DIAGNOSTIC SOIL AND TISSUE TESTS FOR EVALUATING THE NITROGEN NUTRITIONAL STATUS OF POTATO (Solanum Tuberosum)

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ABSTRACT

DIAGNOSTIC SOIL AND TISSUE TESTS FOR EVALUATING THE NITROGEN NUTRITIONAL STATUS OF POTATO (*Solanum tuberosum*)

by Eduardo Fernandez Tunon

The relative value of soil tests and tissue tests for diagnosing the nutritional status of potatoes, with specific reference to nitrogen, was studied in two field experiments in 1968. The Sebago variety was used on Conover loam at East Lansing; Russet Burbanks were used on McBride sandy loam on the Comden farm in Montcalm County.

The nitrogen nutrition was varied at each location by varying rate and time of application of NH_4NO_3.

Soils and petioles were sampled twice during the season: (1) at tuber initiation, just before bloom in July, and (2) in August after tubers had begun to enlarge rapidly as evidenced by the presence of several B-size tubers per hill.

Soil nitrate was determined in .02 N $CuSO_4$ extracts of rapidly air dried plow soil samples (0-10 inch depth). Tissue nitrate was determined in 2% acetic acid extracts of oven dried petioles. Brucine was used for estimating nitrate in both soil and tissue extracts.

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A quick test for petiole nitrate was also used in the field. Intensity and rate of development of blue color with diphenylamine were rated visually and converted to an exponential numerical scale (QTN) which was found to be linearly related to the nitrate concentration in the acetic acid extracts of dried petioles sampled at the same time.

Significant increases in total tuber yield and percentage A-size tubers were obtained at Montcalm for increments of total fertilizer N up to 180 pounds per acre. At East Lansing, additional increases were obtained with 240 pounds N per acre.

Plow-down N had little influence on yields at either location. Both banded and sidedressed N influenced yields at Montcalm, but at East Lansing, major yield responses were associated with sidedressed N applications.

The unusually high total N requirements and the relative ineffectiveness of plow-down N were due to extensive leaching of nitrate during rainy periods in May and June. Leaching resulted in low soil tests for nitrate in July and August and low diagnostic value of the soil tests.

Both the QTN indices and the quantitative determinations for petiole nitrate were useful for diagnosis. Graphical estimates of "critical level" were QTN = 8 and petiole NO_3-N = 2.0 percent.

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Interactions between nitrate and extractable P, K, Ca and Mg in the August samplings of both soils and petioles were examined by simple and multiple correlation and regression analysis.

Reductions of exchangeable K, Ca and Mg were consistent with the view that these bases had been subject to leaching along with nitrate. Reductions of extractable soil phosphate at East Lansing and of soil pH at Montcalm suggested that acidity released by nitrification of ammonium supplied as NH_4NO_3 may have contributed to reduced availability and uptake of P and the observed reductions in petiole P.

Negative correlations between petiole P and petiole nitrate suggest that nitrate competed with phosphate in maintaining a balance between anions and cations in root uptake. Petiole K was positively correlated with petiole P, but negatively correlated with petiole nitrate, Mg and Ca.

The positive correlation between petiole P and K would appear to reflect the positional association of these two nutrients in the fertilizer band. The positive correlations between petiole nitrate, Mg and Ca, on the other hand, would reflect the mobility of nitrate and the fact that nitrate entering the plant would have a better chance of being accompanied by Mg and Ca from soil sources than would the phosphate in the fertilizer band.

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The overall effect of these interactions among N, P, K, Ca and Mg on Russet Burbanks appears to have been to make P the first limiting nutrient in all treatments which received fertilizer N.

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By

Eduardo Fernandez Tunon

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DEDICATION

My sincere gratitude to my parents,
whose example has been the most
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INTRODUCTION

The search for methods to determine the quantities of nutrients in the soil and to assess their availability to crops has been underway since the time of vonLiebig a century ago.

Even though much progress has been made and many improvements in soil management and fertilization have contributed to increasing rates of production, there are still no methods for evaluating nutrient status and fertilizer requirements which are appropriate in all conditions or for all nutrients or all crops.

In the particular case of nitrogen, because of the mobility of its nitrate form, many factors tend to complicate its evaluation.

The objectives of this study were (1) to compare the diagnostic usefulness of soil and tissue analyses for nitrate and (2) to examine interactions between N, P, K, Ca, and Mg in soils and tissues which might influence the responses of potatoes (*Solanum tuberosum*) to fertilizer nitrogen.

LITERATURE REVIEW

Growth Physiology In The Potato Plant

In general ecological considerations of growth of the potato in the field, Milthorpe (27) recognizes three phases:

(a) A period of pre-emergence, in which is considered the establishment of root and leaves, utilizing materials stored in the mother tuber. Soil temperature and the size of sprout at planting time are determinating factors in this step.

(b) A period in which haulm (stalk) growth is predominant.

(c) Tuber growth, a stage closely interrelated with haulm growth.

Among mechanisms involved in tuber initiation, probably the most important phase in the growth of the potato, Slater (2) considers two factors being important:

(a) Short days seem to be more favorable for tuber initiation, than long days. This is probably due to some specific tuber-forming hormone which is produced under short day conditions.

In long days, plants have much greater haulm growth and tuber initiation is delayed.

There are great differences between varieties in their response to photoperiod.

(b) Temperature regime is the second factor involved in these mechanisms. At high temperatures, tuber initiation is delayed. Slater (37) mentions studies made by Borah and Milthorpe (1963). They found that the carbohydrate balance within the plant is involved in determining the time of initiation.

At high temperatures, greater proportions of assimilate are used in root, stem and stolon growth than at lower temperature. Tuber initiation is associated with high concentration of soluble carbohydrate at the stolon tips. In greenhouse experiments, measurement of carbohydrate concentration after a period of low temperature showed an increase in the haulm and stolon tips. Slater's conclusion (37) is that the formation of tubers is related to changes in quantity and proportion of substrate and growth substances at the stolon tips.

Temperature, radiation and photoperiod play an important role in this mechanism.

The conclusion of a study of these factors in the development of potatoes made by Bodlander (6) is that: Low temperature, high light intensity and short days generally accelerate the development of potatoes; stem elongation terminates early, tuber initiation starts early and the plants die early. Under these circumstances small stems and large leaves are formed and tuber growth is stimulated. High temperatures, low light intensity and long days, on the other hand, promote elongation but are unfavourable for leaf expansion and delay tuber formation; stolon growth, second growth of tubers, the formation of wild stolons emerging above the soil and sometimes branching of stems and stolons are also promoted by long days and high temperatures.

Flowering needs high light intensities, long days and intermediate temperatures.

The final tuber yield will be determined by the combined action of these climatological facotrs by influencing tuber initiation, the leaf area duration and the assimilation rate per unit leaf area per day.

The time from emergence to tuber initiation is inversely related to the rate of haulm growth; vigorous stem and leaf growth leads to an appreciable delay in tuber formation. But as tubers develop, competitive effects appear between the growing tubers and the vegetative plant.

Tuber initiation and enlargement can occur only when products of photosynthesis accumulate in the plant in excess of the requirement for growth (50).

If tubers are initiated when only a small leaf area has developed, branch and leaf production cease earlier and existing leaves senesce more quickly, giving smaller final yields than when tubers are initiated on plants with larger vegetative apparatus (49).

There appears to be appreciable migration of nitrogen, phosphorus and potassium from the tops to the tubers during the later stages of tuber growth; nevertheless, uptake from the soil continues throughout most of the life of the plant.

Among the nutrient effects, nitrogen is important. In the early growth period, nitrogen promotes vegetative activity. Augmenting the effect of long days or high temperatures, a moderate to high supply of nitrogen late in the season prolongs growth in tops and tubers and delays their ripening (49).

The effect of moisture supply is similar to the nitrogen supply in its effects. Fluctuations in moisture or temperature act indirectly by regulating the basic metabolism of the plant. Therefore, a period of low moisture supply sets the stage for injurious competitive relationships within the plant when growth processes are stimulated by a subsequent period of improved moisture supply (51).

The growth of lateral branches induced by abundant nitrogen is greater at nodes near the base and tip of the shoot than in the intermediate zone, but the leaves on the main stem are largest at intermediate nodes and are increased in size by additional nitrogen more than those at higher or lower nodes (27).

Watson (49) studied the supply of mineral nutrients that affects the rate of dry matter production chiefly by changing leaf area.

Nitrogen, phosphorus and potassium effects were considered by the same author: Nitrogen increases leaf production by stimulating activity of apical or lateral meristems; it increases leaf expansion and hastens the death of older leaves. Phosphorus also increases meristematic activity and leaf expansion, but these effects begin earlier and are less persistent than for nitrogen. The effect on longevity is variable. The chief effect of potassium is in leaf expansion and delay of maturity.

In the potato growth, tuber initiation is retarded when leaf area expansion is induced by large amounts of fertilizer. If the growing season is prolonged enough, large tuber yield would result from large leaf surface.

A compromise solution in areas of short growing season is to obtain as long a period for tuber growth as possible. This can be obtained by controlling the fertilizer supply so as to develop quickly an adequate leaf surface and then maintain it during the period of tuber bulking (49).

This may call for limited early applications of fertilizer nitrogen followed by judicious sidedressings later.

Potato Quality Considerations

Specific gravity of potatoes has been used as a measure of their suitability for specific methods of food preparation. Potatoes with low specific gravity, because they slough less, are preferred for scalloped potatoes, salads and boiling, whereas those of high specific gravity are preferred for chips, french fries, baking and dehydration (28).

The effect of nitrogen, phosphorus and potassium fertilization on the specific gravity has been studied. Teich and others (43) have shown that on soil types representative of the main potato growing areas (Canada) specific gravity was reduced by application of nitrogen and potassium. Phosphorus affected specific gravity in only one area. Ascorbic acid tended to decrease with increasing nitrogen and potassium, but was unaffected by phosphorus (43).

On the average, specific gravity of potatoes increases with increasing fertilizing rates; specific gravity was greater from rotations with red top than under continuous cultivation (31).

Youngen and others (53) in studies on the influence of fertilizer nitrogen on the yield, grade and specific gravity of potatoes in eastern Oregon concluded from 10 to 14 farms on which the specific gravity determination was made, that increased rates of nitrogen produced statistically significant decreases in specific gravity of potatoes sampled from early tuber set to near maturity. At all rates of nitrogen, specific gravity increased progressively with time as the potatoes approached maturity.

The relationships between specific gravity and total and non-protein nitrogen and ascorbic acid content in the Ontario variety susceptible to precooking discoloration were studied by Mondy and Rieley (28). Total and non-protein nitrogen, expressed on a dry weight basis, decreased as specific gravity increased to the mean specific gravity for the variety. Potatoes having the mean specific gravity had the lowest total and non-protein nitrogen content. Both total and non-protein nitrogen were significantly higher in the center of the tuber than in the cortex tissue. High specific gravity was significantly correlated with high ascorbic acid content. Tubers of low specific gravity showed a greater loss of ascorbic acid during storage than those of high specific gravity.

Soil Nitrogen

The plant nutrient that limits crop production in all the world more than any other is nitrogen. This nutrient is utilized by plants for production of structural proteins, enzymes and numerous nitrogen compounds involved in biochemical and genetic control of all plant functions.

Almost all the nitrogen in the surface of the soil is organically combined. Although plants are capable of utilizing organic forms of nitrogen such as amino-acids and amides, practically all of the organic soil nitrogen cannot be utilized directly by plants (42). Some of it (of the order of 1 to 3% annually) is mineralized by microbial processes during the growing season. This provides a substantial amount of plant available nitrogen in mineral forms (NH_4^+, NO_3^-) (52).

One of the major contributions of soil organic matter to soil fertility is that it supplies a considerable quantity of nitrogen for plant growth and acts as a natural storehouse for this important nutrient. However, the amount of nitrogen made available by mineralization of soil organic matter during the growing season is rarely sufficient to meet the demand for this nutrient in current cropping practices (8).

The transformations of organic nitrogen and available mineral forms have been studied extensively.

The conversion from organic nitrogen to inorganic forms (NH_4^+, NO_2^- and NO_3^-) by microorganisms is known as mineralization. The reverse process is called immobilization.

Mineralization occurs in two steps: Ammonification (organic-$NH_2 \rightarrow NH_4^+$) and nitrification ($NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$).

"Immobilization" is usually used to indicate the transformation of inorganic nitrogen to organic forms. This is a microbiological process which is carried out by microorganisms, using inorganic nitrogen and carbonaceous energy substrates to synthesize cell tissue. In addition to cellular proteins, other forms of organic nitrogen (humic acids) appear which are relatively resistent to further biological breakdown (17, 42, 20).

The C/N ratio in the plant residues added to the soil is an important factor in the process of nitrogen immobilization.

When plant materials with large C/N ratio are added to the soil, much of the nitrogen available in the soil may be utilized by the heterotrophic microorganisms, using it in their own growth.

If the C/N ratio of plant residues is larger than 25 or 30 to 1, biological immobilization is at a maximum and an external source of nitrogen will be needed to satisfy microbial requirements.

When the C/N ratio is 20 or less no external source of nitrogen for maximum microbial activity is needed. Microbial competition with higher plants for available nitrogen can be considered to have been neutralized (3, 21).

Mineralization, on the other hand, is used to indicate the microbiological transformation of organic nitrogen to inorganic forms.

Allison (1) lists the factors which affect rate of release of nitrogen from soil organic matter as: (1) nature of soil organic matter, (2) temperature, (3) moisture, (4) aeration, (5) reaction, (6) supply of inorganic nutrients and (7) nature of soil microflora.

These two processes of immobilization and mineralization occur simultaneously in most soils where organic material is undergoing microbiological degradation (20).

Even though the organic forms containing nitrogen can be taken up by the plants, as was mentioned before, practically the large bulk of nitrogen that plants absorb is as NO_3^- and NH_4^+. Practically, there is little preference between the absorption of NO_3^- or NH_4^+ by plants, since nitrifying microorganisms rapidly oxidize the NH_4^+ form to NO_2^- and then to NO_3^- and plants have little opportunity to utilize it in the NH_4^+ form (41).

Besides clay minerals with expanding lattices can absorb ammonia and sometimes so tightly that it is not readily available to either plants or microorganisms (2).

It is true that ammonium can exist in exchangeable form in the soil, but is quickly transformed to nitrate form (in well aerated soil). Nitrates have high solubility and do not absorb in the colloidal complex of the soil; they are readily lost by leaching (29).

On the other hand, in water logged conditions denitrification can occur and there is a loss of N_2 gas from the nitrate (9).

The availability of soil nitrogen to plants depends upon two categories of factors:

(a) A capacitive factor (amounts and forms of nitrogen in the soil).

(b) Physical-chemical factors (temperature, water level aeration and pH, to mention the most important).

These factors influence the nature and levels of microbial activities in the soil, as well as the effectiveness of plant roots in supplying plant requirements for water and nutrients.

We can anticipate therefore that there will be a shortage of nitrogen in soil for crop needs:

(a) When there is not an adequate supply of available forms or of readily mineralizable organic nitrogen;

(b) In well drained soil, when there is an excess of water (heavy rainfall or irrigation) and leaching of nitrate occurs;

(c) When physical conditions (permeability, aeration, water logging) or chemical (pH) are not appropriate for desired microbial activities or root function.

Soil Tests For Diagnosing Fertilizer N Requirements

As nitrogen readily available for plants is very mobile in the soil, to maintain the correct supply for plant needs it is generally necessary for it to be supplied from outside during the crop season.

That is why in the practice of fertilization it is very important to know the correct amount and the correct time of application of this nutrient in the soil, as well as the requirement at different stages of plant assimilation and utilization.

The necessity to find a method which predicts the need for nitrogen fertilizer was recognized a long time ago. Although the search for such methods has been underway for over a century, it still continues. The lack of generally useful testing methods is due to the dynamic nature of the soil system and the fact that one is dealing with a tremendously varied complex of living organisms.

In earlier times, soil scientists tried to predict the need for nitrogen fertilization by analysis of the mineral nitrogen in soil. However, the amounts of these forms of nitrogen in the soil fluctuate since they are influenced by many external factors (such as nature of the soil, pH, plant growth, weather conditions, season, fertilization, etc.) and other factors already mentioned.

There is not yet one method which will predict the needs for nitrogen fertilization for all types of soils or under different weather conditions. Many biological and chemical methods have been proposed (8).

Allison (1) classifies methods reported in the literature into four types that are in use or have been proposed for measuring probable nitrogen release from soils. These are:

(a) Vegetative tests in the field or greenhouse;

(b) Nitrification tests;

(c) Release by chemical reagents;

(d) Determination of total nitrogen either directly, or indirectly by measuring total organic matter.

In addition, plant tissue analyses for nitrate-nitrogen are of value.

Due to the fact of the dynamic nature of the soil system and that one is dealing with living organisms, useful correlations with any given method appear to be restricted to similar types of soil within the same climatic zone and system of farming and frequently to soil samples collected within a single season.

The relationships between soil nitrogen, nitrate production and yield were largely studied.

MacKay and others (26) studied the relation of soil test values to fertilizer response by potatoes at 18 locations over 3 years in Canada. Bray's modified Mitscherlich equation was used to determine the relationship of potato yields (percent of maximum) to soil - NO_3 production and to nitrogen fertilization. The relationship was closer in fresh soil samples than in those air-dried for 6 months.

The influence of various factors on absolute yields was also assessed by analysis of variance. Highly significant effects were due to the "rates of nitrogen and soil-test values", but the interaction of these two factors was not significant.

The polynomial response curves derived from regression analysis showed that maximum yields were approached at the rate of 200 pounds per acre of applied nitrogen, regardless of soil -NO_3 production values. Tuber yields were also influenced by the soil series; the nitrogen fertilizer requirement was greater for some soils than for others.

Diagnostic Plant Analysis

Soil tests estimate the concentration of a soil nutrient available to the plant. The soil nutrient concentration test value requires special interpretation in accordance with the environmental nature of the soil, kind of crop and climatic conditions. The basis for interpretation must be derived from experience and field calibration experiments with each crop and soil type (or group of similar soil types).

Plant analyses are based on the premise that the amount of a given element in the plant is an indication of the availability of that particular nutrient. The availability may or may not be directly related to the quantity in the soil (45).

The imbalanced nutrition reflected by the shortage of an element is frequently accompanied by abnormally high accumulations of the other elements in the cell sap giving high test values, regardless of the supply.

Two types of plant analysis have been used. One is the tissue test which is made on fresh tissue in the field. The other involves more specific and quantitative chemical analysis made on the whole plant or part of the plant. Plant material, dried, ground and ashed is used if we want to determine the total concentration of the element within the plant. Sometimes a soluble compound or compounds, as example nitrate, or phosphate, are determined in 2% acetic acid extracts of fresh, frozen or dried plant material. These quantitative chemical analyses measure the nutrient composition of the plant at the time of sampling and in the tissue that is sampled.

The basic concept in using plant analysis for guiding fertilizer practice is that an element essential for the growth of a plant must be contained within the plant at sufficient concentrations for optimum plant growth.

Essentially all the potassium in plant tissue is present in solution as the cation. The level of soluble nitrogen or phosphorus in the plant at a given time represents an equilibrium between rate of uptake from the soil and rate of metabolic assimilation within the plant (36).

Establishing a correlation between the nutrient concentration found in the plant at critical periods of growth with final yields or quality parameters makes it possible to establish critical nutrient levels for optimum crop performance. The nutrient concentration found in the plant directly reflects the ability of the plant, at the time of sampling, to acquire nutrients from the soil in the environment in which the plant is growing (47).

Concurrent use of plant tests and soil tests greatly enhances the value of each as a means of determining corrective measures for unbalanced nutrient conditions present in a crop (11).

Each crop and each nutrient is a special problem unto itself, but once the basis for evaluating the nutrient status of the crop has been established the same system can be used and tested over a wide range of soils and climatic conditions with reasonable assurance of success.

The critical concentration necessary for optimum plant growth is determined on a cell basis or, at most, on a tissue basis, using tissue samples which are comprised of cells with similar function (47).

This is practically accomplished by selecting leaves or parts of leaves, or stems or parts of stems for analysis.

It is essential to test that part of the plant which will give the best indication of the nutritional status of the plant with regard to a specific nutrient. As an example, if the supply of nitrogen decreases, the upper part of the plant, in which maximum utilization of plant nutrients is in progress, will show a low test for nitrate. In the case of phosphorus and potassium, the reverse is true, and the lower part of the plant will become deficient first (45).

Ulrich and others (48) determined the NO_3-N content in 2% acetic acetic acid extracts from petioles of recently matured leaves of sugar beet plants receiving increasing amounts of nitrogen. Plotting these values against beet weight, they obtained curves showing that petiole nitrate was not affected by the first 40 pounds of nitrogen application, although the yield increased significantly. For 80 pounds, yield and nitrate content increased simultaneously. After

240 pounds, there was a sharp petiole nitrate increase after each application of nitrogen fertilizer; but yield remained unaffected.

The same authors conclude that it is possible also to determine different zones in these calibration curves; luxury consumption, adequacy and poverty or starvation concentrations. In general, there is a sharp transition between zones of adequacy and deficiency in the calibration curves, and this break identifies the "critical level" of the nutrient.

Nitrogen Fertilizer Practices For Potatoes

According to Cooke (10), fertility of soil is defined as its capacity to produce plants and it depends on land use. Soil productivity integrates the biological, physical, climatic and chemical factors which influence supplies of nutrients, air and water, anchorage of roots, and absence of toxic substances. Chemical fertility is concerned with nutrient supplies. Deficiencies are not an obstacle to productivity, since they are easily corrected by fertilizer, but other chemical and physical properties determine whether soil is a good vehicle for the extra fertility that is added.

Adding extra nutrients now allows us to control chemical soil fertility. The main problems of highly developed agriculture is the diagnosis of deficiencies, as well as to develop the best methods of correcting them.

The potato has heavy plant nutrient requirements for high yield. A good crop of potatoes removes an estimated: 120-160 lb. of N, 7-9 lb. of P, 200-250 lb. of K, 43 lb. of Ca, 18 lb. of Mg and 10-12 lb. of S per acre.

When any one of those more important nutrients is lacking, increasing it should influence plant development and final yield. The best response will occur only when levels of all necessary nutrients meet at least minimum plant requirements (4).

One of the important nutritional problems in potato production concerns the use of nitrogen, especially in relation to other farming practices. The problem of appropriate seasonal availability is more critical where potatoes do not follow a grass-legume crop or where no manure is applied.

The intensity of the nitrogen nutrition varies with the physiological state of the plants. The maximum requirement is in the rapidly growing state. If, at this time, transitional periods of shortage of nitrogen occur, this inconvenience will be reflected in the crop yield.

In the practice of nitrogen fertilization we must keep in mind that readily available nitrogen in soil is related to: type of soil, organic matter content (and C/N ratio), physical and chemical additions to the soil, microorganizms, as well as climatic zone and season, and farming system. These many factors greatly influence observed response to fertilizer nitrogen in field experiments, as well as in the experience of growers. This is why discussions in the literature regarding type of carrier and method and time of application of nitrogen fertilizers are frequently lengthy and often contradictory.

Until the mid 1950's the standard practice seems to have been to apply all or most of the fertilizer for potato in side-bands at planting time.

Sawyer and Dallyn in 1958 (34) give the following conclusions on placement of nitrogen for potatoes: The experimental results on time, method of application and placement of nitrogen for potatoes indicate no increases in yields from methods other than applying all the nitrogen in the row in the standard side-placement method at planting time.

However, with high rates of fertilizer, all applied in the row side bands, greater care must be exercised to obtain precise placement to avoid fertilizer injury to seed and sprouts, particularly under dry soil conditions (16).

Growers on the other hand, are cautioned against using too much nitrogen. Excessive use will delay maturity and may result in tubers lower in dry matter and more susceptible to bruising. Also lower yields may result if weather, insect and disease control are not favorable (15).

Through all the literature, the best practice of potato fertilization at less cost seems to be side dressing part of the nitrogen as ammonium nitrate or urea shortly after emergence, but before they are over approximately 8 inches high. By side-dressing part of the nitrogen, less nitrogen is subject to leaching, particularly on sandy soils, and the hazard of seed-piece burning and injury to the young plants is reduced as compared with applying all the nitrogen in bands at planting time (15).

Smith and Kelly (38) using complete fertilizer found that applying one-half the fertilizer broadcast, then plowed, plus one-half in equal depth bands at planting time resulted in yields of 356 bushels/acre as compared with 323 bushels when 2,400 lb. of 5-10-10/acre was applied all in bands.

Nobrega and Freire (30) reported in field experiments in Sao Paulo: application of nitrogen fertilizer to potatoes in furrows at planting time gave good results only in wet weather.

Applying all the nitrogen as top-dressing provided insufficient nitrogen to the plants during their most active vegetative growth. Part of the nitrogen should be applied near the seed at planting time and the rest top-dressed at sprouting.

Bessey (5) reported for winter potatoes in Arizona on experiments using as much as 160 lb/acre of N. Tests were devised to compare a no N check with 160 lb. of N applied (1) all in planting, (2) half at planting plus half at midseason and (3) all at midseason. By symptom diagnosis and NO_3^- petiole analysis, nitrogen deficiency was determined to be serious by midseason for potatoes receiving no nitrogen at planting. Available nitrogen had been depleted in plots receiving all nitrogen at planting. Both midseason nitrogen treatments kept this off-season crop growing well enough to produce acceptable yields.

In California, studies by Timm and others (44), showed high total yield was obtained with each increase of nitrogen up to 240 pounds per acre. However, yield of U.S. No. 1 tubers increased by the addition of nitrogen up to 120 pound per acre. The increased yields obtained with nitrogen above 120 pound per acre were associated with high yield of off grade tubers.

Plants with less than 8000 ppm of NO_3-N (dry weight basis) showed nitrogen deficiency symptoms and produced lower yields. High levels of nitrogen prolonged active vegetative growth and delayed accumulation of dry matter in tubers.

Without exception, increasing the levels of nitrogen resulted in lower specific gravity of tubers (44).

Increasing rates of nitrogen fertilizer increased the NO_3-N and Ca content and decreased the P content of the stem and/or leaf tissues. Increasing rates of phosphorus reduced the NO_3-N and Ca and increased the P and Mg content of the stem and/or leaf tissues. Excessive nitrogen can cause the plant to become vegetative at the expense of tuberization (39).

However, as was mentioned before, the placement and the time and rate of application of the nitrogen fertilizer are important factors in the correct nitrogen utilization. Although the search has been underway for over a century, there are still no reliable methods for answering the question, "How much, in what form, where, and at what time should a nutrient be added to give a large yield of a given crop of a desired quality?"

Calibration of nutrient diagnostic techniques, including soil and plant tissue testing, with known field responses, holds great promise for a more effective fertilization.

MATERIALS AND METHODS

Field Experiments

Two field experiments were established in 1968 at the following locations:

(a) M.S.U. Soil Experimental Farm, located near East Lansing on the SW 1/4 of NE 1/4 of SE 1/4, section 19, T4N, R1W, Meridan Township, Ingham County.

(b) Montcalm Experimental Farm, located on the SW 1/4 of SW 1/4 of section 8, T11N, R7W, Douglass Township, Montcalm County.

The experiment at East Lansing was located on somewhat poorly drained Conover loam (Mollic ochraqualf). The soil at the Montcalm Experimental Farm was a well-drained McBride fine sandy locam (Alfio Frageorthod). Detailed descriptions of these two soils are given in Appendix A and Appendix B.

The nitrogen treatments outlined in Table 1 were imposed, using a randomized block design with four replications at each location. Nitrogen was supplied as NH_4NO_3. Plowdown applications were broadcast by hand before plowing. Banded nitrogen was metered from a belt-feed hopper and placed simultaneously with banded basal fertilizer (Table 2) in bands of 1-1/2 inches below and 2 inches to the side of the seed. Sidedressed applications were applied by hand just before bloom.

At the time of sidedressing, the Sebago variety at East Lansing had initiated stolons, but tuber enlargement had not commenced and no visible flower buds had formed. In the case of Russet Burbanks at Montcalm, flower buds had formed and tubers up to 1/2 inch in diameter were found under the hills.

Potatoes at both locations had been ridged just before sidedressing. The Burbanks were uniformly 10 to 12 inches high, but the foliage had not closed over the row. The Sebagoes at East Lansing were less advanced and extremely variable (4 to 10 inches).

This East Lansing plot area had been used in 1967 for an experiment involving rates of potassium ranging from zero to 400 pounds K per acre. Potatoes (Sebago variety) had been the crop grown. Carryovers of fertilizer and tillage effects and of disease from 1967 likely contributed to the variable development of Sebagoes at East Lansing in 1968.

The 1968 nitrogen treatments were placed at right angles to the plots which received varying K treatments in 1967. Plot sizes were such that each N treatment overlapped two 1967 K treatments. This made it possible to examine the 1968 data for possible residual effects of varying K applications the previous year. Data will be presented which show that residual K effects were negligible in relation to effects of the 1968 N treatments.

The Burbanks at Montcalm were in the first year of a three-year rotation experiment. This area was clean-fallowed in 1967.

The additions of P and K in basal fertilizer at East Lansing (Table 2) were greater than at Montcalm because of an error in machine calibration for the banded application.

Certified B-size seed was used for both varieties. The Burbanks were spaced 14 inches apart in 32-inch rows. Sebagoes were spaced 9 inches in 32-inch rows. A 10-day spray program was followed for control of insects and blight. Supplemental irrigation (.75 to 1.5 inches per application) was given twice at East Lansing and 7 times at Montcalm (see Figures 1 and 2).

The two center rows of 4-row plots were harvested for yield and specific gravity determinations. Forty linear feet of row was harvested at East Lansing and 50 feet at Montcalm on October 14 and September 27, respectively.

Soil Tests

At each location, soil samples were taken twice, during the season: (1) just before the sidedressed application of nitrogen, and (2) again in August when rapid tuber enlargement

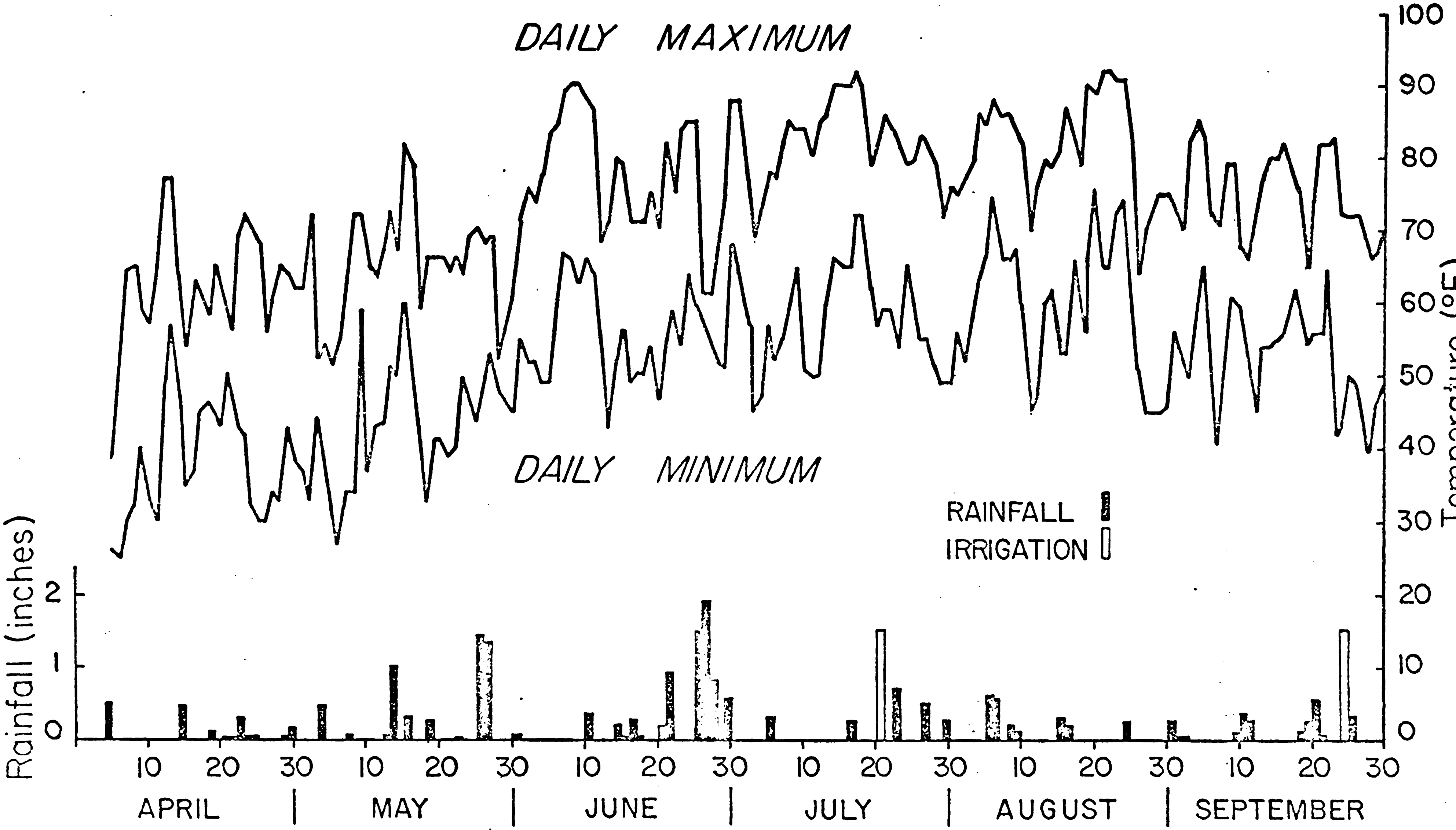

Figure 1. Air temperatures, rainfall and irrigation at East Lansing.

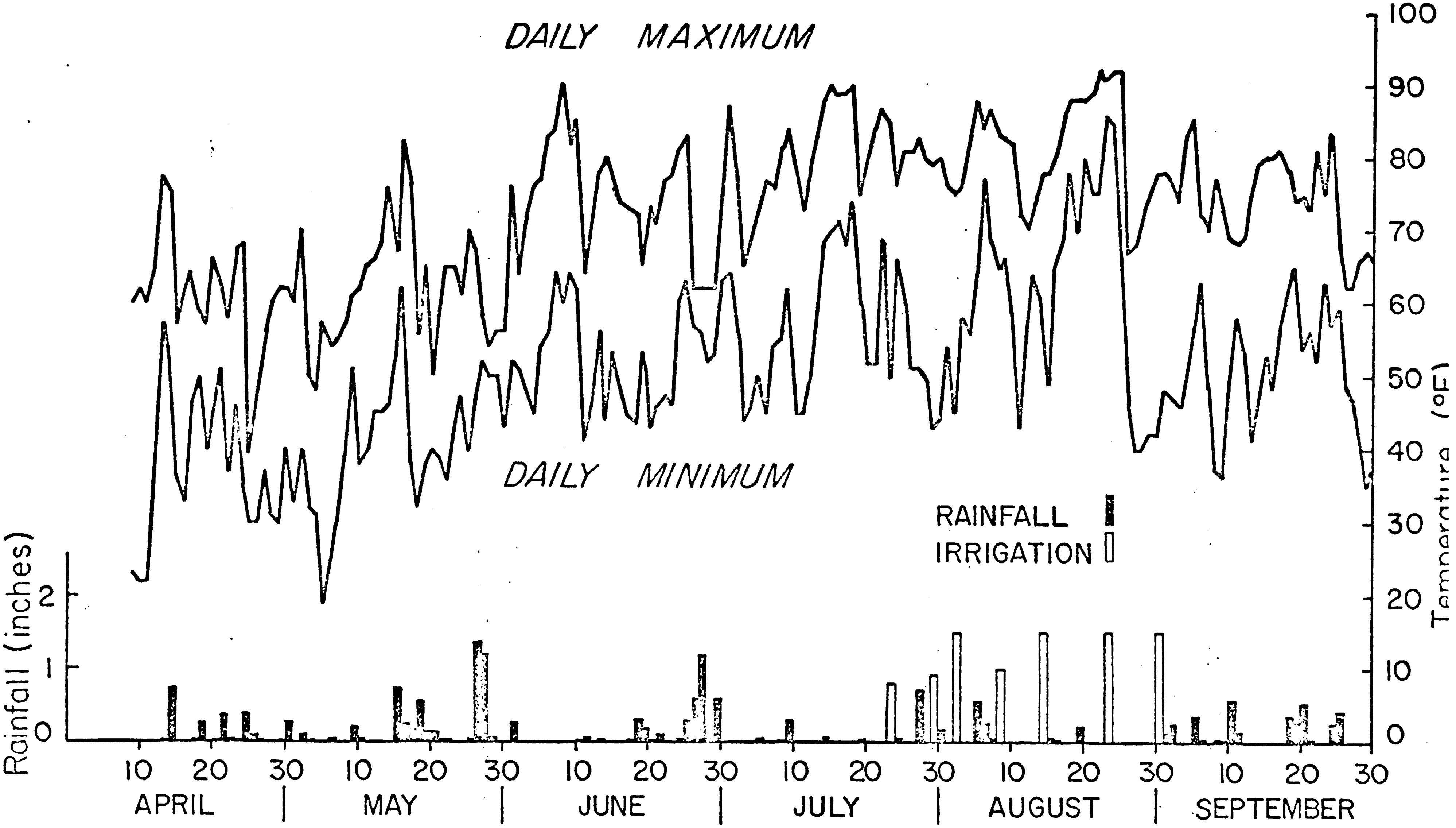

Figure 2. Air temperatures, rainfall and irrigation at Montcalm.

was evidenced by the presence of several B-size tubers per hill (August 13 at East Lansing and August 1 at Montcalm).

Twenty cores through the plow soil (0 to 10 inches) were composited for each plot and screened in the field to remove pebbles and trash (4 mesh screen). Subsamples were spread out in thin layers to dry quickly at 30 to 40 C. They were then ground to pass an 18 mesh sieve before analysis.

Nitrate nitrogen was determined in the samples taken on both dates. Samples were extracted (1:4) with .02N $CuSO_4$ by the method of Jackson (19). Nitrate was determined by a modification of the brucine method described by Greweling and Peech (14). Colorimeter readings at 420 mu were compared with a standard curve covering a range from .3 to 3.0 ppm NO_3-N.

Additional soil tests were run only on the August sampling. Soil pH was determined by glass electrode in 1:1 water suspensions. Lime requirement was estimated using the p-nitrophenol, triethanol-amine buffer of Shoemaker and others (35). Available P was estimated colorimetrically in the Bray P_1 extractant (19).

Exchangeable bases were estimated in Morgan's sodium acetate-acetic acid extracting solution (14). A Coleman flame emission spectrophotometer was used for exchangeable K, with comparisons at 383 mu to a curve with a top standard of 50 ppm. Percent absorbance at 212 mu and 285 mu in a Perkin-Elmer Model 290 atomic absorption unit were compared to standard curves with top standards of 40 ppm Ca and 4 ppm Mg. Results are reported in ppm on the basis of air-dry soil.

Quick Tissue Tests

At the same times that soil samples were taken, quick tests for nitrate in potato petioles were made in the field during the middle of the day (10:00 a.m. to 3:00 p.m.). There was no cloud cover.

For this test, the newest fully developed leaf on the stalk was selected from eight randomly selected plants in the two central rows of each plot. The petiole was cut diagonally with a sharp knife. A drop of 0.2% diphenylamine in concentrated sulfuric acid (22, 12) was placed on the exposed petiole cross section. The intensity of the blue color and the rate of its development were used to rate each petiole on a six-point visual scale. Visual ratings of "zero", "very low", "low", "medium", "high", and "very high" were converted to an exponential numerical scale:

0, 1, 2, 4, 8, and 16. These numerical values for eight petioles were averaged to arrive at a numerical index (QTN) of quick test tissue nitrate for each plot. (The exponential scale was used to approximate Beer's law of light transmission by colored solutions).

Petiole Analyses

A sample comprised of 60 petioles was composited from each plot on July 30 at the Montcalm location and on August 10 at East Lansing. Six petioles representing the fourth or fifth newly developed leaf on a stalk were taken from 10 randomly selected hills in the two central rows of each plot. The samples were dried in a forced draft drier at 70 C. They were then ground in a Wiley mill to pass a 40-mesh screen.

The dried and ground samples were extracted (1:100) with 2% acetic acid. Activated charcoal (1/2 teaspoon per 100 ml) was added to remove interfering pigments.

Nitrate-N, P, K, Ca and Mg were determined in this extract by the same procedures described above for soil samples. Results are reported as percent, dry weight basis.

The petiole samples were collected during the middle of the day (10:00 a.m. to 3:00 p.m.). There was no cloud cover.

Statistical Treatment

Analysis of variance in accordance with a randomized block design was employed to examine the relationship of nitrogen fertilizer treatments to the different soil and plant parameters. Multiple correlation and regression analyses were used to differentiate relationships to rate of N within times of application. Linear and multiple correlation analyses were used to examine interactions among the various nutrients in soils and in petioles (40).

The Michigan State University computing facilities were used for these analyses. Analysis of variance and least squares programs described by Ruble and associates (32) were employed.

RESULTS AND DISCUSSION

Potato Yields And Specific Gravity

At both locations, response to fertilizer nitrogen was shown by significant increases in yield of total tubers and in the percentage of A-size tubers (Table 3). The percentage A-size increased with total yield, the linear correlations between them being highly significant (at East Lansing r = .842, at Montcalm r = .795). There were no significant effects of treatment on specific gravity, although at both locations the highest specific gravities were associated with total N applications of 180 pounds in treatments 7 or 8.

In Figure 3, mean yields for all treatments at each increment of total fertilizer N are plotted graphically. The total yields of Russet Burbanks at the Montcalm location were similar to those for Sebagoes at East Lansing. However, the lower grading percentage for Burbanks resulted in yields of A-size tubers at Montcalm which were lower by 60 percent or more. The difference in grading percentage was probably influenced by the fact that the Burbanks were harvested about two weeks earlier (September 27 vs. October 14). However, the long shape of the Burbanks normally gives this result.

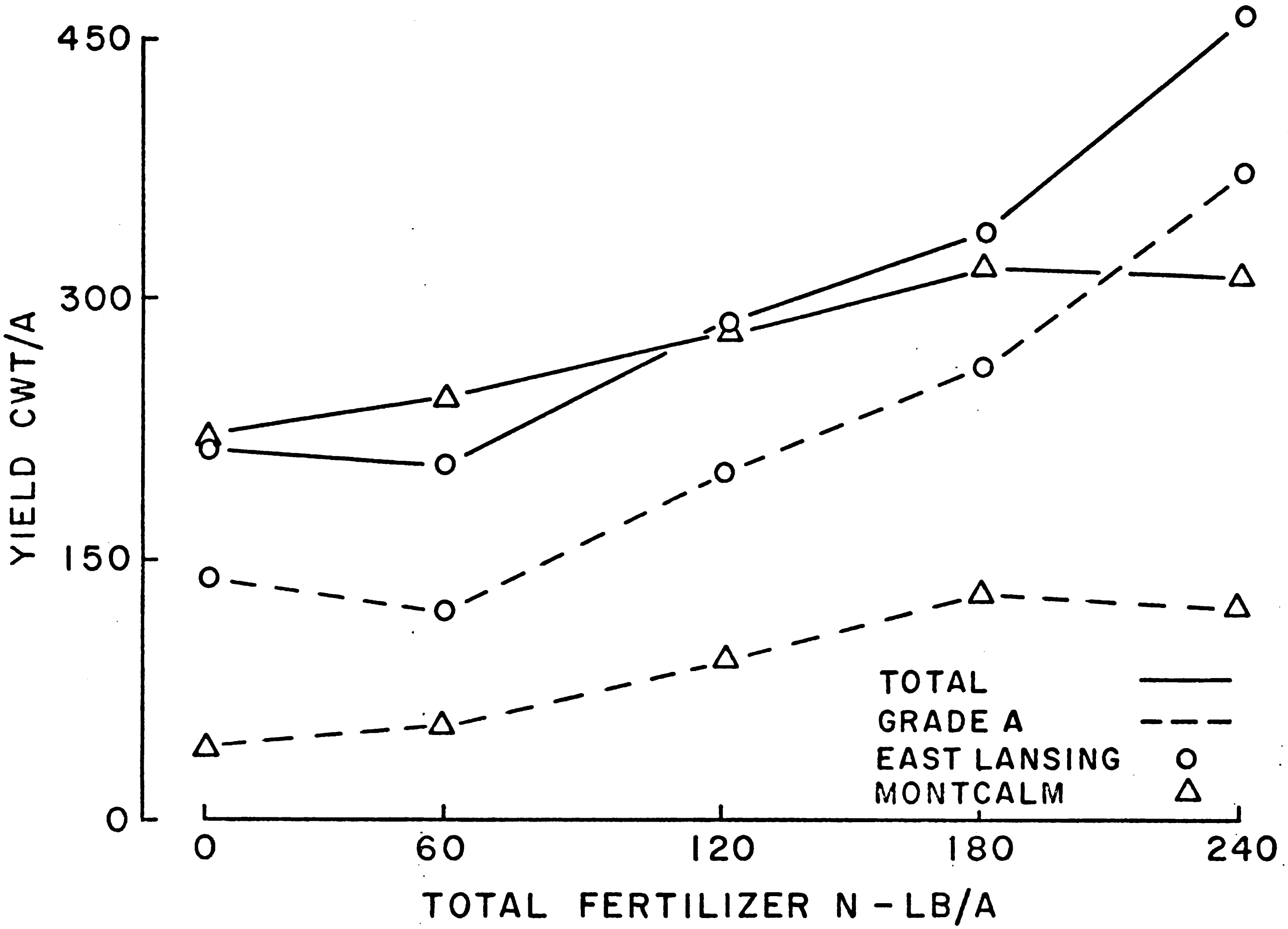

Figure 3. Yields of total and Grade A tubers in relation to total fertilizer N applied.

Total and Grade A yields at East Lansing increased with each increment of total fertilizer N above 60 pounds per acre. At Montcalm, yields leveled off above 180 pounds.

These relationships in Figure 3 do not reflect the very marked differences in effectiveness of nitrogen applied at different times. Linear correlation coefficients in Table 4 indicate that plowdown nitrogen was relatively ineffective in influencing yields at both locations. At East Lansing, yields reflected mainly the influence of sidedressed nitrogen. At Montcalm, both banded and sidedressed N influenced yields significantly.

The evidence in Table 4 is not completely reliable, since neither experiment was set up as a complete factorial of rates x times of application (cf. Table 1). However, the relatively lower efficiency of plowdown nitrogen can be observed in differences in response to different treatments in Table 3.

When 120 pounds of N was split between banded and side-dressed applications (Treatment 4), total yields were greater at both locations than when 120 pounds was plowed down (Treatment 5) or split between plowdown and banded applications (Treatment 3). When 60 pounds of N was banded at East Lansing, yields were significantly higher when an additional 120 pounds was sidedressed later (Treatment 8) than when the additional 120 pounds had been plowed down (Treatment 7).

Two factors may have contributed to the relatively lower efficiency of plowdown nitrogen. In the first place, the plowdown nitrogen cannot contribute to the rapid early development of the potato plant. In the second place, a large proportion of the plowdown N was likely leached by heavy rains to depths where it was not available for the rest of the season (cf. figures 1 and 2).

Rainy periods followed the mid-May plantings at both locations. The latter half of June was also wet and cool, with frequent rains. A series of moderate to heavy rains during the last two weeks of June resulted in greater precipitation at East Lansing than at Montcalm (6.63 inches vs. 3.47). This would have contributed to the apparently lower effectiveness of banded N at East Lansing than at Montcalm.

At both locations, the apparent nitrogen requirement was greater than the 80 to 150 pounds per acre which past experience has indicated to be adequate for maximum yields in Michigan (12). It appears that leaching losses during the cool, rainy, humid periods in late May and late June may have reduced the efficiency of both plowdown and banded N at both locations.

Soil and Petiole Nitrate

The probability that extensive leaching of nitrate occurred is strengthened by the low recoveries of nitrate in the plow soil (0-10 inches) at both locations (Table 5). Nitrate-N in concentrations up to 20 ppm or more is frequently encountered in the plow soil of Michigan potato fields at mid-season or later (12). There is evidence that, under Michigan conditions, soil concentrations less than 20 ppm NO_3-N may be inadequate for several crops during critical mid-season periods in their development (13, 24).

Maximum levels of soil nitrate in Table 5 were very much less than 20 ppm. The fact that significant differences between treatments could be shown over the range of 0.5 to 6 ppm is evidence of the sensitivity of the $CuSO_4$ extraction and brucine analysis procedures that were used.

The July samplings in Table 5 were made just before the sidedressed nitrogen was applied. At East Lansing, similar soil tests for nitrate would have been expected at this time on treatments 7 and 11. Practically speaking, there was no difference even though nitrate was significantly higher with treatment 11. This apparently was due to the fact that two replications of treatment 11 were on soil of higher inherent fertility.

At the Montcalm location in this July sampling, soil nitrate levels significantly higher than the control were found in plots which had received banded nitrogen.

In the August sampling, only the plots which received 120 pounds of N in the sidedressed application at Montcalm were significantly higher in soil nitrate than the control plots. Although this was the highest yielding treatment (Table 3, Treatment 8), the 6 ppm of NO_3-N observed would have to be considered deficient in the light of previous experience in Michigan.

Two possible explanations for the low soil nitrate values at both locations appear: (1) air-drying of soil samples may have resulted in disappearance of nitrate by microbial processes, which is unlikely, or (2) the plants had access to nitrogen in forms or at soil depths which were not reflected in the tests for nitrate in the plow soil.

The latter probability is supported by the field quick tests (Table 6) for petiole nitrate. Previous experience in Michigan indicates that a "high" quick test (QTN = 8) or a petiole nitrate content of 1.5 to 2% are in the range of adequacy for potato development during the period of rapid tuber enlargement after tuber initiation (46). This range is somewhat higher than critical levels of 1 to 1.4 percent NO_3-N which have been reported by others (44, 46).

On this basis, the data in Tables 6 and 7 indicate that nitrogen was not critically limiting in August at either location with any treatment which included a sidedressed application. At East Lansing, the sidedressing was necessary to maintain 1.5% or higher nitrate-N in the petioles to this critical period of plant and tuber development. At Montcalm, the sidedressing was not necessary if the total N applied was 120 pounds or more and at least a part of the nitrogen was banded (Treatments 3, 6, 7, and 10).

Thus, nitrogen was available to the crop at both locations in amounts which greatly exceeded the amounts indicated by the soil tests in Table 5. As a result, the soil tests were of low diagnostic value in these experiments.

The scatter diagrams in Figures 4 and 5 show that yields were poorly correlated with either the July or the August soils tests at East Lansing. The relationships at Montcalm were somewhat better, but they indicated a leveling off of yields at much lower levels of soil nitrate than past experience in Michigan would support as realistic (12, 13, 24).

At the Montcalm location (Figure 5) there were useful correlations between yields and both the QTN and petiole nitrate values in August. Critical levels to be inferred from these graphs would be QTN = 8 and petiole NO_3-N = 2%.

These estimates of critical level are based, not on the quadratic functions drawn, but on the distribution of scatter points. The distribution of these points would be

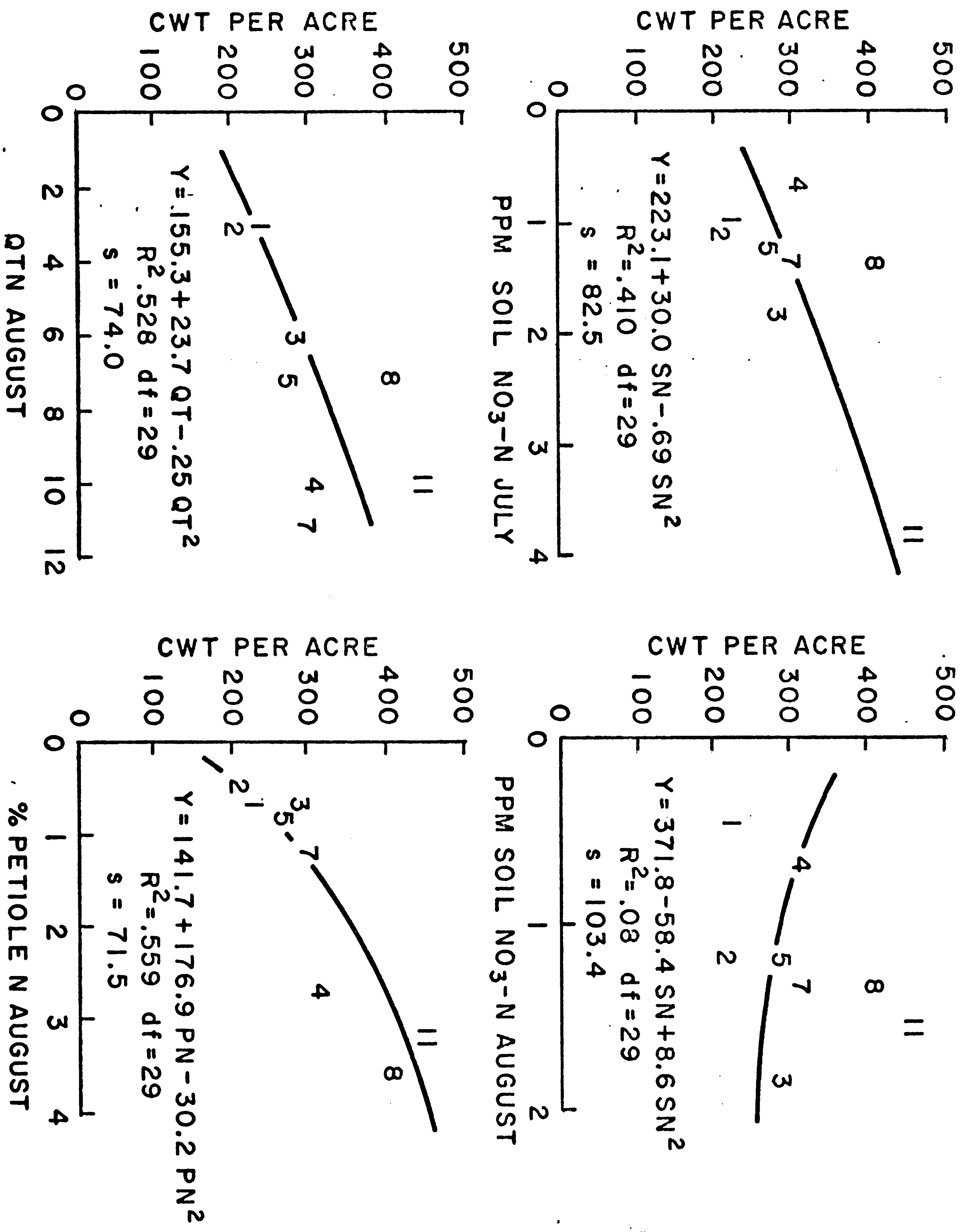

Figure 4. Total tuber yields of Sebagoes in relation to soil and petiole nitrate at East Lansing, 1968. (Numbers correspond to N treatments in Table 1.)

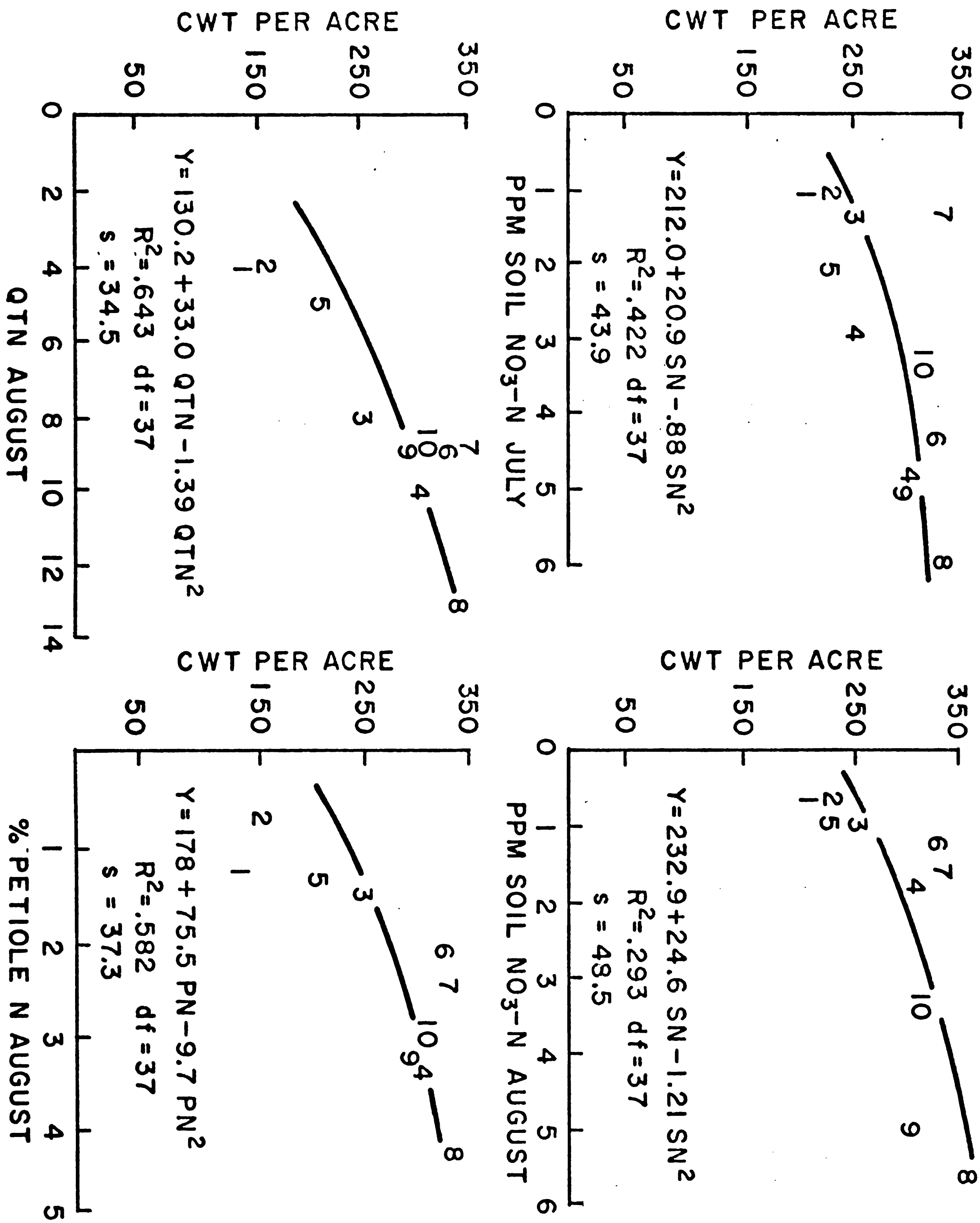

Figure 5. Total tuber yields of Russet Burbanks in relation to soil and petiole nitrate at Montcalm, 1968. (Numbers correspond to N treatments in Table 1.)

better defined by two straight line segments: (1) a positive response segment and (2) a horizontal segment representing adequacy. By definition, the intersection of these two segments is taken as the "critical level" (48).

The data for East Lansing in Figure 4 are not inconsistent with these critical levels. The scatter of points is greater than for Montcalm. This reflects the great soil variability at the East Lansing location.

The QTN scale in Figures 4 and 5 was derived by arbitrarily assigning an exponential series of numbers to descriptive visual estimates of color developed in the field tissue test. The essentially quantitative correspondence between the exponential QTN scale and the nitrate content of petioles is demonstrated in Figure 6. The degree of linearity expressed here is encouraging since it indicates that the colorimetric field test can be calibrated in terms of nitrate content. The standard error of estimate indicated by these data ($s = .43$) could be materially reduced by use of a color chart or a series of permanent color standards (25).

Other Nutrients

There were no significant effects of treatment on soluble P in potato petioles at either location (Table 7). The level

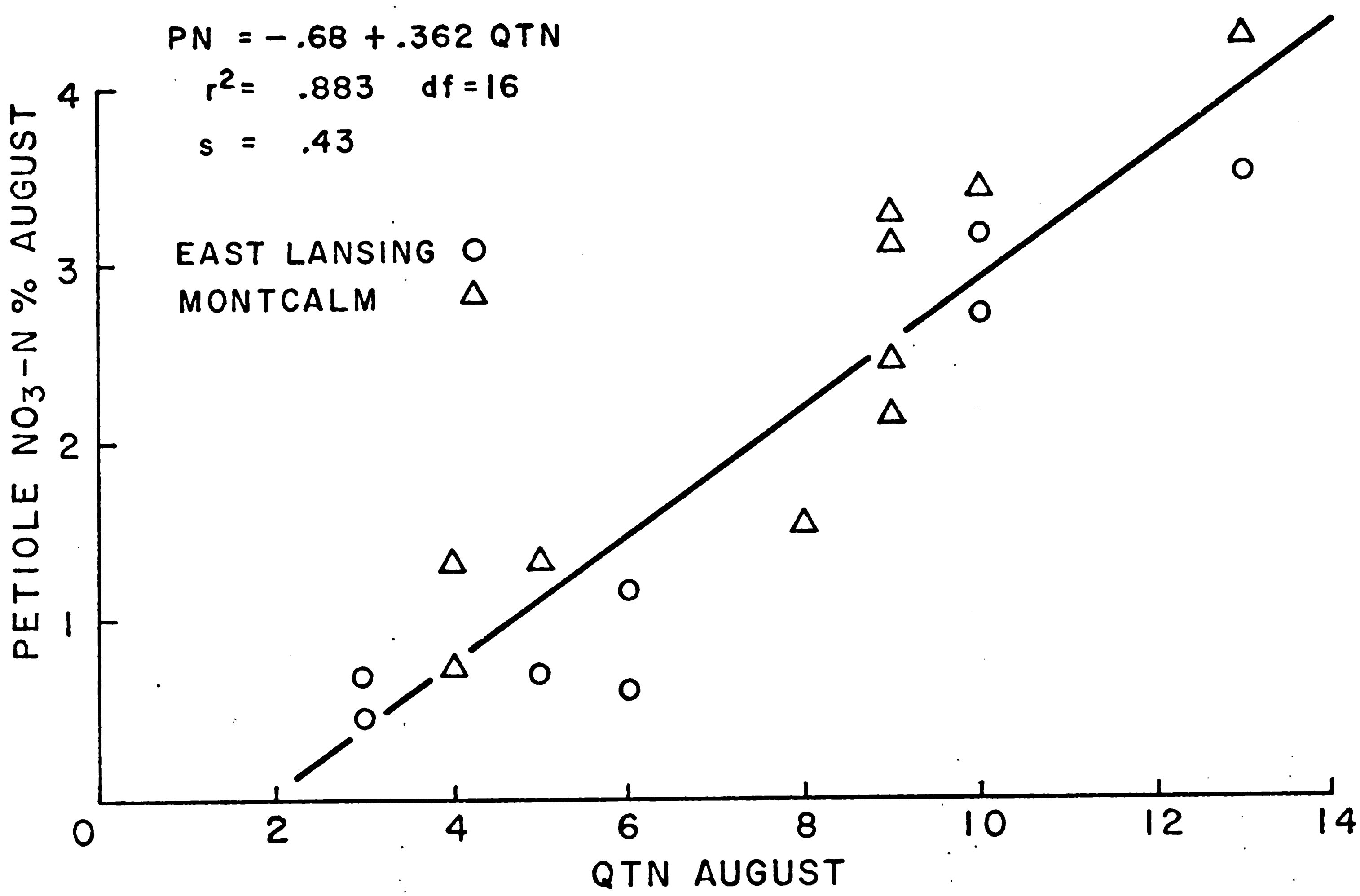

Figure 6. Treatment means for petiole nitrate in relation to mean QTN values in August.

of petiole P in Sebagoes at East Lansing was double that in Russet Burbanks at Montcalm. This was probably due, in part, to the much higher basal application of fertilizer phosphorus at East Lansing (cf. Table 2), since soil phosphorus was higher at Montcalm and very high at both locations (Table 9).

All of the values in Table 7 for soluble petiole phosphate in Burbanks at Montcalm are 0.1% P or less. Tyler _et al_. (46).

The heavy basal application of potash at East Lansing must have contributed to the somewhat higher levels of K in the petioles here than at Montcalm (Table 8), since soil K levels were up to 50% lower at East Lansing (Table 10). Petiole K was significantly reduced by applications of fertilizer N at East Lansing, and there was a similar tendency at Montcalm. None of the values at either location was less than 7.0% which California studies would indicate to be a critical level (25).

Petiole Ca was higher at East Lansing, petiole Mg was much lower, than at Montcalm (Table 8). The lower Mg in petioles at East Lansing was associated also with lower soil tests for Mg (Table 10).

It must be recognized that varietal differences may have contributed also to the above differences between locations in levels of soluble petiole nutrients.

Nutritional Interactions With Nitrogen

Treatment means in Tables 6, 7, and 8 give evidence that potato response to nitrogen fertilizer treatments may have involved rather complicated interactions among the various nutrients. Some of these interactions in their relation to time of fertilizer N application can be seen in Table 11.

Nitrate in the petioles in August reflected mainly the nitrogen supplied in the sidedressed applications at both locations. The banded application was reflected to a lesser extent and the plowdown not at all.

There was a marked tendency for soluble P and K in the petioles to decrease as the applications of fertilizer N increased. However, this effect was not so clearly related to time of application as it was in the case of petiole nitrate. Thus, there did not appear to be a simple reciprocal relationship among sap concentrations of these three nutrients.

Increases in petiole Ca, on the other hand, were related to times of application at both locations in a manner similar to petiole nitrate. A similar relation to time of application was expressed for Mg at Montcalm but not at East Lansing, where the principal increases in Mg content were associated with the plowdown application.

Interactions, within the plant, among K, Ca and Mg were uniquely different at the two locations. This can be seen in the linear correlations presented in Tables 12 and 13.

The last two columns in the second half of Table 12 show that residual K from the 1967 potash experiment at East Lansing had negligible effects on soil and plant parameters relative to the effects of fertilizer N applied in 1968.

Petiole K decreased as soluble Mg increased at both locations. A similar negative correlation between PK and PCa was expressed only at Montcalm.

At both locations, increasing rates of fertilizer N were associated with reductions in petiole K and P and reductions in soil K, Ca and Mg. The statistical significance of these changes were generally low but the probabilities for several were greatly improved when time of N application was taken into consideration.

Multiple correlation analyses of East Lansing data are presented in Table 14 to show how soil K and petiole K and Mg were related to quantities of N in each of the three applications.

The probabilities (P_R) for significance of the overall functions were at a 1 percent or lower level of chance. The signs of the regression coefficients and their probabilities (P_b) indicate that both soil and petiole K were reduced by plowdown and banded applications of N, but that the sidedressed applications promoted increases in both.

The corresponding functions for Montcalm data (Table 15) differed in that decreases in soil and petiole K were associated with all three applications.

The statistical probabilities are less impressive for the Montcalm data. It is suggested, nevertheless, that declines in soil and petiole K accumulated over the three applications may have contributed to the highly significant increases in petiole Mg associated with the sidedressed application at Montcalm. It is further suggested that the increases in soil and petiole K associated with the sidedressing at East Lansing would have tended to oppose differential accumulation of petiole Mg at this time, so that the principle increases in Mg were associated with the plowdown application at East Lansing.

In support of these suggestions, it is to be noted that soil tests for nitrate indicate that much of the applied nitrogen at both locations had leached out of the plow soil by August. The nitrate would have been accompanied by bases. In plowdown and banded applications, it is likely that nitrate would have been accompanied preferentially by fertilizer K. Thus, the effect of percolating nitrate would have been to reduce the availability of K relative to Ca and Mg where NH_4NO_3 was placed in the vicinity of plowdown KCl at

East Lansing and, at both locations, where NH_4NO_3 was banded with the K in 0-20-20.

Soluble phosphate in the petioles decreased with increasing fertilizer N (Tables 12 and 13). At East Lansing (Table 16) this reduction was rather closely associated with the banded application (P_b = 9%) and with a reduction in soil P extractable with the Bray P_1 extractant. At Montcalm (Table 17), reductions in soluble petiole P were associated with both plowdown and banded N and with decreases in soil pH.

The data in Tables 16 and 17 suggest that phosphate equilibria in the soil were influenced by NH_4NO_3 and that acidity produced in the vicinity of nitrifying ammonium may have been involved.

The interactions within the plant between anionic nutrient's (nitrate and phosphate) and cationic nutrients (K, Ca and Mg), which can be inferred from their intercorrelations in Tables 12 and 13, suggest that nitrate competed with phosphate in maintaining a balance between cations and anions in nutrient uptake. A major source of P would have been the fertilizer band. The dominant cation in the fertilizer band would have been the K banded with the P. Thus, it is not surprising that petiole P and K were rather highly intercorrelated.

The soil was the major source of Ca and the only source of Mg. Because of its mobility, nitrate would have been the principal anion to accompany these two cations into the plant. The uptake of these two cations apparently increased as the quantity of nitrate added or formed in the soil increased.

It is apparent from data plotted in Figure 7 that nutritional interactions between plant and soil and among nutrients in the plant may be very complex. The effect of a fertilizer is more than to increase the supply of the added nutrient. It also alters the relation of the plant to other nutrients. The form of the nutrient, its placement and the time of application are further complicating factors, as are rainfall patterns or irrigation practices which give rise to mass movements of soluble nitrate salts.

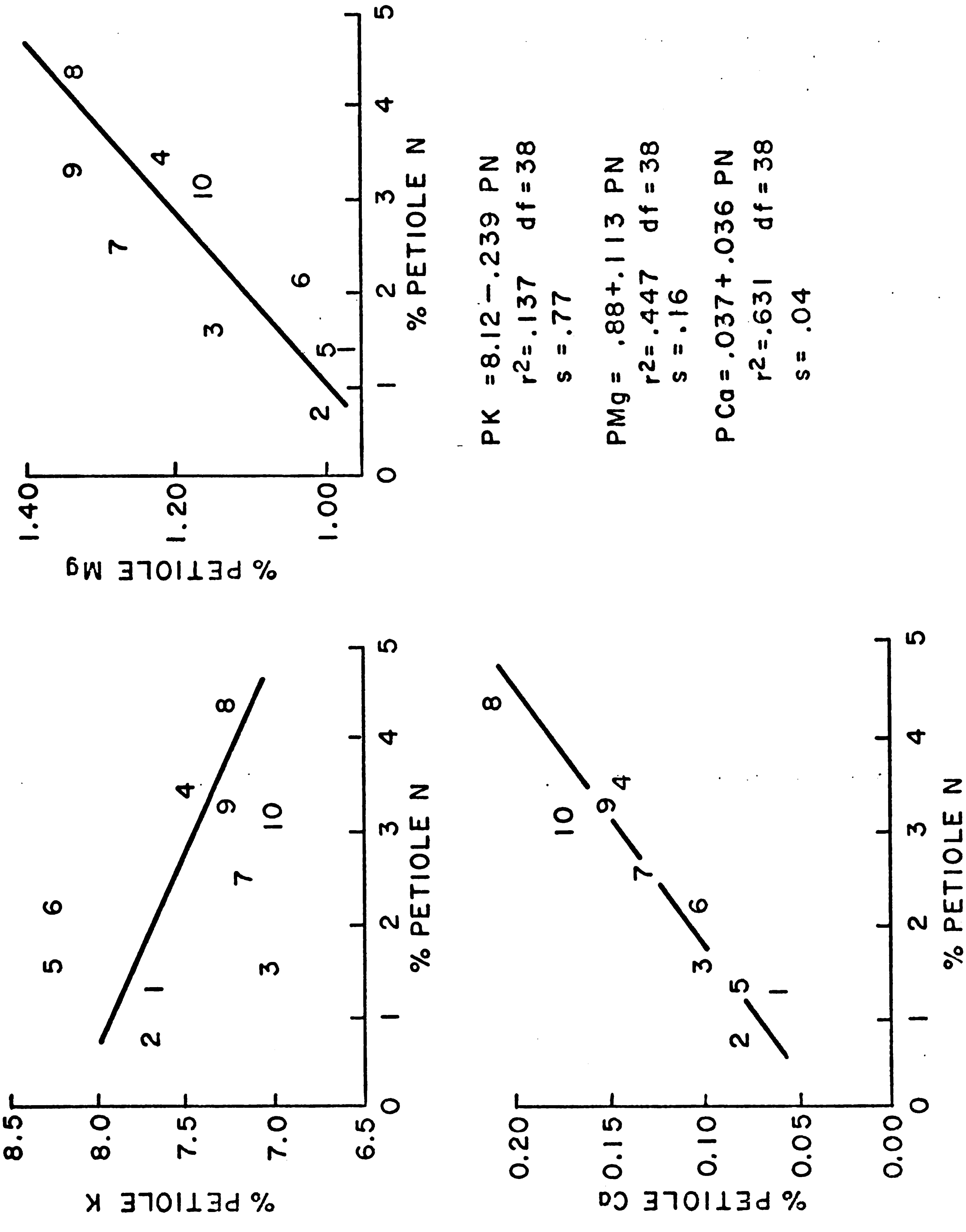

Figure 7. Petiole K, Ca and Mg in relation to petiole N at Montcalm.

SUMMARY AND CONCLUSIONS

The relative diagnostic usefulness of soil and petiole tests for nitrate was studied in two field experiments in which time and rate of nitrogen fertilization were varied. Two varieties of potatoes (Solanum tuberosum) were used. The Sebago variety was grown on Conover loam at East Lansing, and Russet Burbanks were grown on McBride sandy loam at Montcalm.

Soils and petioles were sampled twice for nitrate determinations: (1) at about the time of tuber initiation just before flowering in July, and (2) after rapid tuber enlargement was evidenced by the presence of several B-size tubers (1-1/2 to 2 inches diameter) per hill in August.

A rapid visual field test for petiole nitrate was converted to an arbitrary exponential scale (QTN) for numerical analysis and comparison with quantitative determinations of nitrate in extracts of petioles and of soils.

Nutritional interactions between nitrate and extractable P, K, Ca, and Mg were also examined in the August samplings of soils and petioles.

Analysis of variance and simple and multiple correlation and regression analyses were used in evaluating relationships that existed.

The results of these analyses may be summarized as follows:

1. Response to fertilizer nitrogen was significant in yield of total tubers and in percentage of A-size tubers. No significant effects on specific gravity were observed.
2. Plowdown nitrogen was relatively ineffective in influencing yields at both locations. Both banded and sidedressed nitrogen influenced yields of Burbanks at Montcalm, but at East Lansing the major yield responses with Sebagoes were associated with the sidedressed applications.
3. At Montcalm, a total of 180 pounds fertilizer N per acre was adequate for maximum yields, but at East Lansing additional yield increases occurred at 240 pounds.
4. These unusually high N requirements and the relative inefficiency of plowdown N were due to extensive leaching of nitrate during cool, humid periods of frequent rains in late May and late June.
5. Because of extensive leaching, nitrate levels in the plow soil (0-10 inches) in July and August were unusually low (0.5 to 6 ppm). For this reason the soil tests for nitrate were of low diagnostic

value in both of these experiments. It is likely that their value would have been much greater if samples had been taken to greater depth.

6. Both the QTN indices and the quantitative determinations for petiole nitrate gave very useful correlations with tuber yields of Burbanks at Montcalm. The graphical estimates of "critical level" were QTN = 8 and petiole NO_3-N = 2.0 percent. These values are based on petioles sampled when rapid tuber enlargement was evidenced by the presence of several B-size tubers per hill.
7. Because of greater soil variability at East Lansing and greater scatter of experimental poils, estimates of "critical levels" for Sebagoes were less precise but consistent with those for Burbanks at Montcalm.
8. There was a very strong linear relationship between quantitative values for nitrate in petioles and the exponential QTN index. This indicates that the quick field test can be calibrated in terms of petiole nitrate content.
9. Soluble P and K in petioles were reduced by N fertilizer application at both locations and soluble petiole Ca and Mg were increased. Effects on petiole K and Mg were associated principally with plowdown applications at East Lansing, whereas

effects on petiole Mg at Montcalm were associated primarily with the sidedressing. Increases in petiole Ca at both locations were associated with the sidedressing.

10. Soluble P, K, and Ca in petioles were higher in Sebagoes at East Lansing than in Burbanks at Montcalm. This may have been due to varietal differences, or it may have reflected the higher basal application of 0-20-20 at East Lansing.
11. Petiole P and K were positively correlated with each other. Both were negatively correlated with petiole nitrate, Ca, and Mg.
12. Exchangeable K, Ca and Mg in August soil samples were lower in plots receiving N fertilizer than in control plots. Reductions associated with plowdown or banded applications were significant or approaching significance at East Lansing. Reductions at Montcalm were at a lower order of significance but were associated also with sidedressed N applications. These reductions probably reflect leaching of these bases in association with nitrate.
13. Extractable P was lower in soils receiving plowdown or banded N at East Lansing. Soil pH was lower at Montcalm in soils receiving plowdown or sidedressed

applications. At both locations, acidity released by nitrification of ammonium from NH_4NO_3 may have contributed to reduced availability and uptake of P and the lowered levels of phosphate P in the petioles.

14. At both locations, petiole phosphate tended to be negatively correlated with total fertilizer N and with petiole nitrate. This suggests that nitrate competed with phosphate in maintaining a balance between anions and cations in root uptake. Banded 0-20-20 would have been an important source of phosphate. The dominant cation to accompany P into the root from the fertilizer band would have been K (and to a lesser extent, Ca). The positive correlations between petiole P and K would reflect this positional association of these two nutrients in the fertilizer band. The strongly positive correlations between petiole nitrate, Ca and Mg, on the other hand, would reflect the positional mobility of nitrate in the soil and the fact thatnitrate would have a better chance of being accompanied into the root by Mg and Ca from soil sources than would the phosphate in the fertilizer band.

15. The overall effect of interactions in uptake of nitrate, phosphate, K, Ca, and Mg was such that petiole phosphate concentration was reduced as the rate of plowdown and/or banded fertilizer N increased. In the case of Russet Burbanks at Montcalm, these interactions may have made P the first limiting nutrient in all treatments which received fertilizer N.

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LIST OF TABLES

Table 1. Nitrogen treatments

Treatment No.	Pounds N per acre in NH_4NO_3			N Total
	Plowdown	Banded	Side-dressed[3]	
1	0	0	0	0
2	0	60	0	60
3	60	60	0	120
4	0	60	60	120
5	120	0	0	120
6[1]	0	120	0	120
7	120	60	0	180
8	0	60	120	180
9[1]	60	60	60	180
10	180	60	0	240
11[2]	120	60	60	240

[1]Montcalm location only.

[2]East Lansing only.

[3]Sidedressings applied by hand July 3 at East Lansing, July 5 at Montcalm.

Table 2. Basal fertilizer

Location	Pounds per acre N-P-K		
	Plowed down	Banded	Total
East Lansing	0-0-138	0-105-200	0-105-338[1]
Montcalm	0-0-0	0-44-166	0-44-166[2]

[1] 0-240-405 expressed as N-P_2O_5-K_2O

[2] 0-100-200 expressed as N-P_2O_5-K_2O

Table 3. Potato yields and specific gravity in relation to time and rate of N fertilizer

Treatment No.	Fertilizer N				East Lansing[1]			Montcalm[2]		
	Plow-down	Banded	Sidedr.	Total	Yield cwt	Grade %	Sp. Gr.	Yield cwt	Grade %	Sp. Gr.
1	0	0	0	0	214.6	64.3	1.0713	218.8	20.3	1.0810
2	0	60	0	60	200.8	62.2	1.0723	235.0	23.0	1.0805
3	60	60	0	120	280.4	64.4	1.0735	265.0	30.5	1.0810
4	0	60	60	120	307.6*	73.9	1.0758	305.8*	38.8*	1.0813
5	120	0	0	120	273.2	73.4	1.0755	234.3	24.3	1.0815
6	0	120	0	120	-	-	-	328.8*	36.3*	1.0820
7	120	60	0	180	292.6*	72.4	1.0738	331.0*	39.5*	1.0828
8	0	60	120	180	395.8*	81.4*	1.0770	336.0*	39.3*	1.0820
9	60	60	60	180	-	-	-	302.3*	44.8*	1.0810
10	180	60	0	240	-	-	-	318.0*	39.5*	1.0795
11	120	60	60	240	452.6*	83.2*	1.0735	-	-	-
LSD_{05}					74.8	10.2	N.S.	56.2	13.1	N.S.

[1]Sebago Variety [2]Russet Burbanks *Significantly different from treatment 1 at 5%

Table 4. Linear correlation coefficients (r) between crop parameters and inputs of fertilizer N

	Plow-down	Banded	Side-dressed	Total fertilizer
East Lansing[1]				
Total tubers	.266	.329	.591**	.692**
Grade A %	.240	.176	.508**	.565**
Specific gravity	.021	.109	.339	.262
Montcalm[2]				
Total tubers	.112	.545**	.353*	.598**
Grade A %	.161	.419**	.370*	.593**
Specific gravity	-.089	.050	.078	-.010

[1]df = 30

[2]df = 38

*significant at P_{05}

**significant at P_{01}

Table 5. Nitrate-N in soil in July and August, 1968, in relation to time and rate of N fertilizer

Treat-ment No.	Fertilizer-N Plow-down	Banded	Sidedr.	Total	East Lansing SNO_3 July	SNO_3 Aug.	Montcalm SNO_3 July	SNO_3 Aug.
					ppm	ppm	ppm	ppm
1	0	0	0	0	1.0	.5	1.1	.7
2	0	60	0	60	1.0	1.2	1.1	.7
3	60	60	0	120	1.8	1.2	1.4	1.0
4	0	60	60	120	.7	1.3	4.9*	1.8
5	120	0	0	120	1.2	1.2	2.1	.9
6	0	120	0	120	-	-	4.4*	1.3
7	120	60	0	180	1.3	1.2	1.5	1.7
8	0	60	120	180	1.4	1.3	6.0*	5.7*
9	60	60	60	180	-	-	5.0*	1.6
10	180	60	0	240	-	-	3.4	1.6
11	120	60	60	240	3.9*	1.6	-	-
LSD_{05}					1.16	N.S.	2.68	1.52

*Significantly different from treatment 1 at 5%.

Table 6. QTN index of tissue nitrate in July and August, 1968, in relation to time and rate of N fertilizer

Treat-ment No.	Fertilizer N				East Lansing[1]		Montcalm[2]	
	Plow-down	Banded	Sidedr.	Total	QTN July	QTN Aug.	QTN July	QTN Aug.
1	0	0	0	0	6	3	8	4
2	0	60	0	60	7	3	12*	4
3	60	60	0	120	9	6*	12*	8*
4	0	60	60	120	8	10*	15*	10*
5	120	0	0	120	7	5	9	5
6	0	120	0	120	-	-	14*	9*
7	120	60	0	180	11	6*	12*	9*
8	0	60	120	180	7	13*	15*	13*
9	60	60	60	180	-	-	14*	9*
10	180	60	0	240	-	-	14*	9*
11	120	60	60	240	11	10*	-	-
LSD_{05}					N.S.	2.8	3.0	3.0

[1]Sebago Variety

[2]Russet Burbanks

*Significantly different from treatment No. 1 at 5%

Table 7. Nitrate-N and soluble P content of potato petioles, in August in relation to time and rate of N fertilizer

Treat-ment No.	Fertilizer N				East Lansing[1]		Montcalm[2]	
	Plow-down	Banded	Sidedr.	Total	Petiole N	Petiole P	Petiole N	Petiole P
					%	%	%	%
1	0	0	0	0	0.65	0.25	1.33	0.10
2	0	60	0	60	0.48	0.22	0.75	0.09
3	60	60	0	120	0.67	0.18	1.55	0.08
4	0	60	60	120	2.74*	0.17	3.41*	0.08
5	120	0	0	120	0.72	0.21	1.35	0.09
6	0	120	0	120	-	-	2.15	0.09
7	120	60	0	180	1.17	0.17	2.48*	0.07
8	0	60	120	180	3.56*	0.18	4.30*	0.08
9	60	60	60	180	-	-	3.29*	0.08
10	180	60	0	240	-	-	3.07*	0.07
11	120	60	60	240	3.18*	0.20	-	-
LSD_{05}					0.62	N.S.	1.07	N.S.

[1]Sebago Variety [2]Russet Burbanks *Significantly different from treatment No. 1 at 5%

Table 8. Potato petiole K, Ca and Mg content in relation to time and rate of N fertilizer

Treat-ment No.	Fertilizer N				East Lansing[1]			Montcalm[2]		
	Plow-down	Banded	Sidedr.	Total	Petiole K	Petiole Ca	Petiole Mg	Petiole K	Petiole Ca	Petiole Mg
					%	%	%	%	%	%
1	0	0	0	0	9.81	.21	.32	7.71	.06	.97
2	0	60	0	60	8.87*	.20	.43	7.74	.08	1.00
3	60	60	0	120	8.73*	.26	.47*	7.07	.10	1.15
4	0	60	60	120	8.91*	.43*	.40	7.56	.14*	1.24*
5	120	0	0	120	8.69*	.28	.56*	8.23	.08	.98
6	0	120	0	120	-	-		8.24	.10	1.03
7	120	60	0	180	8.46*	.30	.52*	7.20	.13*	1.27*
8	0	60	120	180	9.45	.53*	.47*	7.32	.21*	1.34*
9	60	60	60	180	-	-	-	7.44	.15*	1.33*
10	180	60	0	240	-	-	-	7.09	.17*	1.17
11	120	60	60	240	9.23	.43*	.52*	-	-	-
LSD_{05}					.60	.11	.13	N.S.	.05	.22

[1]Sebago Variety

[2]Russet Burbanks

*Significantly different from treatment No. 1 at 5%

Table 9. Soil pH, lime requirement and phosphorus in August in relation to time and rate of N fertilizer

Treat-ment No.	Fertilizer N				East Lansing			Montcalm	
	Plow-	Banded	Sidedr.	Total	Soil pH	Soil Lime R	Soil P	Soil pH	Soil P
						ppt	ppm		ppm
1	0	0	0	0	6.08	1.38	73.9	6.90	106.3
2	0	60	0	60	6.33	1.25	69.4	6.90	139.4
3	60	60	0	120	6.33	1.13	61.2	6.85	93.3
4	0	60	60	120	6.08	1.50	74.7	6.80	119.2
5	120	0	0	120	6.38	0.75	81.7	6.85	119.4
6	0	120	0	120	-	-	-	6.88	119.2
7	120	60	0	180	6.25	1.13	64.7	6.80	121.3
8	0	60	120	180	6.05	1.37	83.8	6.65*	116.9
9	60	60	60	180	-	-	-	6.83	103.4
10	180	60	0	240	-	-	-	6.80	132.5
11	120	60	60	240	6.20	1.25	66.9	-	-
LSD_{05}					N.S.	N.S.	N.S.	.13	N.S.

*Significantly different from treatment No. 1 at 5%

Table 10. Soil K, Ca, Mg in August, in relation to time and rate of N fertilizer

Treatment No.	Fertilizer N				East Lansing			Montcalm		
	Plow-down	Banded	Sidedr.	Total	Soil K	Soil Ca	Soil Mg	Soil K	Soil Ca	Soil Mg
					ppm	ppm	ppm	ppm	ppm	ppm
1	0	0	0	0	68.9	512.3	47.8	125.0	406.3	73.4
2	0	60	0	60	68.3	468.8	59.4	104.4	406.3	60.5
3	60	60	0	120	59.9	448.8	43.0	103.4	406.3	63.8
4	0	60	60	120	68.3	406.3	39.9	108.4	385.3	62.1
5	120	0	0	120	74.7	491.3	47.3	148.3	427.5	68.8
6	0	120	0	120	-	-	-	119.8	406.9	68.5
7	120	60	0	180	57.9	406.3	39.9	116.8	406.3	71.8
8	0	60	120	180	85.9	533.5	47.8	108.4	385.0	65.3
9	60	60	60	180	-	-	-	112.5	406.9	65.4
10	180	60	0	240	-	-	-	98.3	364.3	60.6
11	120	60	60	240	70.4	427.5	50.9	-	-	-
LSD_{05}					19.9	N.S.	N.S.	N.S.	N.S.	N.S.

Table 11. Linear correlation coefficients (r) between petiole nutrients and inputs of fertilizer nitrogen[1]

Location	Petiole Nutrient (August)	Plow-down N	Banded N	Side-dressed N	Total fertilizer N
East Lansing	NO_3-N	-.075	.442*	.906**	.653**
	P	-.064	-.369*	-.200	-.309
	K	-.388*	-.233	-.230	-.214
	Ca	-.028	.367*	.794**	.595**
	Mg	.573**	.131	.042	.531**
Montcalm	NO_3-N	.030	.271	.702**	.596**
	P	-.281	-.226	-.037	-.408**
	K	-.163	-.031	-.114	-.244
	Ca	.131	.266	.588**	.621**
	Mg	.075	.195	.470**	.469**

[1]Degrees of freedom: 30 at East Lansing; 38 at Montcalm

*Significant at P_{05}

**Significant at P_{01}

Table 12. Linear correlation coefficients (r) between soil and crop parameters, total fertilizer N (1968) and residual potassium from 1967 at East Lansing

	SNO_3 July	SNO_3 Aug.	QTN July	QTN Aug.	PN	PP	PK
SNO_3 July	1.000	-.073	.62**	.302	.281	.093	.194
SNO_3 Aug.		1.000	-.061	.115	.214	-.263	-.017
QTN July			1.000	.121	.150	.271	.125
QTN Aug.				1.000	.857**	-.446*	.094
PN					1.000	-.264	.254
PP						1.000	.397*
PK							1.000

Table 12, cont.

	PCa	PMg	Yield cwt	Sp. Grav.	% A	Total Fert. N	RESK
SNO_3 July	.358*	.232	.637**	-.208	.521**	.442*	.048
SNO_3 Aug.	.072	.003	-.076	-.118	-.123	.329	-.065
QT July	.357*	.224	.548**	-.241	.522**	.328	.111
QT Aug.	.811**	.265	.726**	.544**	.681**	.657**	.225
PN	.858**	.154	.685**	.357*	.616**	.653**	.063
PP	-.241	-.138	-.026	-.350*	.070	-.309	-.111
PK	.154	-.539**	.153	-.232	.200	-.214	.310
PCa	1.000	.317	.767**	.299	.692**	.595**	.201
PMg		1.000	.426*	.342	.448*	.531**	-.219
Yield cwt			1.000	.261	.842**	.692**	.171
Sp. Grav.				1.000	.339	.262	.050
% A					1.000	.565**	.246
Total N						1.000	-.059

*Significant at 5%

**Significant at 1%

Table 13. Linear correlation coefficients (r) between soil and crop parameters and total fertilizer N applied in 1968 at Montcalm

	SNO_3 July	SNO_3 Aug.	QTN July	QTN Aug.	PN	PP	PK
SNO_3 July	1.000	.554**	.475**	.519**	.626**	-.040	.093
SNO_3 Aug.		1.000	.348*	.544**	.624**	.055	-.010
QTN July			1.000	.652**	.677**	-.429**	-.393*
QTN Aug.				1.000	.803**	-.273	-.376*
PN					1.000	-.255	-.370*
PP						1.000	.407**
PK							1.000

Table 13, cont.

	PCa	PMG	Yield cwt	Sp. Grav.	% A	Total Fert. N
SNO_3 July	.436**	.302	.498**	.112	.545**	.398*
SNO_3 Aug.	.543**	.339*	.374*	.042	.365*	.360*
QTN July	.675**	.616**	.720**	-.016	.743**	.528**
QTN Aug.	.766**	.653**	.733**	.176	.600**	.538**
PN	.794**	.668**	.719**	.084	.666**	.596**
PP	-.420**	-.452**	-.372*	.071	-.232	-.408**
PK	-.614**	-.665**	-.269	-.147	-.164	-.244
PCa	1.000	.814**	.693**	.179	.597**	.621**
PMg		1.000	.582**	.381*	.537**	.459**
Yield cwt			1.000	.267	.795**	.598**
Sp Grav.				1.000	-.052	-.010
% A					1.000	.593**
Total N						1.000

*Significant at 5%

**Significant at 1%

Table 14. Soil K and petiole K and Mg at East Lansing as multiple regression functions of plow-down, handed and sidedressed fertilizer N

Independent variables	Soil K		Petiole K		Petiole Mg	
	Regression coefficients	P_b	Regression coefficients	P_b	Regression coefficients	P_b
Constant	169.	<.0005	9.4	<.0005	.36	<.0005
Plow-down N	-.124	.153	-.0032	.063	.0012	<.0005
Banded N	-.654	.002	-.0092	.022	.0004	.514
Sidedressed N	.332	.013	.0051	.041	.0004	.298
	$R = .627$		$R = .57$		$R = .620$	
	$R^2 = .393$		$R^2 = .33$		$R^2 = .384$	
	$P_R = .003$		$P_R = .01$		$P_R = .003$	

Table 15. Soil K and petiole K and Mg at Montcalm as multiple regression functions of plow-down banded and sidedressed fertilizer N

Independent variables	Soil K		Petiole K		Petiole Mg	
	Regression coefficients	P_b	Regression coefficients	P_b	Regression coefficients	P_b
Constant	260.	< 0.0005	7.9	< 0.0005	.94	< 0.0005
Plowdown N	-.049	.692	-.0032	.164	.0011	.034
Banded N	-.448	.052	-.0015	.724	.0013	.164
Sidedressed N	-.146	.451	-.0041	.255	.0031	< .0005
	$R = .344$		$R = .256$		$R = .576$	
	$R^2 = .118$		$R^2 = .066$		$R^2 = .332$	
	$P_R = 0.204$		$P_R = .479$		$P_R = 0.002$	

Table 16. Soil pH, soil P and petiole P at East Lansing as multiple regression functions of plow-down, banded and sidedressed fertilizer N.

Independent variables	Soil pH		Soil P		Petiole P	
	Regression coefficients	P_b	Regression coefficients	P_b	Regression coefficients	P_b
Constant	6.2	<.0005	158.	<.0005	.240	<.0005
Plowdown N	.0009	.48	-.0366	.71	-.0001	.52
Banded N	.0011	.71	-.4517	.05	-.0007	.09
Sidedressed N	-.0019	.29	.2761	.06	-.0001	.63
	$R = .276$		$R = .430$		$R = .390$	
	$R^2 = .076$		$R^2 = .185$		$R^2 = .152$	
	$P_R = .52$		$P_R = .12$		$P_R = .20$	

Table 17. Soil pH, soil P and petiole P at Montcalm as multiple regression functions of plowdown, banded and sidedressed fertilizer N

Independent variables	Soil pH		Soil P		Petiole P	
	Regression coefficients	P_b	Regression coefficients	P_b	Regression coefficients	P_b
Constant	6.9	<.0005	224.	<.0005	.096	<.0005
Plowdown N	-.0005	.06	.068	.69	-.00009	.02
Banded N	-.0002	.61	.165	.59	-.00012	.07
Sidedressed N	-.0017	<.0005	-.081	.76	-.00005	.35
	$R = .575$		$R = .127$		$R = .426$	
	$R^2 = .330$		$R^2 = .016$		$R^2 = .181$	
	$P_R = .002$		$P_R = .90$		$P_R = .06$	

APPENDIX

APPENDIX A

DRAFT
SUBJECT TO REVIEW

ESTABLISHED SERIES

CONOVER SERIES

Conover series consists of somewhat poorly drained soils developed in loam or silt loam calcareous till in southern Michigan. Conover soils are the somewhat poorly drained member of the drainage sequence which includes the well-drained Miami, the moderately well drained Celina, the poorly drained Brookston soils and very poorly drained Kokomo soils. Blount soils have finer-textured B2t horizons than Conover soils and are developed on clay loam or silty clay loam calcareous till. Locke soils are developed on sandy loam till materials and are generally coarser-textured throughout the soil profile than the Conover soils. Crosby soils are also developed on loam or silt loam calcareous till but have much lighter surface colors than Conover soils. Kibbie soils developed in stratified, lacustrine silts and very fine sands. Mantamora soils developed in 20 to 40 inches of loamy fine sand to sandy loam over loam, silty clay loam, clay loam, or silt loam till materials. Capac soils are the northern analogue of the Conover soils.

Soil Profile: Conover loam

Ap	0-8"	LOAM: very dark grayish brown (10YR 3/2); moderate, fine, granular structure; friable; moderate to high in organic matter content; slightly acid; abrupt smooth boundary. 7 to 11 inches thick.
A2	8-12"	LOAM: grayish brown (10YR 5/2) or brown (10YR 5/3) mottled with yellowish brown (10YR 5/6-5/8) and light brownish gray (10YR 6/2); mottles are common, medium, and distinct; moderate, medium granular to weak, thin, platy structure; friable; medium to slightly acid; clear wavy boundary. 2 to 5 inches thick.

B1	12-16"	LOAM: yellowish brown (10YR 5/4) or light brown (7.5YR 6/4) mottled with dark yellowish brown (10YR 4/4) and light brownish gray (10YR 6/2), mottles are common, medium, subangular blocky structure; friable; slightly to medium acid; clear wavy boundary. 2 to 6 inches thick.
B21t	16-24"	CLAY LOAM: dark yellowish brown (10YR 4/4) or yellowish brown (10YR 5/4) mottled with brownish yellow (10YR 6/8) and grayish brown (10YR 5/2) mottles are common, medium, distinct, moderate, medium to coarse subangular blocky structure; firm; slightly to medium acid; clear to wavy boundary. 6to 12 inches thick.
B22t	24-30"	CLAY LOAM: pale brown (10YR 6/3) or light brownish gray (10YR 6/2) mottled with yellowish brown (10YR 5/6-5/8) and dark yellowish brown (10YR 4/4) mottles are common, medium, and distinct; moderate, coarse subangular structure; firm; slightly acid to mildly alkaline; abrupt irregular boundary. 4 to 14 inches thick.
C1	30"+	LOAM: brown (10YR 5/3) to dark grayish brown (10YR 4/2) mottled with yellowish brown (10YR 5/4-5/6) and light brownish gray (10YR 6/2) mottles are common, medium, distinct; massive or weak, coarse, subangular blocky structure; friable; calcareous.

Range in Characteristics: Fine sandy loam, loam and silt loam types have been mapped. Depth to mottling ranges from 8 to 18 inches. The color of the Ap horizon is very dark gray (10YR 3/1) or very dark brown (10YR 2/2) in some places. The depth to calcareous till C horizon varies from 20 to 42 inches. The textures of B2t horizons are clay loam, silty clay loam, or sandy clay loam.

Topography: Nearly level to gently sloping till plains and moraines. Slopes range from 0 to 6 percent with the dominant range between 0 and 4 percent.

Drainage and Permeability: Somewhat poorly drained. Surface runoff is slow. Permeability is moderate to moderately slow.

Natural Vegetation: Deciduous forest consisting of sugar maple, beech, elm, ash, and hickory.

Use: Largely under cultivation where drainage is adequate to corn, wheat, oats, soybeans, and forage crops. A relatively small proportion is in permanent pasture and farm woodlots.

Soil Management Group: 2.5b

Type Location: Ionia County, Michigan

Distribution: Southern Michigan and Northern Indiana

Series Established: Miami County, Ohio 1916.

Source of Name: Village in Miami County, Ohio
National Cooperative Soil Survey - U.S.A.

Reviewed for temporary use in series file.
Not an official series description.
Classification is tentative.

ORDER: Alfisol

SUBORDER: Aqualf

GREAT GROUPL Ochraqualf

SUBGROUP: Mollic ochraqualf

FAMILY: Fine-loamy, mixed, mesic

APPENDIX B

DRAFT
SUBJECT TO REVIEW

ESTABLISHED SERIES

MC BRIDE SERIES

The McBride series includes well to moderately well drained soils with a Podzol upper sequum and a Gray Wooded lower sequum, with a fragipan horizon, developed in neutral to weakly calcareous sandy loam till. McBride soils are the well to moderately well drained member of the catena that includes the imperfectly drained Coral and the poorly to very poorly drained Ensley soils. The depth to the calcareous till ranges from 42 to 66 inches. The fragipan occurs in the lower part of the A2 horizon of the Gray Wooded sequum. Montcalm soils have coarser textured sola than McBride, lack a fragipan horizon, and have loamy sand C horizons. Isabella soils have finer textured sola than McBride, and are developed in sandy clay loam to sandy clay C horizons. The Freesoil series have thinner and less acid sola than McBride, a thicker fragipan that replaces a part of the Bt horizon, and thus is finer textured in the fragipan than the McBride, and the depth to the C horizon ranges from 24 to 42 inches.

Soil Profile: McBride fine sandy loam

Ap	0-7"	Dark grayish brown (10YR 4/2) to very dark grayish brown (10YR 3/2); fine sandy loam; weak to moderate, fine, granular structure; very friable; slightly to medium acid; abrupt smooth boundary. 6 to 9 inches thick.
Bhir	7-12"	Yellowish brown (10YR 5/4-5/6) to dark yellowish brown (10YR 4/4); fine sandy loam; moderate, medium, granular to weak, fine, subangular blocky structure; very friable; slightly to strongly acid; clear wavy boundary. 3 to 6 inches thick.
A2	12-15"	Pale brown (10YR 6/3) to very pale brown (10YR 7/4); sandy loam to loamy sand; weak, fine, platy structure; slightly firm; medium to strongly acid; abrupt wavy boundary. 2 to 6 inches thick.

A2m	15-22"	Grayish brown (10YR 5/2) to light gray (10YR 7/2); loamy sand to sandy loam; massive to very weak, medium platy structure; brittle and firm; medium to strongly acid; abrupt wavy boundary. 4 to 12 inches thick.
Bt	22-48"	Dark brown (7.5YR 4/4) to strong brown (7.5YR 5/6), sandy clay loam; light gray coatings occur on the cleavage faces in the upper part of the horizon; thin, dark brown clay films occur on some peds; moderate to strong, medium, subangular blocky structure; firm; medium acid; clear wavy boundary. 16 to 36 inches thick.
C	48"+	Brown (7.5YR 5/4 - 10YR 5/3); sandy loam; weak, coarse, subangular blocky structure; friable; slightly acid to calcareous.

Range in Characteristics: Undisturbed areas have a very dark brown (10YR 2/2) A1 horizon, 1 to 3 inches thick, and a light brownish gray (10YR 6/2) or pinkish gray (7.5YR 6/2) A2 horizon, 2 to 6 inches thick. The Bhir horizon is dark brown (7.5YR 4/4) in some areas. The entire A2 horizon of the Gray Wooded sequum is a fragipan horizon in some places. The degree of development of the fragipan ranges from weak to strong. The Bt horizon is reddish brown (5YR 5/4) in some areas, and the texture ranges from fine loam to fine sandy clay loam. Lenses, pockets, and layers of loamy sand occur in the C horizon in numerous areas. Sandy loam, fine sandy loam, and loam types have been mapped. Colors refer to moist conditions.

Topography: Nearly level to steep areas on moraines and till plains.

Drainage and Permeability: Well to moderately well drained. Runoff is medium on the milder slopes and rapid on the steeper slopes. Permeability is moderate.

Natural Vegetation: Sugar maple, beech, and oaks, with lesser quantities of hickory, basswood, and white pine.

Use: The greater proportion is used for general and dairy farming. Corn, oats, wheat, beans, and hay are the principal field crops. A considerable acreage is used for potatoes. The steeper slopes are in pasture or second growth forest.

Distribution: Central and northern Michigan.

Type Location: NW1/4 or SW1/4, Sec. 17, T8N, R8W, Ionia County, Michigan.

Series Established: Montcalm County, Michigan, 1956.

Source of Name: Village in Montcalm County, Michigan
National Cooperative Soil Survey - U.S.A.

ORDER: Spodosol

SUBORDER: Orthod

GREAT GROUP: Frageorthod

SUBGROUP: Alfio frageorthod

FAMILY: Coarse-loamy, mixed, frigid