PHOSPHORUS MOVEMENT IN SOIL EVALUATED BY SOIL SAMPLING TECHNIQUES AND SOIL TEST CORRELATION WITH APPLE LEAF ANALYSIS UNDER TRICKLE IRRIGATION

By

THIENCHAI SUWANVESH

Bachelor of Science in Agriculture
Kasetsart University
Bangkok, Thailand
1968

Master of Science
Oklahoma State University
Stillwater, Oklahoma
1981

Submitted to the faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the degree of
DOCTOR OF PHILOSOPHY
May, 1985

PHOSPHORUS MOVEMENT IN SOIL EVALUATED BY SOIL SAMPLING TECHNIQUES AND SOIL TEST CORRELATION WITH APPLE LEAF ANALYSIS UNDER TRICKLE IRRIGATION

Thesis Approved:

Laurence G. Morrill
Thesis Adviser

Dale E. Weibel

Lester W. Reed

Michael Smith

David T. Hicks

Norman N. Durham
Dean of the Graduate College

ACKNOWLEDGMENT

Grateful appreciation is expressed to my major adviser, Dr. Lawrence G. Morrill, for his outstanding guidance, suggestions, and assistance throughout the study. Appreciation is also expressed to members of my advisory committee, Dr. Lester W. Reed, Dr. Dale E. Weibel, Dr. Michael W. Smith, and Dr. David L. Weeks for their helpful guidance and assistance during my study.

Especially, I would like to express my gratitude to Dr. Michael W. Smith for his generosity and for contributing funds for soil analysis, and to provide some essential experimental materials, including the data for apple leaf analysis. His cooperation was unlimited.

A special expression is extended Dr. David L. Weeks, and Dr. Ronald W. McNew for their assistance in the statistical evaluation of my research data. Any request was taken into account without hesitation or reluctance. Their kindness and consideration are recognized.

Special thanks are sincerely given to Wit Itarut for his drawing of an illustration, and Bradley Barnes for his assistance in the preparation of the manuscript with useful comments and typing. Also my thanks are given to Kenneth H. Karner, the superintendent of the Horticulture Research Station, Perkins, Oklahoma, and his assistant, Brett A.

Fowler for their willing assistance in my field work. All of them are good friends that I have made during the period of my study and they are unforgettable.

Deepest gratitude, respect, and love are expressed to my parents for their love, understanding, anxiety, patience, and support regarding my financial crisis. The same feelings are also expressed to my sisters and brothers who shared my parents' emotional experiences during their waiting in our home country for my success.

Above all, I greatly appreciate my beloved wife, Somruthai, who strikingly exerted her physical and mental efforts to support my study. Her understanding, encouragement, and patience have never been exhausted, or distracted by any humiliation, aggravation, and or discouragement during this ordeal in our lives.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

INTRODUCTION

This dissertation is prepared and organized for publication in the fields of agronomy and horticulture. The writing style of the text, and formats of the tables and other illustrations comply mainly to the regulations of current publications. Simultaneously, some rules in the Thesis Writing Manual of Graduate College, Oklahoma State University are also followed.

The study was composed of three parts involving three separately different studies within the same experiment. The first study, Part I, is the discussion of the soil sampling techniques for tree crops grown under trickle irrigation. The strategy developed in this part brings about a criterion to evaluate the results in the second study, Part II, is the investigation of movement of available P in soil when two types of P fertilizers were applied by two methods of application under trickle irrigation. The third study, Part III, examines the correlation of soil test P with leaf P in apple trees. Results of this study may be used to predict the elemental concentration in apple leaves and the extent of P fertilizer requirements by soil test at the beginning of the season. Similarly, the procedures may apply to other tree crops as well.

PART I

MEASUREMENT OF PHOSPHORUS MOVEMENT IN SOILS FOR PERENNIAL CROPS: I. METHODOLOGY OF SOIL SAMPLE COLLECTION FOR PERENNIAL CROPS

ABSTRACT

Two water-soluble phosphate fertilizers, urea-ammonium polyphosphate (UAPP) and urea phosphate (UP), were applied to two apple cultivars (*Malus domestica* Bork. cvs. 'Redspur Delicious' and 'Goldspur Delecious'). Phospahte (P) movement was determined by systematic soil analysis over a two year period of time. The apples were grown using trickle irrigation and the P sources were supplied by injection or surface application. Soil sampling was systematized by taking samples at the intersection of a randomly selected ray with concentric circles of 15, 30, and 45 cm radii. Four depths: 0-15, 15-30, 30-60, and 60-90 cm were removed for analysis at each intersection. Sampling holes were re-filled with top soil to minimize the effect on subsequent movement of water and soil P within the designated soil sampling volume for each tree.

The sampling procedure was judged to be satisfactory for making P movement determinations and continued evaluations will be feasible until the 12 possible rays have been utilized. This provides sufficient positions to allow

two samplings per year for a six-year period or single annual samplings for 12 years. The technique was shown to be fundamentally and statistically sound and could be used for the evaluation of perennial tree crops response and fertilizer utilization rates vs. soil test values.

INTRODUCTION

An evaluation of soil fertility levels can be made by soil test. The relative values are the indicators of plant nutrient status in soils. However, the reliability and quality of soil samples submitted for analyses are crucial since field sampling errors are generally much greater than analytical errors (Cline, 1944; Peck and Melsted, 1963). Hence, the results of high precision soil testing are applicable to field conditions only if the samples are truely representative (Leaf and Madgwick, 1960).

It is impractical, or impossible to determine the nutrient content of the bulk soil volume of a given area, however, a small composite or representative sample is taken for determination (Leaf and Madgwick, 1960; Peck and Melsted, 1963). From a statistical point of view, a soil sample consists of cores or slices of given dimensions which are considered as sampling units. The soil sample is considered a single sample from the population of all sampling units (Cline, 1944). Naturally, the volume of soil from which the samples are withdrawn possesses some variations in nutrient contents both horizontally and vertically (Cline, 1944; Leaf and Madgwick, 1960). As a result, soil sampling techniques are primarily concerned with the number of sampling units (or the number of borings) and random sampling to obtain an estimate of field conditions. Representative samples will give an unbiased estimate of the mean, and an unbiased estimate of significance and fiducial limits (Cline, 1944; Wilde et al., 1979). For the purpose of soil fertility investigations for field crops, the soil sampling is usually confined to the plow layer (the upper 15 cm layer) for areas of uniform topography and soil characteristics (Wilde et al., 1979). This has been performed with remarkable success for the determination of soil fertility levels or the extent of fertilizer response for annual crops. Systematic procedures or soil sampling for tree crops have not been prescribed for general use because sufficient soil samples for correlation with crop needs have not been obtained. Part of the problem relates to the much larger volume of soil explored by tree crop roots. Typically, tree crop fertilizer needs have been determined by comparative leaf analysis.

It seems logical that soil analyses could reveal nutrient requirements for perennial crops as well as for annual crops. The principal questions to be answered are sampling positions, number of samples to be taken, selection of analytical procedures, time of sampling, and specific requirements of the crop. It is possible that the top soil will best represent the sufficiency or deficiency of a nutrient but the deeper rooting and larger volumes of soil explored by tree crop roots suggest that deeper samples might be reflective of plant nutrient availabilities or requirements as has been suggested by Shaw (1980). Success for all situations cannot be presumed but soil test correlations with crop response to fertilizer addition over a variety of tree crops and soil conditions should show that soil testing is a valuable tool for earlier diagnosis of fertilizer requirements and can improve crop yields and improve fertilizer use efficiency.

MATERIALS AND METHODS

The experiment was conducted in the apple plot at the Horticulture Research Station, Perkins, Oklahoma, during 1982-1983. The 'Delicious' apple/MM 111 trees had been established in Teller loam soil (fine-loamy, mixed, thermic; Udic Argiustolls; Mollisols), 1-3% slope with no-till cultivation. Chemical control of weeds was performed in a 2.4 m wide strip along the tree row. The experiment was initiated when the trees were three years old. A trickle irrigation system was used throughout the period of experimentation.

Experimental Design

A modified split-split plot design was employed with 2 main plots, 5 subplots, 12 sub-sub plots, and 5 replications. The main plots were 'Redspur' and 'Goldspur' cultivars, spaced 10.5 m (34.5 ft) within a row and 7.6 m (25.0 ft) between rows. Each cultivar had 5 rows of 10 trees; 5 trees in each row were randomly selected for the experiment. The P treatments were control (no P), injection of urea-ammonium polyphosphate (UAPP; elemental analysis, 15-12.2-0; liquid)) by emitter, surface application of UAPP, injection of urea phosphate (UP; elemental analysis 17-19.2-0; dissolved solid)) by emitter (dissolved solid) and surface application of UP. Each apple tree received 0.17 kg P per year and 0.2 kg N per tree per year. Ammonium nitrate (33.5-0-0) was added to balance N applications among P treatments. No K fertilizer was used. The injection of P fertilizers was accomplished in four increments during April to May of the year at two-week intervals. Surface applications of UAPP and UP were made in a single application each year by spraying or broadcasting, respectively, in a circular pattern of 1.2 m in diameter around the tree trunk.

Soil Sampling and Collection

Soil samples were taken in midsummer and early fall of both 1982 and 1983. Sampling sites were located at the interactions of a ray and concentric circles of 15, 30, and 45 cm radii from the trickle outlet (emitter). The concentric circles were determined by measuring their radii along the sampling ray for each time. At each intersection four soil samples were taken, 0-15, 15-30, 30-60, and 60-90 cm depths (Fig. 1). The position of a sampling ray was selected randomly for each sampling time; the rays were assigned numbers 1 to 12, resembling a clock dial with the 12 o'clock position due north. The numerical designation of the 1st thru the 12th ray to be sampled in sequence was determined by random selection of the rays for each individual tree. The procedure will accomodate 12 separate soil samplings per tree.

The soil samples were taken by a soil sampling tube which was pushed into the soil profile. The collected samples were placed into labled sampling bags. The sample holes were completely packed with top soil taken from the surrounding unfertilized area. The soil samples were brought to the Soil Testing Laboratory, oven-dried, ground, and seived (2.0 mm). Soil pH, P, and Ca were determined in the samples collected in 1982. In 1983, nitrate-nitrogen (NO_3^--N)), Potassium (K), and magnesium (Mg) were also determined.

Analytical Procedures

Soil pH was determined with a 1:1 soil:water ratio using 15.0 g soil. The mixture was stirred, set for 30 min, and pH determined subsequently while stirring.

Available P was determined by the Bray #1 method in which 1.0 g soil was extracted with 20 mL of 0.03 N NH_4F in 0.025 N HCl solution after a 5 min shaking period. Phosphorus was determined by the method of Watanabe and Olsen (1965) using a spectrophotometer setting of 840 nm.

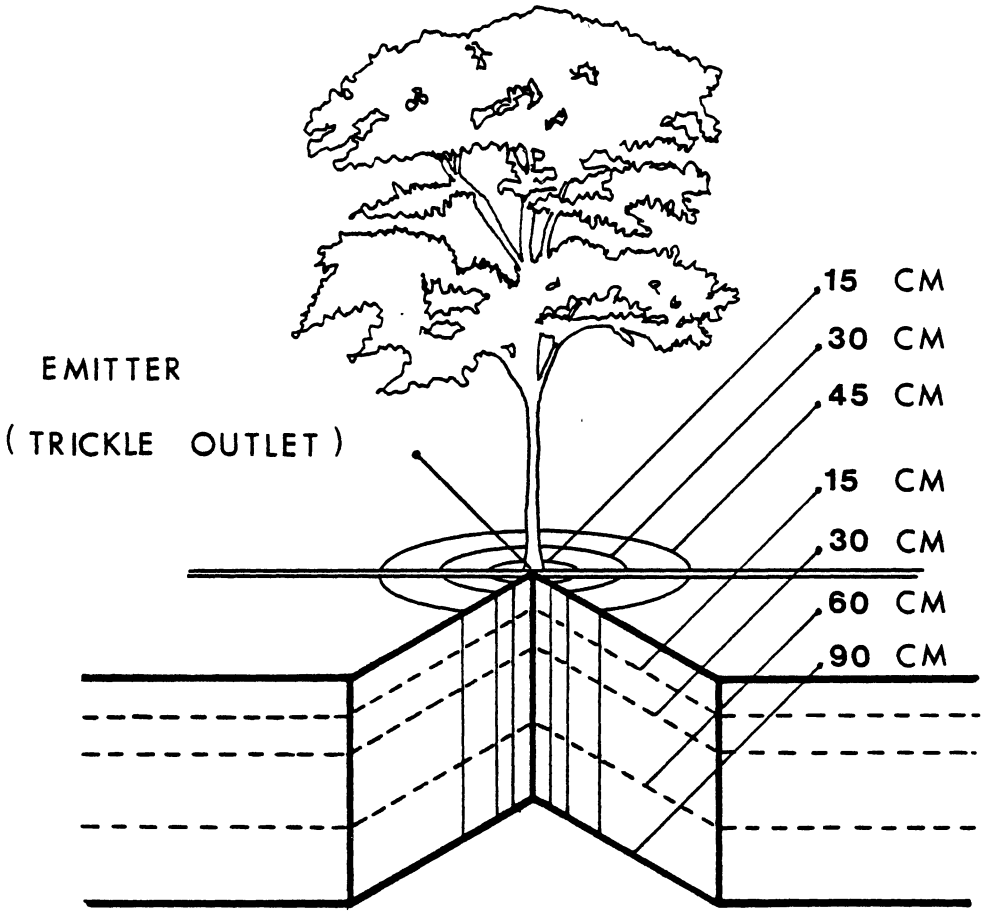


Fig. 1. Soil Sampling Sites at Different Distances and Depths From the Irrigation Emitter

Nitrate-nitrogen (NO_3^--N) in soil was determined with an Orion 901 Ionalyzer after extraction of 10.0 g soil with 25 mL of a 0.015 M $CaSO_4$ solution.

Calcium, K, and Mg were determined by extracting 2.0 g of soil with 10 mL of 1.0 M ammonium acetate after a 5 min shaking period. Potassium was determined directly from the filtered extractant by atomic absorption (AA), using Perkin Elmer 373 at 766.5 nm wavelength. A flame enhancement solution, $LaCl_2$, was added to the filtrate prior to determination of Ca, and Mg by the AA. Wavelength settings of 422.7 and 285.2 nm were used for Ca and Mg, respectively.

Trickle Irrigation System

Water was supplied to the apple trees on a row basis by a trickle irrigation system. The irrigation was provided by laying 1.3 cm (1/2") polyethlene tubing on the ground along the tree rows and placing an emitter (trickle outlet) close to the trunk of each tree. The emitter rate was 3.8 L hr^{-1}. The irrigation water was supplied for 3 hr d^{-1}, each tree received 11.4 L d^{-1}. The water was supplied during early spring to late summer (April to September), but was stopped during periods of heavy rainfall. Emitters were checked regularly for uniform delivery rates.

Data Collection in 1982

Preliminary sampling trials were made in 1981 before data collections began in 1982. Two sets of samples were taken, summer (June 27 to July 5) and fall (November 7 to 19), 1982. The first trickle irrigation of the year was applied on April 6. Surface applications of UAPP (G-UAPP) and UP (G-UP) were made on April 23, and April 30, respectively. Fertilizers were applied via trickle irrigation on April 23, May 10, June 1, and June 14, for the 1st to 4th applications. The trickle irrigation was stopped in September, 1982.

Data Collection in 1983

The experiment was continued in 1983 without modification from 1982 except soil analysis for NO_3^--N, K, and Mg were added. The soil samples were taken in Summer (July 13 to 19) and fall (October 24 to 31).

The trickle irrigation was started on April 11. Application of G-UAPP and G-UP were made on April 22. The applications of P fertilizers through the trickle irrigation were made on April 20, May 5, May 18, and June 1. The trickle irrigation was stopped in early October, 1983.

Statistical Analysis

Soil analysis data were analyzed statistically with the IBM 3081 D computer of the University Computer Center, Oklahoma State University. Analyses of variance were computed on a yearly basis. Regression analysis was used to fit a full second order model in the two variables, distance and depth, using data averaged over the five rays from five different trees. To fit the regression model, an equation was derived as:

$$y = b_{00} + b_{10}(\text{Distance}) + b_{01}(\text{Depth}) + b_{20}(\text{Distance})^2 + b_{02}(\text{Depth})^2 + b_{11}(\text{Distance})(\text{Depth}) \qquad [1]$$

As a result, soil available P contour plots were constructed to illustrate the differences in movement of P in soil (over distance and depth) with fixed cultivar, P source, sampling time, method of P application, and apple cultivar as variables.

RESULTS AND DISCUSSION

Statistical Aspects

There are three experimental units in the experiment; apple trees where cultivars and P treatments were variables, sampling rays where sampling times and year were variables and samples where distance and depth were variables. Apparently, the difference of sampling times is confounded with that of sampling rays, the differences of individual trees (replications) are, likewise, confounded with that of sampling rays of the concentric circles around the trickle outlet.

Within a cultivar, it is much more convenient for P treatments to be applied to a tree row rather than to individual randomly selected trees throughout the whole plot because it was impractical to set up seperate watering systems for individual trees within the same row. The random selection of sampling rays is required to give every ray an equal opportunity to be chosen, or to be selected for each sampling time. Therefore, the unbiased estimates of the means and the unbiased estimates of variances of the samples can be obtained (Cochran and Cox, 1957). If a given ray of a given tree had to be omitted due to encountering a main lateral root of a tree, the ray of next random order was selected. In this case, an apple tree was either an experimental unit or a replication in a tree row. Presumably, the magnitude of the variation among trees in a different rows and different cultivars was about the same as that in trees treated alike in the same row. This conjecture, therefore, leads to the basis of the use of the error term associated with the tree to tree variation to test for differences in cultivars and P treatments.

The random sampling techniques show their virtues and statistical merits such that the differences in available P distribution for cultivars, P treatments, sampling times, distances, and depths were revealed. Thus their differences due to experimental treatments can be separated from the variations in soil, or variations of soil conditions did not mask the differences due to treatment. Such evidences are shown by the analysis of variance of 1982 and 1983 data in Tables I and II, respectively. Further, their differences can be visualized by examining the contour plots of available P distribution in soil (see Fig. 2 and 3). Similar results were also obtained when UP was applied to 'Goldspur'

TABLE I

ANALYSIS OF VARIANCE SHOWING DIFFERENCES OF AVAILABLE SOIL P FOR CULTIVARS, P TREATMENTS, SAMPLING TIMES DISTANCES, AND DEPTHS FROM 1982 DATA

Source of Variance	DF	Sum of Square	Mean Square	F-Value
Cultivar	1	1,894,247	1,894,247	18.29 **
P Treatment	4	9,439,751	2,359,938	22.78 **
Error (a)	36	3,729,385	103,594	
Sampling Time	1	22,907	22,907	0.97 NS
Error (b)	40	1,166,046	29,151	
Distance	2	5,442,466	2,721,233	121.48 **
Depth	3	22,294,157	7,431,386	331.74 **
Distance x Depth	6	1,978,152	329,692	14.72 **
Error (c)	880	19,712,951	22,401	

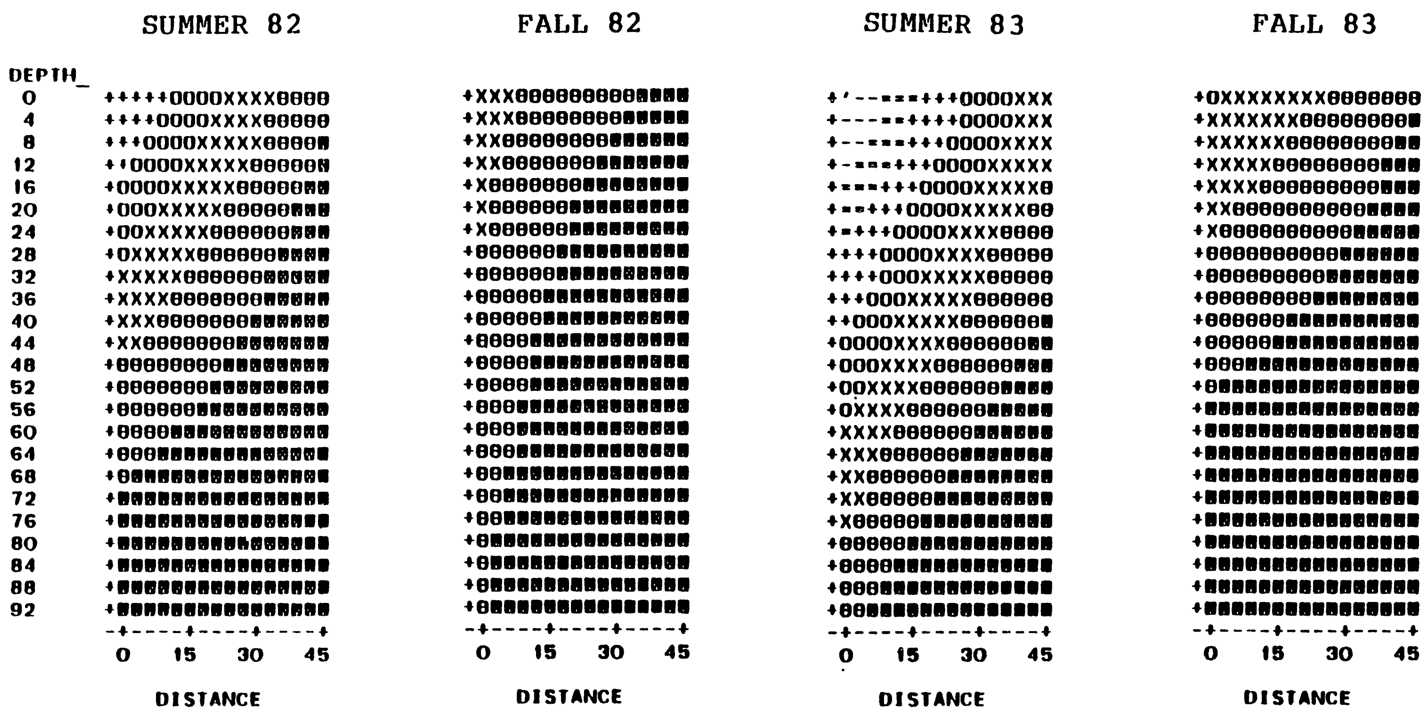
NS = not significantly different
** = highly significant difference (0.01 level)

TABLE II

ANALYSIS OF VARIANCE SHOWING DIFFERENCES OF AVAILABLE SOIL P FOR CULTIVARS, P TREATMENTS, SAMPLING TIMES, DISTANCES, AND DEPTHS FROM 1983 DATA

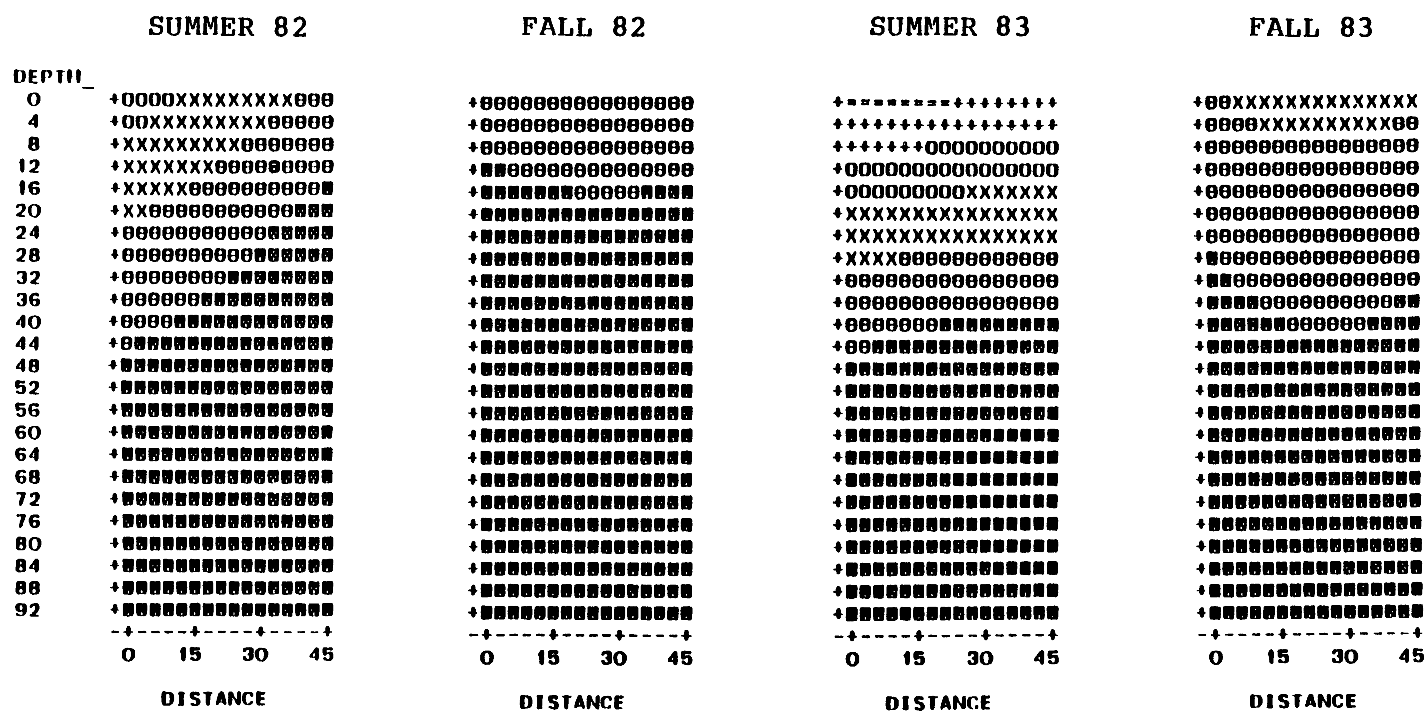
Source of Variance	DF	Sum of Square	Mean Square	F-Value
Cultivar	1	496,296	496,296	4.3 *
P Treatment	4	19,906,941	4,976,735	43.11 **
Error (a)	36	4,155,532	115,431	
Sampling Time	1	888,080	888,080	5.61 *
Error (b)	40	6,330,135	158,253	
Distance	2	6,863,288	3,431,644	146.01 **
Depth	3	51,611,804	17,203,935	731.99 **
Distance x Depth	6	1,931,942	321,990	13.70 **
Error (c)	880	20,682,537	23,503	

* = significantly different (0.05 level)
** = highly significant (0.01 level)



SYMBOL	YHAT
......	-2503.441377 - -2355.804040
''''''	-2355 804040 - -2060.529367
------	-2060 529367 - -1765 254694
======	-1765 254694 - -1469.980020
++++++	-1469.980020 - -1174.705347
000000	-1174.705347 - -879.430674
XXXXXX	-879.430674 - -584.156000
888888	-584.156000 - -288.881327
▩▩▩▩▩▩	-288.881327 - 6.393347
■■■■■■	6.393347 - 154.030683

Fig. 2. Available P Distribution in Soil (mg kg^{-1} soil) with Distance and Depth (cm) from the Trickle Outlet for I-UAPP in 'Goldspur' Cultivar Plots (Highest Density = Lowest P Concentration, etc.)



SYMBOL		YHAT
......	-2503.441377 -	-2355.804040
,,,,,,	-2355.804040 -	-2060.529367
------	-2060.529367 -	-1765.254694
======	-1765.254694 -	-1469.980020
++++++	-1469.980020 -	-1174.705347
000000	-1174.705347 -	-879.430674
XXXXXX	-879.430674 -	-584.156000
888888	-584.156000 -	-288.881327
■■■■■■ (medium)	-288.881327 -	6.393347
■■■■■■ (dense)	6.393347 -	154.030683

Fig. 3. Available P Distribution in Soil (mg kg^{-1} soil) with Distance and Depth (cm) from the Trickle Outlet for G-UAPP in 'Goldspur' Cultivar Plots (Highest Density = Lowest P Concentration, etc.)

cultivar plots with the same methods but are not shown here. Consequently, the results obtained are statistically sound and show the feasibility of using the sampling techniques in further studies.

Practical Aspects

It is necessary that the sampling rays around the trickle outlet for each tree be fixed in an imaginary plane on the soil surface. The marks of ray positions at each tree under study were maintained by using a compass so that the 12 o'clock position ray is aligned with the compass pointer of due north. The metal equipment was kept at such a distance that it did not cause a magnetic deviation. A circular template of 15 cm radius with 12 rays numbered in sequence as a clock dial was used to locate the direction of the selected ray by laying its center on a trickle outlet. This technique results in a consistent, uniform, positioning for each tree and each time.

After, the soil samples were taken, it was crucial that the open sample holes be filled to prevent water from moving into the holes. If the holes are left open, water from rain or irrigation will flow into them and results in a disruption of the normal water flow pattern. The distribution of soluble nutrients is affected such that the sampling of an adjacent ray will not represent a normal field situation. The most suitable material for packing the sample holes is soil of a similar texture and general nutrient content. Wooden rods of the same size and length as the sample holes can be used alternatively, but they will cause some inconvenience to the normal operation within the orchard if exposed or or if they protrude above the soil surface. Also they may decay or be consumed by insects before termination of the experiment.

Rods of glass, ceramic, plastic, or metal might be used but they are not economical. The size required may not be available and would seem to present an undue future complication.

CONCLUSION

The soil sampling techniques used in the experiment gave satisfactory results when the movement of applied P was studied by taking soil sample along random sampling rays around the trickle outlet. The results showed that the sampling techniques associated with randomization can be feasibly applied to the general purpose of soil sampling for perennial crops, especially tree crops. They also have particular value for trickle irrigation and fertilizer injection systems. Statistical evaluation showed that the differences in soil available P at different distances and depths from the trickle outlet were significant, and available P concentrations in the soil changed significantly with time.

The filling of sample holes with top soil after each sampling proved to satisfactorily minimize uncharacteristic water and nutrient distributions. The distances and depths of soil samples to be taken may be varied or modified to meet requirements in particular cases, depending upon growth stages of trees, time and amount of fertilizer(s) applied over time, soil texture, and irrigation rates or rainfall when the integrity of the sampling plan is maintained.

LITERATURE CITED

1. Cline, M. G. 1944. Principles of soil sampling. Soil Sci. 58:275-288.

2. Cochran, W. G. and G. M. Cox. 1957. Experimental Designs. 2nd ed. John Wiley and Sons, New York.

3. Leaf, A. L. and H. A. Madgwick. 1960. Evaluation of chemical analyses of soils and plants as aids in intensive soil management. World For. Cong. Proc. 1:554-556.

4. Peck, T. R. and S. W. Melsted. 1963. Field sampling for soil testing (in Soil Testing and Plant Analysis. L. M. Walsh and J. D. Beaton ed.). Soil Sci. Soc. Amer., Madison, Wis.

5. Shaw, K. 1980. Ecological and agronomic information required in soil testing interpretation (in Soil and Plant Testing Analysis. 1st FAO ed.). Food and Agriculture Organization of the United Nations, Rome.

6. Wilde, S. A., R. B. Corey, J. G. Iyer, and G. K. Voigt. 1979. Soil and Plant analysis for tree culture. 5th revised ed. Oxford and IBH Publishing Co., New Delhi.

7. Watanabe, F. S. and S. R. Olsen. 1965. Test of ascorbic acid method of determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Sci. Soc. Amer. Proc. 29:667-668.

PART II

MEASUREMENT OF PHOSPHORUS MOVEMENT IN SOILS FOR PERENNIAL CROPS: II. MOVEMENT OF APPLIED PHOSPHORUS IN SOILS UNDER TRICKLE IRRIGATION

ABSTRACT

The experiment was conducted in the apple orchard at the Horticulture Research Station, Perkins, Oklahoma, during 1982-1983. Two apple (Malus domestica Bork.) cultivars, 'Redspur' and 'Goldspur' on MM 111 rootstocks were established on a Teller loam soil (fine-loamy, mixed thermic; Udic Argiustolls; Mollisols). A modified split-split plot design was used with two apple cultivars, five P treatments which were comprised of a control (no P), injected UAPP (Urea-ammonium polyphosphate), injected UP (urea phosphate), surface applied UAPP and surface applied UP. Twelve soil samples were withdrawn for each sampling period, four soil depths at each of three distances from an emitter. The soil samples were taken in summer (July) and fall (October) for years 1982 and 1983. Trickle irrigation was applied to trees from April to September. Fertilizer P applications were made at the first irrigation for surface application and the first four injected applications were

made at two-week intervals. Soil pH, nitrate-nitrogen (NO_3^--N), P, Potassium (K), calcium (Ca), and magnesium (Mg) were subsequently determined in the laboratory. The results showed that there were statistically significant differences in available soil P at different distances and depths from the trickle outlet among P treatments. The concentration of available P in the soil decreased with distance and depth from the trickle outlet.

There were significant differences between injection and surface application of P fertilizers, but there were no significant differences between UAPP and UP. In addition, there was no interaction of fertilizer type by method of application. In general, available P concentrations in soil in the 'Redspur' cultivar plots were higher than those in the 'Goldspur' cultivar plots under the same conditions. Hence, the results show that 'Goldspur' apples absorbed more P from the soil than the 'Redspur' apples even though they were developed on the same rootstock.

INTRODUCTION

Phosphates applied to soils as fertilizers may be involved in any of several reaction sequences. The soil reactions of available/soluble P and slowly available P in phosphate fertilizers are distinctive. In essence, the readily available/soluble P plays the most important role in the phosphate utilization by plants in the majority of soils. The fate of readily soluble phosphates applied to soil is dependent upon soil conditions. Readily soluble or plant available P from fertilizers is more prone to form slowly available or unavailable P forms when soil pH is unfavorable (Borggaard, 1983; Haynes, 1983; Kuo and Mikkelsen, 1979; McCormic and Borden, 1974). Also, water soluble P may be lost by surface erosion, move into the soil by percolation (Scarseth and Chandler, 1938) or be depleted by plant uptake. Slowly available P in phosphate fertilizers, on the other hand, may be released into the readily available or soluble forms or become even less available, depending on soil conditions (Black, 1968). Rates of P replenishment and recovery or progress toward unavailability are, therefore, very important to agricultural production and profitability. In addition, the efficiency of P utilization by crops varies with P distribution in the soil profile, rooting pattern, and the crop grown (Bray, 1963).

Distribution and Forms of Native and Added Phosphorus in Soils

Phosphorus moves through soils as soluble orthophosphates with continued movement of percolating water. The orthophosphates may undergo precipitation, crystallization and recrystallization, adsorption and displacement or other transformations in the process (Black, 1968). A quasi-equilibrium can be attained when the P adsorption rate is equal to the P desorption rate in soils and is regulated by the orthophosphate concentration in the soil solution and on soil colloidal surfaces (Novak et al., 1975; Shah et al., 1975). Numerous experiments reviewed on P sorption by Sawhney (1977) show that P uptake during the initially rapid reactions or at low P concentrations, is due to the sorption on clay mineral surfaces while the subsequent slower reactions, is attributed to Al, and Fe phosphate precipitations. Similarly, very little P is leached from soils because reactive surfaces of Fe, Al, and Ca constituents in soils adsorb or precipitate soluble phosphates. Native soil P, is more resistant to chemical extraction than applied P (Logan and McLean, 1973). Application of soluble P to high P fixing acid soils was found to decrease availability of native P whereas addition of P to soils low in P fixing capacity tended to increase availability of native P, however, almost all of the applied P was found in the forms of Al and Fe phosphates (Volk and McLean, 1963). Many observations, on the other hand, indicate that P added to soils would be readily available to plants as the result of dicalcium phosphate dihydrate and dimagnesium phosphate trihydrate formation (Racz and Soper, 1970).

The vertical distribution of P in the top of a prairie loess soil shows a steady decrease in P from the surface downward, and P concentration in the surface layer is not dependent upon the organic matter content (Alway and Rost, 1916). Surface-applied superphosphate was observed to penetrate into a hemispherical shaped zone in a moist soil, and the zone of phosphate distribution was controlled by the phosphate sorption capacity of soil, P moved through soils at decreasing rates as sorption capacities increased (William, 1971). The available P distribution and P sorption capacity in fertilized and virgin soils are similar (Kao and Blancher, 1973). Studies of movement of applied P in some sandy forest soils show that no P from superphosphate was retained to 50 cm depth. Thus, little of the applied superphosphate was available to slash pines (*Pinus elliottii*) since most of their fine roots were located within 20 cm of the surface (Humphreys and Pritchett, 1971). The total distance of movement and the distribution patterns of water soluble P from various phosphatic compounds within a soil column were postulated to be similar (Hashimoto and Lehr, 1973). Loss of P from a light-textured soil was reported as 32% removed by plants and 60% lost with the clay fraction through erosion; but, when rock phosphate was used, 9% of the P was removed by plants and 82% lost through erosion. Hence, downward movement of P in the soil profile was insignificant (Scarseth and Chandler, 1938).

Movement and Accumulation of Phosphates and Some Salts by Irrigation and Water Regime

Movement of P in soils is influenced by soil surface conditions and soil moisture. Most P moves as a component of sediments, and P moving in runoff solutions is mainly inorganic (Reddy et al., 1978). At field capacity, 50 to 80% of water soluble P moves out of the fertilizer grannule within 24 hrs. However, 20 to 50% of the P will move from the granule into the soil at 2 to 4% moisture within the same period of time. (Lawton and Vomocil, 1954). Phosphorus applied over a number of years accumulates, mainly in the plow layer. Loss of P to groundwater from cultivated soil was low when the water table is near the plow layer but measurable. However, when the water table is deep, loss into the water table was very low. (Sawhney, 1978). No pronounced P movement was noted when it was added with drip irrigation, but P was found to stay at the soil surface if broadcast or in the vicinity of the band if banded. However, a relatively higher P concentration was discovered at the 20 cm depth (Keng, et al. 1979). On the contrary, salt accumulation was found in the surface soil midway between drip orifices and at the perimeter of the wetted zone when low-salinity and brackish water was used for drip irrigation. Under these conditions Drip irrigation treatments out-yielded furrow and sprinkler irrigation treatments by about 50 percent (Bernstein and Francois, 1973). Orthophosphate moves a greater distance into the soil with drip irrigation than when banded at the same rate. At relatively high rates, orthophosphate moves considerable distances in the soil profile, 25 cm horizontally and 30 cm vertically. However, the distance of P movement was proportional to the rate of application (Rauschkolb et al., 1976). On the other hand, for the irrigated soil, the field capacity zone was extended 65 to 90 cm horizontally but not more than 12 cm vertically from the trickle outlet. In unfertilized soil, Bray No. 1 extractable phosphate decreased with distance and depth from the trickle outlet. Banding P fertilizer 50 to 80 cm from the outlet increased P at the surface but did not increase P with depth. During each irrigation cycle, trickle irrigation led to cyclic release of both native and applied phosphates (Bacon and Davey, 1982).

The purposes of this investigation may be classified into three perspectives: first, to determine the magnitude of available P accumulation and movement in soil from the point of application over a period of time under trickle irrigation; secondly, to compare the movement characteristics of two forms of phosphate fertilizers by two methods of application; lastly, to find out if crop cultivar influences nutrient utilization and movement into the soil profile.

MATERIALS AND METHODS

The experiment was conducted at the Horticulture Research Station, Perkins, Oklahoma, during 1982-1983. The 'Redspur' and 'Goldspur' apple trees (Malus domestica Bork.) on M 111 rootstocks had been established in a Teller loam soil (fine-loamy, mixed, thermic; Udic Argiustolls; Mollisols), 1-3 % slope, with no-till cultivation. Chemical control of weeds was performed in a 2.4 m wide strip along the tree rows. The experiment was initiated when the trees were three years old Trickle irrigation was used throughout the experiment.

Experimental Design

A modified split-split plot design with 5 replications was used for the experiment, including 2 main plots for 'Redspur' and 'Goldspur' apple cultivars, 5 subplots for P treatments and 12 sub-subplots (sample sites) comprising 3 horizontal distances from the trickle irrigation outlet and 4 depths at each distance. The 'Redspur' and 'Goldspur' apple cultivars assigned to the main plots were grown in rows. The spacing was 10.5 m (34.5 ft) within rows and 7.6 m (25 ft) between rows. Each cultivar had 5 rows of 10 trees, with 5 trees from each row randomly selected for the experiment. The P treatments were: control, injection of urea-ammonium polyphosphate (UAPP; elemental analysis, 15-12.2-0; liquid)) by emitter, injection of urea phosphate (UP; elemental analysis, 17-19.2-0; dissolved solid) by emitter surface application of UAPP and UP in a 1.2 m diameter circle around each tree. All apple trees received 0.17 kg P yr^{-1} except the control treatment. All trees received 0.2 kg N yr^{-1}, and ammonium nitrate (33.5-0-0) was added to balance the N applications among the P treatments due to the different analyses of P fertilizers used. Potassium was not applied. The P fertilizers were applied in 4 increments during April to May of the year at two-week intervals. Surface applications of UAPP and UP were made in one application by spraying and broadcasting, respectively. For injection, the solid fertilizer was dissolved in irrigation water and applied as aforementioned.

Sample sites were located at the intersection of a ray and concentric circles of 15, 30, and 45 cm radii from the trickle outlet (emitter). At each intersection samples were taken at 0-15, 15-30, 30-60, and 60-90 cm form the soil surface. The position of a sampling ray was randomly selected from among 12 rays possible which were layed out like a clock face. The 12 o'clock position was pointed to the north as indicated by a compass. The sampling sites were accurately located by using a template.

Soil Sampling and Analysis

Soil samples were taken in midsummer and early fall, 1982 and 1983. The soil sampling tube was pushed or hammered into the soil profile as required. Samples were placed into labeled sampling bags. Subsequently, the sample holes were completely filled with soil taken from the unfertilized soil surface of the surrounding area.

After collection, soil samples were oven-dried, ground, and seived (2 mm). Soil pH, nitrate-nitrogen (NO_3^--N), P, Potassium (K), calcium (Ca), and magnesium (Mg) were determined.

Soil pH was determined in a 1:1 soil:water ratio using 15 g of soil. The mixture was stirred, set aside for 30 min, and pH was determined with a pH meter while stirring.

Available P was extracted using the Bray I method, 1.0 g of soil was extracted with 20 ml of 0.03 N NH_4F in 0.025 N HCl after a 5 min shaking period. Phosphorus was determined by the method of Watanabe and Olsen (1965) at a spectrophotometer setting of 840 nm.

Trickle Irrigation

Water was supplied to the apple trees on a row basis by a trickle irrigation system. The irrigation was provided by laying 1.3 cm (1/2") polyethelyene tubing on the ground along the tree rows and placing an emitter (trickle outlet) close to the trunk of each tree. The emitter rate was 3.8 L hr^{-1}. The irrigation water was applied for 3 hr d^{-1}, each tree received 11.4 L d^{-1}. The irrigation water was applied during the spring to late summer (April to September). Irrigation was stopped during periods of heavy rainfall. Emitters were checked regularly for uniform delivery.

Data Collection in 1982

After a preliminary study, the experiment was begun in 1982. Two samplings were taken in 1982, summer (June 27 to July 5) and fall (November 7 to 19). The first trickle irrigation of the year was applied April 6. Surface application for both UAPP and UP was made on April 23. Injection of UAPP and UP, was made on April 23, May 10, June 1, and June 14. Trickle irrigation was stopped in September

1982.

Data Collection in 1983

The experiment was continued in 1983 without modification from 1982. The soil samples were taken in summer (July 13 to 19) and fall (October 24 to 31).

Nitrate-nitrogen (NO_3^--N) in soil was determined using an Orion 901 Ionalyzer after 10 g of soil was extracted with 25 mL of 0.03 N $CaSO_4$ solution.

Calcium (Ca), potassium (K), and magnesium (Mg) were determined by extracting 2.0 g of soil with 10 ml of 1.0 N ammonium acetate after shaking for 5 min. Potassium was determined directly from the filtered extractant by atomic adsorption spectrophotometry (AA) using a Perkin-Elmer 373 at 766.5 nm wavelength. A flame enhancement solution ($LaCl_2$) was added to the filterate before the determination of Ca and Mg by AA. The wavelength was set at 422.7 and 285.2 nm for Ca and Mg, respectively.

Trickle irrigation was started on April 11. Surface application of UAPP (G-UAPP) and UP (G-UP) was made on April 22. Injection of UAPP (I-UAPP) and UP (I-UP) through the trickle irrigation system was made on April 20, for the first application, and on May 5, May 18, and June 1, for the 2^{nd} to 4^{th} applications, respectively. Trickle irrigation was stopped in early October 1983.

Statistical Analysis

Soil analysis data were analyzed using the Statistical Analysis System (SAS) on the IBM 3081 D computer at the University Computer Center, Oklahoma State University. Analyses of variance were computed for each year, then each cultivar, and time of sampling. Regression analysis was used to fit a full second order model in the two variables, distance and depth, using data averaged over the five rays of five replicate trees. The regression model was fitted by the equation as shown in Eq. [1] Part I (page 11). Contour plots were constructed to illustrate differences in distribution and movement of available P in soil.

It was presumed that the magnitude of the variation among trees in different rows and different cultivar plots was about the same as that in trees (treated alike) in the same row. This conjecture, therefore, founds the basis of the use of the error term associated with the tree to tree variation to test for differences in cultivars and P treatments.

RESULTS AND DISCUSSION

Horizontal and Vertical Distribution of Applied Phosphorus with Time

Phosphorus movement in soil was evaluated by measuring of available P at each sampling position for each sub-subplot. Results of data analyses showed that there were statistically significant differences in the mean concentrations of available soil P (ASP) at different distances from the trickle outlet, and at different depths below the soil surface in both 1982 and 1983. Also, there were significant interactions of Distance x Depth in both years. The AOV's are shown in Tables III and IV. It was noted that the mean concentrations of ASP at 60-90 cm depth were only slightly changed with time and the changes were not statistically significant. The results show that the concentration of ASP is highest near the trickle outlet and decreases with both distance and depth. Hence, they show that available P moves through soil in both horizontal and vertical directions from the point of application related to rate of water movement.

In general, the distribution of ASP for injection vs. sampling time followed similar patterns, the same is true for surface applications. Thus, all ASP means will not be shown for each particular case. Instead, movements of available P through soil are illustrated in Fig. 4 and 5. These contour plots represent the normal patterns or models of ASP distribution or movement with time. They are contour plots of ASP at different distances and depths from the trickle outlet when UAPP was injected, and surface applied, respectively, to 'Redspur' cultivar plots. In addition, the patterns of means of ASP concentrations in the 'Redspur' cultivar plot are similar in type to those in the 'Goldspur' cultivar plots though different in detail. Contour plots of

TABLE III

AVAILABLE PHOSPHORUS IN SOIL INFLUENCED BY DIFFERENT DISTANCES AND DEPTH FROM THE POINT OF PLACEMENT IN 1982

Source of Variance	DF	Sum of Square	Mean Square	F Value
Distance	2	5,442,466	2,721,233	121.48**
Depth	3	22,294,157	7,431,386	331.74**
Distance x Depth	6	1,978,152	329,692	14.72**
Residuals (Error)	880	19,712,951	22,401	

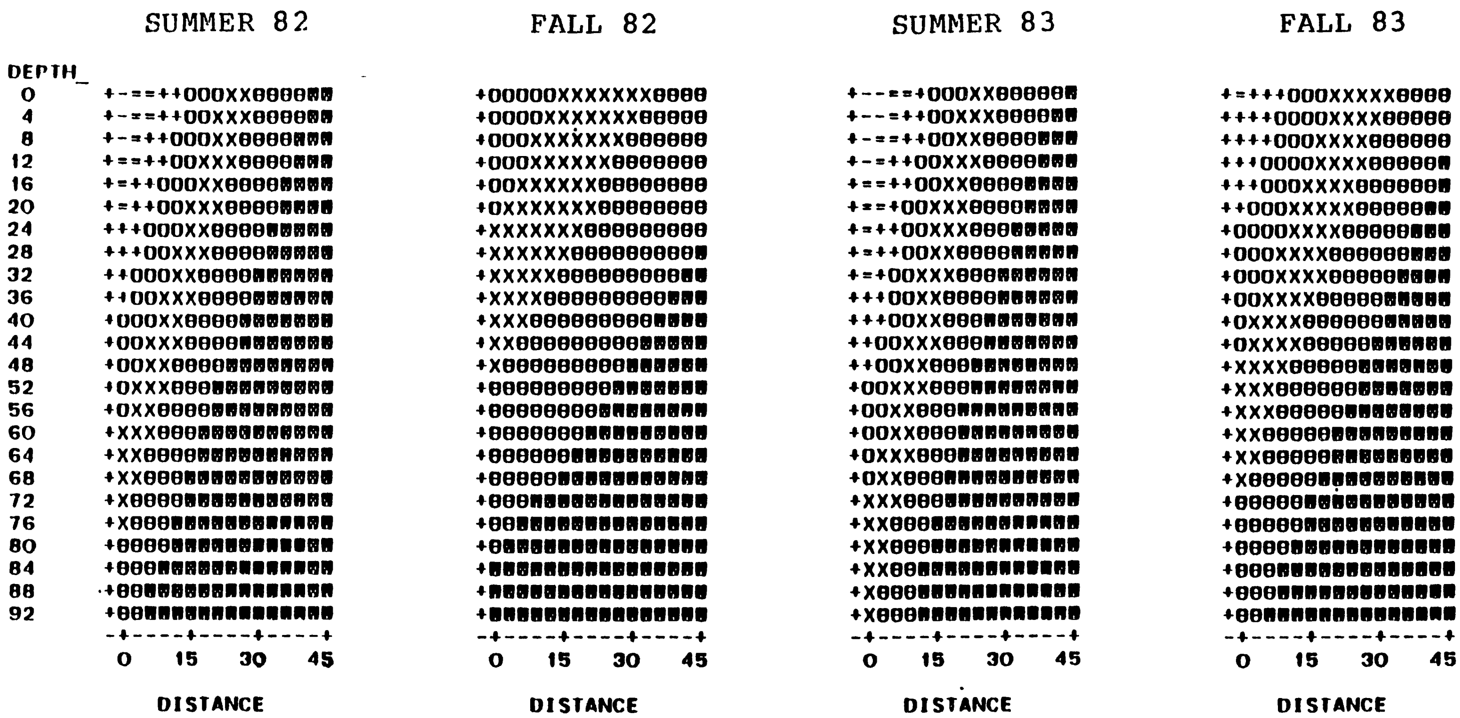
** = Highly significant (0.01)

TABLE IV

AVAILABLE PHOSPHORUS IN SOIL INFLUENCED BY DIFFERENT DISTANCES AND DEPTHS FROM THE POINT OF PLACEMENT IN 1983

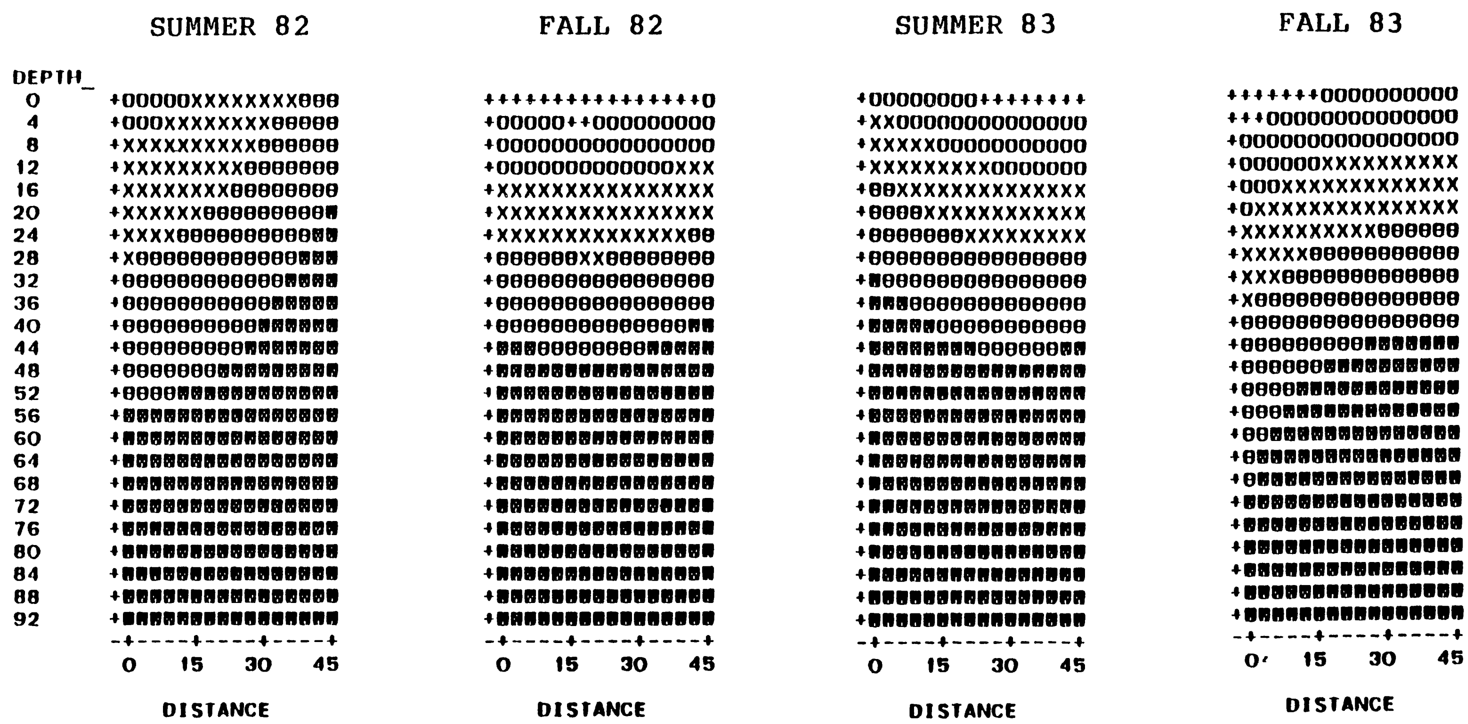
Source of Variance	DF	Sum of Square	Mean Square	F Value
Distance	2	6,863,289	3,431,644	156.01**
Depth	3	51,611,804	17,203,935	731.99**
Distance x Depth	6	1,931,943	321,990	13.70**
Residual (Error)	880	20,682,537	23,503	

** Highly Significant (0.01)



SYMBOL		YHAT	SYMBOL		YHAT	SYMBOL		YHAT
......	-2503.441377 -	-2355.804040	++++++	-1469.980020 -	-1174.705347	■■■■■■	-288.881327 -	6.393347
''''''	-2355.804040 -	-2060.529367	OOOOOO	-1174.705347 -	-879.430674	■■■■■■	6.393347 -	154.030683
------	-2060.529367 -	-1765.254694	XXXXXX	-879.430674 -	-584.156000			
======	-1765.254694 -	-1469.980020	888888	-584.156000 -	-288.881327			

Fig. 4. Available P Distribution in Soil (mg kg^{-1} soil) with Distance and Depth (cm) from the Trickle Outlet for I-UAPP in 'Redspur' Cultivar Plots (Highest Density = Lowest P Concentration, etc.)



SYMBOL	YHAT	SYMBOL	YHAT	SYMBOL	YHAT
......	-2503.441377 - -2355.804040	++++++	-1469.980020 - -1174.705347	■■■■■■	-288.881327 - 6.393347
;;;;;;	-2355.804040 - -2060.529367	000000	-1174.705347 - -879.430674	■■■■■■	6.393347 - 154.030683
------	-2060.529367 - -1765.254694	XXXXXX	-879.430674 - -584.156000		
======	-1765.254694 - -1469.980020	888888	-584.156000 - -288.881327		

Fig. 5. Available P Distribution in Soil (mg kg^{-1} soil) with Distance and Depth (cm) from the Trickle Outlet for G-UAPP in 'Redspur' Cultivar Plots (Highest Density = Lowest P Concentration, etc.)

means of ASP concentrations of the control are not illustrated because of lack of significant differences. Small changes are not visible in the contour plots (See Appendix A).

The changes of ASP concentrations with time in relation to distances and depths illustrated by the contour plots (Appendix A) indicate that available P moves through soil in a conical shaped pattern similar to water infiltration into soil (Bresler, 1975; Williams, 1971). Eventually, applied P moves omnidirectionally into soil, the magnitude of P movement decreases with distance and time and appears to be directly influenced by water movement rate and pattern.

Movement of Applied Phosphorus in Soil as Affected by Different Phosphorus Treatments

Concentrations of ASP are significantly different (0.01) from one another among different P treatments in both 1982 and 1983 (Tables V and VI). Available P concentrations obtained by other P treatments were significantly higher than those obtained in the control at every distance and depth, except at the 60-90 cm depth, in all plots at the same sampling time (data not shown). There were no interactions of Cultivar x P treatment in 1982 or 1983. Analyses of variance were made to find the difference between types of P fertilizers, and methods of application for each cultivar, and sampling time of year. The results indicate that the influence of injection, and surface

TABLE V

AVAILABLE PHOSPHORUS IN SOIL INFLUENCED BY PHOSPHORUS APPLICATION WITH TWO FORMS AND APPLICATION METHODS IN 1982

Source of Variance	DF	Sum of Square	Mean Square	F Value
Cultivar	1	1,894,247	1,894,247	18.29**
P Treatment	4	9,439,751	2,359,938	22.78**
Cultivar x Treatment	4	728,318	182,080	0.16 NS
Error	36	3,729,385		

NS = No significant Difference
** = Highly significant (0.01)

TABLE VI

AVAILABLE PHOSPHORUS IN SOIL INFLUENCED BY PHOSPHORUS APPLICATION WITH TWO FORMS AND APPLICATION METHODS IN 1983

Source of Variance	DF	Sum of Square	Mean Square	F Value
Cultivar	1	496,296	496,296	4.30 *
P Treatment	4	19,906,941	4,976,735	43.11 **
Cultivar x P Treatment	4	678,231	169,558	1.47 NS
Error	36	4,155,532	115,431	

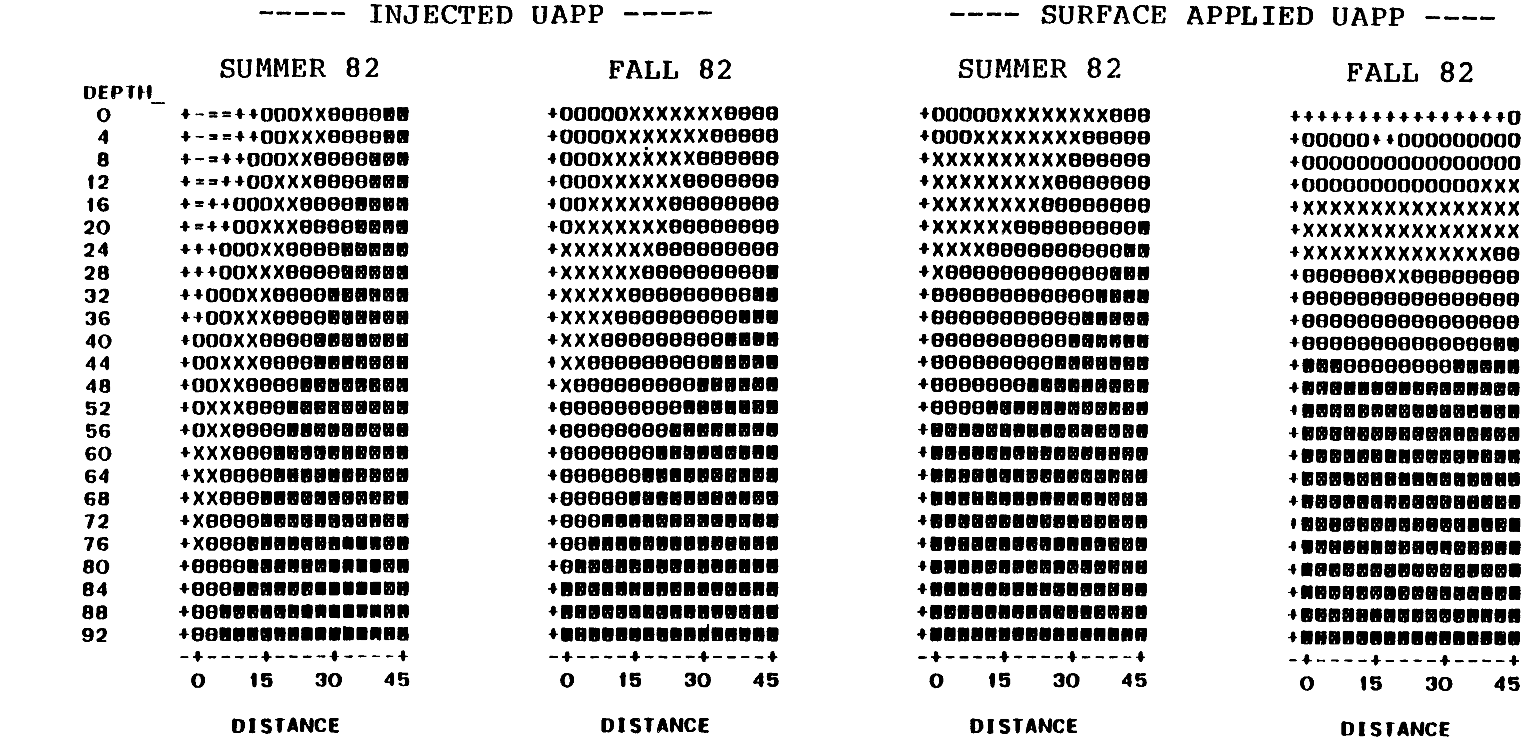
NS = No significant Difference
* = Significant Difference
** = Highly Significant (0.01)

application of P fertilizers on the distribution of ASP are statistically significant at different distances and depths from the trickle outlet. Differences in ASP levels for injection vs. surface application of P are shown by contour plots in Fig. 6 and 7, and marked distinctions were found at depths below 30 and 45 cm horizontally. Apparently, available P moved through soil away from the trickle outlet and downward when P was injected, but much deeper at closer distances. On the other hand, available P moved deeper into soil horizontally when it was surface applied. However, there were no significant differences between UAPP and UP in terms of supplying available P to soil. On the other hand, available P from G-UAPP was found in greater amounts at greater horizontal distances because the P fertilizers were uniformly applied to cover the surface of the sampling volume. Nevertheless, the pattern of P movement in soil resembled a conical shape with some distortions for particular conditions for both I-UAPP and G-UAPP. In addition, there was no Fertilizer Type x Application Method interaction. These results were consistent for all sampling times in 1982 and 1983.

Data analysis further showed that there were significant differences in ASP concentrations at different distances and depths from the trickle outlet and below the soil surface within each P treatment, sampling time, and cultivar plot. Also, there was Distance x Depth interaction in every sampling time of 1982 and 1983, and by cultivar.

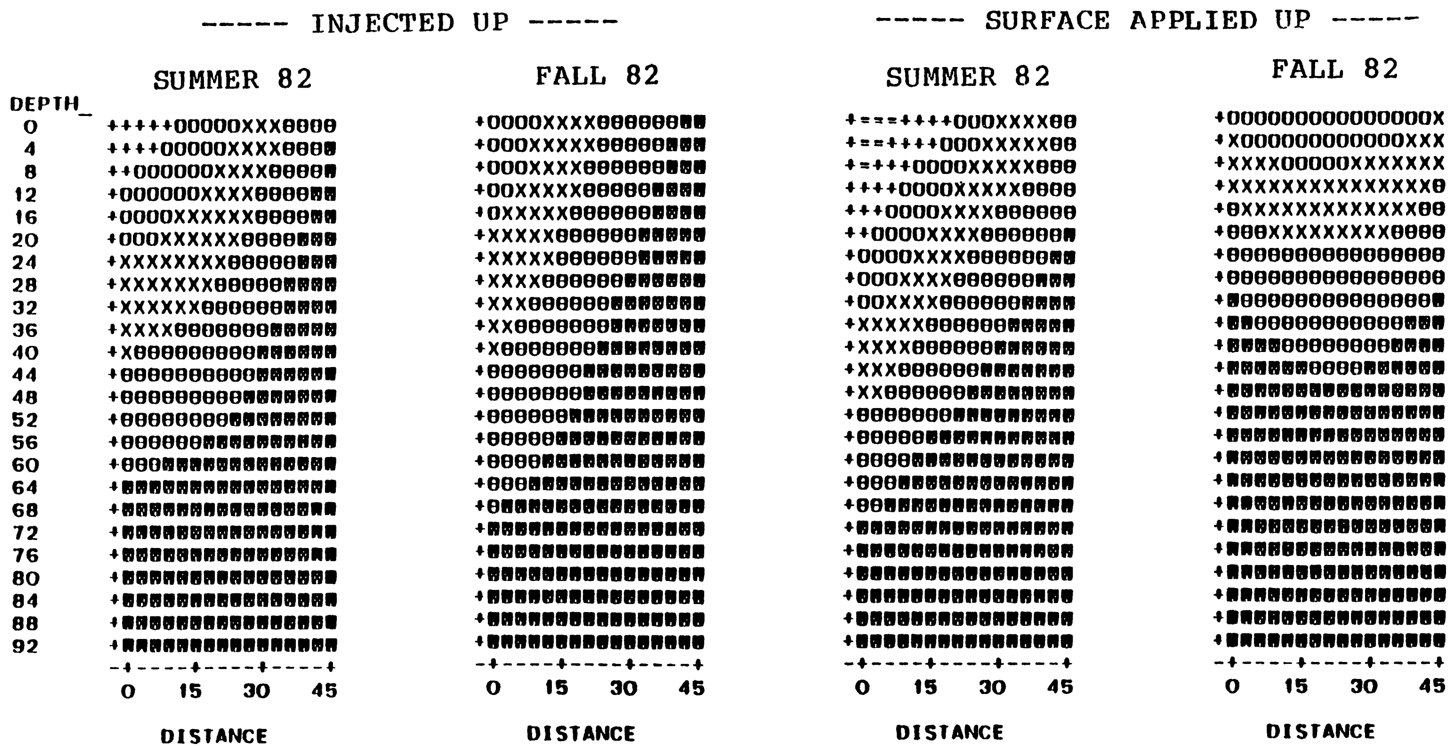
Moreover, there were interactions of Distance x Method of Application, Depth x Method of Application, and Distance x Depth x Method of Application. Since the general patterns of P movement are similar, the 'Redspur' cultivar contour plots are presented as examples (Fig. 6 and 7). In addition, movement patterns of ASP in 1983 follow the same trends as those in 1982. However, the magnitudes of P movement patterns in 1982 and 1983 were different because of a subsequent application and residual affects of P fertilization of 1982.

In the contour plots (Fig. 6), the injection and surface application of UAPP are compared in conjunction with sampling time, while the methods of UP application are compared in Fig. 7. Simultaneously, comparison of UAPP and UP could be made by using the two illustrations. The results indicate that available P from I-UAPP moved through soil in vertical directions further than G-UAPP, this was especially notable near the trickle outlet. Nevertheless, the pattern of P movement in soil resembled a conical shape with some distortions for particular conditions for both I-UAPP and G-UAPP. Moreover, the contour plots of P movement show that available P moves farther in the vertical, but less in horizontal directions in summer than in fall. In addition, higher P concentrations were found at near distances and shallow depths in summer compared with the fall samples. This is because ASP moves with time and addition of water, and this movement is effected by continued irrigation



SYMBOL	YHAT
......	-2503.441377 - -2355.804040
''''''	-2355.804040 - -2060.529367
------	-2060.529367 - -1765.254694
======	-1765.254694 - -1469.980020
++++++	-1469.980020 - -1174.705347
000000	-1174.705347 - -879.430674
XXXXXX	-879.430674 - -584.156000
888888	-584.156000 - -288.881327
■■■■■■	-288.881327 - 6.393347
■■■■■■	6.393347 - 154.030683

Fig. 6. Comparison of Available P Distribution for I-UAPP and G-UAPP at Different Distances vs. Depths in 'Redspur' Cultivar Plots from Two Sampling Times in 1982 (Lowest Density = Highest P Concentration, etc.)



SYMBOL	YHAT	SYMBOL	YHAT	SYMBOL	YHAT
......	-2503.441377 - -2355.804040	++++++	-1469.980020 - -1174.705347	■■■■■■	-288.881327 - 6.393347
''''''	-2355.804040 - -2060.529367	000000	-1174.705347 - -879.430674	■■■■■■	6.393347 - 154.030683
------	-2060.529367 - -1765.254694	XXXXXX	-879.430674 - -584.156000		
======	-1765.254694 - -1469.980020	888888	-584.156000 - -288.881327		

Fig. 7. Comparison of Available P Distribution for I-UP and G-UP at Different Distances vs. Depths in 'Redspur' Cultivar Plots from Two Sampling Times in 1982 (Lowest Density = Highest P Concentration, etc.)

through the summer. However, plant uptake is also involved. The difference in P movement was trivial when applications of UAPP were compared to that of UP. However, movement of available P from I-UAPP was slightly greater than that from I-UP for reasons unknown. It is obvious that the movement of ASP with surface application, either UAPP or UP, was predominant in the horizontal direction from fall until after irrigation stopped. In general, it is inferred that applied P from any source, with any method of application, will move in horizontal and vertical directions under trickle irrigation.

Movement of Applied Phosphorus in Soil as Affected by Apple Cultivar

The results of soil data analysis given in Tables V and VI show that there are highly significant differences between apple cultivars, but there are no P Treatment x Cultivar interactions. However, analysis of data also shows an interaction of Cultivar x Sampling Time x P Treatment x Depth in both 1982 and 1983 (see Appendix B). The concentrations of ASP at different distances and depths in different cultivar plots, at different sampling times, with I-UAPP, and G-UAPP in 1982 are shown in Fig. 8 and 9, respectively. The contour plots of ASP concentrations in 1982 were selected to compare performance of the apple cultivars on the basis of the distribution or movement of ASP when treated with either I-UAPP or G-UAPP. Since there

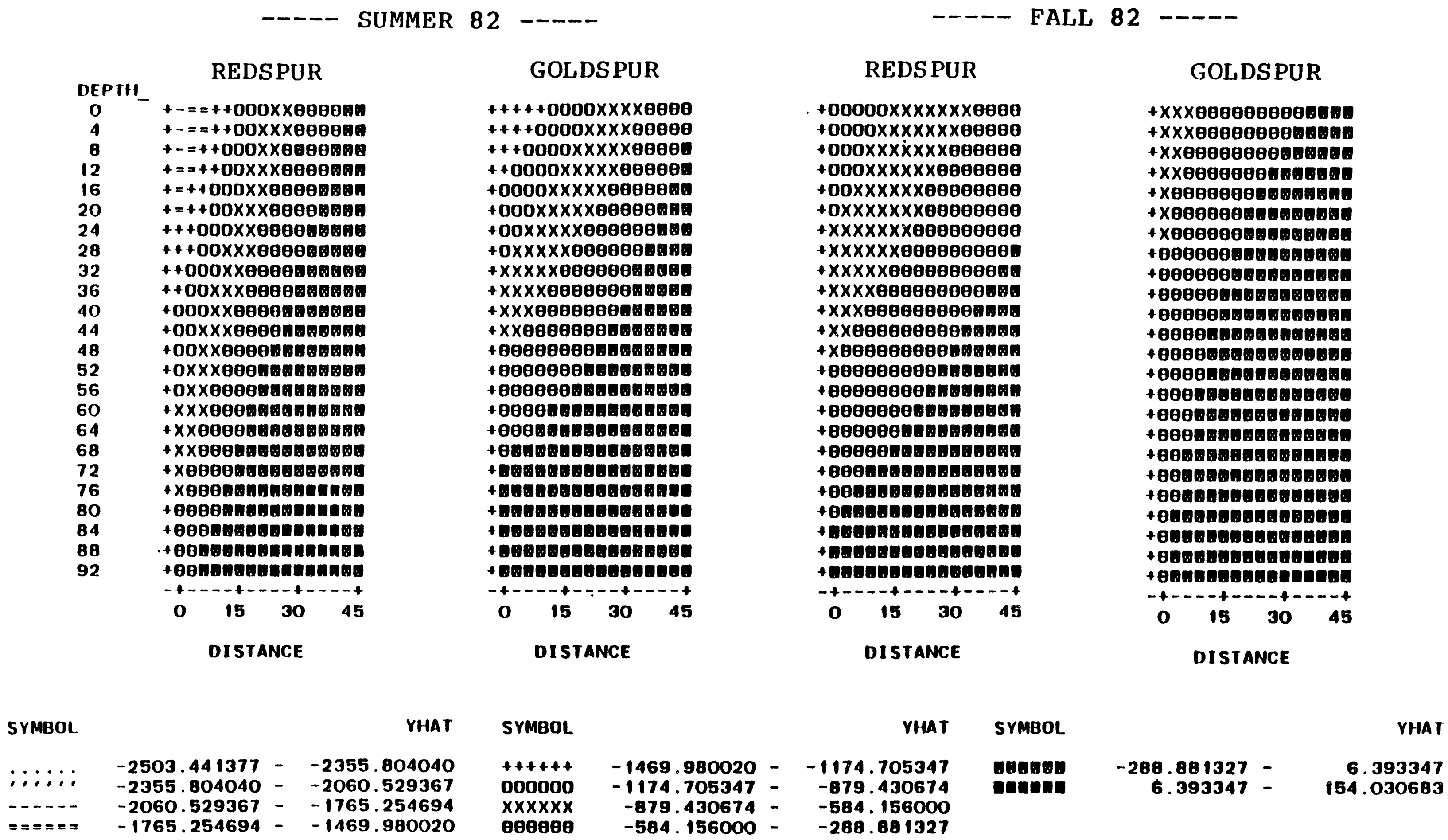
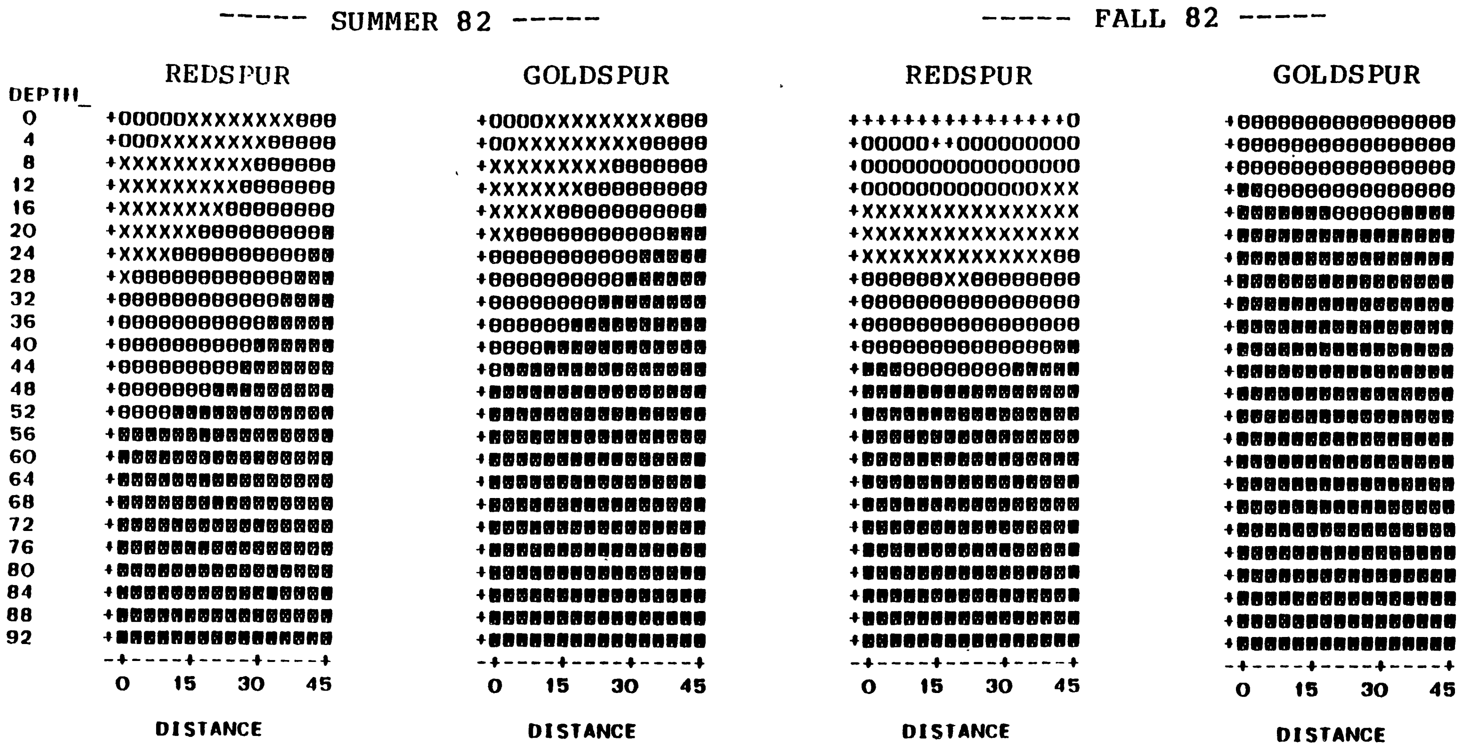


Fig. 8. Comparison of Available Soil P Concentrations in 'Redspur' and 'Goldspur' Cultivar Plots for I-UAPP with Distance vs. Depth (cm) from the Trickle Outlet from Two Sampling Times in 1982 (Lowest Density = Highest P Concentration, etc.)



SYMBOL		YHAT	SYMBOL		YHAT	SYMBOL		YHAT
......	-2503.441377 -	-2355.804040	++++++	-1469.980020 -	-1174.705347	▣▣▣▣▣▣	-288.881327 -	6.393347
''''''	-2355.804040 -	-2060.529367	000000	-1174.705347 -	-879.430674	■■■■■■	6.393347 -	154.030683
------	-2060.529367 -	-1765.254694	XXXXXX	-879.430674 -	-584.156000			
======	-1765.254694 -	-1469.980020	θθθθθθ	-584.156000 -	-288.881327			

Fig. 9. Comparison of Available Soil P Concentrations in 'Redspur' and 'Goldspur' Cultivar Plots for G-UAPP with Distance vs. Depth (cm) from Trickle Outlet from Two Sampling Times in 1982 (Lowest Density = Highest P Concentration, etc.)

is less residual effect for 1982, the comparison is not as easily seen. In addition, the pattern of P movement in soil followed the same trends and characteristics with P treatment in both 1982 and 1983.

CONCLUSION

When soluble P fertilizers were applied to soil under trickle irrigation, available P moves horizontally and vertically through soil from the trickle outlet, and the concentration of ASP decreased with distance and depth showing statistically significant differences. Although there were interactions among apple cultivars, P treatments, times of sampling, distances, and depths, the movement characteristics of available P followed the general trend in most cases. Contour plots of ASP distribution were constructed to illustrate the movement characteristics of ASP in many perspectives for several of the treatments involved. As a result, the available P movement pattern can be visualized as a toroidal zone when surface applied or as a conical shape underneath the trickle outlet. The contour plots shows that only a small amount of applied P reaches the 60-90 cm depths at any sampled horizontal distance.

The analysis of P treatments showed that ASP concentration in all P treatments was significantly higher than in the control at every distance and depth. Phosphorus treatment comparisons were made on the basis of the effects of methods of application, and types of P fertilizers on the

ASP concentration. The results show that there were statistically significant differences between injection and surface application of P fertilizers whereas there were no significant differences between UAPP and UP. In addition, an interaction of Fertilizer Type x Method of Application was not found. Consequently, there were statistical differences among P treatments when the control was excluded. However, available P moved deeper in the vertical direction at nearer distances by injection, than by surface application of P fertilizers. On the other hand, available P from surface application tended to linger at a shallow depth.

The influence of apple cultivars on the available P distribution or movement in soil was also evaluated. The results showed that the concentration of available soil P in the 'Goldspur' cultivar plot was lower than that in the 'Redspur' cultivar plot under the same conditions. The 'Goldspur' apples apparently absorb more P from the soil than the 'Redspur' apples, even though they were grown in the same rootstock. Therefore, it is concluded that the top part of fruit crops has a dominant influence on P absorption from soils. This was also reported by Schneider et al. (1978). Visual observation also supports the evaluation that 'Goldspur' apple trees produced more vigerous vegatative growth than 'Redspur' apple trees during the period of this investigation. The visual observations of more vigerous growth is confirmed by the larger trunk diameters of 'Goldspur' cultivar.

LITERATURE CITED

1. Alway, F. J. and C. O. Rost. 1916. The vertical distribution of phosphorus in the surface soil prairies. Soil Sci. 2:493-497.

2. Bacon, P. E. and B. G. Davey. 1982. Nutrient availability under trickle irrigation. I. Distribution of water and Bray no. 1 phosphate. Soil Sci. Soc. of Amer. J. 46:981-987.

3. Bernstein, L. and L. E. Francois. 1973. Comparison of drip, furrow and sprinkler irrigation. Soil Sci. 115:73-86.

4. Black, C. A. 1968. Soil-plant relationships. 2nd ed., John Wiley and Sons, Inc. New York.

5. Borggaard, O. K. 1983. The influence of iron oxides on phosphate adsorption by soil. J. Soil Sci. 34: 333-341.

6. Bray, R. H. 1963. Conformation of the nutrient mobility concept of soil-plant relationships. Soil Sci. 95:124-130.

7. Bresler, E. 1975. Two-dimentional transport of solute during nonsteady infiltration from a trickle source. Soil Sci. Soc. Amer. Proc. 39:604-613.

8. Hashimoto, I. and J. R. Lehr. 1973. Mobility of polyphosphates in soil. Soil Sci. Soc. Amer. Proc. 37:36-41.

9. Haynes, R. J. 1983. Effect of lime and phosphate application on the adsorption of phosphate, sulfate, and molybdate by a Spodosol. Soil Soc. 135:221-227.

10. Humphreys, F. R. and W. L. Pritchett. 1971. Phosphorus adsorption and movement in some sandy forest soils. Soil Sci. Soc. Amer. Proc. 35:495-500.

11. Kao, C. W. and R. W. Blanchar. 1973. Distribution and chemistry of phosphorus in an Albaqualf soil after 82 years of phosphate fertilization. J. Environ. Qual. 2:237-240.

12. Keng, J. C. W., T. W. Scott, and M. A. Lugo-Lopez. 1979. Fertilizer management with drip irrigation in an Oxisol. Agron. J. 71:971-980.

13. Kuo, S. and D. S. Mikkelsen. 1979. Effect of magnesium on phosphate adsorption by calcium carbonate. Soil Sci. 127:65-69.

14. Lawton, K. and J. A. Vomocil. 1954. The dissolution and migration of phosphorus from grannular superphosphate in some Michigan soils. Soil Sci. Soc. Amer. Proc. 18:26-32.

15. Logan, T. J. and E. O. McLean. 1973. Nature of phosphorus retention and adsorption with depth in soil columns. Soil Sci. Soc. Amer. Proc. 37:351-355.

16. McCormick, L. H. and F. Y. Borden. 1974. The occurence of aluminum-phosphate precipitate in plant roots. Soil Sci. Soc. Amer. Proc. 38:931-934.

17. Novak, L. T., D. C. Adriano, G. A. Coulman, and D. B. Shah. 1975. Phosphorus movement in soils: Theoretical aspects. J. Environ. Qual. 4:93-99.

18. Racz, G. J. and R. J. Soper. 1970. Solubility of phosphorus added to four Manitoba soils with different calcium and magnesium contents. Plant Soil. 32:303-315.

19. Rauschkolb, R. S., D. E. Rolston, R. J. Miller, A. B. Carlton, and R. G. Burau. 1976. Phosphorus fertilization with drip irrigation. Soil Sci. Soc, Amer. J. 40:68-72.

20. Reddy, G. Y., E. O. McLean, G. D. Hoyt, and T. J. Logan. 1978. Effects of soil, cover crop, and nutrient source on amounts and forms of phosphorus movement under simulated rainfall conditions. J. Environ. Qual. 7:50-54.

21. Sawhney, B. L. 1977. Predicting phosphate movement through soil columns. J. Environ. Qual. 6:86-89.

22. Sawhney, B. L. 1978. Leaching of phosphate from agricultural soils to groundwater. Water Air Soil Pollut. 9:499-505.

23. Scarseth, G. D. and W. V. Chandler. 1938. Loesses of phosphate from a light-textured soil in Alabama and its relation to some aspects of soil conservation. J. Amer. Soc. Agron. 30:361-374.

24. Schneider, G. W., C. E. Chaplin, and D. C. Martin. 1978. Effects of apple rootstock, tree spacing, and cultivar on fruit and tree size, yield, and foliar mineral composition. J. Amer. Soc. Hort. Sci. 103:230-232.

25. Shah, D. B. G. A. Coulman, L. T. Novak, and B. G. Ellis. 1975. A mathematical model for phosphorus movement in soils. J. Environ. Qual. 4:87-92.

26. Volk, V. V. and E. O. McLean. 1963. The fate of applied phosphorus in four Ohio soils. Soil Sci. Soc. Amer. Proc. 27:53-58.

27. Watanabe, F. S. and S. R. Olsen. 1965. Test of an ascorbic acid method of determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Sci. Soc. Amer. Proc. 29:667-678.

28. Williams, C. H. 1971. Reaction of surface-applied superphosphate with soil. II. Movement of the phosphorus and sulphur into the soil. Aust. J. Soil Res. 9:95-106.

PART III

CORRELATION OF SOIL TEST P WITH APPLE LEAF P WHEN APPLIED WITH TRICKLE IRRIGATION

Abstract

Soil test determinations for phosphorus (P), nitrate-nitrogen (NO_3^--N), calcium (Ca), potassium (K), and magnesium (Mg) were made in conjunction with a field experiment designed to evaluate P movements in soil when applied to young apple trees (*Malus domestica* Bork. cvs. 'Redspur' and 'Goldspur') under trickle irrigation. Apple leaf analyses revealed a low but statistically significant correlation between soil test P and leaf analysis P. No significant correlations were found for NO_3^--N, K, Ca, or Mg for any of the 12 sampling locations 15, 30, and 45 cm away (horizontally) from the trickle outlet and at 0-15, 15-30, 30-60, and 60-90 cm depths at each distance, samples taken 30 and 45 cm away from the emitter at the 0-15 cm depth were best correlated with leaf P concentration.

Introduction

Over the last 40 years, soil test procedures for determination of plant available P and methods for correlation with annual field crop response to applied P have been developed such that the need for P fertilization is estimated with reasonable precision for many crops (Alley and Bertch, 1983; Bishop et al., 1967; Bray 1948; 1958; Fixen and Carson, 1978; Khan and Zende, 1976; Peaslee, 1978; Varvel et al., 1978; Verma, and Tripathi, 1982). For field crops, the P can be applied prior to the active growing season and benefits from fertilization can be realized in that year. Methods and a data base for making meaningful fertilizer recommendations for perennial fruit crops via soil test have not been developed adequately (Kenworthy, 1948; Rom and Arrington, 1974; Taylor, 1975; Wear and Cope, 1976). Leaf analyses taken during the growing season will show the relative adequacy of P but fertilizer application will be of little value to that year's crop. Fruit growers would benefit from the development of a reliable soil test-crop response evaluation system allowing for soil samples taken in the fall or spring to predict the need for P in the coming season. The successful use of soil tests for predicting fertilizer needs for pasture and other perennial forage crop species indicate that the probability of success is reasonable (Grigg, 1972; Kroth and Mattas, 1976; Spencer and Glendinning, 1980).

Any success in correlating soil test and leaf P from this effort would logically lead to additional experimentation involving several levels of P application. Continued success would eventually lead to the satisfactory use of soil testing for predicting tree crop fertilizer needs.

Materials and Methods

The experiment was carried out at the Horticulture Research Station, Perkins, Oklahoma on 'Redspur' and 'Goldspur' apple trees on MM 111 rootstocks in connection with a P movement study in soil under trickle irrigation. Soil samples were taken periodically at 12 positions along a randomly selected ray 15, 30, and 45 cm from the trickle outlet and four depths of 0-15, 15-30, 30-60, and 60-90 cm at each radial distance. Soil P was determined with the Bray no. 1 extractant with solution to soil ratio of 20:1. Phosphorus was determined by the method of Watanabe and Olsen (1965) with a spectrophotometer setting of 840 nm. Other nutrient elements, K, Ca, and Mg were determined by extraction of 2.0 g of soil with 10 ml of 1.0 N ammonium acetate, and shaking for 5 min prior to filtration and filtration. Potassium was determined directly from the filtered extractant by Atomic Absorption Spectrophotometer (AA), using a Perkin-Elmer 373 at 766.5 nm wavelength. A flame enhancement solution, $LaCl_2$, was added to the filtrate before determination of Ca and Mg by AA. The wavelength was set at 422.7 for Ca and 285.2 nm for Mg. Nitrate-Nitrogen (NO_3^--N) in soil was determined with an Orion 901 Ionalyzer after extracting 10 g of soil with 25 ml of 0.03 N $CaSO_4$ solution.

Elemental concentrations of apple leaves were analyzed in Fruit and Nut Physiology Laboratory. Fifty leaves were taken from the central portion of each experimental tree in July. The sampled leaves were washed in 0.01% Liquinox, than in 0.1 N HCl, and were subsequently rinsed with deionized water twice. Samples were oven-dried at 75°C, ground in a Wiley mill and passed through a 1.0 mm^2 screen. The ground samples were stored in air-tight glass jars awaiting analysis. After samples had been redried at 80°C for 24 hr, they were dry ashed in an oven at 500°C for 6 hr. Later, P was determined colorimetrically and K, Ca, and Mg and other elements on a Perkin-Elmer 303 Atomic absorption Spectrophotometer. The macro-Kjaldahl method was used for N determination.

Correlation of soil test P values with leaf analysis P were computed by a multiple regression procedure using the Statistical Analysis System (SAS) allowing a comparison of one, or any combination of soil test result to be considered. The multiple regression analysis was composed of soil tests of nutrient elements at different distances and depths from the trickle outlet as independent variables, and apple leaf analyses as dependent variable for N, P, K, Ca, and Mg.

Regressions were calculated on the bases of the sampling time, and year, over apple cultivars and P treatments. The general equation was derived as:

$$\hat{Y} = \quad X_{ij} \ (i, \text{ and } j = 1,2,3) \qquad [2]$$

where, $\hat{Y}$ = estimated leaf analysis of a desired nutrient element in percent.

X_{ij} = soil test of a desired nutrient element in mg/kg soil at the distance i and depth j.

by substitution of subscripts i and j:

X_{11} = soil test at the 15 cm distance and 0-15 cm depth.

X_{12} = soil test at the 15 cm distance and 15-30 cm depth.

X_{13} = soil test at the 15 cm distance and 30-60 cm depth.

X_{21} = soil test at the 30 cm distance and 0-15 cm depth.

X_{22} = soil test at the 30 cm distance and 15-30 cm depth.

X_{23} = soil test at the 30 cm distance and 30-60 cm depth.

X_{31} = soil test at the 45 cm distance and 0-15 cm depth.

X_{32} = soil test at the 45 cm distance and 15-30 cm depth.

X_{33} = soil test at the 45 cm distance and 30-60 cm depth.

then, the general equation of the model is:

$$\hat{Y} = b_{00}+b_{11}X_{11}+ \ldots +b_{21}X_{21}+ \ldots +b_{33}X_{33} \qquad [3]$$

However, the independent variable which contributes a statistically significant effect is selected for the regression model. The soil test values at the 60-90 cm depth at any distance were not included in the analysis of variance of the multiple regression model because they did not contribute any significance for the nutrient elements investigated in this study.

Results

When the regression analysis of soil test and leaf analysis for P was computed for each year and sampling time, there were no statistically significant regression coefficients in regression models in either summer or fall samples in 1982. But there were significant regression coefficients in both summer and fall, 1983 (Tables VII and VIII) producing an $R^2 = 0.15$ ($p=.006$) and 0.08 ($p=.046$) for summer and fall (1983), respectively. The location of the soil sample with the best correlation with leaf analysis was 30 cm from the trickle outlet and 0-15 cm depth (X_{21}) for summer and 45 cm from the trickle outlet and 0-15 cm depth (X_{31}) for fall. The percent P in apple leaves can be predicted by the following equations :

		Root MSE	
Summer, 1983:	$\hat{Y} = 0.1549 + 0.00001228 X_{21}$	0.0138	[4]
Fall, 1983:	$\hat{Y} = 0.1588 + 0.00001220 X_{31}$	0.0144	[5]

The results of correlation of soil test P with leaf analysis of P and some additional information are shown in Table IX.

There were no statistically significant regression coefficients in the models for N, K, Ca, and Mg for any sampling during the period of the study.

TABLE VII

LINEAR REGRESSION ANALYSIS OF SOIL TEST AT THE 30 cm DISTANCE AND 0-15 cm DEPTH FROM THE SUMMER SAMPLES AND LEAF P IN THE 1983 EXPERIMENT

Source of Variance	DF	Sum of Square	Mean Square	F Value
Total (corrected)	49	0.01078		
Regression	1	0.001593	0.001593	8.32**
Residuals	48	0.009191	0.0001915	

** Highly significant (0.01)

TABLE VIII

LINEAR REGRESSION ANALYSIS OF SOIL TEST AT THE 45 cm DISTANCE AND 0-15 cm DEPTH FROM THE FALL SAMPLES AND LEAF P IN THE 1983 EXPERIMENT

Source of Variance	DF	Sum of Square	Mean Square	F Value
Total (corrected)	49	0.01078		
Regression	1	0.0008676	0.0008676	4.199 *
Residuals	48	0.009917	0.0002066	

* significant (0.05)

TABLE IX

CORRELATION OF SOIL TEST WITH LEAF ANALYSIS PHOSPHORUS IN THE SUMMER AND FALL SAMPLES IN 1983

Soil Test	Year	Sampling Time	Sample I. D. $(X_{ij})^+$	R^2 Value	Predicted Leaf Analysis (%)
P	1983	Summer	X_{21}	0.1477 *	$0.1550 + 0.00001228\ X_{21}$
	1983	Fall	X_{31}	0.0804 *	$0.1558 + 0.00001220\ X_{31}$

+ X_{ij} used as the sample identification:

i = Distance:
1 = 15 cm
2 = 30 cm
3 = 45 cm

j = Depth:
1 = 0-15 cm
2 = 15-30 cm
3 = 30-45 cm

Discussion

The results of soil test correlation with leaf analysis indicated that only soil test P significantly correlated with the percent P in apple leaves, whereas soil test NO_3^--N, K, Ca, and Mg did not correlate with percent N, K, Ca, and Mg, respectively, in apple leaves.

Soil test correlations with leaf analysis for the nutrient elements considered are not adequate. If the experiment had been specifically designed to determine soil-leaf content correlations better results would have been expected. Moreover, the correlation of soil test and leaf analysis from the fall samples of the year might not give information of plant nutrient uptake during the early rapid growth of a fruit tree. Perhaps the withdrawal of nutrients during the previous season's growth accounts for the lower correlation coefficient and was inducive to the lower extent of reliability. The fact that the best correlation position for fall was at a greater distance from the tree supports this conclusion.

The failure to obtain a significant correlation of soil test with leaf analysis for P in 1982 might be the result of insufficient available P in soil to cause differences in crop utilization.

Conclusion

A significant correlation of soil test P with leaf P was found in 1983 but R^2 values were very low. Thus, soil test correlations with leaf analysis obtained must be examined with caution. The experiment was not primarily designed for the correlation of leaf P with soil test. Application of P fertilizers at several rates might yield much higher R^2 values. Soil tests for NO_3^--N, K, Ca, and Mg failed to correlate with leaf analyses because N was uniformly applied to all treatments and no K, Ca, or Mg was added to the soil. The results of the study might be verified and improved if P is applied at different rates allowing P utilization by tree crops to be proportional to the varied amounts of P present in the soil. A study of the same nature could be made for the other nutrients provided a soil containing minimal levels is used.

Further study of soil test correlation with leaf content of nutrient elements in perennial crops is recommended using several application levels. The timing and frequency of soil and leaf sample collections should be considered in such a study.

Literature Cited

1. Alley, M. M. and P. M. Bertsch. 1983. Phosphorus application to newly-cleared coastal plain soils: Corn (Zea Mays L.) response and soil test calibration data. Commun. Soil Sci. Plant Anal. 14:335-346.

2. Bishop, R. F., C. R. MacEachern, and D. C. MacKay. 1967. The relation of soil test values to fertilizer response by the potato. IV. Available phosphorus and phosphatic fertilizer requirements. Can. J. Soil Sci. 47:175-185.

3. Bray, R. H. 1948. Correlation of soil tests with crop response to added fertilizers and with fertilizer requirement (in Diagnostic techniques for soils and crops, H. B. Kitchen, Ed.). The American Potash Institute, Washington, D. C.

4. ______. 1958. The correlation of a phosphorus soil test with the response of wheat through a modified Mitscherlich equation. Soil Sci. Soc. Amer. Proc. 22: 314-317.

5. Fixen, P. E. and P. L. Carson. 1978. Relationship between soil test and small grain response to P fertilization in field experiments. Agron. J. 70:838-844.

6. Grigg, J. L. 1972. Prediction of plant response to fertilizers by soil tests. III. The relationship between levels of soil phosphorus and responses to applied phosphorus in pasture topdressing trials. N. Z. J. Agric. Res. 15:643-652.

7. Kenworthy, A. L. 1948. Interrelationship between the nutrient content of soil, leaves, and trunk circumference of peach trees. Proc. Amer. Soc. Hort. Sci. 51:209-215.

8. Khan, A. A. and G. K. Zende. 1976. Correlation of soil-test values with the response of maize and sorghum to available Zn and P. Indian J. Agric. Sci. 46:259-265.

9. Kroth, E. M. and Richard Mattas. 1976. Soil test values of several soils under forage crops. Commun. Soil Sci. Plant Anal. 7:713-725.

10. Peaslee, D. E. 1978. Relationships between relative crop yields, soil test phosphorus levels, and fertilizer requirements for phosphorus. Commun. Soil Sci. Plant Anal. 9:429-442.

11. Rom, R. C. and E. H. Arrington. 1974. Relationship of soil and foliar tests in assaying the nutrient status of peach orchards. Proceeding of the 95th Annual Meeting:49-54 (Proc. Ark. State Hort. Soc.).

12. Spencer, K. and J. S. Glendinning. 1980. Critical soil test values for predicting the phosphorus and sulfur status of subhumid temperate pastures. Aust. J. Soil Res. 18:435-445.

13. Taylor, B. K. 1975. Response of newly planted peach and apple trees to superphosphate. Aust. J. Agric. Res. 26:521-528.

14. Varvel, G. E., F. N. Anderson, and G. A. Peterson. 1981. Soil test correlation problems with two phosphorus methods on similar soils. Agron. J. 73:516-520.

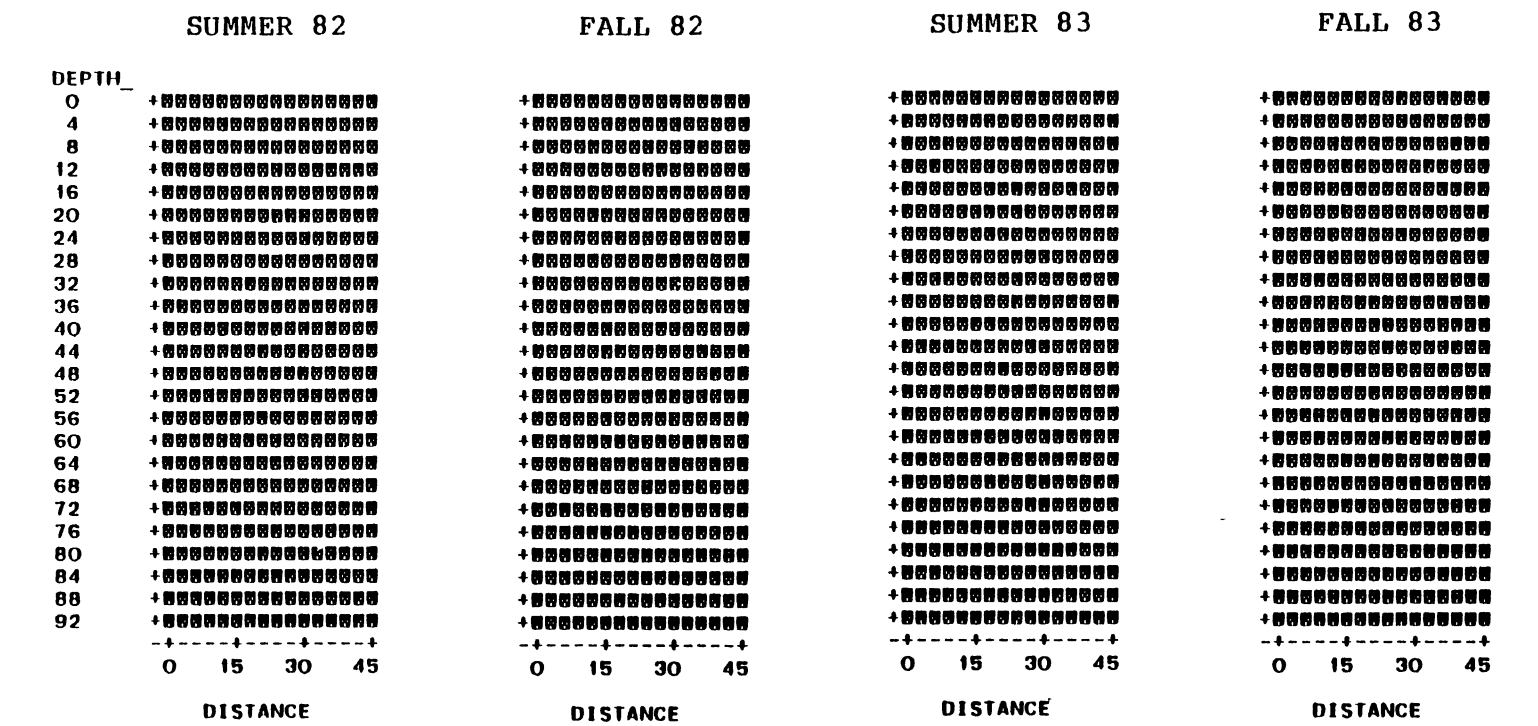
15. Verma, T. S. and B. R. Tripathi. 1982. Evaluation of chemical methods for the determination of available phosphorus in waterlogged alfisols: 2. Suitability of soil test methods in relation to plant growth parameters. Soil Sci. 134:294-299.

16. Wear, J. I. and J. T. Cope. 1976. Relationship between soil test values and analysis of pecan leaves taken at three dates. Commun. Soil Sci. Plant Anal. 7:241-252.

17. Watanabe, F. S. and S. R. Olsen. 1965. Test of and ascorbic acid method of determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Sci. Soc. Amer. Proc. 29:677-678.

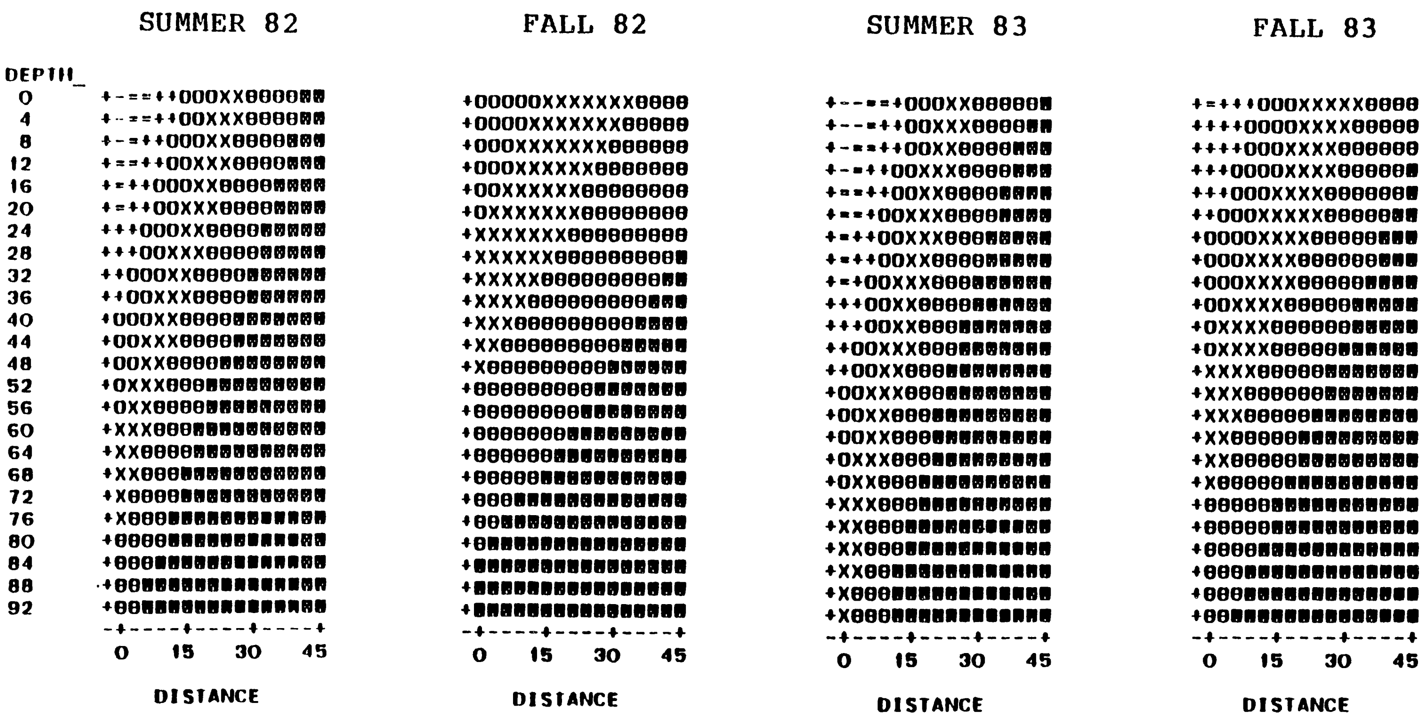
APPENDIX A

CONTOUR PLOTS OF AVAILABLE SOIL P DISTRIBUTION



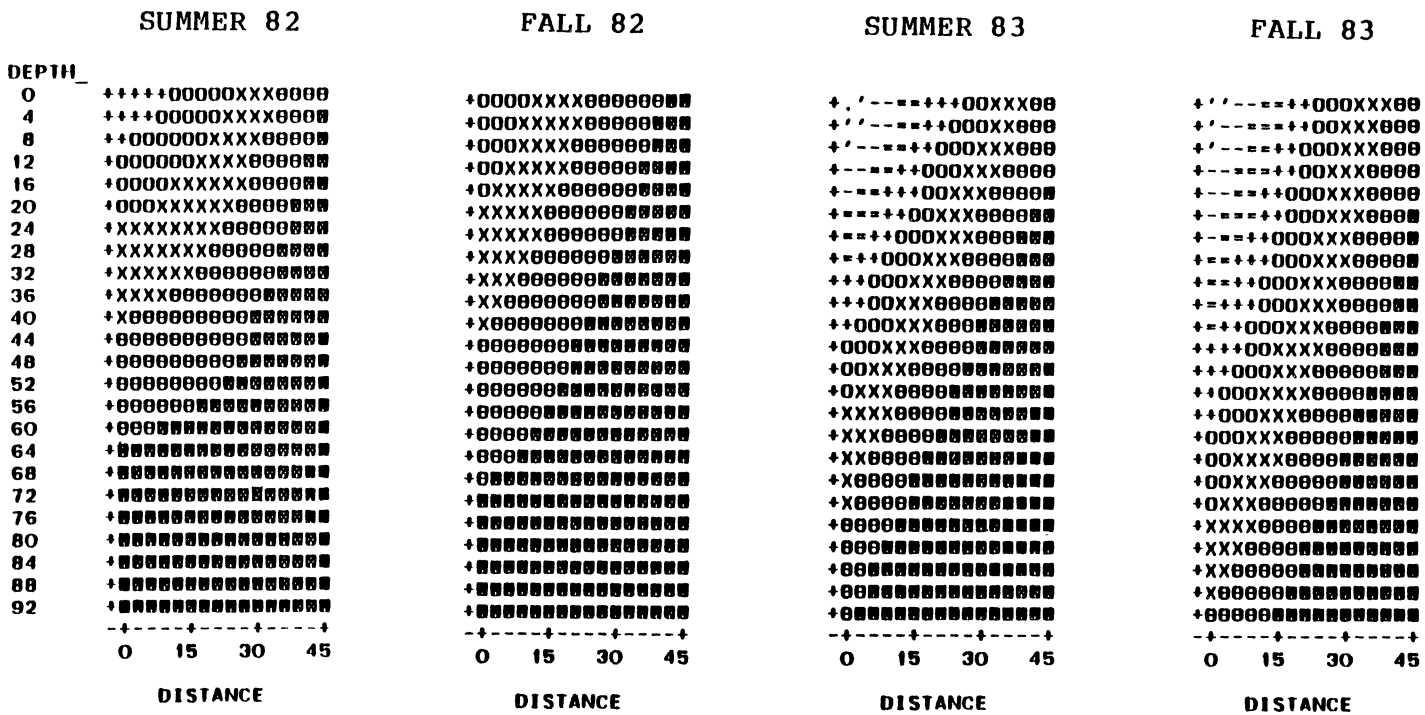
SYMBOL		YHAT	SYMBOL		YHAT	SYMBOL		YHAT
......	-2503 441377 -	-2355.804040	++++++	-1469.980020 -	-1174.705347	▦▦▦▦▦▦	-288.881327 -	6.393347
''''''	-2355 804040 -	-2060.529367	000000	-1174.705347 -	-879.430674	■■■■■■	6.393347 -	154 030683
------	-2060.529367 -	-1765.254694	XXXXXX	-879.430674 -	-584.156000			
======	-1765.254694 -	-1469.980020	888888	-584.156000 -	-288.881327			

Fig. 10. Available P Distribution in Soil (mg kg^{-1} soil) with Distance and Depth (cm) from the Trickle Outlet for Control in 'Redspur' Cultivar Plots (Highest Density = Lowest P Concentration, etc.)



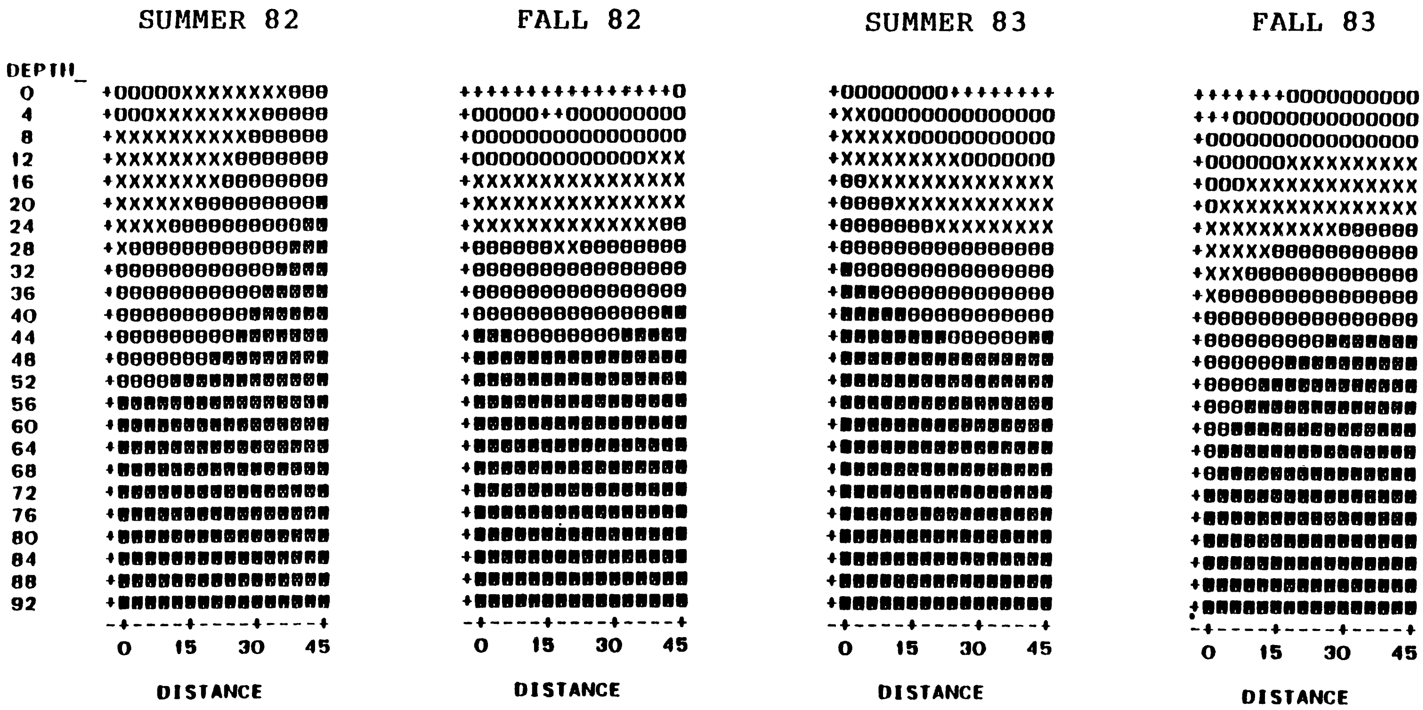
SYMBOL	YHAT
......	-2503.441377 - -2355.804040
''''''	-2355.804040 - -2060.529367
------	-2060 529367 - -1765.254694
======	-1765 254694 - -1469 980020
++++++	-1469.980020 - -1174.705347
000000	-1174.705347 - -879.430674
XXXXXX	-879.430674 - -584.156000
θθθθθθ	-584.156000 - -288.881327
ΘΘΘΘΘΘ	-288.881327 - 6.393347
■■■■■■	6.393347 - 154.030683

Fig. 11. Available P Distribution in Soil (mg kg^{-1} soil) with Distance and Depth (cm) from the Trickle Outlet for I-UAPP in 'Redspur' Cultivar Plots (Highest Density = Lowest P Concentration, etc.)



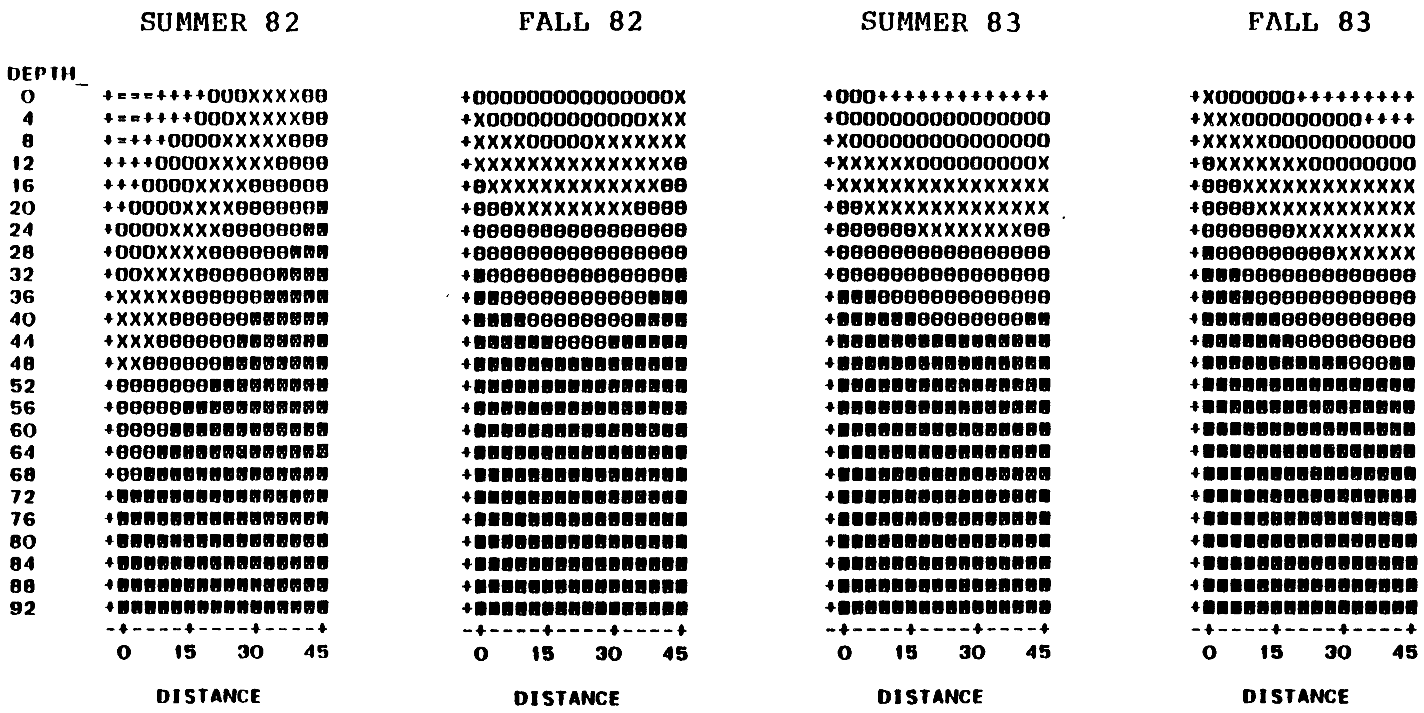
SYMBOL	YHAT	SYMBOL	YHAT	SYMBOL	YHAT
......	-2503.441377 - -2355.804040	++++++	-1469.980020 - -1174.705347	ΘΘΘΘΘΘ	-288.881327 - 6.393347
''''''	-2355.804040 - -2060.529367	000000	-1174.705347 - -879 430674	■■■■■■	6.393347 - 154.030683
------	-2060.529367 - -1765.254694	XXXXXX	-879.430674 - -584.156000		
======	-1765.254694 - -1469.980020	θθθθθθ	-584.156000 - -288.881327		

Fig. 12. Available P Distribution in Soil (mg kg^{-1} soil) with Distance and Depth (cm) from the Trickle Outlet for I-UP in 'Redspur' Cultivar Plots (Highest Density = Lowest P Concentration, etc.)



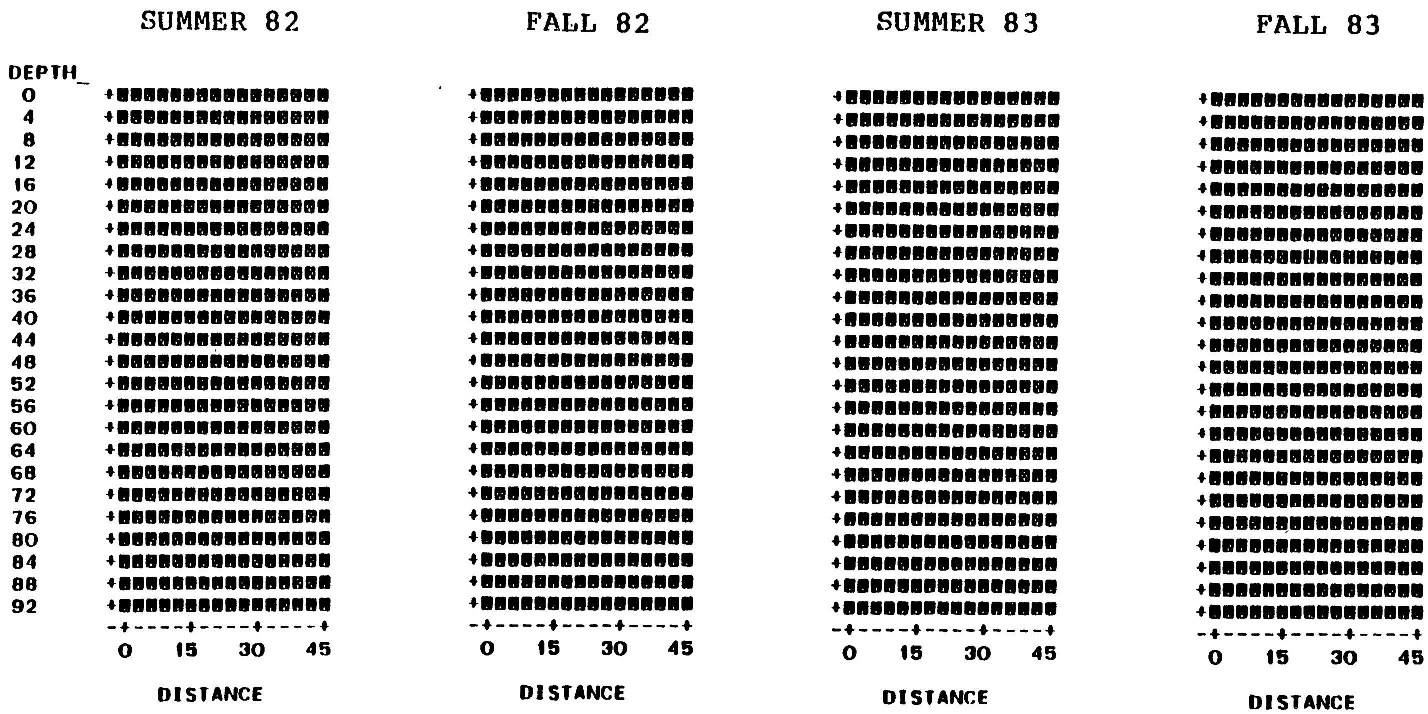
SYMBOL		YHAT	SYMBOL		YHAT	SYMBOL		YHAT
::::::	-2503.441377 -	-2355.804040	++++++	-1469.980020 -	-1174.705347	■■■■■■	-288.881327 -	6.393347
;;;;;;	-2355.804040 -	-2060.529367	000000	-1174.705347 -	-879.430674	■■■■■■	6.393347 -	154.030683
------	-2060.529367 -	-1765.254694	XXXXXX	-879.430674 -	-584.156000			
======	-1765.254694 -	-1469.980020	θθθθθθ	-584.156000 -	-288.881327			

Fig. 13. Available P Distribution in Soil (mg kg^{-1} soil) with Distance and Depth (cm) from the Trickle Outlet for G-UAPP in 'Redspur' Cultivar Plots (Highest Density = Lowest P Concentration, etc.)



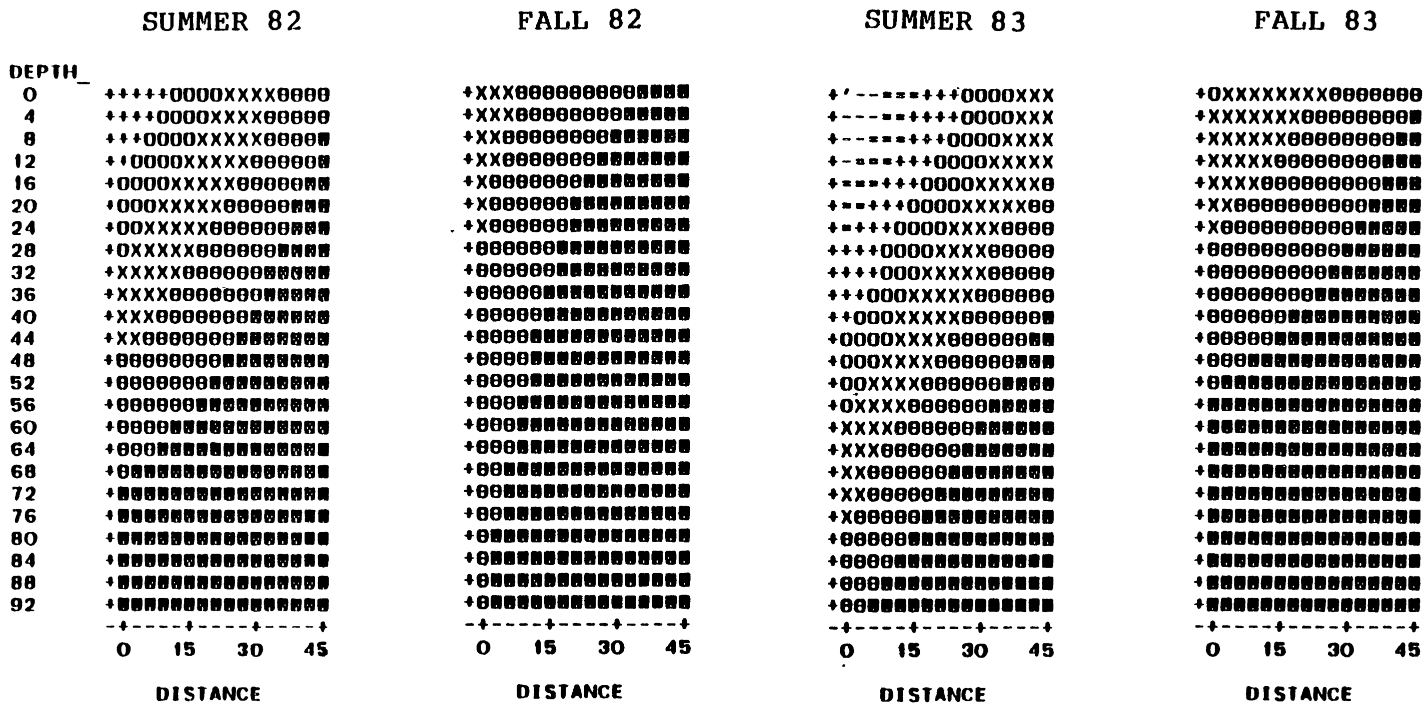
SYMBOL		YHAT	SYMBOL		YHAT	SYMBOL		YHAT
......	-2503.441377 -	-2355.804040	++++++	-1469.980020 -	-1174.705347	▓▓▓▓▓▓	-288.881327 -	6.393347
,,,,,,	-2355 804040 -	-2060 529367	000000	-1174.705347 -	-879.430674	██████	6.393347 -	154.030683
------	-2060.529367 -	-1765.254694	XXXXXX	-879.430674 -	-584.156000			
======	-1765.254694 -	-1469.980020	888888	-584.156000 -	-288.881327			

Fig. 14. Available P Distribution in Soil (mg kg^{-1} soil) with Distance and Depth (cm) from the Trickle Outlet for G-UP in 'Redspur' Cultivar Plots (Highest Density = Lowest P Concentration, etc.)



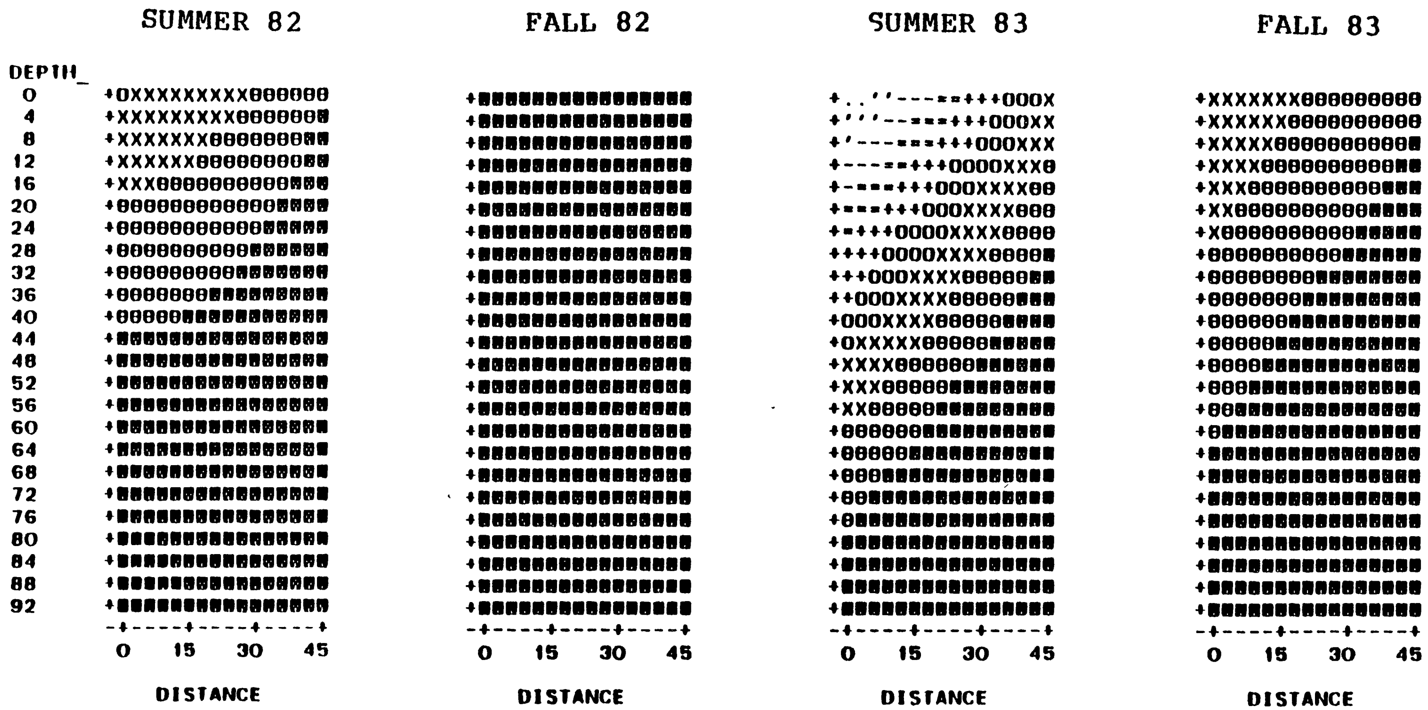
SYMBOL		YHAT	SYMBOL		YHAT	SYMBOL		YHAT
......	-2503.441377 -	-2355.804040	++++++	-1469.980020 -	-1174.705347	■■■■■■	-288.881327 -	6.393347
''''''	-2355 804040 -	-2060.529367	000000	-1174.705347 -	-879.430674	■■■■■■	6.393347 -	154.030683
------	-2060.529367 -	-1765.254694	XXXXXX	-879.430674 -	-584.156000			
======	-1765.254694 -	-1469.980020	888888	-584.156000 -	-288.881327			

Fig. 15. Available P Distribution in Soil (mg kg^{-1} soil) with Distance and Depth (cm) from the Trickle Outlet for Control in 'Goldspur' Cultivar Plots (Highest Density = Lowest P Concentration, etc.)



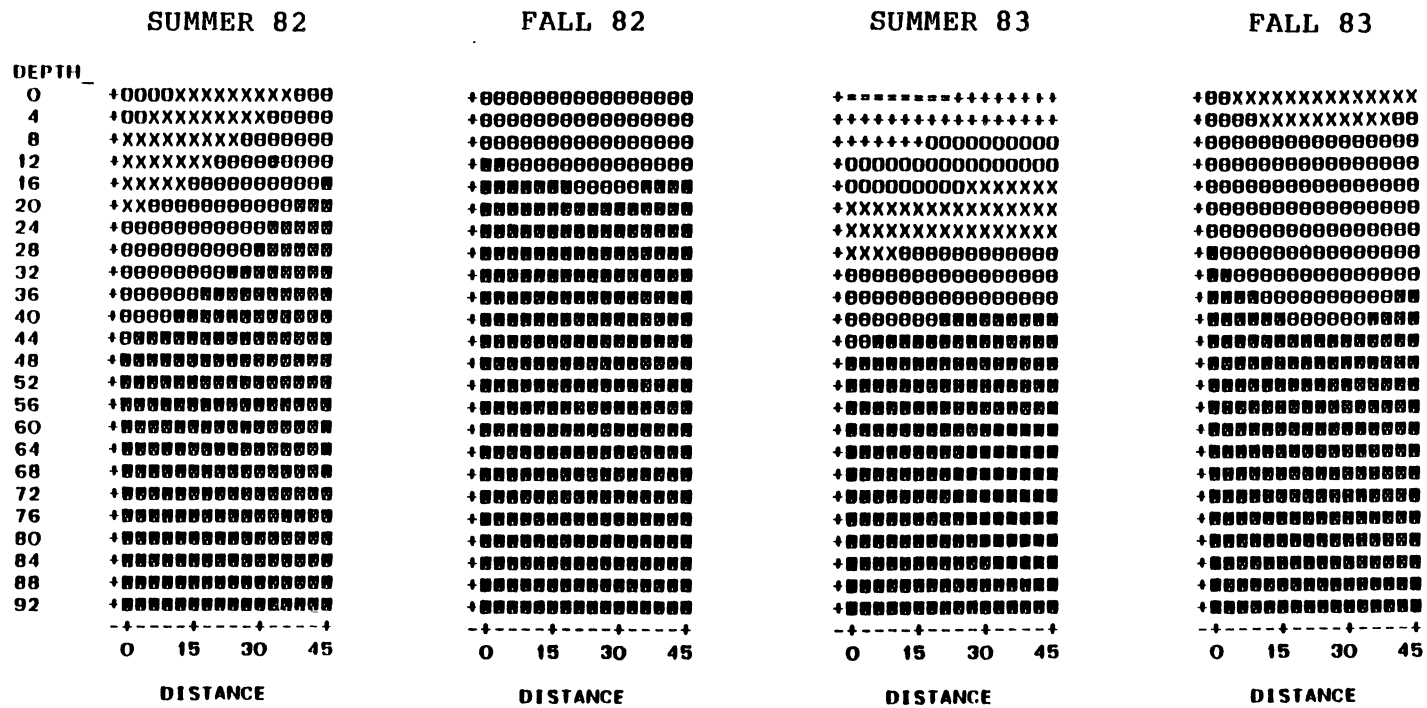
SYMBOL		YHAT	SYMBOL		YHAT	SYMBOL		YHAT
.	-2503.441377 -	-2355.804040	++++++	-1469.980020 -	-1174.705347	■■■■■■	-288.881327 -	6.393347
''''''	-2355.804040 -	-2060.529367	000000	-1174.705347 -	-879.430674	■■■■■■	6.393347 -	154.030683
------	-2060.529367 -	-1765.254694	XXXXXX	-879.430674 -	-584.156000			
-=====	-1765.254694 -	-1469.980020	888888	-584.156000 -	-288.881327			

Fig. 16. Available P Distribution in Soil (mg kg^{-1} soil) with Distance and Depth (cm) from the Trickle Outlet for I-UAPP in 'Goldspur' Cultivar Plots (Highest Density = Lowest P Concentration, etc.)



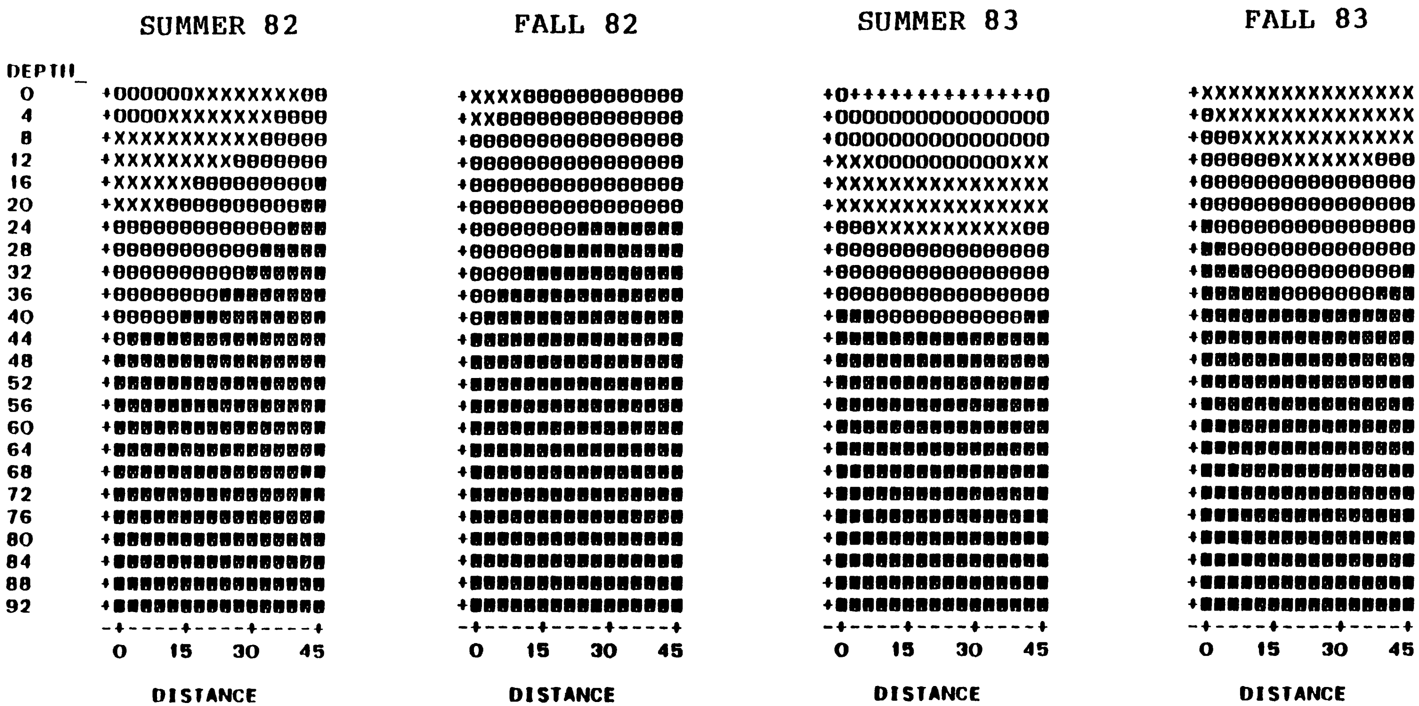
SYMBOL	YHAT	
......	-2503.441377 -	-2355.804040
''''''	-2355.804040 -	-2060.529367
------	-2060.529367 -	-1765.254694
======	-1765.254694 -	-1469.980020
++++++	-1469.980020 -	-1174.705347
OOOOOO	-1174.705347 -	-879.430674
XXXXXX	-879.430674 -	-584.156000
888888	-584.156000 -	-288.881327
■■■■■■ (grey)	-288.881327 -	6.393347
■■■■■■ (solid)	6.393347 -	154.030683

Fig. 17. Available P Distribution in Soil (mg kg^{-1} soil) with Distance and Depth (cm) from the Trickle Outlet for I-UP in 'Goldspur' Cultivar Plots (Highest Density = Lowest P Concentration, etc.)



SYMBOL		YHAT	SYMBOL		YHAT	SYMBOL		YHAT
::::::	-2503.441377 -	-2355.804040	++++++	-1469.980020 -	-1174.705347	■■■■■■	-288.881327 -	6.393347
,,,,,,	-2355.804040 -	-2060.529367	000000	-1174.705347 -	-879.430674	■■■■■■	6.393347 -	154.030683
------	-2060.529367 -	-1765.254694	XXXXXX	-879.430674 -	-584.156000			
======	-1765.254694 -	-1469.980020	888888	-584.156000 -	-288.881327			

Fig. 18. Available P Distribution in Soil (mg kg^{-1} soil) with Distance and Depth (cm) from the Trickle Outlet for G-UAPP in 'Goldspur' Cultivar Plots (Highest Density = Lowest P Concentration, etc.)



SYMBOL	YHAT	
......	-2503.441377 -	-2355.804040
,,,,,,	-2355.804040 -	-2060.529367
------	-2060.529367 -	-1765.254694
======	-1765.254694 -	-1469.980020
++++++	-1469.980020 -	-1174.705347
000000	-1174.705347 -	-879.430674
XXXXXX	-879.430674 -	-584.156000
θθθθθθ	-584.156000 -	-288.881327
▩▩▩▩▩▩	-288.881327 -	6.393347
■■■■■■	6.393347 -	154.030683

Fig. 19. Available P Distribution in Soil (mg kg^{-1} soil) with Distance and Depth (cm) from the Trickle Outlet for G-UP in 'Goldspur' Cultivar Plots (Highest Density = Lowest P Concentration, etc.)

APPENDIX B

INTERACTION OF CULTIVAR, P TREATMENT, SAMPLING TIME, DISTANCE, AND DEPTH IN STATISTICS

TABLE X

ANALYSIS OF VARIANCE SHOWING CULTIVAR, P TREATMENT, SAMPLING TIME, DISTANCE, AND DEPTH INTERACTIONS FOR AVAILABLE SOIL P FROM 1982 DATA

Source	DF	SS	MS	F-Value
Cultivar x Distance	2	529,935	264,968	11.83 **
Cultivar x Depth	3	955,582	318,527	14.22 **
Cult x Dist x Depth	6	244,481	41,580	1.68 NS
Cult x P Treat x Dist	8	281,998	35,250	1.57 NS
Cult x P Treat x Depth	12	470,732	39,228	1.75 NS
Cult x P Trt x Dist x Depth	24	707,415	29,476	1.32 NS
Cult x Time x P Trt x Dist	10	159,361	15,396	0.71 NS
Cult x Time x P Trt x Depth	15	1,165,920	77,728	3.47 **
Cult x Time x P Trt x Dist x Depth	30	220,979	7,366	0.33 NS
Error	880	19,712,951	22,401	

NS = no significant difference
** = highly significant (0.01)

TABLE XI

ANALYSIS OF VARIANCE SHOWING CULTIVAR, P TREATMENT, SAMPLING TIME, DISTANCE, AND DEPTH INTERACTIONS FOR AVAILABLE SOIL P FROM 1983 DATA

Source	DF	SS	MS	F-Value
Cultivar x Distance	2	180,052	90,026	3.83 *
Cultivar x Depth	3	71,090	23,697	1.01 NS
Cult x Dist x Depth	6	50,284	8,381	0.36 NS
Cult x P Treat x Dist	8	960,792	120,099	5.11 **
Cult x P Treat x Depth	12	465,399	38,783	1.65 NS
Cult x P Trt x Dist x Depth	24	421,686	17,570	0.75 NS
Cult x Time x P Trt x Dist	10	596,975	59,698	2.54 **
Cult x Time x P Trt x Depth	15	2,286,431	152,429	6.49 **
Cult x Time x P Trt x Dist x Depth	30	410,506	13,684	0.58 NS
Error	880	20,682,537	23,503	

NS = no significant difference
* = significant difference (0.05)
** = highly significant (0.01)

VITA 2

Thienchai Suwanvesh

Candidate for the Degree of

Doctor of Philosophy

Thesis: PHOSPHORUS MOVEMENT IN SOIL EVALUATED BY SOIL SAMPLING TECHNIQUES AND SOIL TEST CORRELATION WITH APPLE LEAF ANALYSIS UNDER TRICKLE IRRIGATION

Major Field: Soil Science

Biographical:

Personal Data: Born in Saraburi, Thailand, September 2, 1944, the son of Mr. and Mrs. Chimma Suwanvesh. Married to Somruthai Benjamas, March 9, 1971.

Education: Graduated from Triem Udomsuksa High School, Bangkok, Thailand, in April 1963; received the Bachelor of Science degree in Agriculture from Kasetsart University, Bangkok, Thailand, in June, 1968; received the Master of Science degree from Oklahoma State University, Stillwater, Oklahoma in May 1981; completed requirements for the Doctor of Philosophy degree in Soil Science from Oklahoma State University in May, 1985.

Professional Experience: Fourth Class Agriculturist, Agricultural Chemistry Division, Department of Agriculture (Thailand), 1968-1975; Soil and Fertilizer Division; Department of Agriculture (Thailand), Ministry of Agriculture and Cooperatives, 1975-1977; Fifth Class Agriculturist, Experimental and Demonstration Farm, Undersecretary Department, Ministry of Agriculture and Cooperatives, 1978-1983; Chief of Administration and Management Division, Experimental and Demonstration Farm for Irrigated Agricultured, Undersecretary Department, Ministry of Agriculture and Cooperatives, 1983-present.

Award: FAO/UNDP Fellowship, 1978-1980.