMarco, 1975; McLaren and Swift, 1977;

Bettany et al., 1980). Dick et al. (1988) found that long-term applications of animal manure and pea vine caused a significant increase in arylsulfatase activity compared to soils that received only wheat straw residue.

A series of experimental plots at the Columbia Basin Agricultural Research Center in Pendleton, Oregon, provided a unique opportunity to study the long-term effects of agricultural practices on soil properties and processes. In the semi-arid region of eastern Oregon, under a winter wheat-fallow system, treatments were established in 1931 that included: straw incorporated (N_0); spring burn of straw (N_0SB); fall burn of straw (N_0FB); straw plus 45 kg N ha^{-1} 2 yr^{-1} (N_{45}); spring burn plus 45 kg N ha^{-1} 2 yr^{-1} ($N_{45}SB$); straw plus 90 kg N ha^{-1} 2 yr^{-1} (N_{90}); spring burn plus 90 kg N ha^{-1} 2 yr^{-1} ($N_{90}SB$); straw plus 2.24 Mg pea vine ha^{-1} 2 yr^{-1} (PV); and straw plus 22.4 Mg strawy beef manure ha^{-1} 2 yr^{-1} (M) (Table 3.1). Except for a single application of 56 kg $CaSO_4$-S ha^{-1} in 1967, the soils received no other S fertilization. The management of the plots has remained virtually unchanged for the last 60 years.

The objectives of this study were 1) to examine the cumulative effects of long-term residue management and N fertilization on the plant availability of S, and 2) to examine the soil profile distribution of S fractions.

Table 3.1. History of Residue Utilization Plots from 1931 to 1989. Pendleton Agricultural Research Center, Oregon (adapted from Rasmussen et al. 1989).

Residue Treatment	Description of Residue Management†	N applied per crop	S applied per crop
		--kg ha^{-1} 2 yr^{-1}--	
N$_0$	Straw incorporated into the soil	0	0
N$_0$FB	Wheat straw burned in the fall	0	0
N$_0$SB	Wheat straw burned in the spring	0	0
N$_{45}$	Straw incorporated into the soil	45(34)§	0
N$_{45}$SB	Wheat straw burned in the spring‡	45(0)§	0
N$_{90}$	Straw incorporated into the soil	90(34)§	0
N$_{90}$SB	Wheat straw burned in the spring‡	90(0)§	0
PV	Straw plus 2.24 Mg ha^{-1} 2yr^{-1} of pea vines incorporated into soil	34(40)¶#	2.7#
M	Straw plus 22.4 Mg ha^{-1} 2yr^{-1} strawy manure incorporated into soil	111#	27.5#

† All treatments moldboard plowed 20 cm deep in late March or early April of the fallow year. Pea vines and manure applied 1-3 days prior to plowing.

‡ Initiated in 1979, straw incorporated from 1931-1978.

§ Nitrogen rates changed in 1967, number in parentheses is for 1931-1966.

¶ Pea vine input changed in 1950, prior to 1950 pea vines included pea seed, number in parentheses, after 1950 pea vines included only vines and pods, N input based on chemical analysis from 1976-1987.

Strawy manure and pea vine N and S input based on chemical analysis from 1976-1987.

MATERIALS AND METHODS

Greenhouse Experiment

Six treatments from the Residue Utilization Experiment Plots

(Table 3.1) were selected for a greenhouse study (N_0, N_0SB, N_{90}, $N_{90}SB$,

PV, M). The soils were collected in November 1988, from the 0 to 20 cm

depth, passed through a 15-mm screen, and stored field-moist in sealed

bags at 4°C. One kg (oven-dry basis) of soil was put into plastic non-

draining pots (14 x 9 cm) and amended with $CaSO_4 \cdot 2H_2O$ at rates of 0, 10,

20 or 40 mg S kg^{-1} soil. Because these soils do not respond to K (P. E.

Rasmussen, personal communication), only supplemental amounts of N

and P were added at the rate of 320 mg N kg^{-1} soil as NH_4NO_3 and 80 mg

P kg^{-1} soil as $Ca(H_2PO_4)_2 \cdot H_2O$. A control treatment was included for each

soil treatment.

Ryegrass (*Lolium perenne* L.) was used as the indicator plant. One

g of seed was planted in each pot. The soils were maintained at

gravimetric water content of 30% by daily watering with deionized water to

replace the amount lost during the previous 24 hours, as determined by

weighing 10 randomly selected pots. Three times weekly all pots were

weighed and adjusted to the preselected weight. Lighting in the

greenhouse was maintained for 15 hour days and daily temperature ranged

from 20 to 25°C.

The ryegrass plants were cut at a height of 1 cm from the soil surface every 30 days for a total of four cuttings. After each cutting, the plant material was dried at 65°C, weighed, ground to pass a 0.37 mm sieve, and analyzed for total S. All pre- and post-experiment soil samples were analyzed for exchangeable SO_4 and pH. Pre-experiment soils were also analyzed for total C, N and S.

The design of the experiment was a 6 x 4 randomized-complete-block factorial with four replications, six residue treated soils, and four S rates. The repeated cuttings were considered to be a split plot in time. SAS software program with the general linear models and ANOVA subprogram was used to perform ANOVA procedures (SAS Institute, 1985).

Soil profile

The Residue Utilization Plots are on a Walla Walla silt loam soil (coarse-silty, mixed, mesic Typic Haploxerolls). The area is slightly sloping with each treatment being replicated on the upper and lower slope areas. All nine of the long-term residue plots were subsampled in August 1988, from 0-15 cm, 15-30 cm, and at 30 cm increments to the basalt bedrock. Each plot sample was the result of 8-12 composite samples. The depth to bedrock varied with landscape position; the upper slope position was sampled to 210 cm and the lower slope position was sampled to 120 cm. Soil samples were dried and passed through a 2-mm sieve and analyzed

for extractable SO₄ and pH. Prior to analysis for total C, N and S, and S

fractions, soil samples were ground to pass a 0.149 mm sieve.

Analytical procedures

Total plant S was determined by a modified alkaline oxidation

procedure (Dick and Tabatabai, 1977) where a portion of the digested

sample was removed for S analysis by hydroidic acid (HI) distillation on a

Johnson Nishita apparatus (Johnson and Nishita, 1952) followed by digest

analysis for P (Appendix 8). Total soil S was determined by alkaline

oxidation procedure (Dick and Tabatabai, 1977) followed by distillation

(Johnson and Nishita, 1952). Available SO_4 was extracted with 16 mM

$Ca(H_2PO_4)\cdot H_2O$ and measured on a Dionex Ion Chromatograph (Santa

Clara, CA) (Dick and Tabatabai, 1979). Hydroidic reducible S was

determined by distillation (Johnson and Nishita, 1952). Ester sulfate was

calculated by subtracting $Ca(H_2PO_4)$ extractable SO_4 from HI reducible S.

Carbon-bonded S was determined by distillation with Raney Ni alloy (Lowe

and DeLong, 1963).

Total C was determined by combustion and infrared detection on a

carbon analyzer (Dohrman, Santa Clara, CA). Total N was determined by

Kjeldahl digestion, NaOH distillation, and measured by titration with 25 mM

H_2SO_4 in boric acid indicator (Bremner, 1970). Soil pH was measured

using a glass electrode on a pH meter (soil:water ratio 1:2).

RESULTS AND DISCUSSION

Greenhouse Experiment

Plant growth response

Ryegrass DMY from the manure treated soil was significantly higher (>50%) than all other soil treatments at the zero rate of greenhouse applied S (Table 3.2). Ryegrass DMY from the manure treated soil was 20% higher at the 30 day cutting, increasing to >50% higher at the 120 day cutting (Fig. 3.1). Increasing the rate of applied S increased the DMY of all treatments, including the manure treated soil, indicating that all the soils required additional S to maximize yields. There was no significant difference in DMY between the 20 and 40 mg S kg^{-1} soil rate (Fig. 3.2). At the highest rate of applied S there was no difference in DMY for any of the soil treatments. The greenhouse results indicate that the yield advantage of long-term manure applications can be overcome by adequate additions of inorganic S.

Long-term applications of 2.24 Mg pea vine ha^{-1} 2 yr^{-1} did not significantly increase ryegrass DMY over long-term field treatments that did not receive inorganic N in the field. Long-term field results from the Residue Utilization Plots indicate that wheat yields from the pea vine soils are similar to that of the N_{90} soils (Rasmussen et al., 1989). However, under greenhouse conditions yields showed that 2.24 Mg pea vine ha^{-1}

2 yr^{-1} (Table 3.1) were not sufficient to maintain yields. Studies by Larson et al.,(1972) indicate that as much as 6 Mg ha^{-1} yr^{-1} are needed to maintain levels of S in soils and plant yields.

Soils that had a history of wheat straw burning without added N (N_0SB) reduced DMY when greenhouse applications of S were low (0 or 10 mg S kg^{-1}) (Table 3.2). Greenhouse results indicate that the increased mineralization from the N application or the wheat straw incorporation was probably responsible for additional S being made available for plant uptake.

Table 3.2. Effect of greenhouse S application rate on cumulative dry matter yield of ryegrass on soils from the Residue Utilization Plots.

Residue	S application rate (mg kg^{-1} soil)			
Treatment	0	10	20	40
		g pot^{-1}		
N_0	2.17 b	5.13 c	7.47 b	7.72 a
N_0SB	1.91 c	5.00 d	7.43 b	7.55 a
N_{90}	2.28 b	5.75 b	7.49 b	7.42 a
N_{90}SB	2.18 b	5.58 c	7.64 ab	7.64 a
PV	2.12 b	4.92 d	7.48 b	7.64 a
M	3.39 a	6.72 a	7.97 a	7.96 a

Means within a column followed by the same letter are not significantly different at P=0.01 LSD level.
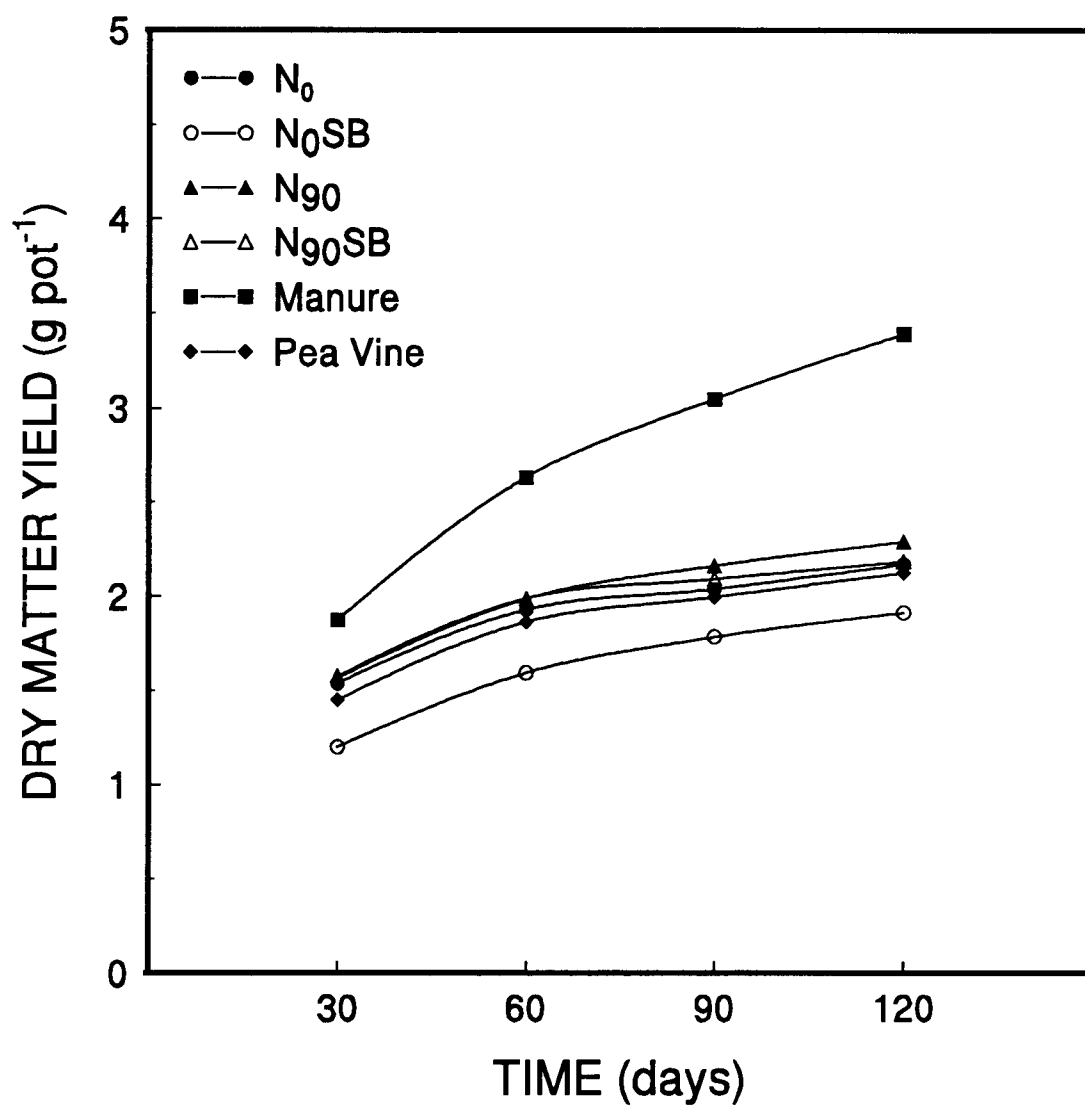
Fig. 3.1. Cumulative ryegrass dry matter yield in the absence of a greenhouse S application on soils from the Residue Utilization Experiment Plots.
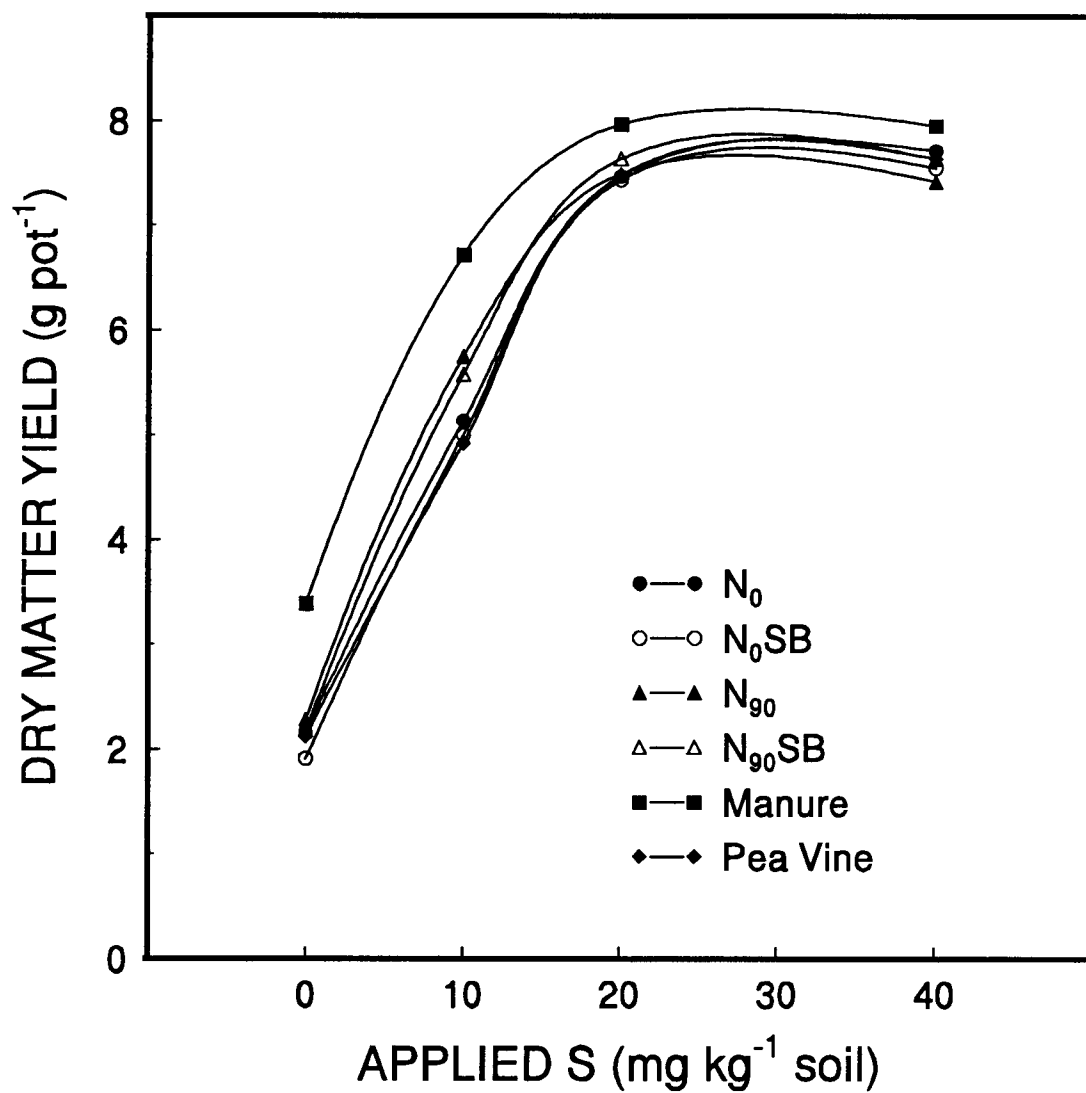
Fig. 3.2. Cumulative ryegrass dry matter yield with increasing rates of greenhouse applied S on soils from the Residue Utilization Experiment Plots.

Analysis of the Residue Utilization Plot soils prior to the greenhouse experiment showed that the manure treated soil had about 30% more total S and 75% more SO_4 than the other treatments (Table 3.3). However, with the exception of the manure treated soil during the first 30 days, the concentration of S in the ryegrass was not affected by the rate of applied S or the residue history of the soil (data not shown).

Actual uptake of S by the ryegrass followed similar patterns to DMY. The manure treated soil had significantly greater S uptake at the lower rates of applied S (0 or 10 mg S kg^{-1} soil) (Table 3.4). Cumulative 120 day S uptake from the manure treated soil at the control rate was 86% greater than the other treatments, indicating that substantially more S was being mineralized from this soil. At the highest rates of applied S, there was no significant difference among any of the soil treatments. Unlike DMY, S uptake continued to increase for all treatments with increasing rates of applied S. Since DMY stabilized at the 20 mg rate, the additional S uptake at the 40 mg rate was probably in the form of luxury consumption. In a field study of these soils it was determined that S additions from the manure treatment are in excess of crop requirements and that additional S is being mineralized and lost from the system (Castellano and Dick, 1988).

Table 3.3. Results of soil chemical analysis from Residue Utilization Plot soils (0-20 cm depth) prior to the greenhouse experiment.

Residue Treatment	Total C	Total N	Total S	SO_4	C:N:S ratio	pH
	$g \ kg^{-1}$	------$mg \ kg^{-1}$------				
N_0	9.80 d	827 c	119 d	3.5 c	82.4:6.9:1	6.36
N_0SB	9.98 d	854 c	142 b	3.7 b	70.3:6.0:1	6.77
N_{90}	10.55 c	818 d	130 c	2.5 d	81.2:6.3:1	5.90
$N_{90}SB$	10.76 c	806 d	127 c	2.6 d	84.7:6.3:1	6.01
PV	11.49 b	922 b	129 c	3.4 c	89.1:7.1:1	6.56
M	14.00 a	1214 a	170 a	6.1 a	82.4:7.1:1	6.89

Means within a column followed by the same letter are not significantly different at P=0.05 LSD level.

Table 3.4. Effect of greenhouse S application rate on cumulative S uptake of ryegrass on soils from the Residue Utilization Plots.

Residue Treatment	S application rate ($mg \ kg^{-1}$ soil)			
	0	10	20	40
	--------------------------$mg \ pot^{-1}$--------------------------			
N_0	3.01 b	10.36 b	17.67 a	26.32 a
N_0SB	2.76 b	8.17 c	17.25 a	23.25 a
N_{90}	2.67 b	10.77 b	17.06 a	27.97 a
$N_{90}SB$	2.74 b	11.49 b	17.54 a	24.41 a
PV	2.76 b	11.08 b	16.92 a	24.61 a
M	5.60 a	13.50 a	19.76 a	28.44 a

Means within a column followed by the same letter are not significantly different at P=0.05 LSD level.

A history of wheat straw burning had little effect on the level of S

uptake (Table 3.4). At the 0 rate of applied S, there was no difference in S

uptake between soils from the burn and no burn treatments, an indication of

the overall low level of S in these soils. With the application of only 10 mg

S kg^{-1} soil, N_0SB had significantly less S uptake than N_0, possibly an

indication than burning of wheat straw without additional N, had an effect on

mineralization rates. Sulfur is available in precipitation and pollution from

the atmosphere, but because of the relatively low industrial activity in this

region, sulfate deposition averages only 0.8 kg S ha^{-1} yr^{-1} ($\pm$0.4)

(unpublished data, National Atmospheric Deposition Program, Fort Collins,

CO).

Greenhouse soil

All soils from the Residue Utilization Plots were analyzed for

available SO_4 following the greenhouse experiment (Table 3.5). All the pots

showed signs of S deficiency. Since N and S deficiency symptoms are

often mistaken, an analysis of the soils for extractable NO_3 (data not

shown) determined that at low S rates, large concentrations of NO_3

remained in the soil, which indicated that S was the limiting nutrient. At the

highest rate of applied S, there was a large concentration of SO_4 and no

NO_3 in the soil, which indicated that N was the limiting nutrient.

Table 3.5. Soil chemical analysis for extractable SO_4 on Residue Utilization Plot soils following greenhouse experiment.

Residue	S application rate (mg kg^{-1} soil)			
Treatment	0	10	20	40
	----------------------------mg S kg^{-1}soil----------------------------			
N_0	0.81 ab	0.93 a	0.82 c	8.30 a
N_0SB	0.43 b	1.02 a	0.85 c	8.22 a
N_{90}	0.85 ab	1.05 a	1.12 ab	7.16 a
$N_{90}SB$	0.49 b	1.14 a	0.98 bc	7.09 a
PV	1.83 a	0.92 a	0.86 c	8.07 a
M	1.52 ab	1.14 a	1.31 a	8.70 a

Means within a column followed by the same letter are not significantly different at P=0.05 LSD level.

Soil Profile

Due to the difference in the soil profile depths, the results were divided into upper slope position (deeper) and lower slope position (shallower) (Fig. 3.3-3.7). A coefficient of simple determination (r) was used to evaluate the relationship between soil chemical parameters (Table 3.6).

Total S in the upper portion (0-100 cm) of the soil profile ranged from 100-200 mg kg^{-1} soil (Fig. 3.3). All soils showed high concentrations of total S in the upper 15 cm of the profile, with the manure treated soil having significantly higher levels than the other treatments. Total S concentration decreased in the upper 100 cm of the profile with increasing depth. Below 100 cm, many of the plots, especially those receiving organic residues or higher rates of inorganic N, had large accumulations of total S.

Concentration of SO_4 in the soil profile was generally under 5 mg kg^{-1} soil and was relatively constant with depth (Fig 3.4). The manure treated soil had some accumulation of SO_4 in the lower portion of the profile which was probably due to SO_4 leaching of surface mineralized S.

Concentration of ester sulfate was very similar to that of total S throughout the profile (Fig. 3.3 and 3.5). Most of the accumulation of total S in the lower portion of the profile could be accounted for in the form of ester sulfate. Ester sulfate is of biological origin. Thus it was unexpected to find large accumulations in the subsoil. An examination of profile total C and ester sulfate indicates a significant correlation (.807) (Table 3.5). Two

possible explanations could be put forward: 1) low molecular weight organic compounds containing ester sulfate could have moved through the soil profile; or 2) that SO_4 moved through the profile and was then immobilized to ester sulfate at depths. The first explanation appears more plausible because it is generally recognized that fungi and not bacteria are responsible for ester sulfate levels (Saggar et al., 1981) and fungi primarily exist in the surface soil (Atlas and Bartha, 1987).

Carbon-bonded S is mainly a measure of the amino acids cystine and methionine (Freney, 1986). The concentration of C-bonded S in the upper portion of the profile was generally under 20 mg S kg^{-1} soil for most of the soil treatments (Fig. 3.6). The manure treated soil had increased concentrations of C-bonded S in the upper 15 cm of the soil profile. Since C-bonded S has been found to be correlated to microbial biomass, it is reasonable that the application of 22.4 kg manure ha^{-1} 2 yr^{-1} would result in elevated levels of C-bonded S. Carbon-bonded S does not appear to move through the soil because it is decreasing in concentration with increasing depth.

Residual S is resistant to hydrolysis by strong acids or bases (Freney, 1986). Residual S was consistent throughout the soil profile (Fig. 3.7). The manure treated soil had increased levels of residual S in the upper 15 cm of the profile but was not significantly different than other treatments in the lower portion of the profile.

Table 3.6. Coefficient of simple determination (r)† for total C, N, and S and S fractions for Residue Utilization Plot soils.

	Total C	Total N	Total S	SO_4	Ester sulfate	C-bonded S	Residual S	C:S ratio	N:S ratio
Depth	.07	-.88 ‡	.12	-.22 ‡	.35	-.72 ‡	-.59 ‡	-.12	-.67 ‡
Total C		-.06	.82 ‡	.32	.81 ‡	.15	.11	.81 ‡	-.49 ‡
Total N			-.06	.20 ‡	-.30 ‡	.71 ‡	.66 ‡	.10	.70 ‡
Total S				.29 ‡	.95 ‡	.15	.30 ‡	.44 ‡	-.62 ‡
Ext. SO_4					.17	.38 ‡	.30 ‡	.32 ‡	-.10
Ester sulfate						-.10	-.01	.43 ‡	-.72 ‡
C-bonded S							.60 ‡	.24	.31 ‡
Residual S								.02	.19 ‡
C:S ratio									-.24 ‡

† n = 123.

‡ significant at p=0.05.
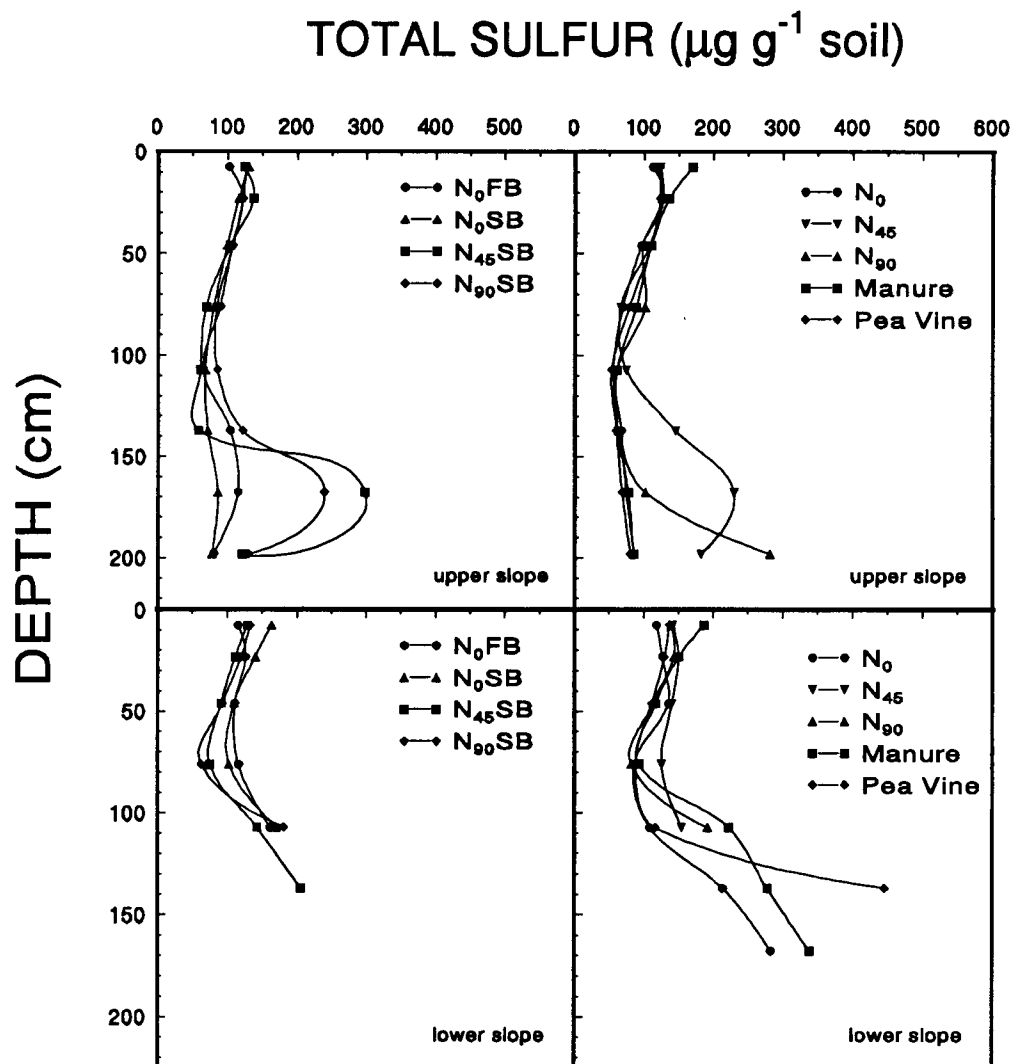
Fig. 3.3. Soil profile distribution of total S from the upper (deeper) and the lower (shallower) slopes from the Residue Utilization Plots.
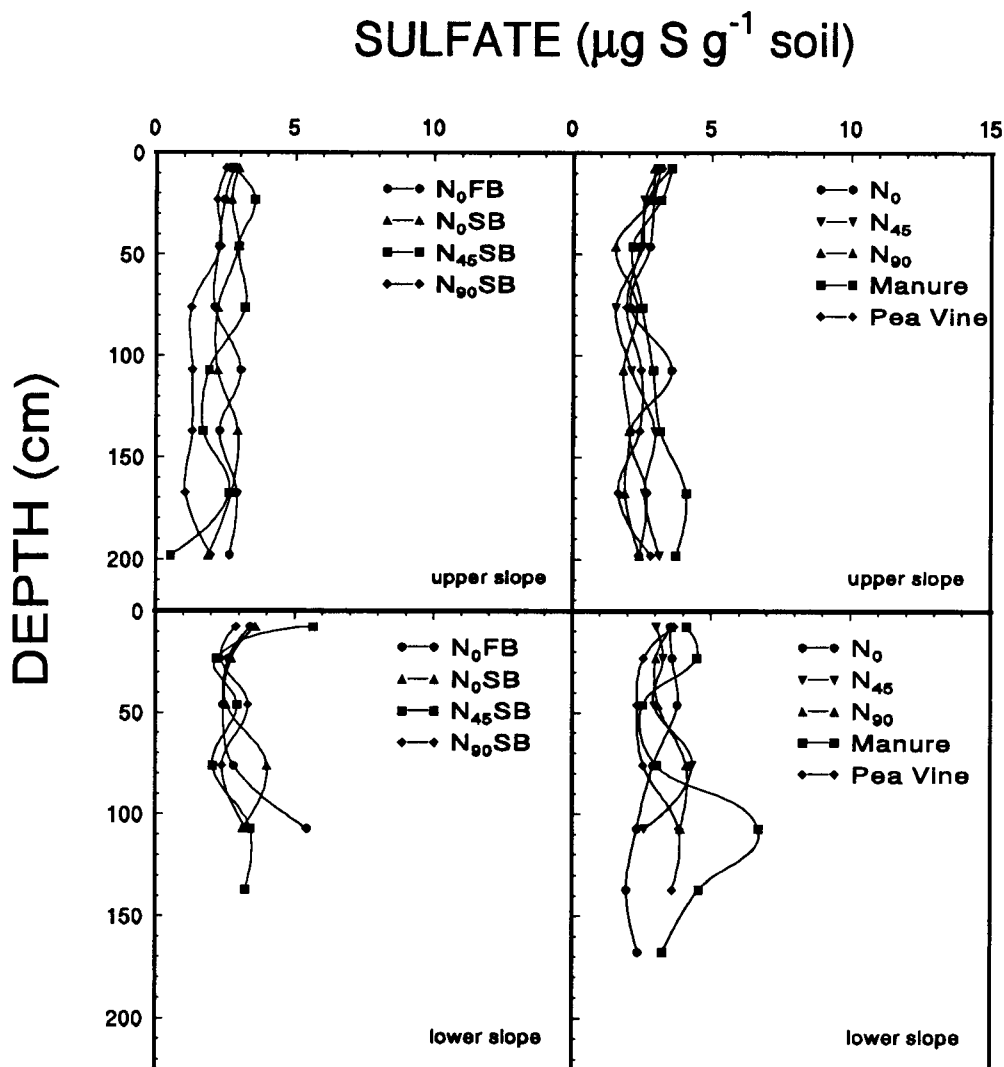
Fig. 3.4. Soil profile distribution of extractable SO_4 from the upper (deeper) and the lower (shallower) slopes from the Residue Utilization Plots.

ESTER SULFATE (μg S g^{-1} soil)
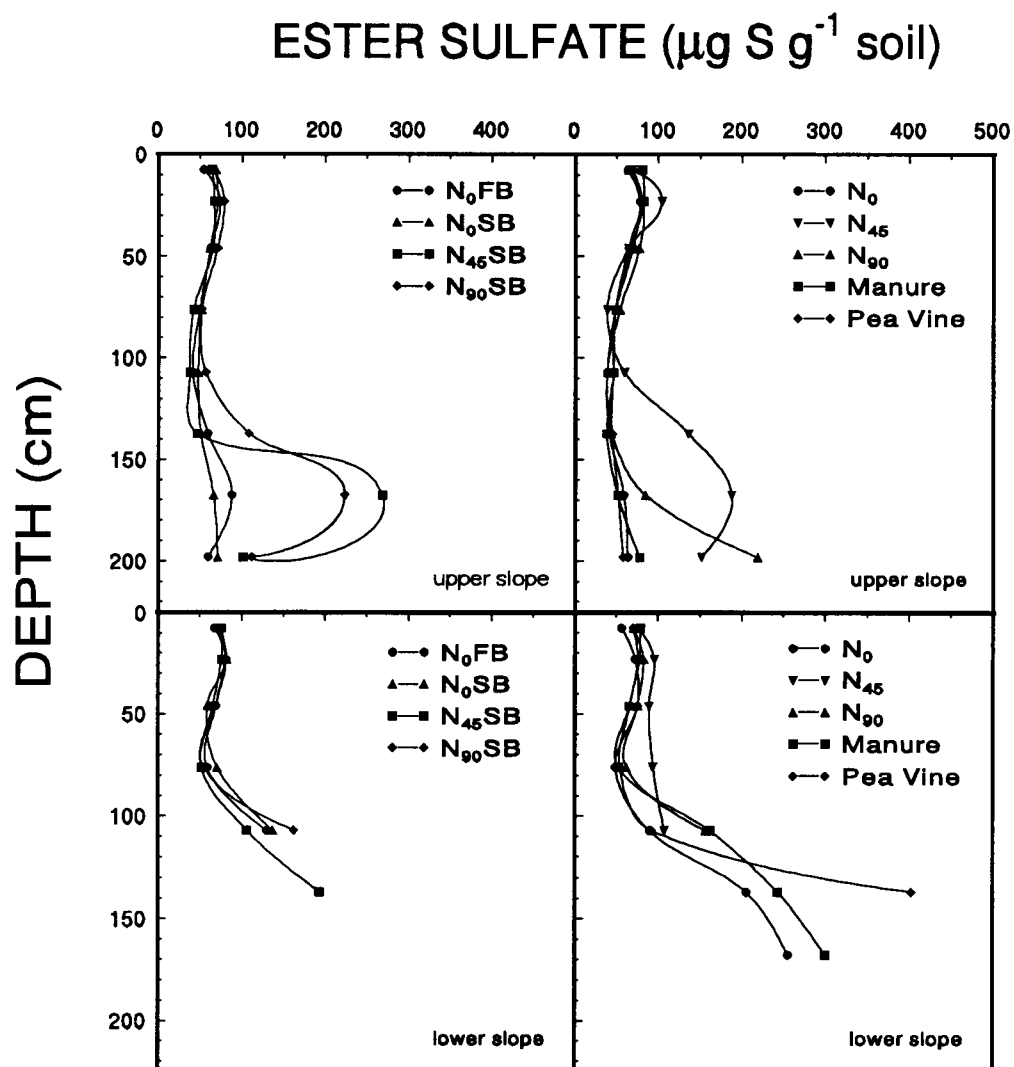
Fig. 3.5. Soil profile distribution of ester sulfate from the upper (deeper) and the lower (shallower) slopes from the Residue Utilization Plots.

C-BONDED SULFUR (μg g^{-1} soil)
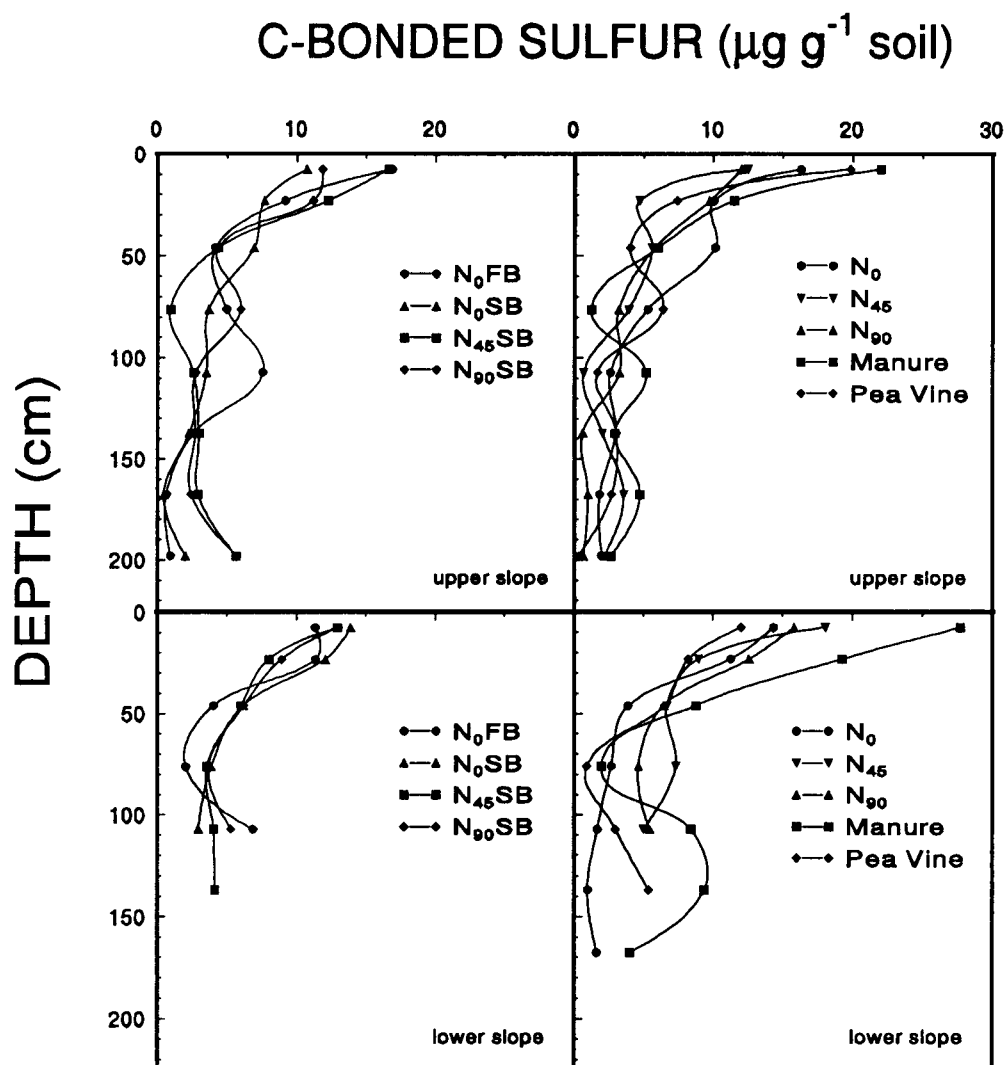
Fig. 3.6. Soil profile distribution of C-bonded S from the upper (deeper) and the lower (shallower) slopes from the Residue Utilization Plots.
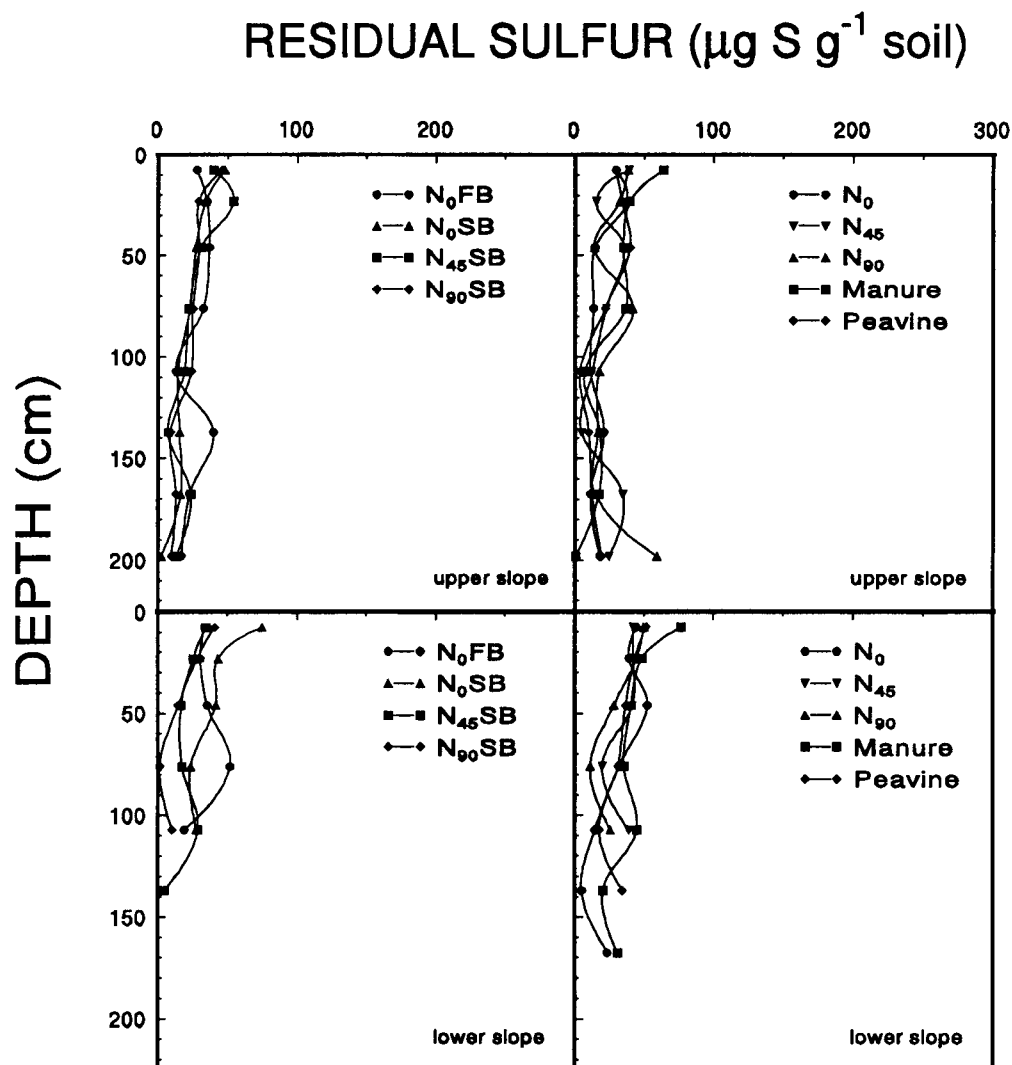
Fig. 3.7. Soil profile distribution of Residual S from the upper (deeper) and the lower (shallower) slopes from the Residue Utilization Plots.

CONCLUSIONS

In the absence of inorganic SO_4 applications, ryegrass DMY and S uptake in the greenhouse was significantly higher when the soil had a history of animal manure application. Under greenhouse conditions, additional S was required to maximize biomass production. The addition of pea vine did not affect the DMY or S uptake of ryegrass in the greenhouse experiment. A history of field burning had little effect on DMY or S uptake by ryegrass. At high rates of applied S, excess S was taken up by the plant in the form of luxury consumption. Results from the greenhouse study indicate that yield advantages of manure applications can be overcome with high rates of inorganic S applications and adequate N applications.

Analysis of the soil profile from the long-term plots showed accumulations of total S mainly at the bottom of the profile. A significant correlation between total C, S and ester sulfate indicates that the form of S that has accumulated at the bottom of some profiles is most likely due to leaching of ester sulfate compounds. Carbon-bonded S has accumulated near the surface of many of the profiles, with the manure treated soil showing significantly higher concentrations.

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CONCLUSIONS

1) In the absence of inorganic N applications to the soil, ryegrass dry matter yield (DMY) in the greenhouse was greater from the manure treated soil when compared to the soils that received pea vine or inorganic N treatments. Under greenhouse conditions, additional N was required on all soils to maximize biomass productivity.

Ryegrass DMY response to P in the greenhouse was unaffected by the P rate or the long-term residue management history of the soil. Even though no inorganic P fertilizer had been added to these soils for the last 60 years, it appeared that a sufficient quantity of plant available P remained in the soil to maximize DMY of ryegrass. The manure treated soil had almost twice the amount of available P for plant uptake as the other long-term soil treatments.

In the absence of inorganic SO_4 applications, ryegrass DMY in the greenhouse was significantly higher when the soil had a history of animal manure application. Under greenhouse conditions, additional S was required to maximize biomass production.

Uptake of N, P, and S from the manure treated soil was significantly greater than all other treatments, indicating that the addition of animal manure can make a significant nutrient contribution for plant uptake.

Because of the relatively low rate of pea vine residue incorporated into the long-term plots (2.2 Mg ha^{-1} 2 yr^{-1}), soil from this treatment had no significant influence on DMY.

Although soil from long-term straw burned plots showed a trend of lower greenhouse DMY, the results were generally not significant.

2) Analysis of the distribution of N in the soil profiles indicated that the decline of total N in treatments receiving zero or 90 kg inorganic N ha^{-1} 2 yr^{-1} may have stabilized and reached an equilibrium in the last 10 years. Concentration of extractable NO$_3$ in the 90-150 cm portion of the manure treated plot from the lower landscape position was > 12 mg N kg^{-1} soil. Although the application rate of 22.4 Mg animal manure ha^{-1} 2 yr^{-1} provided significantly more residual N for subsequent crop yields and has maintained soil fertility, accumulations of NO$_3$ indicate that mineralization may not be concurrent with crop demands.

Analysis of the soil profile from the long-term plots showed that in the absence of P fertilization over the past 60 years, concentrations of total and available forms of P remained high. Most plots increased in total P, extractable PO$_4$, and inorganic P with increased depth. Significant concentrations of extractable PO$_4$ appeared to be accumulating in the lower portion of many of the residue plots.

Analysis of the soil profile from the long-term plots showed accumulations of total S near the surface and at the bottom of the profile.

A significant correlation among total C, and S, and ester sulfate indicates that the form of S that has accumulated at the bottom of some profiles is most likely ester sulfates. Carbon-bonded S has accumulated near the surface of many of the profiles, with the manure treated soil showing significantly higher concentrations.

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APPENDICES

Appendix 1. Ryegrass dry matter yield and N, P, and S concentrations as affected by greenhouse applied N, P, and S (subscript [mg kg^{-1} soil]) on soils from Residue Utilization Experiment Plots (L=lower, U=upper).

Residue History	N P S applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					g pot^{-1}		--------mg g^{-1}--------	
N_0	N_0 P_0 S_0	L	30	1	0.53	21.21	5.20	3.33
N_0	N_0 P_0 S_0	L	30	2	0.62	18.69	4.80	3.77
N_0	N_0 P_0 S_0	U	30	1	0.57	21.55	5.69	2.51
N_0	N_0 P_0 S_0	U	30	2	0.60	20.84	6.04	3.70
N_0	N_{80} P_{80} S_{40}	L	30	1	1.50	41.33	6.50	3.21
N_0	N_{80} P_{80} S_{40}	L	30	2	1.81	37.62	6.50	4.04
N_0	N_{80} P_{80} S_{40}	U	30	1	1.86	30.40	6.25	4.87
N_0	N_{80} P_{80} S_{40}	U	30	2	1.70	44.95	6.93	4.93
N_0	N_{160} P_{80} S_{40}	L	30	1	2.12	47.77	5.86	4.27
N_0	N_{160} P_{80} S_{40}	L	30	2	1.92	58.85	4.46	3.50
N_0	N_{160} P_{80} S_{40}	U	30	1	1.98	47.55	5.49	1.53
N_0	N_{160} P_{80} S_{40}	U	30	2	2.15	56.14	7.27	3.77
N_0	N_{320} P_0 S_{40}	L	30	1	1.99	54.36	2.85	3.50
N_0	N_{320} P_0 S_{40}	L	30	2	1.90	62.21	1.73	3.70
N_0	N_{320} P_0 S_{40}	U	30	1	1.94	57.81	2.85	2.69
N_0	N_{320} P_0 S_{40}	U	30	2	1.61	61.97	2.43	3.90
N_0	N_{320} P_{20} S_{40}	L	30	1	2.04	49.83	3.35	3.50
N_0	N_{320} P_{20} S_{40}	L	30	2	2.20	53.36	2.77	3.77
N_0	N_{320} P_{20} S_{40}	U	30	1	1.90	62.08	4.08	2.46
N_0	N_{320} P_{20} S_{40}	U	30	2	1.91	55.99	4.21	4.18
N_0	N_{320} P_{40} S_{40}	L	30	1	1.88	56.31	4.63	3.39
N_0	N_{320} P_{40} S_{40}	L	30	2	2.26	55.46	4.11	3.00
N_0	N_{320} P_{40} S_{40}	U	30	1	1.80	60.08	4.25	3.14
N_0	N_{320} P_{40} S_{40}	U	30	2	2.34	56.48	5.09	3.48
N_0	N_{320} P_{80} S_0	L	30	1	1.39	46.55	4.95	1.53
N_0	N_{320} P_{80} S_0	L	30	2	1.62	44.43	4.06	1.74
N_0	N_{320} P_{80} S_0	U	30	1	1.60	48.05	5.57	1.64
N_0	N_{320} P_{80} S_0	U	30	2	1.54	44.30	4.50	1.38
N_0	N_{320} P_{80} S_{10}	L	30	1	2.12	50.65	4.35	1.49
N_0	N_{320} P_{80} S_{10}	L	30	2	2.11	52.86	4.20	3.31
N_0	N_{320} P_{80} S_{10}	U	30	1	1.54	44.34	4.80	2.40
N_0	N_{320} P_{80} S_{10}	U	30	2	2.09	51.45	5.14	4.23
N_0	N_{320} P_{80} S_{20}	L	30	1	1.86	61.53	4.35	2.75
N_0	N_{320} P_{80} S_{20}	L	30	2	2.04	49.41	5.30	2.87
N_0	N_{320} P_{80} S_{20}	U	30	1	1.86	53.06	5.11	2.81
N_0	N_{320} P_{80} S_{20}	U	30	2	1.80	55.66	5.78	2.87
N_0	N_{320} P_{80} S_{40}	L	30	1	1.89	57.54	5.32	3.44
N_0	N_{320} P_{80} S_{40}	L	30	2	2.20	52.06	5.11	3.37
N_0	N_{320} P_{80} S_{40}	U	30	1	1.83	56.22	5.49	3.00
N_0	N_{320} P_{80} S_{40}	U	30	2	2.05	49.96	5.80	3.53

Residue History	NPS applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					$g\ pot^{-1}$		$mg\ g^{-1}$	
N_0SB	$N_0\ P_0\ S_0$	L	30	1	0.62	21.47	5.88	3.90
N_0SB	$N_0\ P_0\ S_0$	L	30	2	0.55	21.77	5.41	3.84
N_0SB	$N_0\ P_0\ S_0$	U	30	1	0.52	21.14	5.39	2.63
N_0SB	$N_0\ P_0\ S_0$	U	30	2	0.24	22.40	5.41	4.25
N_0SB	$N_{80}\ P_{80}\ S_{40}$	L	30	1	1.75	36.73	5.88	3.80
N_0SB	$N_{80}\ P_{80}\ S_{40}$	L	30	2	1.65	42.40	6.33	3.70
N_0SB	$N_{80}\ P_{80}\ S_{40}$	U	30	1	1.15	47.74	5.69	3.53
N_0SB	$N_{80}\ P_{80}\ S_{40}$	U	30	2	1.21	44.97	6.29	3.97
N_0SB	$N_{160}\ P_{80}\ S_{40}$	L	30	1	2.06	47.72	5.69	3.26
N_0SB	$N_{160}\ P_{80}\ S_{40}$	L	30	2	1.89	54.66	6.69	3.25
N_0SB	$N_{160}\ P_{80}\ S_{40}$	U	30	1	1.47	45.42	5.32	3.00
N_0SB	$N_{160}\ P_{80}\ S_{40}$	U	30	2	2.06	52.62	7.85	3.77
N_0SB	$N_{320}\ P_0\ S_{40}$	L	30	1	2.01	59.89	3.38	3.57
N_0SB	$N_{320}\ P_0\ S_{40}$	L	30	2	2.53	61.97	1.86	3.00
N_0SB	$N_{320}\ P_0\ S_{40}$	U	30	1	1.64	57.20	3.92	3.37
N_0SB	$N_{320}\ P_0\ S_{40}$	U	30	2	1.22	63.83	3.00	4.18
N_0SB	$N_{320}\ P_{20}\ S_{40}$	L	30	1	1.85	56.18	4.16	2.90
N_0SB	$N_{320}\ P_{20}\ S_{40}$	L	30	2	1.82	59.13	3.91	3.90
N_0SB	$N_{320}\ P_{20}\ S_{40}$	U	30	1	1.95	53.88	4.18	2.93
N_0SB	$N_{320}\ P_{20}\ S_{40}$	U	30	2	2.01	57.15	4.50	4.04
N_0SB	$N_{320}\ P_{40}\ S_{40}$	L	30	1	1.73	57.33	4.92	3.07
N_0SB	$N_{320}\ P_{40}\ S_{40}$	L	30	2	2.36	55.01	4.27	2.75
N_0SB	$N_{320}\ P_{40}\ S_{40}$	U	30	1	1.93	56.55	4.74	2.97
N_0SB	$N_{320}\ P_{40}\ S_{40}$	U	30	2	2.03	56.20	5.26	3.14
N_0SB	$N_{320}\ P_{80}\ S_0$	L	30	1	1.72	53.92	5.84	1.74
N_0SB	$N_{320}\ P_{80}\ S_0$	L	30	2	1.15	44.84	4.80	1.85
N_0SB	$N_{320}\ P_{80}\ S_0$	U	30	1	0.89	49.74	5.11	1.84
N_0SB	$N_{320}\ P_{80}\ S_0$	U	30	2	1.05	42.78	4.05	1.64
N_0SB	$N_{320}\ P_{80}\ S_{10}$	L	30	1	2.13	49.78	5.10	2.18
N_0SB	$N_{320}\ P_{80}\ S_{10}$	L	30	2	1.78	56.40	4.51	3.12
N_0SB	$N_{320}\ P_{80}\ S_{10}$	U	30	1	1.64	46.38	5.11	0.47
N_0SB	$N_{320}\ P_{80}\ S_{10}$	U	30	2	1.58	60.15	5.46	3.12
N_0SB	$N_{320}\ P_{80}\ S_{20}$	L	30	1	2.11	52.99	6.09	3.44
N_0SB	$N_{320}\ P_{80}\ S_{20}$	L	30	2	2.11	58.61	5.49	3.00
N_0SB	$N_{320}\ P_{80}\ S_{20}$	U	30	1	2.07	55.31	4.50	2.63
N_0SB	$N_{320}\ P_{80}\ S_{20}$	U	30	2	2.10	55.44	5.88	2.87
N_0SB	$N_{320}\ P_{80}\ S_{40}$	L	30	1	1.82	58.48	5.47	3.50
N_0SB	$N_{320}\ P_{80}\ S_{40}$	L	30	2	1.89	55.83	4.74	3.37
N_0SB	$N_{320}\ P_{80}\ S_{40}$	U	30	1	1.75	52.28	5.63	3.27
N_0SB	$N_{320}\ P_{80}\ S_{40}$	U	30	2	1.73	46.23	5.49	3.27

Residue History	N P S applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					$g\ pot^{-1}$		--------$mg\ g^{-1}$--------	
N_{90}	$N_0\ P_0\ S_0$	L	30	1	0.64	22.70	4.83	3.63
N_{90}	$N_0\ P_0\ S_0$	L	30	2	0.67	23.40	5.11	3.37
N_{90}	$N_0\ P_0\ S_0$	U	30	1	0.62	23.50	5.73	3.50
N_{90}	$N_0\ P_0\ S_0$	U	30	2	0.43	21.57	6.36	4.04
N_{90}	$N_{80}\ P_{80}\ S_{40}$	L	30	1	1.71	43.56	5.69	4.33
N_{90}	$N_{80}\ P_{80}\ S_{40}$	L	30	2	1.80	39.64	6.09	4.04
N_{90}	$N_{80}\ P_{80}\ S_{40}$	U	30	1	1.98	44.32	5.10	4.33
N_{90}	$N_{80}\ P_{80}\ S_{40}$	U	30	2	2.02	36.21	6.05	4.18
N_{90}	$N_{160}\ P_{80}\ S_{40}$	L	30	1	2.12	46.94	5.78	3.40
N_{90}	$N_{160}\ P_{80}\ S_{40}$	L	30	2	1.89	54.81	5.01	3.02
N_{90}	$N_{160}\ P_{80}\ S_{40}$	U	30	1	2.20	44.80	5.39	3.00
N_{90}	$N_{160}\ P_{80}\ S_{40}$	U	30	2	2.26	53.12	6.13	3.37
N_{90}	$N_{320}\ P_0\ S_{40}$	L	30	1	1.78	50.37	2.32	4.11
N_{90}	$N_{320}\ P_0\ S_{40}$	L	30	2	1.75	54.73	1.74	3.57
N_{90}	$N_{320}\ P_0\ S_{40}$	U	30	1	2.11	53.19	3.38	3.50
N_{90}	$N_{320}\ P_0\ S_{40}$	U	30	2	2.47	65.24	1.74	3.77
N_{90}	$N_{320}\ P_{20}\ S_{40}$	L	30	1	1.98	63.20	3.54	3.23
N_{90}	$N_{320}\ P_{20}\ S_{40}$	L	30	2	2.02	53.75	3.34	3.77
N_{90}	$N_{320}\ P_{20}\ S_{40}$	U	30	1	2.38	55.01	3.09	2.61
N_{90}	$N_{320}\ P_{20}\ S_{40}$	U	30	2	2.14	52.62	3.48	3.63
N_{90}	$N_{320}\ P_{40}\ S_{40}$	L	30	1	2.34	68.93	4.03	3.50
N_{90}	$N_{320}\ P_{40}\ S_{40}$	L	30	2	1.88	50.85	4.18	3.18
N_{90}	$N_{320}\ P_{40}\ S_{40}$	U	30	1	2.55	57.87	3.69	2.45
N_{90}	$N_{320}\ P_{40}\ S_{40}$	U	30	2	2.53	51.95	4.20	3.01
N_{90}	$N_{320}\ P_{80}\ S_0$	L	30	1	1.70	50.13	6.13	1.33
N_{90}	$N_{320}\ P_{80}\ S_0$	L	30	2	1.44	45.03	4.06	1.33
N_{90}	$N_{320}\ P_{80}\ S_0$	U	30	1	1.59	49.87	4.50	1.64
N_{90}	$N_{320}\ P_{80}\ S_0$	U	30	2	1.53	44.60	3.91	1.33
N_{90}	$N_{320}\ P_{80}\ S_{10}$	L	30	1	2.30	52.01	4.95	2.52
N_{90}	$N_{320}\ P_{80}\ S_{10}$	L	30	2	2.01	52.47	4.35	3.63
N_{90}	$N_{320}\ P_{80}\ S_{10}$	U	30	1	2.24	50.67	4.65	2.17
N_{90}	$N_{320}\ P_{80}\ S_{10}$	U	30	2	2.30	63.36	4.51	3.26
N_{90}	$N_{320}\ P_{80}\ S_{20}$	L	30	1	2.30	48.96	5.78	3.25
N_{90}	$N_{320}\ P_{80}\ S_{20}$	L	30	2	2.34	56.01	5.30	0.94
N_{90}	$N_{320}\ P_{80}\ S_{20}$	U	30	1	2.20	54.38	4.35	2.87
N_{90}	$N_{320}\ P_{80}\ S_{20}$	U	30	2	2.19	51.86	4.92	3.31
N_{90}	$N_{320}\ P_{80}\ S_{40}$	L	30	1	1.95	55.42	5.35	3.90
N_{90}	$N_{320}\ P_{80}\ S_{40}$	L	30	2	2.02	52.28	4.74	3.53
N_{90}	$N_{320}\ P_{80}\ S_{40}$	U	30	1	2.56	53.43	4.57	3.12
N_{90}	$N_{320}\ P_{80}\ S_{40}$	U	30	2	2.58	50.85	4.74	3.37

Residue History	N P S applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					g pot^{-1}	--------mg g^{-1}--------		
$N_{90}SB$	N_0 P_0 S_0	L	30	1	0.52	23.24	4.83	3.77
$N_{90}SB$	N_0 P_0 S_0	L	30	2	0.63	19.95	4.80	3.25
$N_{90}SB$	N_0 P_0 S_0	U	30	1	0.95	18.21	4.72	2.36
$N_{90}SB$	N_0 P_0 S_0	U	30	2	0.49	19.36	5.41	3.25
$N_{90}SB$	N_{80} P_{80} S_{40}	L	30	1	1.72	40.24	5.45	3.92
$N_{90}SB$	N_{80} P_{80} S_{40}	L	30	2	1.81	37.64	6.29	3.63
$N_{90}SB$	N_{80} P_{80} S_{40}	U	30	1	2.04	35.95	5.51	4.30
$N_{90}SB$	N_{80} P_{80} S_{40}	U	30	2	1.89	37.73	6.09	4.67
$N_{90}SB$	N_{160} P_{80} S_{40}	L	30	1	2.29	46.86	5.35	2.71
$N_{90}SB$	N_{160} P_{80} S_{40}	L	30	2	2.26	51.37	6.13	3.90
$N_{90}SB$	N_{160} P_{80} S_{40}	U	30	1	2.32	44.75	4.90	3.13
$N_{90}SB$	N_{160} P_{80} S_{40}	U	30	2	2.63	49.63	6.69	3.00
$N_{90}SB$	N_{320} P_0 S_{40}	L	30	1	2.23	55.75	2.32	3.50
$N_{90}SB$	N_{320} P_0 S_{40}	L	30	2	1.77	61.84	1.87	3.63
$N_{90}SB$	N_{320} P_0 S_{40}	U	30	1	2.23	49.02	2.32	3.31
$N_{90}SB$	N_{320} P_0 S_{40}	U	30	2	2.07	55.94	1.60	4.04
$N_{90}SB$	N_{320} P_{20} S_{40}	L	30	1	2.25	49.57	3.37	2.23
$N_{90}SB$	N_{320} P_{20} S_{40}	L	30	2	2.32	62.42	3.62	3.63
$N_{90}SB$	N_{320} P_{20} S_{40}	U	30	1	2.21	54.86	3.05	3.14
$N_{90}SB$	N_{320} P_{20} S_{40}	U	30	2	2.04	56.46	5.41	3.90
$N_{90}SB$	N_{320} P_{40} S_{40}	L	30	1	2.24	55.34	4.38	3.03
$N_{90}SB$	N_{320} P_{40} S_{40}	L	30	2	1.99	46.18	4.18	3.00
$N_{90}SB$	N_{320} P_{40} S_{40}	U	30	1	2.41	45.73	3.52	3.57
$N_{90}SB$	N_{320} P_{40} S_{40}	U	30	2	2.39	57.37	4.06	2.87
$N_{90}SB$	N_{320} P_{80} S_0	L	30	1	1.78	50.52	5.56	1.38
$N_{90}SB$	N_{320} P_{80} S_0	L	30	2	1.59	43.93	3.91	1.23
$N_{90}SB$	N_{320} P_{80} S_0	U	30	1	1.51	46.38	5.11	1.64
$N_{90}SB$	N_{320} P_{80} S_0	U	30	2	1.42	44.62	4.21	1.64
$N_{90}SB$	N_{320} P_{80} S_{10}	L	30	1	2.29	49.76	4.50	3.13
$N_{90}SB$	N_{320} P_{80} S_{10}	L	30	2	2.27	50.19	7.87	3.06
$N_{90}SB$	N_{320} P_{80} S_{10}	U	30	1	2.57	49.33	3.91	2.65
$N_{90}SB$	N_{320} P_{80} S_{10}	U	30	2	2.51	54.25	4.20	3.09
$N_{90}SB$	N_{320} P_{80} S_{20}	L	30	1	2.02	52.19	5.49	2.95
$N_{90}SB$	N_{320} P_{80} S_{20}	L	30	2	2.06	59.91	5.49	3.50
$N_{90}SB$	N_{320} P_{80} S_{20}	U	30	1	2.17	63.01	3.91	2.40
$N_{90}SB$	N_{320} P_{80} S_{20}	U	30	2	2.59	59.84	4.64	2.52
$N_{90}SB$	N_{320} P_{80} S_{40}	L	30	1	1.97	53.56	5.49	3.48
$N_{90}SB$	N_{320} P_{80} S_{40}	L	30	2	2.13	47.07	4.55	3.00
$N_{90}SB$	N_{320} P_{80} S_{40}	U	30	1	2.05	54.25	4.92	3.27
$N_{90}SB$	N_{320} P_{80} S_{40}	U	30	2	2.20	54.10	4.79	2.87

Residue History	N P S applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					g pot^{-1}		---------mg g^{-1}---------	
PV	N_0 P_0 S_0	L	30	1	0.54	23.29	5.69	2.92
PV	N_0 P_0 S_0	L	30	2	0.61	20.40	6.36	4.04
PV	N_0 P_0 S_0	U	30	1	0.59	21.90	5.69	3.00
PV	N_0 P_0 S_0	U	30	2	0.57	23.05	6.04	3.44
PV	N_{80} P_{80} S_{40}	L	30	1	1.74	44.19	6.25	3.90
PV	N_{80} P_{80} S_{40}	L	30	2	1.74	56.72	6.50	4.55
PV	N_{80} P_{80} S_{40}	U	30	1	1.88	38.16	5.51	3.57
PV	N_{80} P_{80} S_{40}	U	30	2	1.71	36.93	6.13	3.90
PV	N_{160} P_{80} S_{40}	L	30	1	2.12	47.42	5.53	2.87
PV	N_{160} P_{80} S_{40}	L	30	2	1.84	59.41	6.13	3.37
PV	N_{160} P_{80} S_{40}	U	30	1	1.81	50.91	5.22	3.19
PV	N_{160} P_{80} S_{40}	U	30	2	1.78	50.89	7.85	3.50
PV	N_{320} P_0 S_{40}	L	30	1	1.56	62.42	2.85	3.90
PV	N_{320} P_0 S_{40}	L	30	2	1.95	66.39	1.87	4.18
PV	N_{320} P_0 S_{40}	U	30	1	1.81	59.89	3.11	3.84
PV	N_{320} P_0 S_{40}	U	30	2	1.74	58.13	2.43	3.90
PV	N_{320} P_{20} S_{40}	L	30	1	1.94	64.44	3.77	2.98
PV	N_{320} P_{20} S_{40}	L	30	2	2.08	57.18	4.21	4.93
PV	N_{320} P_{20} S_{40}	U	30	1	2.22	47.96	3.49	2.73
PV	N_{320} P_{20} S_{40}	U	30	2	1.87	53.92	4.06	3.90
PV	N_{320} P_{40} S_{40}	L	30	1	1.97	59.10	4.39	2.39
PV	N_{320} P_{40} S_{40}	L	30	2	1.82	57.35	4.86	3.37
PV	N_{320} P_{40} S_{40}	U	30	1	1.86	57.00	4.68	2.29
PV	N_{320} P_{40} S_{40}	U	30	2	1.98	52.90	4.63	3.36
PV	N_{320} P_{80} S_0	L	30	1	1.57	51.19	5.41	1.43
PV	N_{320} P_{80} S_0	L	30	2	1.39	45.90	4.50	1.81
PV	N_{320} P_{80} S_0	U	30	1	1.40	47.81	4.80	1.61
PV	N_{320} P_{80} S_0	U	30	2	1.44	45.12	4.80	1.43
PV	N_{320} P_{80} S_{10}	L	30	1	1.80	49.76	4.80	2.66
PV	N_{320} P_{80} S_{10}	L	30	2	1.80	51.73	4.82	4.06
PV	N_{320} P_{80} S_{10}	U	30	1	2.32	50.13	5.11	3.00
PV	N_{320} P_{80} S_{10}	U	30	2	1.87	51.47	4.82	3.70
PV	N_{320} P_{80} S_{20}	L	30	1	2.20	55.83	4.21	2.68
PV	N_{320} P_{80} S_{20}	L	30	2	2.03	51.93	5.49	2.87
PV	N_{320} P_{80} S_{20}	U	30	1	1.98	67.43	4.65	2.75
PV	N_{320} P_{80} S_{20}	U	30	2	1.89	55.81	5.88	2.52
PV	N_{320} P_{80} S_{40}	L	30	1	1.70	54.55	5.11	4.04
PV	N_{320} P_{80} S_{40}	L	30	2	2.00	44.47	4.99	3.90
PV	N_{320} P_{80} S_{40}	U	30	1	2.10	54.38	5.13	3.37
PV	N_{320} P_{80} S_{40}	U	30	2	2.04	45.34	5.49	3.00

Residue History	N P S applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					g pot^{-1}		--------mg g^{-1}--------	
M	N_0 P_0 S_0	L	30	1	0.74	22.81	5.84	3.90
M	N_0 P_0 S_0	L	30	2	0.82	26.19	6.04	4.77
M	N_0 P_0 S_0	U	30	1	0.84	18.50	5.88	3.37
M	N_0 P_0 S_0	U	30	2	0.84	25.56	5.72	4.32
M	N_{80} P_{80} S_{40}	L	30	1	1.94	39.44	6.31	3.23
M	N_{80} P_{80} S_{40}	L	30	2	1.60	43.47	6.29	2.52
M	N_{80} P_{80} S_{40}	U	30	1	1.87	35.97	5.88	3.37
M	N_{80} P_{80} S_{40}	U	30	2	2.07	39.11	6.50	2.81
M	N_{160} P_{80} S_{40}	L	30	1	1.99	46.60	5.84	2.98
M	N_{160} P_{80} S_{40}	L	30	2	1.87	59.04	6.98	3.00
M	N_{160} P_{80} S_{40}	U	30	1	2.16	44.47	5.30	3.23
M	N_{160} P_{80} S_{40}	U	30	2	2.10	52.41	7.85	2.87
M	N_{320} P_0 S_{40}	L	30	1	2.03	53.95	5.01	3.57
M	N_{320} P_0 S_{40}	L	30	2	2.32	61.51	3.00	3.77
M	N_{320} P_0 S_{40}	U	30	1	1.94	56.05	4.46	3.63
M	N_{320} P_0 S_{40}	U	30	2	2.40	60.13	3.59	3.77
M	N_{320} P_{20} S_{40}	L	30	1	1.65	53.86	4.92	3.19
M	N_{320} P_{20} S_{40}	L	30	2	1.98	52.10	4.80	3.50
M	N_{320} P_{20} S_{40}	U	30	1	1.99	53.08	5.22	3.16
M	N_{320} P_{20} S_{40}	U	30	2	2.45	51.73	5.11	4.04
M	N_{320} P_{40} S_{40}	L	30	1	2.39	59.47	4.92	3.36
M	N_{320} P_{40} S_{40}	L	30	2	1.89	59.58	5.28	3.52
M	N_{320} P_{40} S_{40}	U	30	1	2.06	58.82	5.11	2.98
M	N_{320} P_{40} S_{40}	U	30	2	1.96	51.86	5.69	3.17
M	N_{320} P_{80} S_0	L	30	1	1.80	53.97	6.69	2.29
M	N_{320} P_{80} S_0	L	30	2	2.05	44.99	4.65	2.18
M	N_{320} P_{80} S_0	U	30	1	1.83	52.62	5.41	2.07
M	N_{320} P_{80} S_0	U	30	2	1.81	45.73	4.65	2.46
M	N_{320} P_{80} S_{10}	L	30	1	2.10	50.95	4.95	3.26
M	N_{320} P_{80} S_{10}	L	30	2	2.24	52.17	4.51	3.31
M	N_{320} P_{80} S_{10}	U	30	1	2.19	48.33	4.80	3.54
M	N_{320} P_{80} S_{10}	U	30	2	2.21	51.08	5.46	3.50
M	N_{320} P_{80} S_{20}	L	30	1	1.88	53.79	6.29	3.37
M	N_{320} P_{80} S_{20}	L	30	2	1.96	54.79	5.88	3.12
M	N_{320} P_{80} S_{20}	U	30	1	2.30	60.62	4.35	2.63
M	N_{320} P_{80} S_{20}	U	30	2	2.63	51.71	5.59	3.25
M	N_{320} P_{80} S_{40}	L	30	1	1.74	50.95	5.69	3.27
M	N_{320} P_{80} S_{40}	L	30	2	2.01	51.80	4.92	3.49
M	N_{320} P_{80} S_{40}	U	30	1	2.28	52.45	5.01	3.37
M	N_{320} P_{80} S_{40}	U	30	2	2.66	47.48	5.49	3.61

Residue History	N P S applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					g pot^{-1}		---------mg g^{-1}---------	
N_0	N_0 P_0 S_0	L	60	1	0.26	18.28	4.38	2.86
N_0	N_0 P_0 S_0	L	60	2	0.23	17.22	4.55	2.63
N_0	N_0 P_0 S_0	U	60	1	0.27	20.27	4.55	2.50
N_0	N_0 P_0 S_0	U	60	2	0.14	23.16	4.74	3.16
N_0	N_{80} P_{80} S_{40}	L	60	1	0.60	18.78	5.26	4.33
N_0	N_{80} P_{80} S_{40}	L	60	2	0.58	14.87	4.47	4.49
N_0	N_{80} P_{80} S_{40}	U	60	1	0.52	19.32	5.39	3.17
N_0	N_{80} P_{80} S_{40}	U	60	2	0.43	20.79	5.30	4.96
N_0	N_{160} P_{80} S_{40}	L	60	1	1.60	21.79	4.22	4.43
N_0	N_{160} P_{80} S_{40}	L	60	2	1.82	25.56	4.20	3.48
N_0	N_{160} P_{80} S_{40}	U	60	1	1.79	22.16	4.55	3.63
N_0	N_{160} P_{80} S_{40}	U	60	2	1.67	23.27	3.69	2.81
N_0	N_{320} P_0 S_{40}	L	60	1	2.47	43.56	2.04	3.25
N_0	N_{320} P_0 S_{40}	L	60	2	1.96	47.66	2.59	3.76
N_0	N_{320} P_0 S_{40}	U	60	1	2.59	44.53	2.87	4.20
N_0	N_{320} P_0 S_{40}	U	60	2	2.13	47.48	2.42	3.50
N_0	N_{320} P_{20} S_{40}	L	60	1	2.93	42.84	2.53	4.18
N_0	N_{320} P_{20} S_{40}	L	60	2	2.57	48.09	2.67	2.87
N_0	N_{320} P_{20} S_{40}	U	60	1	2.32	47.48	3.32	5.07
N_0	N_{320} P_{20} S_{40}	U	60	2	2.56	43.38	3.05	3.84
N_0	N_{320} P_{40} S_{40}	L	60	1	2.94	41.80	3.34	3.58
N_0	N_{320} P_{40} S_{40}	L	60	2	2.94	49.33	2.72	3.18
N_0	N_{320} P_{40} S_{40}	U	60	1	3.17	45.19	3.44	4.33
N_0	N_{320} P_{40} S_{40}	U	60	2	3.04	43.60	3.77	3.77
N_0	N_{320} P_{80} S_0	L	60	1	0.35	49.13	4.61	0.66
N_0	N_{320} P_{80} S_0	L	60	2	0.41	44.41	4.29	0.72
N_0	N_{320} P_{80} S_0	U	60	1	0.41	53.32	4.54	1.00
N_0	N_{320} P_{80} S_0	U	60	2	0.39	53.58	4.47	1.45
N_0	N_{320} P_{80} S_{10}	L	60	1	2.01	38.72	4.03	2.19
N_0	N_{320} P_{80} S_{10}	L	60	2	2.16	37.36	5.47	1.20
N_0	N_{320} P_{80} S_{10}	U	60	1	2.31	41.63	4.29	2.58
N_0	N_{320} P_{80} S_{10}	U	60	2	2.30	38.11	4.15	1.29
N_0	N_{320} P_{80} S_{20}	L	60	1	2.83	43.82	4.92	3.18
N_0	N_{320} P_{80} S_{20}	L	60	2	2.68	46.86	4.47	3.18
N_0	N_{320} P_{80} S_{20}	U	60	1	2.74	45.90	5.11	3.31
N_0	N_{320} P_{80} S_{20}	U	60	2	2.64	47.94	4.03	2.54
N_0	N_{320} P_{80} S_{40}	L	60	1	3.08	41.78	4.38	3.63
N_0	N_{320} P_{80} S_{40}	L	60	2	2.46	44.32	4.20	3.70
N_0	N_{320} P_{80} S_{40}	U	60	1	3.09	42.84	5.05	3.77
N_0	N_{320} P_{80} S_{40}	U	60	2	2.55	46.83	4.41	5.05

Residue History	N P S applied			Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
							g pot^{-1}	---------mg g^{-1}---------		
N_0SB	N_0	P_0	S_0	L	60	1	0.26	18.60	4.55	2.81
N_0SB	N_0	P_0	S_0	L	60	2	0.25	17.50	4.34	2.81
N_0SB	N_0	P_0	S_0	U	60	1	0.22	21.64	4.92	2.68
N_0SB	N_0	P_0	S_0	U	60	2	0.18	19.60	4.68	3.11
N_0SB	N_{80}	P_{80}	S_{40}	L	60	1	0.54	19.73	4.96	5.39
N_0SB	N_{80}	P_{80}	S_{40}	L	60	2	0.56	16.78	5.11	4.83
N_0SB	N_{80}	P_{80}	S_{40}	U	60	1	0.57	19.77	7.35	4.77
N_0SB	N_{80}	P_{80}	S_{40}	U	60	2	0.59	17.76	5.01	4.96
N_0SB	N_{160}	P_{80}	S_{40}	L	60	1	1.50	21.29	4.20	3.37
N_0SB	N_{160}	P_{80}	S_{40}	L	60	2	1.78	22.92	4.55	3.25
N_0SB	N_{160}	P_{80}	S_{40}	U	60	1	1.89	28.19	4.81	4.90
N_0SB	N_{160}	P_{80}	S_{40}	U	60	2	1.77	24.41	4.47	3.13
N_0SB	N_{320}	P_0	S_{40}	L	60	1	2.83	40.74	2.26	3.02
N_0SB	N_{320}	P_0	S_{40}	L	60	2	2.62	45.21	2.30	3.77
N_0SB	N_{320}	P_0	S_{40}	U	60	1	2.52	46.96	2.72	3.46
N_0SB	N_{320}	P_0	S_{40}	U	60	2	1.29	48.09	3.42	3.78
N_0SB	N_{320}	P_{20}	S_{40}	L	60	1	2.77	46.51	3.00	4.40
N_0SB	N_{320}	P_{20}	S_{40}	L	60	2	2.73	45.22	3.69	3.85
N_0SB	N_{320}	P_{20}	S_{40}	U	60	1	2.75	41.63	4.16	4.33
N_0SB	N_{320}	P_{20}	S_{40}	U	60	2	2.83	46.16	3.19	3.40
N_0SB	N_{320}	P_{40}	S_{40}	L	60	1	2.86	45.83	3.69	2.40
N_0SB	N_{320}	P_{40}	S_{40}	L	60	2	2.94	45.73	3.44	3.76
N_0SB	N_{320}	P_{40}	S_{40}	U	60	1	2.63	48.48	3.99	3.15
N_0SB	N_{320}	P_{40}	S_{40}	U	60	2	2.86	46.81	3.84	3.61
N_0SB	N_{320}	P_{80}	S_0	L	60	1	0.49	49.18	4.03	0.43
N_0SB	N_{320}	P_{80}	S_0	L	60	2	0.35	55.01	4.41	0.67
N_0SB	N_{320}	P_{80}	S_0	U	60	1	0.35	55.27	3.67	1.05
N_0SB	N_{320}	P_{80}	S_0	U	60	2	0.37	57.31	3.19	1.33
N_0SB	N_{320}	P_{80}	S_{10}	L	60	1	2.25	39.59	3.82	1.80
N_0SB	N_{320}	P_{80}	S_{10}	L	60	2	1.96	39.83	4.20	1.43
N_0SB	N_{320}	P_{80}	S_{10}	U	60	1	2.14	38.14	2.79	2.21
N_0SB	N_{320}	P_{80}	S_{10}	U	60	2	1.93	41.50	5.45	0.56
N_0SB	N_{320}	P_{80}	S_{20}	L	60	1	2.96	41.91	4.45	2.69
N_0SB	N_{320}	P_{80}	S_{20}	L	60	2	2.53	45.49	4.88	3.65
N_0SB	N_{320}	P_{80}	S_{20}	U	60	1	2.92	44.34	4.20	1.66
N_0SB	N_{320}	P_{80}	S_{20}	U	60	2	2.65	50.78	4.29	2.52
N_0SB	N_{320}	P_{80}	S_{40}	L	60	1	3.14	43.12	4.92	3.82
N_0SB	N_{320}	P_{80}	S_{40}	L	60	2	2.50	44.86	4.47	3.25
N_0SB	N_{320}	P_{80}	S_{40}	U	60	1	2.76	47.65	5.20	3.63
N_0SB	N_{320}	P_{80}	S_{40}	U	60	2	2.10	48.69	4.38	2.87

Residue History	N P S applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					g pot^{-1}		--------mg g^{-1}--------	
N_{90}	N_0 P_0 S_0	L	60	1	0.28	19.12	4.57	2.99
N_{90}	N_0 P_0 S_0	L	60	2	0.26	16.41	4.22	2.29
N_{90}	N_0 P_0 S_0	U	60	1	0.19	21.51	4.20	2.63
N_{90}	N_0 P_0 S_0	U	60	2	0.15	19.69	4.57	3.28
N_{90}	N_{80} P_{80} S_{40}	L	60	1	0.59	18.50	5.71	5.57
N_{90}	N_{80} P_{80} S_{40}	L	60	2	0.56	15.76	4.23	5.08
N_{90}	N_{80} P_{80} S_{40}	U	60	1	0.55	19.02	4.77	7.10
N_{90}	N_{80} P_{80} S_{40}	U	60	2	0.60	15.85	4.23	6.44
N_{90}	N_{160} P_{80} S_{40}	L	60	1	1.72	21.68	3.44	3.50
N_{90}	N_{160} P_{80} S_{40}	L	60	2	1.89	23.20	4.55	3.63
N_{90}	N_{160} P_{80} S_{40}	U	60	1	1.83	23.31	3.85	4.11
N_{90}	N_{160} P_{80} S_{40}	U	60	2	1.69	20.06	3.96	3.18
N_{90}	N_{320} P_0 S_{40}	L	60	1	2.47	43.58	2.26	3.61
N_{90}	N_{320} P_0 S_{40}	L	60	2	1.87	47.16	2.26	3.85
N_{90}	N_{320} P_0 S_{40}	U	60	1	2.06	49.57	2.61	3.44
N_{90}	N_{320} P_0 S_{40}	U	60	2	2.79	41.78	2.72	3.89
N_{90}	N_{320} P_{20} S_{40}	L	60	1	3.02	42.24	2.44	3.76
N_{90}	N_{320} P_{20} S_{40}	L	60	2	2.21	47.59	2.59	3.42
N_{90}	N_{320} P_{20} S_{40}	U	60	1	2.91	39.09	2.87	4.62
N_{90}	N_{320} P_{20} S_{40}	U	60	2	2.84	42.80	2.72	3.66
N_{90}	N_{320} P_{40} S_{40}	L	60	1	3.11	39.68	2.87	3.50
N_{90}	N_{320} P_{40} S_{40}	L	60	2	2.62	50.98	2.42	2.87
N_{90}	N_{320} P_{40} S_{40}	U	60	1	2.74	49.02	3.32	2.69
N_{90}	N_{320} P_{40} S_{40}	U	60	2	3.01	44.43	3.27	4.33
N_{90}	N_{320} P_{80} S_0	L	60	1	0.47	49.89	3.79	0.56
N_{90}	N_{320} P_{80} S_0	L	60	2	0.35	51.54	3.52	0.61
N_{90}	N_{320} P_{80} S_0	U	60	1	0.43	49.57	4.01	0.68
N_{90}	N_{320} P_{80} S_0	U	60	2	0.43	52.88	3.91	0.30
N_{90}	N_{320} P_{80} S_{10}	L	60	1	2.22	36.45	3.85	1.44
N_{90}	N_{320} P_{80} S_{10}	L	60	2	2.00	36.55	4.47	1.43
N_{90}	N_{320} P_{80} S_{10}	U	60	1	2.37	38.16	3.69	1.95
N_{90}	N_{320} P_{80} S_{10}	U	60	2	2.44	37.27	4.16	1.22
N_{90}	N_{320} P_{80} S_{20}	L	60	1	2.92	40.78	4.52	2.87
N_{90}	N_{320} P_{80} S_{20}	L	60	2	2.61	44.19	4.11	2.93
N_{90}	N_{320} P_{80} S_{20}	U	60	1	3.21	42.26	4.01	1.91
N_{90}	N_{320} P_{80} S_{20}	U	60	2	2.81	43.10	4.20	3.00
N_{90}	N_{320} P_{80} S_{40}	L	60	1	3.23	41.84	4.55	3.86
N_{90}	N_{320} P_{80} S_{40}	L	60	2	2.60	43.34	4.55	3.86
N_{90}	N_{320} P_{80} S_{40}	U	60	1	2.98	40.98	4.55	4.61
N_{90}	N_{320} P_{80} S_{40}	U	60	2	2.72	43.89	4.16	3.92

Residue History	N P S applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					g pot^{-1}		--------mg g^{-1}--------	
$N_{90}SB$	N_0 P_0 S_0	L	60	1	0.09	28.23	5.12	3.91
$N_{90}SB$	N_0 P_0 S_0	L	60	2	0.22	18.65	3.91	3.19
$N_{90}SB$	N_0 P_0 S_0	U	60	1	0.24	20.58	4.65	2.46
$N_{90}SB$	N_0 P_0 S_0	U	60	2	0.26	18.78	4.16	2.40
$N_{90}SB$	N_{80} P_{80} S_{40}	L	60	1	0.60	31.37	4.77	5.39
$N_{90}SB$	N_{80} P_{80} S_{40}	L	60	2	0.64	16.85	4.36	5.08
$N_{90}SB$	N_{80} P_{80} S_{40}	U	60	1	0.59	18.89	4.61	6.00
$N_{90}SB$	N_{80} P_{80} S_{40}	U	60	2	0.64	17.84	4.45	4.97
$N_{90}SB$	N_{160} P_{80} S_{40}	L	60	1	1.40	19.60	3.82	2.63
$N_{90}SB$	N_{160} P_{80} S_{40}	L	60	2	1.87	24.54	5.49	3.70
$N_{90}SB$	N_{160} P_{80} S_{40}	U	60	1	1.62	20.49	3.70	3.65
$N_{90}SB$	N_{160} P_{80} S_{40}	U	60	2	1.39	20.95	3.89	4.20
$N_{90}SB$	N_{320} P_0 S_{40}	L	60	1	1.82	42.54	1.96	3.21
$N_{90}SB$	N_{320} P_0 S_{40}	L	60	2	1.74	47.42	1.50	2.69
$N_{90}SB$	N_{320} P_0 S_{40}	U	60	1	2.73	45.86	2.11	3.44
$N_{90}SB$	N_{320} P_0 S_{40}	U	60	2	2.36	47.87	2.56	2.23
$N_{90}SB$	N_{320} P_{20} S_{40}	L	60	1	2.80	42.09	2.26	3.74
$N_{90}SB$	N_{320} P_{20} S_{40}	L	60	2	2.15	46.85	2.05	3.12
$N_{90}SB$	N_{320} P_{20} S_{40}	U	60	1	3.02	42.19	2.58	3.96
$N_{90}SB$	N_{320} P_{20} S_{40}	U	60	2	2.51	47.61	2.69	2.67
$N_{90}SB$	N_{320} P_{40} S_{40}	L	60	1	2.53	46.70	2.86	3.32
$N_{90}SB$	N_{320} P_{40} S_{40}	L	60	2	2.47	52.10	2.87	3.39
$N_{90}SB$	N_{320} P_{40} S_{40}	U	60	1	2.95	44.93	3.06	3.12
$N_{90}SB$	N_{320} P_{40} S_{40}	U	60	2	2.80	52.54	2.72	1.24
$N_{90}SB$	N_{320} P_{80} S_0	L	60	1	0.48	49.87	3.02	0.56
$N_{90}SB$	N_{320} P_{80} S_0	L	60	2	0.33	55.66	3.96	0.43
$N_{90}SB$	N_{320} P_{80} S_0	U	60	1	0.39	50.06	3.11	0.80
$N_{90}SB$	N_{320} P_{80} S_0	U	60	2	0.45	53.97	3.60	0.74
$N_{90}SB$	N_{320} P_{80} S_{10}	L	60	1	1.99	36.82	4.18	1.69
$N_{90}SB$	N_{320} P_{80} S_{10}	L	60	2	2.06	36.99	3.70	0.99
$N_{90}SB$	N_{320} P_{80} S_{10}	U	60	1	2.02	41.13	4.06	1.98
$N_{90}SB$	N_{320} P_{80} S_{10}	U	60	2	2.33	35.36	4.20	1.18
$N_{90}SB$	N_{320} P_{80} S_{20}	L	60	1	2.50	43.91	4.20	3.00
$N_{90}SB$	N_{320} P_{80} S_{20}	L	60	2	2.04	46.88	4.18	3.12
$N_{90}SB$	N_{320} P_{80} S_{20}	U	60	1	3.25	41.33	4.11	1.90
$N_{90}SB$	N_{320} P_{80} S_{20}	U	60	2	3.06	39.94	4.38	3.26
$N_{90}SB$	N_{320} P_{80} S_{40}	L	60	1	2.69	42.86	4.38	3.50
$N_{90}SB$	N_{320} P_{80} S_{40}	L	60	2	1.86	47.20	4.04	3.19
$N_{90}SB$	N_{320} P_{80} S_{40}	U	60	1	2.87	46.33	3.19	3.44
$N_{90}SB$	N_{320} P_{80} S_{40}	U	60	2	2.60	47.31	4.04	3.40

Residue History	NPS applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					g pot^{-1}		-------mg g^{-1}-------	
PV	N_0 P_0 S_0	L	60	1	0.29	20.08	5.30	2.87
PV	N_0 P_0 S_0	L	60	2	0.27	16.76	4.06	2.40
PV	N_0 P_0 S_0	U	60	1	0.24	22.44	4.81	2.69
PV	N_0 P_0 S_0	U	60	2	0.30	18.63	4.20	2.87
PV	N_{80} P_{80} S_{40}	L	60	1	0.56	20.16	4.20	5.51
PV	N_{80} P_{80} S_{40}	L	60	2	0.61	17.04	4.70	5.41
PV	N_{80} P_{80} S_{40}	U	60	1	0.58	21.12	5.41	5.49
PV	N_{80} P_{80} S_{40}	U	60	2	0.60	17.24	5.51	5.08
PV	N_{160} P_{80} S_{40}	L	60	1	1.54	21.03	3.99	4.41
PV	N_{160} P_{80} S_{40}	L	60	2	1.75	22.03	4.47	3.61
PV	N_{160} P_{80} S_{40}	U	60	1	1.85	25.13	4.74	3.90
PV	N_{160} P_{80} S_{40}	U	60	2	1.98	31.81	4.39	3.57
PV	N_{320} P_0 S_{40}	L	60	1	1.91	47.96	2.29	3.16
PV	N_{320} P_0 S_{40}	L	60	2	2.46	43.06	2.11	3.63
PV	N_{320} P_0 S_{40}	U	60	1	1.99	46.14	2.87	3.52
PV	N_{320} P_0 S_{40}	U	60	2	2.03	45.60	2.64	3.66
PV	N_{320} P_{20} S_{40}	L	60	1	2.60	42.95	2.84	4.56
PV	N_{320} P_{20} S_{40}	L	60	2	2.53	44.57	2.87	3.37
PV	N_{320} P_{20} S_{40}	U	60	1	2.86	43.79	3.06	3.92
PV	N_{320} P_{20} S_{40}	U	60	2	2.58	45.46	2.75	3.25
PV	N_{320} P_{40} S_{40}	L	60	1	3.22	42.62	3.16	3.30
PV	N_{320} P_{40} S_{40}	L	60	2	2.67	52.58	3.52	3.81
PV	N_{320} P_{40} S_{40}	U	60	1	2.97	45.40	3.44	3.50
PV	N_{320} P_{40} S_{40}	U	60	2	3.04	47.20	3.39	3.62
PV	N_{320} P_{80} S_0	L	60	1	0.49	52.86	3.85	0.75
PV	N_{320} P_{80} S_0	L	60	2	0.41	47.98	3.69	0.47
PV	N_{320} P_{80} S_0	U	60	1	0.36	52.54	4.11	0.66
PV	N_{320} P_{80} S_0	U	60	2	0.39	52.56	3.85	0.76
PV	N_{320} P_{80} S_{10}	L	60	1	2.02	39.74	4.13	2.06
PV	N_{320} P_{80} S_{10}	L	60	2	1.71	39.90	5.71	1.23
PV	N_{320} P_{80} S_{10}	U	60	1	1.99	38.88	4.32	2.54
PV	N_{320} P_{80} S_{10}	U	60	2	2.26	38.57	5.73	1.63
PV	N_{320} P_{80} S_{20}	L	60	1	3.27	36.27	4.65	2.75
PV	N_{320} P_{80} S_{20}	L	60	2	2.30	47.22	4.10	3.23
PV	N_{320} P_{80} S_{20}	U	60	1	2.60	45.71	5.11	3.03
PV	N_{320} P_{80} S_{20}	U	60	2	2.86	49.28	4.41	3.00
PV	N_{320} P_{80} S_{40}	L	60	1	2.63	47.46	4.85	3.50
PV	N_{320} P_{80} S_{40}	L	60	2	2.06	47.92	4.92	3.52
PV	N_{320} P_{80} S_{40}	U	60	1	2.98	45.48	5.05	3.85
PV	N_{320} P_{80} S_{40}	U	60	2	2.35	45.01	4.39	3.44

Residue History	N P S applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					g pot^{-1}		--------mg g^{-1}--------	
M	N_0 P_0 S_0	L	60	1	0.45	19.62	5.43	4.37
M	N_0 P_0 S_0	L	60	2	0.41	17.89	5.12	4.04
M	N_0 P_0 S_0	U	60	1	0.36	20.75	4.74	4.33
M	N_0 P_0 S_0	U	60	2	0.41	18.10	5.69	3.90
M	N_{80} P_{80} S_{40}	L	60	1	0.68	19.54	6.21	5.41
M	N_{80} P_{80} S_{40}	L	60	2	0.82	20.36	4.74	4.04
M	N_{80} P_{80} S_{40}	U	60	1	0.69	20.42	5.03	4.77
M	N_{80} P_{80} S_{40}	U	60	2	0.70	17.24	5.43	4.73
M	N_{160} P_{80} S_{40}	L	60	1	1.94	26.95	5.11	4.93
M	N_{160} P_{80} S_{40}	L	60	2	2.09	27.30	4.52	3.76
M	N_{160} P_{80} S_{40}	U	60	1	1.68	23.20	4.29	3.97
M	N_{160} P_{80} S_{40}	U	60	2	1.96	22.33	6.03	3.46
M	N_{320} P_0 S_{40}	L	60	1	2.73	46.46	3.03	3.49
M	N_{320} P_0 S_{40}	L	60	2	2.66	46.49	1.75	3.80
M	N_{320} P_0 S_{40}	U	60	1	3.00	42.17	3.87	4.31
M	N_{320} P_0 S_{40}	U	60	2	2.89	43.15	3.42	3.00
M	N_{320} P_{20} S_{40}	L	60	1	3.40	43.06	3.69	4.33
M	N_{320} P_{20} S_{40}	L	60	2	2.65	45.85	3.52	3.58
M	N_{320} P_{20} S_{40}	U	60	1	3.07	46.11	4.06	3.80
M	N_{320} P_{20} S_{40}	U	60	2	3.01	40.82	3.87	3.44
M	N_{320} P_{40} S_{40}	L	60	1	3.21	39.52	4.06	3.78
M	N_{320} P_{40} S_{40}	L	60	2	2.98	49.93	4.03	4.00
M	N_{320} P_{40} S_{40}	U	60	1	3.07	45.75	4.29	3.23
M	N_{320} P_{40} S_{40}	U	60	2	3.02	47.94	3.97	3.00
M	N_{320} P_{80} S_0	L	60	1	0.83	46.12	4.34	0.70
M	N_{320} P_{80} S_0	L	60	2	0.75	45.03	5.26	0.77
M	N_{320} P_{80} S_0	U	60	1	0.72	43.21	4.74	0.92
M	N_{320} P_{80} S_0	U	60	2	0.73	45.33	4.74	0.94
M	N_{320} P_{80} S_{10}	L	60	1	2.64	41.15	4.01	1.73
M	N_{320} P_{80} S_{10}	L	60	2	2.65	37.68	4.47	1.43
M	N_{320} P_{80} S_{10}	U	60	1	2.45	39.33	4.55	2.17
M	N_{320} P_{80} S_{10}	U	60	2	2.48	41.80	4.22	1.53
M	N_{320} P_{80} S_{20}	L	60	1	2.52	44.67	5.20	3.35
M	N_{320} P_{80} S_{20}	L	60	2	2.43	47.90	4.83	2.00
M	N_{320} P_{80} S_{20}	U	60	1	3.03	42.48	4.73	2.66
M	N_{320} P_{80} S_{20}	U	60	2	2.76	47.29	4.54	3.25
M	N_{320} P_{80} S_{40}	L	60	1	2.94	47.46	4.92	4.37
M	N_{320} P_{80} S_{40}	L	60	2	2.37	47.59	4.52	2.87
M	N_{320} P_{80} S_{40}	U	60	1	3.16	41.82	5.49	3.77
M	N_{320} P_{80} S_{40}	U	60	2	2.82	42.84	5.11	5.04

Residue History	N P S applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					$g\ pot^{-1}$		$mg\ g^{-1}$	
N_0	$N_0\ P_0\ S_0$	L	90	1	0.17	19.08	5.51	2.56
N_0	$N_0\ P_0\ S_0$	L	90	2	0.23	17.30	4.74	2.66
N_0	$N_0\ P_0\ S_0$	U	90	1	0.23	17.24	4.38	2.54
N_0	$N_0\ P_0\ S_0$	U	90	2	0.26	14.68	3.74	2.12
N_0	$N_{80}\ P_{80}\ S_{40}$	L	90	1	0.28	17.35	5.49	8.37
N_0	$N_{80}\ P_{80}\ S_{40}$	L	90	2	0.26	16.93	5.07	9.59
N_0	$N_{80}\ P_{80}\ S_{40}$	U	90	1	0.30	16.61	5.30	7.65
N_0	$N_{80}\ P_{80}\ S_{40}$	U	90	2	0.33	16.15	4.75	7.02
N_0	$N_{160}\ P_{80}\ S_{40}$	L	90	1	0.62	11.81	3.89	6.65
N_0	$N_{160}\ P_{80}\ S_{40}$	L	90	2	0.63	12.79	3.77	6.18
N_0	$N_{160}\ P_{80}\ S_{40}$	U	90	1	0.60	13.44	4.74	6.69
N_0	$N_{160}\ P_{80}\ S_{40}$	U	90	2	0.61	12.88	3.77	6.86
N_0	$N_{320}\ P_0\ S_{40}$	L	90	1	2.17	14.70	1.81	2.68
N_0	$N_{320}\ P_0\ S_{40}$	L	90	2	3.02	17.61	1.25	2.46
N_0	$N_{320}\ P_0\ S_{40}$	U	90	1	2.07	13.57	2.27	2.43
N_0	$N_{320}\ P_0\ S_{40}$	U	90	2	3.32	18.58	1.41	2.53
N_0	$N_{320}\ P_{20}\ S_{40}$	L	90	1	1.48	14.64	2.56	3.00
N_0	$N_{320}\ P_{20}\ S_{40}$	L	90	2	2.10	13.12	2.11	2.36
N_0	$N_{320}\ P_{20}\ S_{40}$	U	90	1	2.72	14.96	2.23	2.23
N_0	$N_{320}\ P_{20}\ S_{40}$	U	90	2	2.60	13.25	2.11	1.98
N_0	$N_{320}\ P_{40}\ S_{40}$	L	90	1	1.80	16.28	2.72	2.29
N_0	$N_{320}\ P_{40}\ S_{40}$	L	90	2	1.34	13.20	2.94	3.25
N_0	$N_{320}\ P_{40}\ S_{40}$	U	90	1	1.74	14.09	2.92	2.39
N_0	$N_{320}\ P_{40}\ S_{40}$	U	90	2	1.42	13.07	3.06	2.86
N_0	$N_{320}\ P_{80}\ S_0$	L	90	1	0.16	57.44	4.55	0.94
N_0	$N_{320}\ P_{80}\ S_0$	L	90	2	0.05	58.37	4.20	0.93
N_0	$N_{320}\ P_{80}\ S_0$	U	90	1	0.07	58.27	2.92	0.77
N_0	$N_{320}\ P_{80}\ S_0$	U	90	2	0.16	58.86	3.69	0.75
N_0	$N_{320}\ P_{80}\ S_{10}$	L	90	1	0.70	50.89	7.31	0.47
N_0	$N_{320}\ P_{80}\ S_{10}$	L	90	2	0.70	46.75	5.69	0.94
N_0	$N_{320}\ P_{80}\ S_{10}$	U	90	1	0.84	44.34	5.20	0.56
N_0	$N_{320}\ P_{80}\ S_{10}$	U	90	2	0.62	46.49	5.01	0.94
N_0	$N_{320}\ P_{80}\ S_{20}$	L	90	1	1.81	14.12	2.79	1.42
N_0	$N_{320}\ P_{80}\ S_{20}$	L	90	2	2.37	13.72	2.70	2.37
N_0	$N_{320}\ P_{80}\ S_{20}$	U	90	1	2.09	13.99	3.34	1.23
N_0	$N_{320}\ P_{80}\ S_{20}$	U	90	2	2.54	14.53	3.97	1.05
N_0	$N_{320}\ P_{80}\ S_{40}$	L	90	1	1.46	14.16	1.90	3.51
N_0	$N_{320}\ P_{80}\ S_{40}$	L	90	2	2.77	15.07	3.03	2.04
N_0	$N_{320}\ P_{80}\ S_{40}$	U	90	1	1.76	15.07	3.35	2.18
N_0	$N_{320}\ P_{80}\ S_{40}$	U	90	2	2.60	13.44	3.06	2.09

Residue History	N P S applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					g pot^{-1}		--------mg g^{-1}--------	
N_0SB	N_0 P_0 S_0	L	90	1	0.19	17.76	5.47	2.53
N_0SB	N_0 P_0 S_0	L	90	2	0.19	17.67	5.18	2.81
N_0SB	N_0 P_0 S_0	U	90	1	0.23	17.41	4.10	2.62
N_0SB	N_0 P_0 S_0	U	90	2	0.25	22.09	3.79	2.49
N_0SB	N_{80} P_{80} S_{40}	L	90	1	0.29	17.45	5.65	8.32
N_0SB	N_{80} P_{80} S_{40}	L	90	2	0.27	15.69	5.39	9.14
N_0SB	N_{80} P_{80} S_{40}	U	90	1	0.25	15.24	4.52	6.78
N_0SB	N_{80} P_{80} S_{40}	U	90	2	0.27	15.89	4.50	7.58
N_0SB	N_{160} P_{80} S_{40}	L	90	1	0.46	14.18	4.03	6.29
N_0SB	N_{160} P_{80} S_{40}	L	90	2	0.68	12.51	3.55	5.57
N_0SB	N_{160} P_{80} S_{40}	U	90	1	0.70	11.75	4.01	6.22
N_0SB	N_{160} P_{80} S_{40}	U	90	2	0.60	12.92	5.73	6.08
N_0SB	N_{320} P_0 S_{40}	L	90	1	1.56	13.68	2.86	2.75
N_0SB	N_{320} P_0 S_{40}	L	90	2	1.70	12.60	2.44	2.63
N_0SB	N_{320} P_0 S_{40}	U	90	1	2.60	13.55	2.20	2.03
N_0SB	N_{320} P_0 S_{40}	U	90	2	3.03	20.14	1.82	2.87
N_0SB	N_{320} P_{20} S_{40}	L	90	1	2.05	14.18	2.58	2.14
N_0SB	N_{320} P_{20} S_{40}	L	90	2	2.24	14.44	1.09	2.29
N_0SB	N_{320} P_{20} S_{40}	U	90	1	1.86	14.64	3.03	2.41
N_0SB	N_{320} P_{20} S_{40}	U	90	2	1.70	12.40	3.03	2.65
N_0SB	N_{320} P_{40} S_{40}	L	90	1	1.87	15.96	2.94	2.28
N_0SB	N_{320} P_{40} S_{40}	L	90	2	1.30	13.88	3.08	3.45
N_0SB	N_{320} P_{40} S_{40}	U	90	1	1.85	12.81	2.79	1.80
N_0SB	N_{320} P_{40} S_{40}	U	90	2	1.65	13.36	3.19	3.28
N_0SB	N_{320} P_{80} S_0	L	90	1	0.23	59.58	5.65	0.84
N_0SB	N_{320} P_{80} S_0	L	90	2	0.20	54.48	6.09	0.86
N_0SB	N_{320} P_{80} S_0	U	90	1	0.16	58.15	4.11	0.95
N_0SB	N_{320} P_{80} S_0	U	90	2	0.17	57.21	3.89	1.14
N_0SB	N_{320} P_{80} S_{10}	L	90	1	0.73	46.47	5.73	1.00
N_0SB	N_{320} P_{80} S_{10}	L	90	2	0.76	45.81	8.26	0.94
N_0SB	N_{320} P_{80} S_{10}	U	90	1	0.82	44.30	5.28	0.99
N_0SB	N_{320} P_{80} S_{10}	U	90	2	0.73	43.21	7.06	0.78
N_0SB	N_{320} P_{80} S_{20}	L	90	1	1.50	13.68	3.13	2.18
N_0SB	N_{320} P_{80} S_{20}	L	90	2	2.24	14.44	3.00	1.53
N_0SB	N_{320} P_{80} S_{20}	U	90	1	1.55	14.27	3.69	1.74
N_0SB	N_{320} P_{80} S_{20}	U	90	2	2.37	13.64	2.87	1.14
N_0SB	N_{320} P_{80} S_{40}	L	90	1	1.68	13.92	3.27	2.01
N_0SB	N_{320} P_{80} S_{40}	L	90	2	2.46	16.48	3.40	1.96
N_0SB	N_{320} P_{80} S_{40}	U	90	1	2.18	15.59	4.04	2.12
N_0SB	N_{320} P_{80} S_{40}	U	90	2	3.07	15.72	3.19	2.28

Residue History	N P S applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					g pot^{-1}		--------mg g^{-1}--------	
N_{90}	N_0 P_0 S_0	L	90	1	0.18	17.43	5.43	2.64
N_{90}	N_0 P_0 S_0	L	90	2	0.21	18.04	5.30	2.73
N_{90}	N_0 P_0 S_0	U	90	1	0.16	18.00	3.55	2.45
N_{90}	N_0 P_0 S_0	U	90	2	0.17	14.59	3.65	2.18
N_{90}	N_{80} P_{80} S_{40}	L	90	1	0.19	20.19	5.49	9.64
N_{90}	N_{80} P_{80} S_{40}	L	90	2	0.24	16.48	4.94	8.42
N_{90}	N_{80} P_{80} S_{40}	U	90	1	0.25	16.04	5.30	9.24
N_{90}	N_{80} P_{80} S_{40}	U	90	2	0.26	16.24	4.63	10.79
N_{90}	N_{160} P_{80} S_{40}	L	90	1	0.46	14.38	3.69	7.04
N_{90}	N_{160} P_{80} S_{40}	L	90	2	0.62	13.36	3.44	6.71
N_{90}	N_{160} P_{80} S_{40}	U	90	1	0.50	14.12	3.85	7.06
N_{90}	N_{160} P_{80} S_{40}	U	90	2	0.52	13.96	3.58	6.86
N_{90}	N_{320} P_0 S_{40}	L	90	1	2.59	14.01	1.92	1.99
N_{90}	N_{320} P_0 S_{40}	L	90	2	3.06	18.15	1.31	2.60
N_{90}	N_{320} P_0 S_{40}	U	90	1	2.61	16.50	2.87	2.96
N_{90}	N_{320} P_0 S_{40}	U	90	2	1.24	14.81	3.03	4.61
N_{90}	N_{320} P_{20} S_{40}	L	90	1	1.86	13.55	1.75	2.81
N_{90}	N_{320} P_{20} S_{40}	L	90	2	2.68	14.66	2.04	2.39
N_{90}	N_{320} P_{20} S_{40}	U	90	1	1.68	13.29	2.97	3.27
N_{90}	N_{320} P_{20} S_{40}	U	90	2	1.99	14.05	2.72	2.56
N_{90}	N_{320} P_{40} S_{40}	L	90	1	1.24	13.83	3.00	3.39
N_{90}	N_{320} P_{40} S_{40}	L	90	2	2.59	14.68	2.26	2.27
N_{90}	N_{320} P_{40} S_{40}	U	90	1	1.69	13.81	3.03	2.86
N_{90}	N_{320} P_{40} S_{40}	U	90	2	1.20	13.81	3.08	4.07
N_{90}	N_{320} P_{80} S_0	L	90	1	0.17	57.56	2.78	0.92
N_{90}	N_{320} P_{80} S_0	L	90	2	0.19	56.97	3.51	0.93
N_{90}	N_{320} P_{80} S_0	U	90	1	0.18	56.85	3.65	0.81
N_{90}	N_{320} P_{80} S_0	U	90	2	0.16	58.51	3.65	0.41
N_{90}	N_{320} P_{80} S_{10}	L	90	1	0.77	49.48	5.67	0.66
N_{90}	N_{320} P_{80} S_{10}	L	90	2	0.86	45.75	5.01	0.66
N_{90}	N_{320} P_{80} S_{10}	U	90	1	0.79	46.47	5.11	0.56
N_{90}	N_{320} P_{80} S_{10}	U	90	2	0.83	40.65	5.47	0.99
N_{90}	N_{320} P_{80} S_{20}	L	90	1	1.55	14.35	3.52	1.75
N_{90}	N_{320} P_{80} S_{20}	L	90	2	1.94	13.88	2.89	1.43
N_{90}	N_{320} P_{80} S_{20}	U	90	1	1.39	14.42	3.97	1.71
N_{90}	N_{320} P_{80} S_{20}	U	90	2	1.99	12.77	3.11	1.43
N_{90}	N_{320} P_{80} S_{40}	L	90	1	1.39	14.07	3.27	2.63
N_{90}	N_{320} P_{80} S_{40}	L	90	2	2.43	18.00	2.90	2.18
N_{90}	N_{320} P_{80} S_{40}	U	90	1	1.23	14.48	3.42	4.46
N_{90}	N_{320} P_{80} S_{40}	U	90	2	1.45	13.55	3.35	3.25

Residue History	N P S applied			Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
							g pot^{-1}		---------mg g^{-1}---------	
$N_{90}SB$	N_0	P_0	S_0	L	90	1	0.21	16.59	3.85	2.19
$N_{90}SB$	N_0	P_0	S_0	L	90	2	0.22	16.02	2.87	2.39
$N_{90}SB$	N_0	P_0	S_0	U	90	1	0.18	18.80	4.77	2.75
$N_{90}SB$	N_0	P_0	S_0	U	90	2	0.17	16.98	4.74	2.52
$N_{90}SB$	N_{80}	P_{80}	S_{40}	L	90	1	0.21	17.80	4.94	8.54
$N_{90}SB$	N_{80}	P_{80}	S_{40}	L	90	2	0.29	16.33	4.48	8.09
$N_{90}SB$	N_{80}	P_{80}	S_{40}	U	90	1	0.27	16.70	5.32	7.45
$N_{90}SB$	N_{80}	P_{80}	S_{40}	U	90	2	0.24	17.43	4.74	8.68
$N_{90}SB$	N_{160}	P_{80}	S_{40}	L	90	1	0.45	12.51	4.06	6.88
$N_{90}SB$	N_{160}	P_{80}	S_{40}	L	90	2	0.61	14.07	3.85	6.57
$N_{90}SB$	N_{160}	P_{80}	S_{40}	U	90	1	0.53	12.84	3.44	7.20
$N_{90}SB$	N_{160}	P_{80}	S_{40}	U	90	2	0.48	14.07	3.60	7.67
$N_{90}SB$	N_{320}	P_0	S_{40}	L	90	1	2.83	18.58	1.53	2.53
$N_{90}SB$	N_{320}	P_0	S_{40}	L	90	2	3.32	19.67	1.01	2.53
$N_{90}SB$	N_{320}	P_0	S_{40}	U	90	1	1.73	13.99	2.69	3.62
$N_{90}SB$	N_{320}	P_0	S_{40}	U	90	2	2.31	14.64	1.89	2.40
$N_{90}SB$	N_{320}	P_{20}	S_{40}	L	90	1	1.24	14.68	2.84	4.31
$N_{90}SB$	N_{320}	P_{20}	S_{40}	L	90	2	2.75	16.67	1.82	2.40
$N_{90}SB$	N_{320}	P_{20}	S_{40}	U	90	1	1.33	13.86	3.03	4.71
$N_{90}SB$	N_{320}	P_{20}	S_{40}	U	90	2	2.50	13.70	2.26	2.27
$N_{90}SB$	N_{320}	P_{40}	S_{40}	L	90	1	1.76	13.68	2.47	2.40
$N_{90}SB$	N_{320}	P_{40}	S_{40}	L	90	2	2.28	14.05	1.96	2.18
$N_{90}SB$	N_{320}	P_{40}	S_{40}	U	90	1	1.39	18.54	2.79	3.49
$N_{90}SB$	N_{320}	P_{40}	S_{40}	U	90	2	1.94	13.90	3.03	2.86
$N_{90}SB$	N_{320}	P_{80}	S_0	L	90	1	0.13	59.46	3.70	0.56
$N_{90}SB$	N_{320}	P_{80}	S_0	L	90	2	0.12	65.62	3.65	0.74
$N_{90}SB$	N_{320}	P_{80}	S_0	U	90	1	0.09	65.50	3.80	0.56
$N_{90}SB$	N_{320}	P_{80}	S_0	U	90	2	0.07	63.17	3.54	0.69
$N_{90}SB$	N_{320}	P_{80}	S_{10}	L	90	1	0.61	47.53	5.39	1.34
$N_{90}SB$	N_{320}	P_{80}	S_{10}	L	90	2	0.69	48.26	4.94	1.42
$N_{90}SB$	N_{320}	P_{80}	S_{10}	U	90	1	0.77	41.54	5.69	1.04
$N_{90}SB$	N_{320}	P_{80}	S_{10}	U	90	2	0.77	46.75	5.49	1.69
$N_{90}SB$	N_{320}	P_{80}	S_{20}	L	90	1	2.35	15.59	2.18	1.23
$N_{90}SB$	N_{320}	P_{80}	S_{20}	L	90	2	2.92	16.33	2.72	1.34
$N_{90}SB$	N_{320}	P_{80}	S_{20}	U	90	1	1.48	14.07	3.65	2.07
$N_{90}SB$	N_{320}	P_{80}	S_{20}	U	90	2	1.22	13.72	3.55	1.72
$N_{90}SB$	N_{320}	P_{80}	S_{40}	L	90	1	2.16	13.99	2.89	1.76
$N_{90}SB$	N_{320}	P_{80}	S_{40}	L	90	2	3.00	18.50	3.03	2.72
$N_{90}SB$	N_{320}	P_{80}	S_{40}	U	90	1	1.70	14.51	3.52	3.31
$N_{90}SB$	N_{320}	P_{80}	S_{40}	U	90	2	2.17	15.07	3.29	2.69

Residue History	NPS applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					$g\ pot^{-1}$		---------$mg\ g^{-1}$---------	
PV	$N_0\ P_0\ S_0$	L	90	1	0.22	18.82	2.79	2.41
PV	$N_0\ P_0\ S_0$	L	90	2	0.25	15.13	3.84	2.17
PV	$N_0\ P_0\ S_0$	U	90	1	0.27	16.37	3.92	2.27
PV	$N_0\ P_0\ S_0$	U	90	2	0.30	15.44	3.84	2.18
PV	$N_{80}\ P_{80}\ S_{40}$	L	90	1	0.27	16.50	4.90	7.45
PV	$N_{80}\ P_{80}\ S_{40}$	L	90	2	0.29	16.78	4.90	10.07
PV	$N_{80}\ P_{80}\ S_{40}$	U	90	1	0.28	17.02	5.45	7.45
PV	$N_{80}\ P_{80}\ S_{40}$	U	90	2	0.27	16.06	4.83	8.58
PV	$N_{160}\ P_{80}\ S_{40}$	L	90	1	0.55	12.94	3.79	7.27
PV	$N_{160}\ P_{80}\ S_{40}$	L	90	2	0.58	14.57	3.87	5.92
PV	$N_{160}\ P_{80}\ S_{40}$	U	90	1	0.59	12.81	4.01	6.09
PV	$N_{160}\ P_{80}\ S_{40}$	U	90	2	0.63	12.60	3.39	6.73
PV	$N_{320}\ P_0\ S_{40}$	L	90	1	3.11	18.39	1.56	2.55
PV	$N_{320}\ P_0\ S_{40}$	L	90	2	2.31	16.78	1.65	2.13
PV	$N_{320}\ P_0\ S_{40}$	U	90	1	3.00	15.63	1.70	2.28
PV	$N_{320}\ P_0\ S_{40}$	U	90	2	3.23	18.30	2.23	2.23
PV	$N_{320}\ P_{20}\ S_{40}$	L	90	1	2.22	15.46	2.29	2.24
PV	$N_{320}\ P_{20}\ S_{40}$	L	90	2	2.21	13.49	2.14	2.17
PV	$N_{320}\ P_{20}\ S_{40}$	U	90	1	1.68	13.70	2.73	2.54
PV	$N_{320}\ P_{20}\ S_{40}$	U	90	2	2.50	15.03	2.08	1.98
PV	$N_{320}\ P_{40}\ S_{40}$	L	90	1	1.58	13.42	2.84	2.61
PV	$N_{320}\ P_{40}\ S_{40}$	L	90	2	2.41	13.79	2.53	1.96
PV	$N_{320}\ P_{40}\ S_{40}$	U	90	1	2.08	15.44	2.76	1.94
PV	$N_{320}\ P_{40}\ S_{40}$	U	90	2	2.22	13.20	2.56	1.98
PV	$N_{320}\ P_{80}\ S_0$	L	90	1	0.09	60.64	3.30	0.79
PV	$N_{320}\ P_{80}\ S_0$	L	90	2	0.12	60.40	4.16	0.74
PV	$N_{320}\ P_{80}\ S_0$	U	90	1	0.15	59.46	4.38	0.75
PV	$N_{320}\ P_{80}\ S_0$	U	90	2	0.17	54.25	3.54	0.68
PV	$N_{320}\ P_{80}\ S_{10}$	L	90	1	0.74	46.79	5.51	1.32
PV	$N_{320}\ P_{80}\ S_{10}$	L	90	2	0.72	45.29	5.20	0.84
PV	$N_{320}\ P_{80}\ S_{10}$	U	90	1	0.63	49.52	5.45	0.58
PV	$N_{320}\ P_{80}\ S_{10}$	U	90	2	0.68	45.64	4.92	0.77
PV	$N_{320}\ P_{80}\ S_{20}$	L	90	1	1.18	14.87	3.85	1.33
PV	$N_{320}\ P_{80}\ S_{20}$	L	90	2	2.61	14.92	3.03	1.24
PV	$N_{320}\ P_{80}\ S_{20}$	U	90	1	2.15	14.83	3.60	1.14
PV	$N_{320}\ P_{80}\ S_{20}$	U	90	2	2.22	15.24	3.35	1.31
PV	$N_{320}\ P_{80}\ S_{40}$	L	90	1	2.52	15.24	3.19	1.96
PV	$N_{320}\ P_{80}\ S_{40}$	L	90	2	2.62	15.61	3.18	2.29
PV	$N_{320}\ P_{80}\ S_{40}$	U	90	1	1.40	13.25	3.11	2.97
PV	$N_{320}\ P_{80}\ S_{40}$	U	90	2	2.97	15.16	2.98	1.74

Residue History	N P S applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					$g\ pot^{-1}$		---------mg g^{-1}---------	
M	$N_0\ P_0\ S_0$	L	90	1	0.31	20.49	6.21	4.36
M	$N_0\ P_0\ S_0$	L	90	2	0.40	16.83	5.78	3.88
M	$N_0\ P_0\ S_0$	U	90	1	0.37	18.63	5.80	3.97
M	$N_0\ P_0\ S_0$	U	90	2	0.38	16.54	5.99	4.17
M	$N_{80}\ P_{80}\ S_{40}$	L	90	1	0.39	16.89	5.92	7.52
M	$N_{80}\ P_{80}\ S_{40}$	L	90	2	0.42	17.17	5.20	6.90
M	$N_{80}\ P_{80}\ S_{40}$	U	90	1	0.43	17.26	6.46	8.05
M	$N_{80}\ P_{80}\ S_{40}$	U	90	2	0.42	17.30	6.03	9.14
M	$N_{160}\ P_{80}\ S_{40}$	L	90	1	0.70	12.53	4.83	5.57
M	$N_{160}\ P_{80}\ S_{40}$	L	90	2	0.78	13.12	4.38	5.66
M	$N_{160}\ P_{80}\ S_{40}$	U	90	1	0.61	14.14	5.22	6.50
M	$N_{160}\ P_{80}\ S_{40}$	U	90	2	0.67	13.99	4.41	6.84
M	$N_{320}\ P_0\ S_{40}$	L	90	1	2.22	13.44	3.19	2.65
M	$N_{320}\ P_0\ S_{40}$	L	90	2	2.23	13.86	2.61	2.29
M	$N_{320}\ P_0\ S_{40}$	U	90	1	2.02	13.44	3.55	2.56
M	$N_{320}\ P_0\ S_{40}$	U	90	2	1.90	13.51	3.03	2.77
M	$N_{320}\ P_{20}\ S_{40}$	L	90	1	1.79	14.29	3.69	3.14
M	$N_{320}\ P_{20}\ S_{40}$	L	90	2	2.90	14.57	1.38	2.09
M	$N_{320}\ P_{20}\ S_{40}$	U	90	1	1.71	17.19	3.60	3.27
M	$N_{320}\ P_{20}\ S_{40}$	U	90	2	1.44	14.29	3.55	3.70
M	$N_{320}\ P_{40}\ S_{40}$	L	90	1	1.29	14.64	3.85	4.06
M	$N_{320}\ P_{40}\ S_{40}$	L	90	2	2.43	13.66	2.97	2.07
M	$N_{320}\ P_{40}\ S_{40}$	U	90	1	1.63	15.55	2.87	2.97
M	$N_{320}\ P_{40}\ S_{40}$	U	90	2	2.18	14.66	3.19	2.55
M	$N_{320}\ P_{80}\ S_0$	L	90	1	0.45	56.61	5.61	0.87
M	$N_{320}\ P_{80}\ S_0$	L	90	2	0.40	52.11	5.30	0.84
M	$N_{320}\ P_{80}\ S_0$	U	90	1	0.42	52.94	5.47	0.88
M	$N_{320}\ P_{80}\ S_0$	U	90	2	0.40	53.30	5.82	0.75
M	$N_{320}\ P_{80}\ S_{10}$	L	90	1	1.04	34.37	5.49	0.75
M	$N_{320}\ P_{80}\ S_{10}$	L	90	2	1.33	31.70	5.51	0.92
M	$N_{320}\ P_{80}\ S_{10}$	U	90	1	1.16	36.84	5.99	1.04
M	$N_{320}\ P_{80}\ S_{10}$	U	90	2	1.19	35.06	7.65	0.84
M	$N_{320}\ P_{80}\ S_{20}$	L	90	1	2.73	14.38	3.35	1.51
M	$N_{320}\ P_{80}\ S_{20}$	L	90	2	2.91	21.70	3.19	1.53
M	$N_{320}\ P_{80}\ S_{20}$	U	90	1	1.85	14.03	2.64	1.98
M	$N_{320}\ P_{80}\ S_{20}$	U	90	2	1.76	14.09	3.52	2.06
M	$N_{320}\ P_{80}\ S_{40}$	L	90	1	2.47	14.57	3.44	2.32
M	$N_{320}\ P_{80}\ S_{40}$	L	90	2	3.16	17.56	3.52	2.29
M	$N_{320}\ P_{80}\ S_{40}$	U	90	1	1.62	15.16	3.69	3.39
M	$N_{320}\ P_{80}\ S_{40}$	U	90	2	1.39	14.27	4.20	3.78

Residue History	N P S applied			Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
							g pot^{-1}		--------mg g^{-1}--------	
N_0	N_0	P_0	S_0	L	120	1	0.20	16.92	7.71	2.47
N_0	N_0	P_0	S_0	L	120	2	0.21	18.24	6.13	2.14
N_0	N_0	P_0	S_0	U	120	1	0.30	15.75	7.38	2.17
N_0	N_0	P_0	S_0	U	120	2	0.29	16.94	5.28	2.04
N_0	N_{80}	P_{80}	S_{40}	L	120	1	0.30	19.19	9.67	14.39
N_0	N_{80}	P_{80}	S_{40}	L	120	2	0.24	18.24	7.00	10.54
N_0	N_{80}	P_{80}	S_{40}	U	120	1	0.31	18.83	8.89	12.06
N_0	N_{80}	P_{80}	S_{40}	U	120	2	0.34	16.94	6.23	11.02
N_0	N_{160}	P_{80}	S_{40}	L	120	1	0.34	16.82	8.91	11.45
N_0	N_{160}	P_{80}	S_{40}	L	120	2	0.30	17.77	3.29	11.32
N_0	N_{160}	P_{80}	S_{40}	U	120	1	0.26	16.46	10.20	12.88
N_0	N_{160}	P_{80}	S_{40}	U	120	2	0.38	17.29	5.88	9.73
N_0	N_{320}	P_0	S_{40}	L	120	1	0.71	13.50	3.34	5.41
N_0	N_{320}	P_0	S_{40}	L	120	2	0.88	14.57	2.89	3.66
N_0	N_{320}	P_0	S_{40}	U	120	1	0.89	13.03	3.89	3.92
N_0	N_{320}	P_0	S_{40}	U	120	2	0.96	13.15	2.87	2.87
N_0	N_{320}	P_{20}	S_{40}	L	120	1	0.55	15.87	4.38	5.66
N_0	N_{320}	P_{20}	S_{40}	L	120	2	0.54	14.45	3.67	5.69
N_0	N_{320}	P_{20}	S_{40}	U	120	1	0.92	12.55	3.34	3.28
N_0	N_{320}	P_{20}	S_{40}	U	120	2	0.80	12.55	2.44	3.52
N_0	N_{320}	P_{40}	S_{40}	L	120	1	0.74	13.86	4.61	4.18
N_0	N_{320}	P_{40}	S_{40}	L	120	2	0.47	14.92	3.30	6.11
N_0	N_{320}	P_{40}	S_{40}	U	120	1	0.65	16.11	4.03	4.77
N_0	N_{320}	P_{40}	S_{40}	U	120	2	0.47	16.46	4.92	7.27
N_0	N_{320}	P_{80}	S_0	L	120	1	0.12	52.82	6.69	1.12
N_0	N_{320}	P_{80}	S_0	L	120	2	0.10	41.90	5.15	1.29
N_0	N_{320}	P_{80}	S_0	U	120	1	0.15	50.57	4.43	0.65
N_0	N_{320}	P_{80}	S_0	U	120	2	0.15	53.30	5.11	0.82
N_0	N_{320}	P_{80}	S_{10}	L	120	1	0.32	58.04	6.69	0.95
N_0	N_{320}	P_{80}	S_{10}	L	120	2	0.26	60.29	7.28	0.69
N_0	N_{320}	P_{80}	S_{10}	U	120	1	0.29	61.00	7.28	0.70
N_0	N_{320}	P_{80}	S_{10}	U	120	2	0.16	57.56	6.25	0.62
N_0	N_{320}	P_{80}	S_{20}	L	120	1	0.62	15.52	4.72	1.22
N_0	N_{320}	P_{80}	S_{20}	L	120	2	0.67	15.87	4.48	0.88
N_0	N_{320}	P_{80}	S_{20}	U	120	1	0.64	15.63	4.18	0.95
N_0	N_{320}	P_{80}	S_{20}	U	120	2	0.70	13.98	4.13	1.03
N_0	N_{320}	P_{80}	S_{40}	L	120	1	0.68	13.38	4.23	4.46
N_0	N_{320}	P_{80}	S_{40}	L	120	2	0.83	13.74	3.35	3.99
N_0	N_{320}	P_{80}	S_{40}	U	120	1	0.77	13.98	3.52	4.80
N_0	N_{320}	P_{80}	S_{40}	U	120	2	0.84	13.98	3.55	4.47

Residue History	N P S applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					g pot^{-1}	---------mg g^{-1}---------		
N_0SB	N_0 P_0 S_0	L	120	1	0.22	19.42	7.88	2.54
N_0SB	N_0 P_0 S_0	L	120	2	0.23	16.11	6.44	3.25
N_0SB	N_0 P_0 S_0	U	120	1	0.26	17.29	5.71	2.06
N_0SB	N_0 P_0 S_0	U	120	2	0.25	15.63	4.31	2.49
N_0SB	N_{80} P_{80} S_{40}	L	120	1	0.36	17.06	5.69	15.06
N_0SB	N_{80} P_{80} S_{40}	L	120	2	0.28	16.23	8.65	18.50
N_0SB	N_{80} P_{80} S_{40}	U	120	1	0.36	16.46	7.43	15.33
N_0SB	N_{80} P_{80} S_{40}	U	120	2	0.28	17.53	6.63	19.44
N_0SB	N_{160} P_{80} S_{40}	L	120	1	0.32	17.17	8.10	11.05
N_0SB	N_{160} P_{80} S_{40}	L	120	2	0.34	17.06	6.61	11.12
N_0SB	N_{160} P_{80} S_{40}	U	120	1	0.31	17.29	6.80	8.11
N_0SB	N_{160} P_{80} S_{40}	U	120	2	0.32	17.06	6.91	9.16
N_0SB	N_{320} P_0 S_{40}	L	120	1	0.63	15.28	4.36	5.56
N_0SB	N_{320} P_0 S_{40}	L	120	2	0.51	15.40	3.80	5.26
N_0SB	N_{320} P_0 S_{40}	U	120	1	0.69	13.27	3.43	4.04
N_0SB	N_{320} P_0 S_{40}	U	120	2	0.89	13.27	3.37	3.78
N_0SB	N_{320} P_{20} S_{40}	L	120	1	0.70	14.69	3.82	4.80
N_0SB	N_{320} P_{20} S_{40}	L	120	2	0.76	14.92	3.44	5.28
N_0SB	N_{320} P_{20} S_{40}	U	120	1	0.64	13.74	3.97	4.93
N_0SB	N_{320} P_{20} S_{40}	U	120	2	0.55	13.98	3.99	5.57
N_0SB	N_{320} P_{40} S_{40}	L	120	1	0.76	14.09	4.15	3.89
N_0SB	N_{320} P_{40} S_{40}	L	120	2	0.50	14.92	4.15	6.09
N_0SB	N_{320} P_{40} S_{40}	U	120	1	0.65	14.21	4.45	5.07
N_0SB	N_{320} P_{40} S_{40}	U	120	2	0.57	14.09	2.47	4.77
N_0SB	N_{320} P_{80} S_0	L	120	1	0.17	53.77	7.37	1.08
N_0SB	N_{320} P_{80} S_0	L	120	2	0.20	55.43	6.31	1.05
N_0SB	N_{320} P_{80} S_0	U	120	1	0.07	52.64	1.99	0.95
N_0SB	N_{320} P_{80} S_0	U	120	2	0.08	50.09	4.32	1.13
N_0SB	N_{320} P_{80} S_{10}	L	120	1	0.47	35.06	6.93	1.04
N_0SB	N_{320} P_{80} S_{10}	L	120	2	0.41	56.73	8.91	0.65
N_0SB	N_{320} P_{80} S_{10}	U	120	1	0.39	58.27	8.00	0.91
N_0SB	N_{320} P_{80} S_{10}	U	120	2	0.28	54.36	7.00	0.65
N_0SB	N_{320} P_{80} S_{20}	L	120	1	0.61	14.33	4.01	1.56
N_0SB	N_{320} P_{80} S_{20}	L	120	2	0.78	14.45	4.36	0.93
N_0SB	N_{320} P_{80} S_{20}	U	120	1	0.55	14.92	4.90	0.94
N_0SB	N_{320} P_{80} S_{20}	U	120	2	0.68	14.81	4.72	1.33
N_0SB	N_{320} P_{80} S_{40}	L	120	1	0.58	15.63	4.13	4.68
N_0SB	N_{320} P_{80} S_{40}	L	120	2	0.75	14.81	3.69	4.18
N_0SB	N_{320} P_{80} S_{40}	U	120	1	0.85	13.74	3.52	3.92
N_0SB	N_{320} P_{80} S_{40}	U	120	2	0.94	13.50	3.62	3.93

Residue History	NPS applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					$g\ pot^{-1}$		--------$mg\ g^{-1}$--------	
N_{90}	N_0 P_0 S_0	L	120	1	0.26	18.48	6.91	2.40
N_{90}	N_0 P_0 S_0	L	120	2	0.30	17.41	5.63	2.32
N_{90}	N_0 P_0 S_0	U	120	1	0.23	15.25	4.36	2.21
N_{90}	N_0 P_0 S_0	U	120	2	0.21	18.60	4.50	2.58
N_{90}	N_{80} P_{80} S_{40}	L	120	1	0.36	17.06	8.05	13.29
N_{90}	N_{80} P_{80} S_{40}	L	120	2	0.29	18.95	6.46	15.78
N_{90}	N_{80} P_{80} S_{40}	U	120	1	0.25	17.88	8.73	13.87
N_{90}	N_{80} P_{80} S_{40}	U	120	2	0.25	17.06	7.17	14.69
N_{90}	N_{160} P_{80} S_{40}	L	120	1	0.33	16.58	8.25	11.12
N_{90}	N_{160} P_{80} S_{40}	L	120	2	0.35	16.58	5.96	9.87
N_{90}	N_{160} P_{80} S_{40}	U	120	1	0.31	18.60	8.65	10.33
N_{90}	N_{160} P_{80} S_{40}	U	120	2	0.31	18.71	6.71	9.64
N_{90}	N_{320} P_0 S_{40}	L	120	1	0.88	12.44	3.86	3.93
N_{90}	N_{320} P_0 S_{40}	L	120	2	0.92	12.91	2.84	3.35
N_{90}	N_{320} P_0 S_{40}	U	120	1	0.76	13.38	4.54	4.97
N_{90}	N_{320} P_0 S_{40}	U	120	2	0.48	16.23	4.40	7.71
N_{90}	N_{320} P_{20} S_{40}	L	120	1	0.67	15.52	4.36	5.39
N_{90}	N_{320} P_{20} S_{40}	L	120	2	0.76	13.62	3.02	3.67
N_{90}	N_{320} P_{20} S_{40}	U	120	1	0.58	15.40	4.34	6.29
N_{90}	N_{320} P_{20} S_{40}	U	120	2	0.59	13.74	3.49	5.70
N_{90}	N_{320} P_{40} S_{40}	L	120	1	0.51	14.45	5.09	6.50
N_{90}	N_{320} P_{40} S_{40}	L	120	2	0.79	12.79	3.11	4.76
N_{90}	N_{320} P_{40} S_{40}	U	120	1	0.61	13.74	4.36	5.92
N_{90}	N_{320} P_{40} S_{40}	U	120	2	0.45	16.34	4.75	7.25
N_{90}	N_{320} P_{80} S_0	L	120	1	0.08	49.83	5.86	1.03
N_{90}	N_{320} P_{80} S_0	L	120	2	0.19	45.01	3.79	1.03
N_{90}	N_{320} P_{80} S_0	U	120	1	0.13	54.96	4.20	0.84
N_{90}	N_{320} P_{80} S_0	U	120	2	0.11	53.30	3.65	0.38
N_{90}	N_{320} P_{80} S_{10}	L	120	1	0.55	32.93	6.13	0.97
N_{90}	N_{320} P_{80} S_{10}	L	120	2	0.36	53.77	6.50	0.29
N_{90}	N_{320} P_{80} S_{10}	U	120	1	0.53	37.66	6.09	1.16
N_{90}	N_{320} P_{80} S_{10}	U	120	2	0.43	37.19	6.93	0.89
N_{90}	N_{320} P_{80} S_{20}	L	120	1	0.72	14.45	4.11	1.99
N_{90}	N_{320} P_{80} S_{20}	L	120	2	0.59	15.87	4.10	1.33
N_{90}	N_{320} P_{80} S_{20}	U	120	1	0.58	14.81	4.43	1.23
N_{90}	N_{320} P_{80} S_{20}	U	120	2	0.62	13.86	3.67	1.23
N_{90}	N_{320} P_{80} S_{40}	L	120	1	0.66	15.16	4.43	5.86
N_{90}	N_{320} P_{80} S_{40}	L	120	2	0.80	13.98	3.19	4.18
N_{90}	N_{320} P_{80} S_{40}	U	120	1	0.54	14.92	4.72	7.02
N_{90}	N_{320} P_{80} S_{40}	U	120	2	0.54	14.21	4.01	6.31

Residue History	N P S applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					g pot^{-1}	---------mg g^{-1}---------		
$N_{90}SB$	N_0 P_0 S_0	L	120	1	0.30	17.77	4.65	2.51
$N_{90}SB$	N_0 P_0 S_0	L	120	2	0.27	15.04	4.52	2.08
$N_{90}SB$	N_0 P_0 S_0	U	120	1	0.23	18.71	7.95	2.37
$N_{90}SB$	N_0 P_0 S_0	U	120	2	0.25	18.48	5.67	2.19
$N_{90}SB$	N_{80} P_{80} S_{40}	L	120	1	0.20	17.53	8.63	10.58
$N_{90}SB$	N_{80} P_{80} S_{40}	L	120	2	0.29	18.71	6.38	16.89
$N_{90}SB$	N_{80} P_{80} S_{40}	U	120	1	0.30	18.71	3.01	10.54
$N_{90}SB$	N_{80} P_{80} S_{40}	U	120	2	0.23	20.13	6.69	12.32
$N_{90}SB$	N_{160} P_{80} S_{40}	L	120	1	0.35	17.06	7.62	11.08
$N_{90}SB$	N_{160} P_{80} S_{40}	L	120	2	0.35	15.63	6.69	10.51
$N_{90}SB$	N_{160} P_{80} S_{40}	U	120	1	0.31	18.71	6.95	9.37
$N_{90}SB$	N_{160} P_{80} S_{40}	U	120	2	0.32	16.46	5.32	10.73
$N_{90}SB$	N_{320} P_0 S_{40}	L	120	1	1.01	12.79	2.27	3.65
$N_{90}SB$	N_{320} P_0 S_{40}	L	120	2	0.98	12.44	2.11	3.36
$N_{90}SB$	N_{320} P_0 S_{40}	U	120	1	0.68	14.69	3.48	7.49
$N_{90}SB$	N_{320} P_0 S_{40}	U	120	2	0.65	13.15	3.84	5.56
$N_{90}SB$	N_{320} P_{20} S_{40}	L	120	1	0.70	16.58	4.29	6.09
$N_{90}SB$	N_{320} P_{20} S_{40}	L	120	2	0.82	14.69	3.14	4.21
$N_{90}SB$	N_{320} P_{20} S_{40}	U	120	1	0.54	15.63	4.18	6.86
$N_{90}SB$	N_{320} P_{20} S_{40}	U	120	2	0.68	14.92	3.77	4.46
$N_{90}SB$	N_{320} P_{40} S_{40}	L	120	1	0.59	15.75	3.94	5.90
$N_{90}SB$	N_{320} P_{40} S_{40}	L	120	2	0.72	14.21	3.01	4.27
$N_{90}SB$	N_{320} P_{40} S_{40}	U	120	1	0.62	13.98	3.82	5.88
$N_{90}SB$	N_{320} P_{40} S_{40}	U	120	2	0.65	14.57	3.58	6.65
$N_{90}SB$	N_{320} P_{80} S_0	L	120	1	0.05	42.64	3.40	1.48
$N_{90}SB$	N_{320} P_{80} S_0	L	120	2	0.08	54.83	3.99	1.35
$N_{90}SB$	N_{320} P_{80} S_0	U	120	1	0.12	54.25	6.09	1.57
$N_{90}SB$	N_{320} P_{80} S_0	U	120	2	0.12	55.90	4.01	0.47
$N_{90}SB$	N_{320} P_{80} S_{10}	L	120	1	0.32	57.80	5.53	1.02
$N_{90}SB$	N_{320} P_{80} S_{10}	L	120	2	0.23	59.46	6.09	0.46
$N_{90}SB$	N_{320} P_{80} S_{10}	U	120	1	0.44	32.22	6.23	0.94
$N_{90}SB$	N_{320} P_{80} S_{10}	U	120	2	0.44	40.98	3.65	0.85
$N_{90}SB$	N_{320} P_{80} S_{20}	L	120	1	0.93	13.15	3.37	1.07
$N_{90}SB$	N_{320} P_{80} S_{20}	L	120	2	0.89	14.81	3.94	0.83
$N_{90}SB$	N_{320} P_{80} S_{20}	U	120	1	0.58	16.58	4.23	1.47
$N_{90}SB$	N_{320} P_{80} S_{20}	U	120	2	0.49	17.53	4.92	1.42
$N_{90}SB$	N_{320} P_{80} S_{40}	L	120	1	0.84	11.61	3.52	2.65
$N_{90}SB$	N_{320} P_{80} S_{40}	L	120	2	0.90	13.50	3.27	3.70
$N_{90}SB$	N_{320} P_{80} S_{40}	U	120	1	0.69	14.45	3.89	5.85
$N_{90}SB$	N_{320} P_{80} S_{40}	U	120	2	0.72	15.52	3.75	5.99

Residue History	N P S applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					$g\ pot^{-1}$		---------$mg\ g^{-1}$--------	
PV	$N_0\ P_0\ S_0$	L	120	1	0.33	17.29	6.32	2.18
PV	$N_0\ P_0\ S_0$	L	120	2	0.25	16.34	4.54	2.23
PV	$N_0\ P_0\ S_0$	U	120	1	0.22	17.29	5.69	1.81
PV	$N_0\ P_0\ S_0$	U	120	2	0.28	18.48	5.11	1.78
PV	$N_{80}\ P_{80}\ S_{40}$	L	120	1	0.34	16.70	5.10	14.29
PV	$N_{80}\ P_{80}\ S_{40}$	L	120	2	0.33	17.65	7.13	12.91
PV	$N_{80}\ P_{80}\ S_{40}$	U	120	1	0.33	18.24	9.50	12.55
PV	$N_{80}\ P_{80}\ S_{40}$	U	120	2	0.30	18.48	7.13	12.13
PV	$N_{160}\ P_{80}\ S_{40}$	L	120	1	0.39	18.24	7.18	8.18
PV	$N_{160}\ P_{80}\ S_{40}$	L	120	2	0.37	15.16	4.90	9.98
PV	$N_{160}\ P_{80}\ S_{40}$	U	120	1	0.40	15.40	8.91	9.89
PV	$N_{160}\ P_{80}\ S_{40}$	U	120	2	0.40	15.40	5.28	9.37
PV	$N_{320}\ P_0\ S_{40}$	L	120	1	1.02	13.03	2.59	3.23
PV	$N_{320}\ P_0\ S_{40}$	L	120	2	0.67	14.69	3.50	7.48
PV	$N_{320}\ P_0\ S_{40}$	U	120	1	1.04	12.32	2.93	3.26
PV	$N_{320}\ P_0\ S_{40}$	U	120	2	0.90	13.03	2.95	3.13
PV	$N_{320}\ P_{20}\ S_{40}$	L	120	1	0.70	14.21	3.65	4.23
PV	$N_{320}\ P_{20}\ S_{40}$	L	120	2	0.68	13.38	3.52	4.18
PV	$N_{320}\ P_{20}\ S_{40}$	U	120	1	0.64	14.45	4.39	4.79
PV	$N_{320}\ P_{20}\ S_{40}$	U	120	2	0.63	14.81	3.22	3.86
PV	$N_{320}\ P_{40}\ S_{40}$	L	120	1	0.62	14.69	4.23	5.74
PV	$N_{320}\ P_{40}\ S_{40}$	L	120	2	0.73	13.27	3.02	4.34
PV	$N_{320}\ P_{40}\ S_{40}$	U	120	1	0.72	13.38	4.55	4.65
PV	$N_{320}\ P_{40}\ S_{40}$	U	120	2	0.70	13.74	2.41	4.04
PV	$N_{320}\ P_{80}\ S_0$	L	120	1	0.11	59.93	4.61	1.15
PV	$N_{320}\ P_{80}\ S_0$	L	120	2	0.12	49.76	4.41	1.10
PV	$N_{320}\ P_{80}\ S_0$	U	120	1	0.14	50.22	4.36	0.28
PV	$N_{320}\ P_{80}\ S_0$	U	120	2	0.14	51.75	4.82	1.32
PV	$N_{320}\ P_{80}\ S_{10}$	L	120	1	0.32	54.96	5.69	0.85
PV	$N_{320}\ P_{80}\ S_{10}$	L	120	2	0.28	58.15	5.55	0.93
PV	$N_{320}\ P_{80}\ S_{10}$	U	120	1	0.30	55.19	7.83	0.83
PV	$N_{320}\ P_{80}\ S_{10}$	U	120	2	0.25	61.12	4.92	0.38
PV	$N_{320}\ P_{80}\ S_{20}$	L	120	1	0.53	17.06	5.26	1.57
PV	$N_{320}\ P_{80}\ S_{20}$	L	120	2	0.74	15.28	4.16	0.84
PV	$N_{320}\ P_{80}\ S_{20}$	U	120	1	0.65	15.40	4.96	0.82
PV	$N_{320}\ P_{80}\ S_{20}$	U	120	2	0.71	14.09	4.74	1.03
PV	$N_{320}\ P_{80}\ S_{40}$	L	120	1	0.83	13.03	3.26	3.69
PV	$N_{320}\ P_{80}\ S_{40}$	L	120	2	0.88	12.79	3.82	4.79
PV	$N_{320}\ P_{80}\ S_{40}$	U	120	1	0.50	15.87	4.15	6.92
PV	$N_{320}\ P_{80}\ S_{40}$	U	120	2	0.98	13.74	3.05	3.62

Residue History	N P S applied	Slope position	Time (days)	Rep #	Dry yield	N conc.	P conc.	S conc.
					$g\ pot^{-1}$		$mg\ g^{-1}$	
M	$N_0\ P_0\ S_0$	L	120	1	0.41	18.71	9.37	4.23
M	$N_0\ P_0\ S_0$	L	120	2	0.39	16.11	6.48	3.60
M	$N_0\ P_0\ S_0$	U	120	1	0.30	18.95	6.24	3.84
M	$N_0\ P_0\ S_0$	U	120	2	0.41	19.19	6.91	3.84
M	$N_{80}\ P_{80}\ S_{40}$	L	120	1	0.39	20.49	11.26	8.37
M	$N_{80}\ P_{80}\ S_{40}$	L	120	2	0.36	18.71	8.07	8.35
M	$N_{80}\ P_{80}\ S_{40}$	U	120	1	0.43	18.00	9.20	8.37
M	$N_{80}\ P_{80}\ S_{40}$	U	120	2	0.43	18.71	8.24	9.03
M	$N_{160}\ P_{80}\ S_{40}$	L	120	1	0.43	17.88	9.70	10.73
M	$N_{160}\ P_{80}\ S_{40}$	L	120	2	0.52	17.65	7.28	9.64
M	$N_{160}\ P_{80}\ S_{40}$	U	120	1	0.42	17.53	10.39	8.91
M	$N_{160}\ P_{80}\ S_{40}$	U	120	2	0.46	16.11	6.35	11.12
M	$N_{320}\ P_0\ S_{40}$	L	120	1	0.85	13.50	4.22	4.76
M	$N_{320}\ P_0\ S_{40}$	L	120	2	0.71	13.74	4.01	4.80
M	$N_{320}\ P_0\ S_{40}$	U	120	1	0.78	14.69	4.71	5.41
M	$N_{320}\ P_0\ S_{40}$	U	120	2	0.62	16.11	4.55	5.90
M	$N_{320}\ P_{20}\ S_{40}$	L	120	1	0.66	16.82	5.09	5.59
M	$N_{320}\ P_{20}\ S_{40}$	L	120	2	0.80	16.11	6.71	4.46
M	$N_{320}\ P_{20}\ S_{40}$	U	120	1	0.63	15.16	5.49	6.28
M	$N_{320}\ P_{20}\ S_{40}$	U	120	2	0.54	17.53	5.55	7.38
M	$N_{320}\ P_{40}\ S_{40}$	L	120	1	0.62	16.11	6.29	6.42
M	$N_{320}\ P_{40}\ S_{40}$	L	120	2	0.78	14.21	3.85	5.08
M	$N_{320}\ P_{40}\ S_{40}$	U	120	1	0.63	16.94	5.49	6.08
M	$N_{320}\ P_{40}\ S_{40}$	U	120	2	0.73	13.98	4.55	6.02
M	$N_{320}\ P_{80}\ S_0$	L	120	1	0.37	56.14	7.81	1.26
M	$N_{320}\ P_{80}\ S_0$	L	120	2	0.36	49.27	6.52	1.13
M	$N_{320}\ P_{80}\ S_0$	U	120	1	0.34	52.35	7.40	1.42
M	$N_{320}\ P_{80}\ S_0$	U	120	2	0.30	54.36	6.50	1.06
M	$N_{320}\ P_{80}\ S_{10}$	L	120	1	0.76	18.95	5.69	0.72
M	$N_{320}\ P_{80}\ S_{10}$	L	120	2	0.81	18.95	4.99	0.68
M	$N_{320}\ P_{80}\ S_{10}$	U	120	1	0.90	20.37	6.48	0.92
M	$N_{320}\ P_{80}\ S_{10}$	U	120	2	0.72	22.27	6.13	0.91
M	$N_{320}\ P_{80}\ S_{20}$	L	120	1	0.90	13.74	3.70	1.75
M	$N_{320}\ P_{80}\ S_{20}$	L	120	2	0.91	14.21	4.18	1.44
M	$N_{320}\ P_{80}\ S_{20}$	U	120	1	0.69	15.52	5.05	2.28
M	$N_{320}\ P_{80}\ S_{20}$	U	120	2	0.61	15.16	5.09	2.17
M	$N_{320}\ P_{80}\ S_{40}$	L	120	1	0.90	13.15	3.42	2.78
M	$N_{320}\ P_{80}\ S_{40}$	L	120	2	0.99	11.37	3.82	3.39
M	$N_{320}\ P_{80}\ S_{40}$	U	120	1	0.70	15.40	4.74	5.93
M	$N_{320}\ P_{80}\ S_{40}$	U	120	2	0.62	15.87	5.28	6.86

Appendix 2. Soil chemical analysis on soils from Residue Utilization
Experiment Plots prior to greenhouse experiment (L=lower U=upper).

Residue history	Slope position	Total carbon	Total nitrogen	Ext. NO_3	Ext. NH_4
		$g\ kg^{-1}$	-----------$mg\ kg^{-1}$--------		
N_0	L	9.95	814	9.0	2.8
N_0SB	L	10.91	843	12.8	2.4
N_{90}	L	11.14	868	15.0	2.5
$N_{90}SB$	L	10.94	768	12.5	2.7
PV	L	11.86	930	11.9	3.0
M	L	15.55	1186	30.4	3.2
N_0	U	9.64	840	12.5	3.5
N_0SB	U	9.05	864	12.9	2.6
N_{90}	U	9.95	768	14.7	2.9
$N_{90}SB$	U	10.57	844	13.4	3.2
PV	U	11.12	913	15.5	2.8
M	U	12.45	1241	25.9	3.6

Residue history	Slope position	pH	Total sulfur	Ext. SO_4	Total phosphorus	Ext. PO_4
			--------------------$mg\ kg^{-1}$-------------------			
N_0	L	6.45	104	3.4	759	22.7
N_0SB	L	6.90	94	3.4	542	30.1
N_{90}	L	5.95	80	2.0	539	18.4
$N_{90}SB$	L	6.19	91	2.1	505	16.9
PV	L	6.66	112	3.3	561	25.0
M	L	6.83	107	6.1	591	53.9
N_0	U	6.27	104	3.6	691	32.0
N_0SB	U	6.64	192	4.1	714	39.8
N_{90}	U	5.84	91	3.1	633	23.3
$N_{90}SB$	U	5.83	104	3.2	539	19.9
PV	U	6.45	100	3.5	676	28.9
M	U	6.94	149	6.1	768	58.8

Appendix 3. Soil chemical analysis on soils following greenhouse experiment with varying rate$ of applied N, P, and S (subscript [mg kg^{-1}]) on soils from Residue Utilization Experiment Plots (L=lower U=upper).

Residue history	N P S applied	Slope position	Rep	pH	ext. NO$_3$	ext. NH$_4$	ext. SO$_4$	ext. PO$_4$
					--------------------μg g^{-1} soil--------------			
N$_0$	N$_0$ P$_0$ S$_0$	L	1	6.63	0.56	5.40	0.85	14.44
N$_0$	N$_0$ P$_0$ S$_0$	L	2	6.66	2.42	4.30	0.90	11.95
N$_0$	N$_0$ P$_0$ S$_0$	U	1	6.48	5.98	5.00	0.86	18.59
N$_0$	N$_0$ P$_0$ S$_0$	U	2	6.56	0.91	4.60	1.14	18.02
N$_0$	N$_{80}$ P$_{80}$ S$_{40}$	L	1	6.34	1.04	4.30	14.39	35.36
N$_0$	N$_{80}$ P$_{80}$ S$_{40}$	L	2	6.33	2.96	7.00	8.17	41.83
N$_0$	N$_{80}$ P$_{80}$ S$_{40}$	U	1	5.95	6.92	6.80	9.34	42.42
N$_0$	N$_{80}$ P$_{80}$ S$_{40}$	U	2	6.23	1.78	6.10	14.04	33.98
N$_0$	N$_{160}$ P$_{80}$ S$_{40}$	L	1	6.15	2.45	7.70	8.90	33.16
N$_0$	N$_{160}$ P$_{80}$ S$_{40}$	L	2	6.15	3.18	5.50	11.10	25.02
N$_0$	N$_{160}$ P$_{80}$ S$_{40}$	U	1	6.04	1.70	6.30	14.47	39.18
N$_0$	N$_{160}$ P$_{80}$ S$_{40}$	U	2	5.97	1.58	5.30	9.64	37.32
N$_0$	N$_{320}$ P$_0$ S$_{40}$	L	1	6.06	0.28	3.30	13.15	14.99
N$_0$	N$_{320}$ P$_0$ S$_{40}$	L	2	6.05	0.28	3.00	8.20	14.66
N$_0$	N$_{320}$ P$_0$ S$_{40}$	U	1	6.02	0.00	3.40	6.29	19.17
N$_0$	N$_{320}$ P$_0$ S$_{40}$	U	2	5.95	0.00	3.10	7.23	21.99
N$_0$	N$_{320}$ P$_{20}$ S$_{40}$	L	1	6.11	0.46	3.60	10.31	18.59
N$_0$	N$_{320}$ P$_{20}$ S$_{40}$	L	2	6.17	0.29	3.40	8.20	18.02
N$_0$	N$_{320}$ P$_{20}$ S$_{40}$	U	1	5.95	0.23	3.80	9.69	21.99
N$_0$	N$_{320}$ P$_{20}$ S$_{40}$	U	2	5.95	0.33	4.20	7.66	24.04
N$_0$	N$_{320}$ P$_{40}$ S$_{40}$	L	1	6.08	0.40	3.80	8.75	18.13
N$_0$	N$_{320}$ P$_{40}$ S$_{40}$	L	2	5.92	1.31	3.80	9.06	16.66
N$_0$	N$_{320}$ P$_{40}$ S$_{40}$	U	1	5.96	2.05	4.00	9.34	22.35
N$_0$	N$_{320}$ P$_{40}$ S$_{40}$	U	2	6.00	0.48	5.00	7.51	22.71
N$_0$	N$_{320}$ P$_{80}$ S$_0$	L	1	5.16	386.51	10.00	0.53	45.95
N$_0$	N$_{320}$ P$_{80}$ S$_0$	L	2	5.24	332.58	11.00	0.41	46.10
N$_0$	N$_{320}$ P$_{80}$ S$_0$	U	1	5.12	325.69	21.00	0.32	56.20
N$_0$	N$_{320}$ P$_{80}$ S$_0$	U	2	5.13	244.54	16.00	1.98	50.92
N$_0$	N$_{320}$ P$_{80}$ S$_{10}$	L	1	6.06	29.62	9.30	1.19	27.40
N$_0$	N$_{320}$ P$_{80}$ S$_{10}$	L	2	5.98	62.71	9.80	0.82	27.40
N$_0$	N$_{320}$ P$_{80}$ S$_{10}$	U	1	5.78	57.65	7.40	0.92	34.12
N$_0$	N$_{320}$ P$_{80}$ S$_{10}$	U	2	5.77	66.43	8.50	0.79	34.94
N$_0$	N$_{320}$ P$_{80}$ S$_{20}$	L	1	6.21	0.57	4.10	0.68	28.81
N$_0$	N$_{320}$ P$_{80}$ S$_{20}$	L	2	6.21	0.39	4.90	0.78	27.27
N$_0$	N$_{320}$ P$_{80}$ S$_{20}$	U	1	6.12	0.72	3.70	0.94	33.84
N$_0$	N$_{320}$ P$_{80}$ S$_{20}$	U	2	6.04	0.87	5.00	0.89	39.91
N$_0$	N$_{320}$ P$_{80}$ S$_{40}$	L	1	6.06	0.53	5.76	7.54	52.59
N$_0$	N$_{320}$ P$_{80}$ S$_{40}$	L	2	5.65	0.41	5.92	7.78	43.03
N$_0$	N$_{320}$ P$_{80}$ S$_{40}$	U	1	5.94	0.68	5.69	9.78	52.93
N$_0$	N$_{320}$ P$_{80}$ S$_{40}$	U	2	6.01	0.27	6.95	8.12	53.95

Residue history	N P S applied	Slope position	Rep	pH	ext. NO_3	ext. NH_4	ext. SO_4	ext. PO_4
						$\mu g\ g^{-1}$ soil		
N_0SB	$N_0\ P_0\ S_0$	L	1	6.96	0.93	4.60	0.88	18.36
N_0SB	$N_0\ P_0\ S_0$	L	2	7.01	2.19	5.00	0.93	15.32
N_0SB	$N_0\ P_0\ S_0$	U	1	6.80	1.11	5.00	0.97	24.65
N_0SB	$N_0\ P_0\ S_0$	U	2	6.84	4.39	5.30	0.90	20.80
N_0SB	$N_{80}\ P_{80}\ S_{40}$	L	1	6.61	1.66	6.20	17.77	45.95
N_0SB	$N_{80}\ P_{80}\ S_{40}$	L	2	6.68	0.90	6.90	11.38	46.26
N_0SB	$N_{80}\ P_{80}\ S_{40}$	U	1	6.46	4.57	6.90	9.59	54.12
N_0SB	$N_{80}\ P_{80}\ S_{40}$	U	2	6.44	2.83	7.20	17.52	59.41
N_0SB	$N_{160}\ P_{80}\ S_{40}$	L	1	6.37	3.40	8.80	11.63	38.89
N_0SB	$N_{160}\ P_{80}\ S_{40}$	L	2	6.62	3.84	6.50	6.89	35.63
N_0SB	$N_{160}\ P_{80}\ S_{40}$	U	1	6.19	2.42	6.30	13.61	44.24
N_0SB	$N_{160}\ P_{80}\ S_{40}$	U	2	6.27	5.12	5.40	11.41	42.88
N_0SB	$N_{320}\ P_0\ S_{40}$	L	1	6.51	0.81	3.00	9.36	19.05
N_0SB	$N_{320}\ P_0\ S_{40}$	L	2	6.44	7.15	3.00	9.68	19.05
N_0SB	$N_{320}\ P_0\ S_{40}$	U	1	6.22	0.00	3.50	9.25	23.31
N_0SB	$N_{320}\ P_0\ S_{40}$	U	2	6.27	0.00	3.80	6.42	23.07
N_0SB	$N_{320}\ P_{20}\ S_{40}$	L	1	6.46	0.44	3.20	10.01	25.39
N_0SB	$N_{320}\ P_{20}\ S_{40}$	L	2	6.54	0.68	3.20	10.15	23.19
N_0SB	$N_{320}\ P_{20}\ S_{40}$	U	1	6.21	1.19	3.60	9.92	29.07
N_0SB	$N_{320}\ P_{20}\ S_{40}$	U	2	6.19	0.30	3.40	7.51	28.81
N_0SB	$N_{320}\ P_{40}\ S_{40}$	L	1	6.54	1.72	3.80	7.87	21.75
N_0SB	$N_{320}\ P_{40}\ S_{40}$	L	2	6.54	1.58	4.10	7.12	17.23
N_0SB	$N_{320}\ P_{40}\ S_{40}$	U	1	6.22	0.46	3.30	8.64	27.78
N_0SB	$N_{320}\ P_{40}\ S_{40}$	U	2	6.19	0.42	3.60	6.45	25.15
N_0SB	$N_{320}\ P_{80}\ S_0$	L	1	5.66	308.92	5.00	0.34	51.75
N_0SB	$N_{320}\ P_{80}\ S_0$	L	2	5.60	303.55	5.00	0.68	50.27
N_0SB	$N_{320}\ P_{80}\ S_0$	U	1	5.43	277.24	11.00	0.34	41.83
N_0SB	$N_{320}\ P_{80}\ S_0$	U	2	5.45	157.96	11.00	0.37	58.15
N_0SB	$N_{320}\ P_{80}\ S_{10}$	L	1	6.58	4.92	6.40	1.30	32.22
N_0SB	$N_{320}\ P_{80}\ S_{10}$	L	2	6.24	5.18	9.70	1.15	33.03
N_0SB	$N_{320}\ P_{80}\ S_{10}$	U	1	6.08	40.43	9.40	0.85	43.33
N_0SB	$N_{320}\ P_{80}\ S_{10}$	U	2	6.14	30.64	8.60	0.79	41.23
N_0SB	$N_{320}\ P_{80}\ S_{20}$	L	1	6.57	0.99	4.90	0.79	34.94
N_0SB	$N_{320}\ P_{80}\ S_{20}$	L	2	6.59	0.77	6.00	0.98	34.25
N_0SB	$N_{320}\ P_{80}\ S_{20}$	U	1	6.26	0.65	4.60	0.83	38.60
N_0SB	$N_{320}\ P_{80}\ S_{20}$	U	2	6.29	0.45	4.90	0.81	42.57
N_0SB	$N_{320}\ P_{80}\ S_{40}$	L	1	6.43	1.00	4.82	9.45	55.67
N_0SB	$N_{320}\ P_{80}\ S_{40}$	L	2	6.38	0.50	5.37	8.70	51.92
N_0SB	$N_{320}\ P_{80}\ S_{40}$	U	1	6.16	0.45	5.53	8.35	65.23
N_0SB	$N_{320}\ P_{80}\ S_{40}$	U	2	6.16	0.42	6.32	6.38	60.14

Residue history	N P S applied	Slope position	Rep	pH	ext. NO$_3$	ext. NH$_4$	ext. SO$_4$	ext. PO$_4$
					---------------------μg g^{-1} soil-------------			
N$_{90}$	N$_0$ P$_0$ S$_0$	L	1	6.16	1.14	5.50	1.23	13.24
N$_{90}$	N$_0$ P$_0$ S$_0$	L	2	6.23	1.61	4.80	0.90	11.63
N$_{90}$	N$_0$ P$_0$ S$_0$	U	1	6.02	0.82	5.50	1.96	17.91
N$_{90}$	N$_0$ P$_0$ S$_0$	U	2	6.13	2.70	4.30	1.57	12.49
N$_{90}$	N$_{80}$ P$_{80}$ S$_{40}$	L	1	5.94	2.73	5.50	9.34	37.74
N$_{90}$	N$_{80}$ P$_{80}$ S$_{40}$	L	2	5.85	1.66	6.70	17.91	39.33
N$_{90}$	N$_{80}$ P$_{80}$ S$_{40}$	U	1	5.74	1.37	4.60	12.97	45.32
N$_{90}$	N$_{80}$ P$_{80}$ S$_{40}$	U	2	5.87	4.14	6.60	8.77	47.20
N$_{90}$	N$_{160}$ P$_{80}$ S$_{40}$	L	1	5.80	2.15	8.40	10.46	34.53
N$_{90}$	N$_{160}$ P$_{80}$ S$_{40}$	L	2	5.83	3.22	6.90	5.89	31.55
N$_{90}$	N$_{160}$ P$_{80}$ S$_{40}$	U	1	5.63	3.39	7.20	14.21	35.77
N$_{90}$	N$_{160}$ P$_{80}$ S$_{40}$	U	2	5.67	3.74	5.10	11.81	32.89
N$_{90}$	N$_{320}$ P$_0$ S$_{40}$	L	1	5.78	0.00	3.50	9.03	14.66
N$_{90}$	N$_{320}$ P$_0$ S$_{40}$	L	2	5.72	0.52	3.50	7.55	14.88
N$_{90}$	N$_{320}$ P$_0$ S$_{40}$	U	1	5.61	0.00	3.80	9.41	20.22
N$_{90}$	N$_{320}$ P$_0$ S$_{40}$	U	2	5.61	0.00	3.20	7.65	22.35
N$_{90}$	N$_{320}$ P$_{20}$ S$_{40}$	L	1	5.76	0.59	3.40	8.89	17.91
N$_{90}$	N$_{320}$ P$_{20}$ S$_{40}$	L	2	5.75	0.28	4.10	7.07	17.91
N$_{90}$	N$_{320}$ P$_{20}$ S$_{40}$	U	1	5.57	0.26	3.40	7.99	21.39
N$_{90}$	N$_{320}$ P$_{20}$ S$_{40}$	U	2	5.51	0.69	3.80	8.68	23.80
N$_{90}$	N$_{320}$ P$_{40}$ S$_{40}$	L	1	5.73	0.82	3.70	7.68	19.17
N$_{90}$	N$_{320}$ P$_{40}$ S$_{40}$	L	2	5.70	2.32	3.90	8.09	12.49
N$_{90}$	N$_{320}$ P$_{40}$ S$_{40}$	U	1	5.60	0.37	3.60	8.25	19.98
N$_{90}$	N$_{320}$ P$_{40}$ S$_{40}$	U	2	5.56	0.63	4.00	6.51	18.13
N$_{90}$	N$_{320}$ P$_{80}$ S$_0$	L	1	4.88	355.85	14.00	0.65	48.64
N$_{90}$	N$_{320}$ P$_{80}$ S$_0$	L	2	4.88	389.96	5.00	1.71	49.29
N$_{90}$	N$_{320}$ P$_{80}$ S$_0$	U	1	4.72	283.67	11.00	0.50	51.59
N$_{90}$	N$_{320}$ P$_{80}$ S$_0$	U	2	4.65	320.78	6.00	0.55	53.95
N$_{90}$	N$_{320}$ P$_{80}$ S$_{10}$	L	1	5.81	3.62	8.70	1.25	29.07
N$_{90}$	N$_{320}$ P$_{80}$ S$_{10}$	L	2	5.60	43.29	12.20	0.84	29.58
N$_{90}$	N$_{320}$ P$_{80}$ S$_{10}$	U	1	5.66	3.41	9.20	1.28	34.53
N$_{90}$	N$_{320}$ P$_{80}$ S$_{10}$	U	2	5.68	2.54	7.80	0.84	28.81
N$_{90}$	N$_{320}$ P$_{80}$ S$_{20}$	L	1	5.85	0.50	4.80	1.05	26.14
N$_{90}$	N$_{320}$ P$_{80}$ S$_{20}$	L	2	5.81	0.35	5.40	1.12	29.71
N$_{90}$	N$_{320}$ P$_{80}$ S$_{20}$	U	1	5.67	0.39	5.30	1.03	31.42
N$_{90}$	N$_{320}$ P$_{80}$ S$_{20}$	U	2	5.61	0.35	5.20	1.25	33.03
N$_{90}$	N$_{320}$ P$_{80}$ S$_{40}$	L	1	5.76	0.40	5.61	7.64	42.72
N$_{90}$	N$_{320}$ P$_{80}$ S$_{40}$	L	2	5.77	0.33	7.11	7.97	38.32
N$_{90}$	N$_{320}$ P$_{80}$ S$_{40}$	U	1	5.58	0.31	6.47	6.51	51.09
N$_{90}$	N$_{320}$ P$_{80}$ S$_{40}$	U	2	5.49	0.51	5.53	6.50	45.79

Residue history	N P S applied	Slope position	Rep	pH	ext. NO_3	ext. NH_4	ext. SO_4	ext. PO_4
					\------------------μg g^{-1} soil-------------			
$N_{90}SB$	N_0 P_0 S_0	L	1	6.31	0.70	6.30	1.22	11.95
$N_{90}SB$	N_0 P_0 S_0	L	2	6.37	1.15	5.70	1.85	11.74
$N_{90}SB$	N_0 P_0 S_0	U	1	6.10	2.64	4.40	2.01	14.66
$N_{90}SB$	N_0 P_0 S_0	U	2	6.13	3.00	5.40	0.74	14.11
$N_{90}SB$	N_{80} P_{80} S_{40}	L	1	6.07	3.42	6.50	12.59	38.60
$N_{90}SB$	N_{80} P_{80} S_{40}	L	2	6.11	1.19	6.90	13.29	35.63
$N_{90}SB$	N_{80} P_{80} S_{40}	U	1	5.96	13.25	12.20	6.93	26.14
$N_{90}SB$	N_{80} P_{80} S_{40}	U	2	5.96	1.25	7.70	16.14	36.61
$N_{90}SB$	N_{160} P_{80} S_{40}	L	1	6.01	2.28	8.80	9.40	27.65
$N_{90}SB$	N_{160} P_{80} S_{40}	L	2	5.97	2.26	6.30	5.44	26.39
$N_{90}SB$	N_{160} P_{80} S_{40}	U	1	5.61	1.89	7.70	5.04	23.92
$N_{90}SB$	N_{160} P_{80} S_{40}	U	2	5.81	1.99	4.90	12.40	30.24
$N_{90}SB$	N_{320} P_0 S_{40}	L	1	5.92	0.00	3.10	8.06	12.81
$N_{90}SB$	N_{320} P_0 S_{40}	L	2	5.86	0.65	3.60	5.85	13.57
$N_{90}SB$	N_{320} P_0 S_{40}	U	1	5.63	0.98	3.40	9.59	19.17
$N_{90}SB$	N_{320} P_0 S_{40}	U	2	5.63	0.23	3.20	8.75	18.13
$N_{90}SB$	N_{320} P_{20} S_{40}	L	1	5.92	0.65	4.40	8.03	19.29
$N_{90}SB$	N_{320} P_{20} S_{40}	L	2	5.76	0.34	4.10	7.42	16.55
$N_{90}SB$	N_{320} P_{20} S_{40}	U	1	5.63	0.26	3.40	7.42	21.51
$N_{90}SB$	N_{320} P_{20} S_{40}	U	2	5.62	0.23	3.30	7.82	19.05
$N_{90}SB$	N_{320} P_{40} S_{40}	L	1	5.89	0.85	3.90	7.99	20.45
$N_{90}SB$	N_{320} P_{40} S_{40}	L	2	5.85	0.63	4.30	8.22	13.79
$N_{90}SB$	N_{320} P_{40} S_{40}	U	1	5.66	0.61	4.20	7.49	19.52
$N_{90}SB$	N_{320} P_{40} S_{40}	U	2	5.55	0.55	4.90	6.99	19.29
$N_{90}SB$	N_{320} P_{80} S_0	L	1	5.06	231.38	6.00	0.44	39.76
$N_{90}SB$	N_{320} P_{80} S_0	L	2	5.08	201.79	6.00	0.41	47.84
$N_{90}SB$	N_{320} P_{80} S_0	U	1	4.78	422.49	11.00	0.59	45.79
$N_{90}SB$	N_{320} P_{80} S_0	U	2	4.73	331.45	10.00	0.50	51.09
$N_{90}SB$	N_{320} P_{80} S_{10}	L	1	5.76	32.12	7.30	1.40	30.24
$N_{90}SB$	N_{320} P_{80} S_{10}	L	2	6.65	62.87	9.60	0.83	31.16
$N_{90}SB$	N_{320} P_{80} S_{10}	U	1	5.79	3.31	9.20	1.44	29.19
$N_{90}SB$	N_{320} P_{80} S_{10}	U	2	5.77	3.09	8.00	0.90	33.57
$N_{90}SB$	N_{320} P_{80} S_{20}	L	1	5.95	0.35	4.80	1.07	24.78
$N_{90}SB$	N_{320} P_{80} S_{20}	L	2	6.01	0.70	5.10	0.84	25.64
$N_{90}SB$	N_{320} P_{80} S_{20}	U	1	5.72	0.42	4.90	1.06	33.57
$N_{90}SB$	N_{320} P_{80} S_{20}	U	2	5.75	0.53	5.50	0.93	34.25
$N_{90}SB$	N_{320} P_{80} S_{40}	L	1	5.97	0.36	4.90	6.09	47.52
$N_{90}SB$	N_{320} P_{80} S_{40}	L	2	5.89	0.33	6.08	6.58	36.61
$N_{90}SB$	N_{320} P_{80} S_{40}	U	1	5.58	0.70	6.00	8.00	47.36
$N_{90}SB$	N_{320} P_{80} S_{40}	U	2	5.20	0.28	5.45	7.67	50.92

Residue history	N P S applied	Slope position	Rep	pH	ext. NO$_3$	ext. NH$_4$	ext. SO$_4$	ext. PO$_4$
							------μg g^{-1} soil-------	
PV	N$_0$ P$_0$ S$_0$	L	1	6.72	0.93	4.40	0.84	16.10
PV	N$_0$ P$_0$ S$_0$	L	2	6.77	3.42	4.80	1.09	15.21
PV	N$_0$ P$_0$ S$_0$	U	1	6.68	1.42	6.50	1.13	20.57
PV	N$_0$ P$_0$ S$_0$	U	2	6.72	1.58	5.30	0.62	19.40
PV	N$_{80}$ P$_{80}$ S$_{40}$	L	1	6.40	1.31	6.20	8.97	47.20
PV	N$_{80}$ P$_{80}$ S$_{40}$	L	2	6.23	0.95	7.20	17.62	49.29
PV	N$_{80}$ P$_{80}$ S$_{40}$	U	1	6.33	1.94	6.70	16.24	46.26
PV	N$_{80}$ P$_{80}$ S$_{40}$	U	2	6.43	13.24	6.60	10.44	46.73
PV	N$_{160}$ P$_{80}$ S$_{40}$	L	1	6.19	0.42	7.80	13.79	31.55
PV	N$_{160}$ P$_{80}$ S$_{40}$	L	2	6.22	0.37	6.20	10.23	40.49
PV	N$_{160}$ P$_{80}$ S$_{40}$	U	1	6.17	2.25	6.40	8.26	37.04
PV	N$_{160}$ P$_{80}$ S$_{40}$	U	2	6.28	2.20	5.40	10.93	36.05
PV	N$_{320}$ P$_0$ S$_{40}$	L	1	6.25	0.54	4.20	5.61	18.25
PV	N$_{320}$ P$_0$ S$_{40}$	L	2	6.17	0.26	3.00	9.09	18.02
PV	N$_{320}$ P$_0$ S$_{40}$	U	1	6.12	0.00	2.90	5.02	22.23
PV	N$_{320}$ P$_0$ S$_{40}$	U	2	6.07	0.65	3.90	9.02	20.45
PV	N$_{320}$ P$_{20}$ S$_{40}$	L	1	6.28	0.42	3.40	8.93	22.59
PV	N$_{320}$ P$_{20}$ S$_{40}$	L	2	6.28	0.32	3.50	8.01	19.63
PV	N$_{320}$ P$_{20}$ S$_{40}$	U	1	6.15	0.74	4.80	9.30	26.52
PV	N$_{320}$ P$_{20}$ S$_{40}$	U	2	6.09	0.77	3.70	9.78	25.15
PV	N$_{320}$ P$_{40}$ S$_{40}$	L	1	6.24	0.94	3.90	7.28	20.57
PV	N$_{320}$ P$_{40}$ S$_{40}$	L	2	5.93	0.69	3.80	7.75	19.05
PV	N$_{320}$ P$_{40}$ S$_{40}$	U	1	6.12	0.54	3.90	7.74	23.92
PV	N$_{320}$ P$_{40}$ S$_{40}$	U	2	6.11	0.29	5.80	6.84	23.31
PV	N$_{320}$ P$_{80}$ S$_0$	L	1	5.29	415.94	10.00	0.69	52.59
PV	N$_{320}$ P$_{80}$ S$_0$	L	2	5.33	282.83	7.00	0.65	52.26
PV	N$_{320}$ P$_{80}$ S$_0$	U	1	5.22	307.17	8.00	3.38	58.51
PV	N$_{320}$ P$_{80}$ S$_0$	U	2	5.19	248.49	18.00	2.59	55.67
PV	N$_{320}$ P$_{80}$ S$_{10}$	L	1	6.04	48.78	9.00	1.19	34.80
PV	N$_{320}$ P$_{80}$ S$_{10}$	L	2	6.01	90.63	11.00	0.87	33.03
PV	N$_{320}$ P$_{80}$ S$_{10}$	U	1	6.01	40.92	6.80	0.84	36.19
PV	N$_{320}$ P$_{80}$ S$_{10}$	U	2	6.04	52.04	11.30	0.77	36.89
PV	N$_{320}$ P$_{80}$ S$_{20}$	L	1	6.32	0.96	4.60	0.85	30.37
PV	N$_{320}$ P$_{80}$ S$_{20}$	L	2	6.39	0.45	5.30	0.96	31.69
PV	N$_{320}$ P$_{80}$ S$_{20}$	U	1	6.27	0.73	4.60	0.83	37.04
PV	N$_{320}$ P$_{80}$ S$_{20}$	U	2	6.24	0.46	5.00	0.79	39.91
PV	N$_{320}$ P$_{80}$ S$_{40}$	L	1	6.23	0.35	6.16	7.84	51.09
PV	N$_{320}$ P$_{80}$ S$_{40}$	L	2	6.25	0.36	5.76	6.94	51.09
PV	N$_{320}$ P$_{80}$ S$_{40}$	U	1	6.06	0.39	5.45	9.24	68.99
PV	N$_{320}$ P$_{80}$ S$_{40}$	U	2	6.12	0.31	5.76	8.24	57.61

Residue history	N P S applied	Slope position	Rep	pH	ext. NO_3	ext. NH_4	ext. SO_4	ext. PO_4
					---------------------$\mu g\ g^{-1}$ soil-------------			
M	$N_0\ P_0\ S_0$	L	1	7.18	3.72	4.40	1.46	34.12
M	$N_0\ P_0\ S_0$	L	2	7.24	3.62	5.50	1.35	33.43
M	$N_0\ P_0\ S_0$	U	1	7.24	0.93	4.70	1.18	39.04
M	$N_0\ P_0\ S_0$	U	2	7.30	2.01	4.20	1.33	38.03
M	$N_{80}\ P_{80}\ S_{40}$	L	1	6.88	8.90	5.40	11.49	67.19
M	$N_{80}\ P_{80}\ S_{40}$	L	2	6.90	2.24	7.30	9.43	63.50
M	$N_{80}\ P_{80}\ S_{40}$	U	1	6.85	0.91	7.50	11.48	67.99
M	$N_{80}\ P_{80}\ S_{40}$	U	2	7.13	0.81	6.90	13.76	65.23
M	$N_{160}\ P_{80}\ S_{40}$	L	1	6.79	1.15	8.40	17.59	48.00
M	$N_{160}\ P_{80}\ S_{40}$	L	2	6.70	1.34	4.20	8.86	65.23
M	$N_{160}\ P_{80}\ S_{40}$	U	1	6.72	1.37	6.60	10.26	54.29
M	$N_{160}\ P_{80}\ S_{40}$	U	2	6.79	1.46	6.20	10.75	52.26
M	$N_{320}\ P_0\ S_{40}$	L	1	6.79	0.94	3.90	9.69	38.32
M	$N_{320}\ P_0\ S_{40}$	L	2	6.70	0.45	3.20	7.99	32.89
M	$N_{320}\ P_0\ S_{40}$	U	1	6.65	0.85	3.60	10.66	35.49
M	$N_{320}\ P_0\ S_{40}$	U	2	6.69	0.44	3.50	9.87	38.89
M	$N_{320}\ P_{20}\ S_{40}$	L	1	6.67	0.71	3.80	9.92	43.63
M	$N_{320}\ P_{20}\ S_{40}$	L	2	6.79	0.74	3.90	9.12	41.53
M	$N_{320}\ P_{20}\ S_{40}$	U	1	6.75	0.64	3.80	8.10	44.70
M	$N_{320}\ P_{20}\ S_{40}$	U	2	6.70	0.73	4.00	8.52	47.52
M	$N_{320}\ P_{40}\ S_{40}$	L	1	6.72	0.80	4.10	7.90	39.33
M	$N_{320}\ P_{40}\ S_{40}$	L	2	6.61	0.54	4.30	8.10	34.39
M	$N_{320}\ P_{40}\ S_{40}$	U	1	6.70	0.64	4.10	11.02	44.55
M	$N_{320}\ P_{40}\ S_{40}$	U	2	6.60	0.59	4.30	9.29	41.23
M	$N_{320}\ P_{80}\ S_0$	L	1	6.02	188.91	9.00	0.65	74.20
M	$N_{320}\ P_{80}\ S_0$	L	2	5.93	196.98	12.00	2.40	74.63
M	$N_{320}\ P_{80}\ S_0$	U	1	5.99	221.27	6.00	2.60	75.06
M	$N_{320}\ P_{80}\ S_0$	U	2	5.92	174.96	13.00	0.43	82.04
M	$N_{320}\ P_{80}\ S_{10}$	L	1	6.79	3.23	7.10	1.33	51.59
M	$N_{320}\ P_{80}\ S_{10}$	L	2	6.82	1.40	7.80	1.06	51.26
M	$N_{320}\ P_{80}\ S_{10}$	U	1	6.72	2.20	6.10	1.16	58.15
M	$N_{320}\ P_{80}\ S_{10}$	U	2	6.80	1.65	7.60	1.01	56.90
M	$N_{320}\ P_{80}\ S_{20}$	L	1	6.80	0.76	5.40	1.09	57.79
M	$N_{320}\ P_{80}\ S_{20}$	L	2	6.75	0.92	5.40	1.68	54.29
M	$N_{320}\ P_{80}\ S_{20}$	U	1	6.72	1.18	5.10	1.31	61.25
M	$N_{320}\ P_{80}\ S_{20}$	U	2	6.72	0.84	4.80	1.15	64.07
M	$N_{320}\ P_{80}\ S_{40}$	L	1	6.73	0.47	6.08	4.56	81.11
M	$N_{320}\ P_{80}\ S_{40}$	L	2	6.55	0.54	6.32	9.05	79.96
M	$N_{320}\ P_{80}\ S_{40}$	U	1	6.61	0.75	6.55	10.03	92.21
M	$N_{320}\ P_{80}\ S_{40}$	U	2	6.63	1.76	6.40	11.17	86.61

Appendix 4. Carbon, nitrogen, and nitrogen fraction concentrations from soil chemical analysis on soil profile of Residue Utilization Experiment Plots (L=lower U=upper).

Residue history	Sampled depth	Slope position	Total C	Total N	Ext. NO_3	Ext. NH_4
	cm		mg g^{-1}		µg g^{-1}	
N_0	0-15	L	10.91	1008	1.6	6.8
N_0	15-30	L	8.98	948	0.8	4.2
N_0	30-60	L	7.29	980	0.7	4.2
N_0	60-90	L	5.10	696	0.5	4.7
N_0	90-120	L	9.83	430	0.7	3.5
N_0	120-150	L	10.41	376	0.8	3.4
N_0	150-180	L	21.95	327	2.0	2.1
N_0FB	0-15	L	10.42	945	1.4	4.4
N_0FB	15-30	L	9.63	919	0.8	4.3
N_0FB	30-60	L	5.55	870	0.6	3.7
N_0FB	60-90	L	4.66	801	0.6	2.6
N_0FB	90-120	L	19.88	682	0.8	2.6
N_0SB	0-15	L	11.42	1007	2.2	4.9
N_0SB	15-30	L	8.49	1005	1.1	4.3
N_0SB	30-60	L	5.80	760	1.2	4.3
N_0SB	60-90	L	5.67	665	0.9	4.2
N_0SB	90-120	L	17.70	567	0.9	3.8
N_{45}	0-15	L	11.72	947	1.8	6.6
N_{45}	15-30	L	10.06	995	1.1	8.7
N_{45}	30-60	L	8.46	880	0.6	3.2
N_{45}	60-90	L	13.03	702	0.7	2.1
N_{45}	90-120	L	19.76	801	0.6	3.4
N_{45}SB	0-15	L	10.22	662	1.3	8.8
N_{45}SB	15-30	L	8.46	728	0.8	4.8
N_{45}SB	30-60	L	5.68	677	0.7	4.7
N_{45}SB	60-90	L	6.34	388	1.1	4.5
N_{45}SB	90-120	L	17.54	262	1.4	4.9
N_{45}SB	120-150	L	51.13	333	2.2	9.7
N_{90}	0-15	L	13.39	1015	1.3	6.7
N_{90}	15-30	L	9.83	944	1.0	4.7
N_{90}	30-60	L	6.12	764	0.6	2.4
N_{90}	60-90	L	4.04	585	0.7	5.3
N_{90}	90-120	L	22.80	594	1.1	4.1
N_{90}SB	0-15	L	11.03	817	1.8	6.8
N_{90}SB	15-30	L	8.57	781	0.8	4.0
N_{90}SB	30-60	L	5.61	557	0.5	5.2
N_{90}SB	60-90	L	5.83	531	0.4	4.5
N_{90}SB	90-120	L	26.28	560	1.4	3.5
PV	0-15	L	12.11	900	1.2	4.7
PV	15-30	L	9.60	845	0.7	5.9
PV	30-60	L	7.50	805	0.5	5.5

Residue history	Sampled depth	Slope position	Total C	Total N	Ext. NO_3	Ext. NH_4
	cm		mg g^{-1}	------------μg g^{-1}------------		
PV	60-90	L	4.26	533	1.0	4.0
PV	90-120	L	11.92	381	1.4	2.6
PV	120-150	L	65.18	308	1.1	8.2
M	0-15	L	14.03	1113	1.1	6.7
M	15-30	L	10.93	977	1.5	4.7
M	30-60	L	6.94	715	0.8	4.2
M	60-90	L	4.48	423	1.2	5.0
M	90-120	L	16.63	386	6.5	2.6
M	120-150	L	27.07	295	11.0	5.2
M	150-180	L	38.16	346	12.3	4.8
N_0	0-15	U	10.57	876	1.4	4.3
N_0	15-30	U	9.29	958	0.5	5.2
N_0	30-60	U	6.01	851	0.7	2.1
N_0	60-90	U	3.76	628	0.4	3.1
N_0	90-120	U	2.54	550	0.5	3.7
N_0	120-150	U	2.17	445	0.4	4.2
N_0	150-180	U	3.61	506	0.4	3.4
N_0	180-210	U	6.40	304	0.4	2.2
N_0FB	0-15	U	8.04	778	1.9	6.0
N_0FB	15-30	U	7.28	832	0.7	4.9
N_0FB	30-60	U	5.94	686	0.8	5.4
N_0FB	60-90	U	3.54	597	0.8	4.1
N_0FB	90-120	U	2.44	471	0.5	3.8
N_0FB	120-150	U	3.78	420	0.5	2.0
N_0FB	150-180	U	7.06	516	1.9	2.6
N_0FB	180-210	U	3.50	349	0.5	1.1
N_0SB	0-15	U	11.61	993	1.5	5.8
N_0SB	15-30	U	7.11	830	0.7	4.3
N_0SB	30-60	U	5.71	789	0.7	3.7
N_0SB	60-90	U	5.19	637	0.7	4.2
N_0SB	90-120	U	3.32	690	0.4	4.6
N_0SB	120-150	U	6.68	521	0.4	3.1
N_0SB	150-180	U	4.18	394	0.5	1.4
N_0SB	180-210	U	3.51	372	0.4	1.5
N_{45}	0-15	U	10.80	1047	1.8	5.6
N_{45}	15-30	U	8.81	972	0.9	3.8
N_{45}	30-60	U	6.05	718	0.5	3.7
N_{45}	60-90	U	4.00	551	0.4	3.5
N_{45}	90-120	U	4.86	369	1.8	4.4
N_{45}	120-150	U	12.26	414	2.0	3.1
N_{45}	150-180	U	14.05	377	1.0	1.9

Residue history	Sampled depth	Slope position	Total C	Total N	Ext. NO$_3$	Ext. NH$_4$
	cm		mg g^{-1}		-----µg g^{-1}-----	
N$_{45}$	180-210	U	10.39	303	1.0	1.4
N$_{45}$SB	0-15	U	11.57	876	1.4	5.2
N$_{45}$SB	15-30	U	8.64	835	2.5	5.6
N$_{45}$SB	30-60	U	5.77	772	0.8	4.6
N$_{45}$SB	60-90	U	3.84	613	0.6	4.6
N$_{45}$SB	90-120	U	4.69	491	0.8	4.5
N$_{45}$SB	120-150	U	2.95	340	0.6	3.4
N$_{45}$SB	150-180	U	11.62	304	1.3	3.1
N$_{45}$SB	180-210	U	8.00	249	1.5	1.0
N$_{90}$	0-15	U	10.69	1010	1.2	5.8
N$_{90}$	15-30	U	9.28	986	1.4	3.8
N$_{90}$	30-60	U	5.56	776	1.1	3.7
N$_{90}$	60-90	U	7.63	593	0.5	3.4
N$_{90}$	90-120	U	2.96	479	2.8	5.7
N$_{90}$	120-150	U	3.16	406	0.4	5.6
N$_{90}$	150-180	U	4.54	338	0.4	2.4
N$_{90}$	180-210	U	9.44	297	1.5	1.7
N$_{90}$SB	0-15	U	11.17	949	1.1	6.8
N$_{90}$SB	15-30	U	9.46	978	0.8	4.2
N$_{90}$SB	30-60	U	6.89	791	0.5	3.4
N$_{90}$SB	60-90	U	4.99	712	0.3	3.6
N$_{90}$SB	90-120	U	5.78	565	0.8	5.4
N$_{90}$SB	120-150	U	9.46	423	0.6	3.6
N$_{90}$SB	150-180	U	14.95	281	2.4	2.0
N$_{90}$SB	180-210	U	8.86	311	0.7	1.6
PV	0-15	U	10.23	896	1.3	5.2
PV	15-30	U	9.05	783	0.5	4.3
PV	30-60	U	5.93	641	0.4	3.7
PV	60-90	U	3.43	497	0.4	4.9
PV	90-120	U	2.25	284	0.8	3.2
PV	120-150	U	2.25	344	0.4	4.3
PV	150-180	U	2.15	260	0.4	1.6
PV	180-210	U	3.13	214	0.7	1.6
M	0-15	U	11.76	1029	1.7	5.8
M	15-30	U	8.24	850	1.5	4.6
M	30-60	U	4.86	605	0.8	3.7
M	60-90	U	3.47	540	0.4	3.5
M	90-120	U	2.95	365	0.7	4.2
M	120-150	U	2.19	284	0.5	4.0
M	150-180	U	3.42	380	0.5	2.1
M	180-210	U	5.98	167	1.6	2.1

Appendix 5. Total Phosphorus and phosphorus fractions from soil chemical analysis of soil profile from Residue Utilization Experiment Plots (L=lower U=upper).

Residue history	Sampled depth	Slope position	Total P	Ext. PO$_4$	Inorganic P	Organic P
	cm				-µg g^{-1}-	
N$_0$	0-15	L	697	30.5	458.1	238.8
N$_0$	15-30	L	677	25.3	487.0	189.9
N$_0$	30-60	L	742	18.4	450.4	291.3
N$_0$	60-90	L	688	14.4	443.4	244.7
N$_0$	90-120	L	666	18.4	563.4	102.3
N$_0$	120-150	L	796	61.8	708.3	87.5
N$_0$	150-180	L	894	87.2	690.6	203.7
N$_0$FB	0-15	L	781	24.5	510.3	270.9
N$_0$FB	15-30	L	779	18.4	496.3	283.1
N$_0$FB	30-60	L	727	17.5	479.8	247.5
N$_0$FB	60-90	L	687	16.4	507.3	180.0
N$_0$FB	90-120	L	745	22.1	546.4	198.5
N$_0$SB	0-15	L	722	34.5	492.1	230.0
N$_0$SB	15-30	L	760	26.8	481.8	278.1
N$_0$SB	30-60	L	723	17.3	470.6	252.0
N$_0$SB	60-90	L	742	12.3	521.5	220.3
N$_0$SB	90-120	L	712	16.5	556.6	155.0
N$_{45}$	0-15	L	673	22.1	459.8	213.1
N$_{45}$	15-30	L	735	15.5	523.1	212.2
N$_{45}$	30-60	L	803	13.4	526.7	276.8
N$_{45}$	60-90	L	766	13.4	577.9	188.2
N$_{45}$	90-120	L	770	9.3	539.2	230.7
N$_{45}$SB	0-15	L	600	22.2	501.3	98.3
N$_{45}$SB	15-30	L	581	17.1	493.3	87.5
N$_{45}$SB	30-60	L	589	14.6	520.2	68.7
N$_{45}$SB	60-90	L	621	11.3	536.9	83.8
N$_{45}$SB	90-120	L	788	28.0	774.6	13.0
N$_{45}$SB	120-150	L	1263	67.6	1007.1	255.8
N$_{90}$	0-15	L	716	24.3	473.6	242.8
N$_{90}$	15-30	L	724	21.9	482.4	241.9
N$_{90}$	30-60	L	716	16.0	489.6	226.3
N$_{90}$	60-90	L	764	10.2	481.1	282.5
N$_{90}$	90-120	L	855	39.7	638.5	216.7
N$_{90}$SB	0-15	L	570	22.2	477.5	92.2
N$_{90}$SB	15-30	L	572	17.4	497.7	74.4
N$_{90}$SB	30-60	L	656	11.3	506.1	149.6
N$_{90}$SB	60-90	L	630	12.3	526.5	103.4
N$_{90}$SB	90-120	L	742	25.6	547.8	193.9
PV	0-15	L	635	31.5	472.3	163.0
PV	15-30	L	771	27.9	505.5	265.6
PV	30-60	L	689	21.1	516.5	172.6

Residue history	Sampled depth	Slope position	Total P	Ext. PO$_4$	Inorganic P	Organic P
	cm				-------------------µg g^{-1}-------------------	
PV	60-90	L	696	16.0	520.7	175.3
PV	90-120	L	745	16.3	607.6	137.7
PV	120-150	L	867	84.7	582.8	284.3
M	0-15	L	852	54.2	571.6	279.9
M	15-30	L	844	47.2	546.9	296.6
M	30-60	L	793	23.9	513.2	279.5
M	60-90	L	768	13.5	498.4	269.6
M	90-120	L	788	25.9	617.8	170.0
M	120-150	L	678	17.5	547.4	130.5
M	150-180	L	673	28.1	526.1	146.5
N_0	0-15	U	792	31.7	569.0	223.1
N_0	15-30	U	655	30.5	553.4	102.1
N_0	30-60	U	669	21.0	566.2	103.2
N_0	60-90	U	628	15.5	554.3	74.1
N_0	90-120	U	599	10.8	562.1	36.6
N_0	120-150	U	607	15.4	579.4	27.2
N_0	150-180	U	721	19.3	667.6	53.6
N_0	180-210	U	782	20.6	702.3	79.5
N_0FB	0-15	U	749	27.4	545.7	203.4
N_0FB	15-30	U	806	21.5	547.6	258.3
N_0FB	30-60	U	757	19.4	528.8	227.9
N_0FB	60-90	U	760	14.5	525.0	235.5
N_0FB	90-120	U	717	10.0	542.5	174.3
N_0FB	120-150	U	841	15.8	639.1	202.2
N_0FB	150-180	U	914	20.1	707.1	207.0
N_0FB	180-210	U	760	12.7	644.1	115.9
N_0SB	0-15	U	788	39.8	593.7	194.0
N_0SB	15-30	U	781	27.4	581.2	199.9
N_0SB	30-60	U	671	19.8	581.2	89.6
N_0SB	60-90	U	631	16.6	578.7	52.3
N_0SB	90-120	U	672	12.4	567.8	103.8
N_0SB	120-150	U	781	12.9	644.4	136.5
N_0SB	150-180	U	734	12.3	631.1	102.9
N_0SB	180-210	U	723	8.7	569.3	154.0
N_{45}	0-15	U	751	27.6	473.3	277.6
N_{45}	15-30	U	777	18.7	449.2	327.5
N_{45}	30-60	U	552	14.6	453.9	98.4
N_{45}	60-90	U	577	11.8	455.6	121.9
N_{45}	90-120	U	568	16.4	532.1	35.7
N_{45}	120-150	U	782	40.1	745.0	37.3
N_{45}	150-180	U	721	40.8	711.9	8.8

Residue history	Sampled depth	Slope position	Total P	Ext. PO$_4$	Inorganic P	Organic P
	cm				μg g^{-1}	
N$_{45}$	180-210	U	735	24.3	665.5	69.3
N$_{45}$SB	0-15	U	698	26.6	438.5	259.9
N$_{45}$SB	15-30	U	698	22.1	432.1	265.4
N$_{45}$SB	30-60	U	588	14.1	422.1	165.9
N$_{45}$SB	60-90	U	651	12.1	456.6	194.3
N$_{45}$SB	90-120	U	724	12.1	515.8	208.2
N$_{45}$SB	120-150	U	787	12.3	606.2	180.9
N$_{45}$SB	150-180	U	942	34.1	765.3	177.0
N$_{45}$SB	180-210	U	774	34.5	623.3	150.5
N$_{90}$	0-15	U	707	23.2	502.3	205.1
N$_{90}$	15-30	U	658	20.9	472.7	185.0
N$_{90}$	30-60	U	705	12.0	459.5	245.7
N$_{90}$	60-90	U	681	8.4	472.5	208.2
N$_{90}$	90-120	U	689	6.9	502.7	185.9
N$_{90}$	120-150	U	627	7.1	506.4	120.6
N$_{90}$	150-180	U	709	11.4	580.3	128.2
N$_{90}$	180-210	U	808	39.2	652.5	155.9
N$_{90}$SB	0-15	U	728	30.3	469.3	258.7
N$_{90}$SB	15-30	U	739	22.4	467.3	271.3
N$_{90}$SB	30-60	U	778	14.5	449.7	328.7
N$_{90}$SB	60-90	U	754	14.4	465.8	288.4
N$_{90}$SB	90-120	U	756	13.3	549.7	206.2
N$_{90}$SB	120-150	U	866	23.5	644.4	221.1
N$_{90}$SB	150-180	U	978	29.9	752.9	225.3
N$_{90}$SB	180-210	U	918	16.4	770.7	147.3
PV	0-15	U	815	31.7	560.7	254.0
PV	15-30	U	880	29.8	568.6	311.1
PV	30-60	U	777	20.2	551.9	225.5
PV	60-90	U	766	14.7	570.2	196.1
PV	90-120	U	792	10.9	590.2	201.4
PV	120-150	U	802	10.2	606.9	195.5
PV	150-180	U	857	13.7	647.2	209.8
PV	180-210	U	869	9.6	658.3	211.0
M	0-15	U	751	53.1	609.4	141.5
M	15-30	U	842	51.1	621.4	220.9
M	30-60	U	829	28.0	591.1	237.4
M	60-90	U	720	17.7	576.5	143.2
M	90-120	U	729	12.3	584.1	144.8
M	120-150	U	787	10.0	589.7	197.8
M	150-180	U	877	14.5	610.5	266.7
M	180-210	U	942	12.7	779.1	163.3

Appendix 6. Total sulfur and sulfur fractions from soil chemical analysis of soil profile from Residue Utilization Experiment Plots (L=lower U=upper).

Residue history	Sampled depth	Slope position	Total S	Ext. SO$_4$	Ester sulfur	Carbon-bonded sulfur	Resid. sulfur
	cm				---------µg g^{-1}---------		
N$_0$	0-15	L	119	3.5	56.4	14.3	44.5
N$_0$	15-30	L	127	3.6	72.8	11.3	39.1
N$_0$	30-60	L	135	3.8	75.2	3.9	52.5
N$_0$	60-90	L	87	2.9	49.3	2.7	32.1
N$_0$	90-120	L	108	2.3	89.9	1.7	14.6
N$_0$	120-150	L	214	2.0	205.7	1.0	5.1
N$_0$	150-180	L	283	2.4	255.7	1.6	23.7
N$_0$FB	0-15	L	116	3.4	67.5	11.4	33.6
N$_0$FB	15-30	L	126	2.6	81.7	11.4	30.7
N$_0$FB	30-60	L	111	2.4	69.5	4.0	35.5
N$_0$FB	60-90	L	116	2.8	59.2	2.1	51.9
N$_0$FB	90-120	L	161	5.5	130.0	6.9	19.1
N$_0$SB	0-15	L	163	3.6	71.0	13.9	74.9
N$_0$SB	15-30	L	140	2.7	82.2	12.1	43.4
N$_0$SB	30-60	L	110	2.6	59.1	6.2	41.8
N$_0$SB	60-90	L	103	4.0	70.9	3.9	23.9
N$_0$SB	90-120	L	171	3.1	137.4	3.0	27.7
N$_{45}$	0-15	L	142	3.0	78.0	18.1	42.6
N$_{45}$	15-30	L	150	3.3	95.4	9.0	42.6
N$_{45}$	30-60	L	141	2.9	89.4	6.7	41.9
N$_{45}$	60-90	L	126	4.3	94.2	7.3	20.0
N$_{45}$	90-120	L	155	2.6	107.9	5.0	39.1
N$_{45}$SB	0-15	L	129	5.7	75.6	13.0	34.5
N$_{45}$SB	15-30	L	112	2.2	76.0	8.0	25.4
N$_{45}$SB	30-60	L	91	2.9	65.5	6.0	17.0
N$_{45}$SB	60-90	L	75	2.1	52.0	3.6	17.5
N$_{45}$SB	90-120	L	142	3.4	106.1	4.0	28.9
N$_{45}$SB	120-150	L	206	3.2	193.5	4.2	4.8
N$_{90}$	0-15	L	140	3.6	70.4	15.8	49.9
N$_{90}$	15-30	L	143	3.0	82.8	12.6	44.8
N$_{90}$	30-60	L	114	3.1	75.5	6.5	28.4
N$_{90}$	60-90	L	82	4.1	62.2	4.6	11.4
N$_{90}$	90-120	L	192	3.9	156.7	5.4	25.7
N$_{90}$SB	0-15	L	133	2.9	76.0	13.0	41.0
N$_{90}$SB	15-30	L	120	2.4	80.6	8.9	28.3
N$_{90}$SB	30-60	L	94	3.3	69.3	6.2	14.7
N$_{90}$SB	60-90	L	63	2.4	55.0	3.7	1.6
N$_{90}$SB	90-120	L	182	3.3	162.6	5.3	10.4
PV	0-15	L	137	3.7	69.7	12.0	51.4
PV	15-30	L	130	2.6	75.8	8.2	43.4
PV	30-60	L	112	2.3	66.3	6.5	36.8
PV	60-90	L	89	2.6	54.2	0.9	31.3

Residue history	Sampled depth	Slope position	Total S	Ext. SO_4	Ester sulfur	Carbon-bonded sulfur	Resid. sulfur
	cm				$\mu g\ g^{-1}$		
PV	90-120	L	117	3.8	92.2	3.0	17.7
PV	120-150	L	446	3.6	402.6	5.4	34.4
M	0-15	L	187	4.1	78.6	27.7	76.7
M	15-30	L	150	4.5	77.9	19.2	48.8
M	30-60	L	118	2.5	65.6	8.8	40.8
M	60-90	L	94	3.0	52.8	2.0	35.8
M	90-120	L	222	6.7	162.1	8.4	44.9
M	120-150	L	278	4.6	243.3	9.4	20.5
M	150-180	L	338	3.3	299.9	4.0	31.0
N_0	0-15	U	112	3.2	63.4	16.3	29.7
N_0	15-30	U	128	2.9	77.3	10.0	37.6
N_0	30-60	U	97	2.8	69.2	10.1	14.4
N_0	60-90	U	70	2.1	48.8	5.3	13.5
N_0	90-120	U	56	3.5	38.7	2.6	11.4
N_0	120-150	U	68	2.1	41.7	3.0	21.0
N_0	150-180	U	75	2.7	58.7	1.8	11.4
N_0	180-210	U	86	2.4	63.8	2.0	18.1
N_0FB	0-15	U	102	2.8	54.3	16.9	27.9
N_0FB	15-30	U	121	2.5	73.9	9.2	35.2
N_0FB	30-60	U	106	2.3	62.7	4.2	36.9
N_0FB	60-90	U	89	2.1	49.6	5.0	32.7
N_0FB	90-120	U	65	3.0	41.4	7.6	13.1
N_0FB	120-150	U	104	2.3	59.5	2.6	39.7
N_0FB	150-180	U	115	2.9	88.3	0.7	22.9
N_0FB	180-210	U	81	2.6	60.0	0.9	17.0
N_0SB	0-15	U	130	3.0	68.3	10.7	47.9
N_0SB	15-30	U	115	2.7	70.8	7.7	34.3
N_0SB	30-60	U	99	2.9	62.2	6.9	27.3
N_0SB	60-90	U	80	2.2	51.5	3.7	23.0
N_0SB	90-120	U	68	2.2	48.0	3.5	14.5
N_0SB	120-150	U	72	2.9	51.0	2.3	15.6
N_0SB	150-180	U	86	2.7	66.4	0.5	16.5
N_0SB	180-210	U	78	1.9	71.3	2.0	2.8
N_{45}	0-15	U	123	3.1	68.6	12.4	38.9
N_{45}	15-30	U	127	2.6	104.1	4.7	15.3
N_{45}	30-60	U	108	2.5	63.7	5.6	35.7
N_{45}	60-90	U	67	1.5	38.5	3.9	22.6
N_{45}	90-120	U	75	2.1	59.4	0.7	12.6
N_{45}	120-150	U	146	3.0	135.7	2.0	4.9
N_{45}	150-180	U	229	2.6	188.2	3.6	34.8
N_{45}	180-210	U	182	3.1	151.8	2.2	25.0
N_{45}SB	0-15	U	124	2.7	64.3	16.6	40.0

Residue history	Sampled depth	Slope position	Total S	Ext. SO$_4$	Ester sulfur	Carbon-bonded sulfur	Resid. sulfur
	cm					μg g^{-1}	
N$_{45}$SB	15-30	U	137	3.5	66.9	12.3	54.0
N$_{45}$SB	30-60	U	104	3.0	65.5	4.4	31.1
N$_{45}$SB	60-90	U	69	3.2	42.3	0.9	22.6
N$_{45}$SB	90-120	U	61	1.9	37.8	2.6	19.0
N$_{45}$SB	120-150	U	59	1.7	46.9	3.0	7.2
N$_{45}$SB	150-180	U	298	2.6	268.5	2.9	23.8
N$_{45}$SB	180-210	U	121	0.5	101.4	5.7	13.4
N$_{90}$	0-15	U	117	2.9	63.6	12.0	38.2
N$_{90}$	15-30	U	126	2.8	81.2	9.7	32.4
N$_{90}$	30-60	U	98	1.5	77.1	5.8	14.0
N$_{90}$	60-90	U	101	2.3	53.9	3.2	41.9
N$_{90}$	90-120	U	61	1.8	38.6	3.3	17.7
N$_{90}$	120-150	U	63	2.1	43.9	0.6	16.6
N$_{90}$	150-180	U	102	1.9	84.8	1.0	14.6
N$_{90}$	180-210	U	281	2.4	218.9	0.7	59.2
N$_{90}$SB	0-15	U	126	2.5	65.8	11.8	46.0
N$_{90}$SB	15-30	U	121	2.2	78.7	11.2	29.3
N$_{90}$SB	30-60	U	107	2.3	70.8	4.4	29.8
N$_{90}$SB	60-90	U	85	1.3	52.2	6.0	25.2
N$_{90}$SB	90-120	U	85	1.3	57.1	2.8	24.2
N$_{90}$SB	120-150	U	122	1.3	108.6	2.7	9.0
N$_{90}$SB	150-180	U	240	1.1	223.6	2.4	12.9
N$_{90}$SB	180-210	U	129	2.0	111.8	5.7	9.8
PV	0-15	U	122	3.5	68.9	19.8	29.7
PV	15-30	U	123	2.7	79.1	7.4	34.0
PV	30-60	U	110	2.4	63.8	4.0	39.9
PV	60-90	U	79	1.9	48.6	6.4	21.8
PV	90-120	U	54	2.5	46.0	1.7	3.9
PV	120-150	U	60	2.4	44.7	3.1	10.3
PV	150-180	U	69	1.6	52.0	2.7	12.3
PV	180-210	U	81	2.8	58.0	0.3	19.3
M	0-15	U	170	3.5	80.4	22.0	63.9
M	15-30	U	136	3.2	82.2	11.5	39.7
M	30-60	U	110	2.2	67.0	6.0	35.0
M	60-90	U	89	2.5	48.7	1.2	36.5
M	90-120	U	62	2.9	46.4	5.2	7.1
M	120-150	U	63	3.1	38.4	2.9	18.1
M	150-180	U	78	4.1	51.7	4.7	17.4
M	180-210	U	85	3.7	77.7	2.7	0.9

Appendix 7. Walla Walla Series Profile Description

Ap-0 to 15 cm; very dark grayish brown (10YR 3/2) silt loam, grayish brown

(10YR 5/2) dry; weak fine subangular blocky structure ; slightly hard,

friable, slightly sticky and nonplastic; common very fine roots; many

very fine tubular pores; neutral; clear smooth boundry.

BA-15 to 48 cm; dark brown (10YR 3/3) silt loam, brown (10YR 5/3) dry;

weak coarse prismatic structure; slightly hard, friable, slightly sticky

and nonplastic; few very fine roots; many very fine tubular pores;

neutral; gradual wavy boundry.

Bw-48 to 112 cm; brown (10YR 4/3) silt loam, pale brown (10YR 6/3) dry;

weak coarse prismatic structure; slightly hard, friable, slightly sticky

and nonplastic; few very fine roots; common very fine tubular pores;

neutral; clear wavy boundry.

BCk-112 to 152 cm; brown (10YR 5/3) silt loam very pale brown (10YR 7/3)

dry; massive; slightly hard, friable, slightly sticky and nonplastic; few

very fine roots; few very fine tubular pores; strongly effervescent;

disseminated lime; moderately alkaline.

Appendix 8. Modified procedure for combine total sulfur and phosphorus analysis from plant material.

1. Approximately 0.02 g oven dried ground plant sample put into 50 mL round bottom boiling flask.

2. 3 mL NaOBr added, flask swirled gently and let stand for 5 min.

3. Boiling flask placed in 260°-280° C sand bath and contents boiled to dryness plus 30 min. (generally 45-50 min. total). Boiling flask removed from sand bath and allowed to cool for 5 min.

4. 5 mL of deionized H_2O pipetted into boiling flask and returned to sand bath for a few seconds (do not allow to boil).

5. 1 mL of formic acid pipetted into flask and gently swirled.

6. 2 mL aliquot removed from flask and put into Johnson and Nishita distillation flask. Johnson and Nishita distillation for total sulfur conducted and measurement at 720 nm on spectrophotometer (Johnson and Nishita, 1952).

7. 25 mL of 1 M HCl added to remaining 4 mL of solution in boiling flask and swirled gently.

8. 4mL aliquot pipetted from boiling flask into 25 mL vol. flask and analysis for total phosphorus conducted, with measurement at 660 nm on spectrophotometer (Dick and Tabatabai, 1977).

Calculation for total sulfur

$$\frac{(\text{sample absorbance-blank absorbance}) * 6\ mL}{\text{aliquote(mL)} * \text{sample(g)} * \text{slope(abs }\mu g^{-1})} = \mu g\ S\ g^{-1}\ \text{plant material}$$

Calculation for total phosphorus

$$\frac{(\text{sample absorb.-blank absorb.}) * 6\ mL * 29\ mL}{\text{aliquot(mL)} * \text{sample(g)} * \text{slope(abs }\mu g^{-1}) * 4\ mL} = \mu g\ P\ g^{-1}\ \text{plant material}$$