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To the Graduate Council:

I am submitting herewith a dissertation written by Matosinho de Sauza Figueiredo entitled "The relationship of certain soil physical properties to root distribution, nutrient absorption, and yield of corn and soy beans planted in three row arrangements." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant, Soil and Environmental Sciences.

William L. Parks, Major Professor

We have read this dissertation and recommend its acceptance:

L. F. Seatz, F. F. Bell, J. I. Sewell

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a dissertation written by Matosinho de Souza Figueiredo entitled "The Relationship of Certain Soil Physical Properties to Root Distribution, Nutrient Absorption, and Yield of Corn and Soybeans Planted in Three Row Arrangements." I recommend that it be accepted for partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant and Soil Science.

William L. Parks
William L. Parks, Major Professor

We have read this dissertation
and recommend its acceptance:

Frank F. Bell

Lloyd F. Seatz

John S. Howell

Accepted for the Council:

Hilton A. Smith
Vice Chancellor
Graduate Studies and Research

THE RELATIONSHIP OF CERTAIN SOIL PHYSICAL PROPERTIES TO ROOT DISTRIBUTION, NUTRIENT ABSORPTION, AND YIELD OF CORN AND SOYBEANS PLANTED IN THREE ROW ARRANGEMENTS

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee

Matosinho de Souza Figueiredo

March 1975

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ABSTRACT

This investigation was conducted for two seasons (1972 and 1973) on a Sequatchie loam soil at the Plant Science Farm, Knoxville, Tennessee. The effect of bulk density and large pore space on root distribution, nutrient absorption, and yield of corn and soybeans planted at different row arrangements was studied.

Bulk density, large pore space and root volume from soil core samples taken at different distances from the reference row at different times were measured. The amount of plant roots per unit volume of soil gradually increased as the season progressed but decreased late in the season in both corn and soybeans. Root volume data from samples taken at comparable distance from the reference row showed that row arrangement had no effect on root volume for corn and soybeans during both years. Higher bulk density and smaller percentage of large pore space at the 6-12-inch depth generally impaired root penetration by soybean plants, but had less effect on root penetration by the corn plants. The root volume in the surface soil was generally higher close to the row and decreased gradually as the distance from the row increased. Above ground plant samples taken at different times during the growing season were analyzed for their concentration of N, P, K, Ca, and Mg. Generally the nutrient percentages in the above ground corn plants were high early in the season and decreased as the season progressed except for P which was high early in the season, decreased up to 60 days, and then leveled

off in 1972 but increased to higher than the original levels in 1973. The nutrient percentage means for all row arrangements followed the same pattern and generally were not statistically different except for the period from tasseling to filling stage of growth in the 12-24" row arrangement in 1972. N, P, K, Ca, and Mg accumulation in pounds per acre gradually increased up to about 70 days (tasseling stage). During the ear development and filling stage of growth the amount of N, P, and K greatly increased while the increases in Ca and Mg were very small.

In soybeans, N, P. K, Ca, and Mg percentages were higher in the early stages of growth. Percentage of N and P generally decreased for about the first 70 to 80 days after planting and then increased slightly while the percent of K decreased as the season progressed. Ca and Mg percentages tended to level off at a later stage of growth. The amount of N, P, K, Ca and Mg that accumulated in the above ground soybean plants increased gradually for about 70 days. After this period a large increase in content of N and K was observed while the increase of P, Ca and Mg was less pronounced.

Root volume did not account for any yield differences among the row arrangements in corn and soybeans in either year. Corn at 17,424 plants per acre in 1972 produced a lower yield than 20,380 plants per acre in 1973. At the lower plant population in 1972, row arrangements did produce significantly different yields. However, at 20,380 plants per acre in 1973, row arrangement had no effect on corn yield.

Irregular soybean plant distribution and large percentage of lodging occurred in 12" and 12-24" row arrangements which reduced the yield of these treatments and may have accounted for no yield differences among the row arrangements.

TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Corn and soybean crops have generally been planted at 38- to 42-inch row spacings. However, depending on the varieties used and on the region where they were planted, reduction in row spacing has resulted in increased yields of these crops. In 1972, an Illinois soybean record of 83.5 bu./A was established using a twin-row planting pattern in which the basic row width was 27 inches and the twin rows were nine inches apart. The distribution of plants in the crop area affects the amount of light intercepted by canopies which may be reflected in increased yield.

The principal objective of this study was to determine the effect of different row arrangement on the nutrient uptake, root distribution and yield of corn and soybeans.

Bulk density and large pore space were measured at different times to study their effect on root development and yield. The percentage of N, P, K, Ca, and Mg in the above ground plant was measured for each row arrangement at different times to study their effect on crop yield.

CHAPTER II

REVIEW OF SELECTED LITERATURE

I. Corn

Rooting System

A very detailed study by Foth (37) showed that from the seedling to 37 days after planting (knee high) there was an oblique downward trend of corn root growth and that the maximum root weight for this period occurred at the 3- to 6-inch depth followed by the 6- to 9- and 0- to 3-inch depth. From 40 to 50 days after planting a rapid root growth occurred largely as a filling of the upper 12 to 15 inches of the soil in such a way that there was a marked uniformity in root density in most of the upper part of the soil by the 54th day. Little increase in root weight occurred after this date in the 9- to 15-inch depth. A pronounced extension of root growth below 15 inches into the deeper soil layer occurred from 54 to 67 days after planting.

Brace roots which start branching intensively after 67 days increased the root weight about 50% in the area 3 to 9 inches from the plant and in the upper 9 inches of the soil. From 80 days to maturity no significance in root weight or root distribution was apparent. Fehrenbacher and Alexander (34) found that the roots were symetrically distributed around the corn plant and above 70% of the corn roots were located in the 0- to 12-inch depth of the soil layer (68, 69). Dry weight of roots per plant decreased 72% by increasing plant population from 5,000 to 25,000 plants per acre while width and depth of root were decreased by 14% and 33%, respectively. On the per acre basis, however, the yield of dry roots increase with increasing population up to 20,000 plants per acre. A difference in response among the varieties was observed (82). The depth of profuse branching can be affected by changes in soil compaction and aeration related to depth of cultivation (14, 16).

Spacing and Yield

Results of many experiments have shown significant yield increases with decreased row spacings (42, 71, 91, 83, 113). Many workers reported a slight yield increase as the row spacing decreased (16, 20, 21, 38, 61, 63, 70, 79, 92, 112, 114, 136). Generally, rows 20 inches or narrower outyielded 30- and 40-inch row spacings. However, other workers reported no yield differences due to narrow row spacings (14, 19, 59).

Effect of Population

Ear weight decreased with an increase in population (16, 33, 70) and increased with increased time necessary to maturity (33). Colville (21) and Stivers (114) reported that corn grown in 20-inch rows had fewer barrened plants than those grown in 40-inch rows. Brown, et al. (16) stated that corn grain yield was a product of grain per plant and population. Optimum yields were obtained when population ranged from 14,000 to 24,000 plants per acre (23, 118).

Moisture

The increase in yield for narrow rows was attributed to reduction in interplant competition for moisture, nutrients and light as increased shading of the ground surface early in the season reduced weed growth and soil moisture loss (21, 61, 92). Fulton (38) found that the highest yields were obtained where high soil moisture levels were combined with high population and narrow rows. However, Stickler (112) reported higher yields with narrow rows even when moisture was limited. Hoff and Mederski (61) theorized that an equidistant planting pattern reduced competition between roots of adjacent plants for water and nutrients and thereby increased grain yield. Yao, et al. (136) found that even though there was an increase in rate of water use with higher populations the efficiency of water use was highest on 21-inch rows and lowest in the 40-inch rows. He attributed this more efficient use of water to higher light interception in the 21-inch rows. Gates (39) reported that evaporation from bare soil decreased rapidly at 1 or 2 days after an irrigation or rain, while transpiration was not limited as much as 2 weeks later. Colville (22) showed that inadequate population inefficiently used the light energy which in turn increased soil temperature and contributed to greater loss of water by evaporation than by transpiration. Timmons and coworkers (118) reported that water use increased as the population increased from 14,000 to 22,000 plants per acre.

Solar Radiation

Radiation studies revealed that net radiation from the soil was less where rows were narrower (5, 39, 136). A higher light interception has been reported in plants grown in 20-inch rows or less than those grown in 42-inch rows (29, 92, 135, 136). Hoff and Mederski (61) found that equidistant planting improved utilization of the solar energy. Denmead, et al. (29) reported that 73% of the energy expenditure within the corn crop occurred in its upper half. They suggested that spacing rows narrower than 40 inches could increase the energy available for photosynthesis by 15 to 20%. The efficiency with which a foliage canopy intercepts light affects photosynthesis and dry matter production (134).

Properly spaced plants grown at adequate populations increased the utilization of solar energy and substantially increased corn yields.

The beneficial effect of uniform plant spacing on crop response is believed to be due to greater utilization of radiant energy. Within limits, plant population increases have the same effect (22, 100).

Nutrient Status and Yield

Maximum yield depends on an adequate and balanced supply of essential nutrients (49, 106, 125, 126). The mineral nutrition of corn plants appears to influence grain yields mainly by affecting (a) the leaf area produced early in the season (49, 50), and (b) the length of time the leaves remain alive and functioning during grain formation, provided the other factors affecting growth are adequate (50, 106). Shear, Crane and Meyer (106) indicated that if all other factors were constant, plant growth was a function of nutrient intensity and balance. Walter (126) reported that in spite of the fact that N-P-K were not significantly associated with corn yield for any plant part in the early growth stage, the linear effect of P upon yield, with other variability accounted for, was always positive, whether in the whole plant or any plant part at the tasseling stage. A high positive correlation between the percent N, P and K in the corn leaves at silking stage and yield of grain has been found by some investigators (49, 80).

Dry Matter

The accumulation of dry matter in corn tends to follow the characteristic sigmoid shaped curve (6). The rate of dry matter accumulation was slow initially, but increased as more and more leaves emerged, increasing the leaf area exposed to sunlight. Dry matter accumulation followed the same pattern in each of the different plant parts, beginning first with the leaves and leaf sheaths, then the stalk and tassel, followed by the husks, shank and cob, and finally the grain. Sayer (102) and Gorsline, et al. (43) found that the maximum rate of dry matter production occurred during tasseling, silking and after growth in height had ceased. Hanway (49) reported the period of ear filling as being the "critical period." Most of the dry matter produced during this period was transferred to the grain.

Nitrogen

Hanway (50) and others (15, 102) reported that the trend for N accumulation was similar to dry matter production and the greatest rate of N and dry matter accumulation occurred at the same time. The percentage of N in the whole plant decreased as the age of the plant increased due primarily to the dilution effect (11, 15, 50, 61, 103). During maturity, a large part of the total N moved to the grain (52, 100).

Phosphorus

Phosphorus accumulation was reported to be similar in many ways to N accumulation. The maximum amounts were present at the same time as was the N, but the total amount per plant increased toward the end of the season. This was attributed to the large amount of phosphorus which moved into the grain (7, 50, 53, 102, 103). The percent P tended to reach a maximum about the middle of the season and then decreased as the plant matured (15, 81, 102, 103). Gorsline (43) reported that early growth stages had high P concentrations that decreased rapidly until grain formation, then the whole plant P increased.

Potassium

Potassium accumulation reached its peak earlier in the season than did N or P. The maximum rate of accumulation also occurred early in the season. Potassium was not transferred from the plant to the grain in large quantities and was lost from the plant at the end of the season. It has been theorized that K in the whole plant is reduced by loss of leaves, leaching from the leaves by rainwater and loss from the roots (43, 50, 81, 102, 103). The percent K in the plant decreased from the first to the last part of the season as did N (15, 20, 32, 50).

Calcium

The accumulation of Ca by the whole plant paralleled that of the dry matter accumulation and increased to a maximum at maturity with a small loss occurring at the end of the season. The percentage of Ca in the plant decreased as age increased (11, 43, 50, 81, 103).

Magnesium

Magnesium accumulation increased as the dry matter increased throughout the season with losses recorded at maturity (11, 43, 50, 81). Sayre (103) reported that percent Mg increased, then leveled off and decreased at the last of the season.

II. Soybeans

Root System

A study by Mitchell, et al. (78) showed that soybean root systems 21 days after planting consisted primarily of secondary lateral roots that develop from the upper 10 cm of the taproot. Four longitudinal rows of lateral roots spaced at 90 degree intervals around the taproot developed acropetally often within 2.5 cm of the soil. These laterals grew horizontally for 40 to 50 days reaching 35 to 40 cm in length. From 67 to 80 days which is the stage of flowering and beginning of pod formation and a period of high rate of top growth, there was a rapid growth filling the 0 to 23 cm depth of the soil profile to the center of the row. The roots start a deeper downward vertical penetration, from 80 to 102 days that coincides with seed set to maturity. Penetration of taproot growth slowed and rapid rate of downward extension of five to six laterals that had initially grown to variable distances horizontally occurred, thus making lateral root development more important than the taproot (78).

Root dry weight was concentrated in the upper portion of the soil profile with 90% or more in the upper 7.5 cm early in the season and in the upper 15 cm during the remainder of the season. This agrees with the results of the work done by Hanway cited by Mitchell (78), Raper (97), and Mitchell (77). There were differences in behavior among varieties (77, 78, 97). In addition, the root system depended upon the physical characteristics of the soil and moisture conditions. The root systems of soybeans growing in adjacent rows tend not to interpenetrate but turn downward when approached by another root system (97).

Plant Adaptation

It must be pointed out that soybean plants have a great capacity to compensate for plant population. Pendleton and Hartwig (94) reported that reducing stand within a row by various skips had little effect on yield when various length skips made up either 20 or 33% of the row, but yield could be greatly reduced when 50% of the stand was removed and the skips were larger than 100 cm in one case and about 183 cm in another case. Leman and Lambert (67) found that seed weight and seed per pod were not appreciably affected by spacing or population change: the number of seed, pods, and branches per plant decreased with increased plant population. Plant height increased and the pods were set higher above the ground level as the population increased (2, 130). Numerous reports have shown that thick to moderate spacing (1/2 to 4 or 5 inches) produced similar yields, while thinner spacing of about 4 or 5 inches and greater produced lower yield per acre (18, 49, 74, 96).

Varieties react differently to planting rate and row width (94, 96, 132). Narrow rows required more plants per acre for optimum yield than wide rows. Plant distribution was more uniform in narrow rows and plants more quickly occupied the aerial environment than did plants in wide rows (109).

Spacing and Yield

Since 1930, a number of workers have reported that decreased spacing between rows tended to increase soybean yields (17, 67, 68, 74, 94, 117, 131, 132). In general, 10-, 15- and 20-inch rows have produced higher yields than 30- and 40-inch row spacing. The increase for narrow rows was generally greater with early varieties and with late planting dates (64). Research has indicated that the importance of narrow spacing seems to diminish from North to South (57, 61). Although some workers have not indicated any advantage from close rows in the South (14, 19, 59). Thurlow (117) indicated that with changing varieties and with increasing double cropping, which caused delayed planting, closer rows have resulted in increased yields. Yield trials using early maturing varieties have shown slightly higher yield with narrow rows (66, 117).

Hanway (48) in irrigated plots showed that 20- and 30-inch rows had no yield advantage over 40-inch rows. But it was demonstrated that yields will increase as rows were narrowed until leaves of the plants in adjoining rows meet and completely shade the soil. If short plant varieties are grown or the fertility level is such that vegetative growth is somewhat restricted, narrow row spacing usually resulted in higher yields.

Optimum planting rate and row spacing for soybeans should be determined not only for various soybean producing areas, but also for the varieties to be grown. Tall and late maturing varieties would require wider row spacing and lower seeding rates than small and early maturing varieties for optimum yields (5, 64, 133). In addition, the yield advantage obtained in narrow rows was not consistent year after year even on soils which were of the same productivity and type.

Lodging

High seeding rates increased lodging and seed cost (2). Cooper (26) reported that seed yields in the lodged plots were reduced 21-23% when compared to plots where soybean plants were artificially maintained in an upright position. Generally, density within the row and not row spacing was the prime factor causing lodging prior to harvest. Probst (96) reported lodging to increase with increasing density in the row, while height, seed size and maturity were generally unaffected. Wiggins (132) stated that lodging and seed loss due to wind was greater in narrow rows than in wide rows.

Population and Sunlight Interception

Exposure of soybeans planted at different arrangements to sunlight has been investigated by a number of workers (91, 101, 115). Shaw and Weber (105) studying the effect of shading and light interception in soybean planting arrangements observed that the lower leaves of the canopy often received inadequate radiation for maximum photosynthesis. He also observed that most light energy was intercepted in the outer 15 to 30 cm of the row canopy and that shading of adjacent rows was greater in one meter rows than in 1.5 meter rows. Sakamoto and Shaw (101) and Yao and Shaw (135) found that light interception occurred primarily at the periphery of the canopy. When the open space between rows closed or when it was nearly closed, interception was primarily at the top of the canopy. The lower leaves did not receive adequate radiation. An increase in yield could possibly be achieved by selecting varieties whose natural leaf inclination leads to deeper penetration of useful energy to a greater number of leaves. Parks (91) in a study with different row arrangements found that a plant one-skip one system permits the greatest exposure of the plant canopy to light, which causes a higher yield per acre. When light reflectors were placed on each side of the rows, the plant one-skip one system produced additional yield increases of 12 and 22.5 bushels per acre when 72-inch rows of "Lee" soybeans were used.

Composition of Soybean Seeds

Results of research are not consistent as far as seed composition is concerned. It has been found that wide row spacing and decreased plant population result in a small increase in oil content of seed over that in narrow rows and closely spaced plants (30, 47, 129, 131). However, percent protein decreased slightly in wider rows and lower populations.

Population and Water Use

There have been many tentative explanations why narrow row spacing produces favorable yield. Mannering and Johnson (73) in a simulated rain trial, found that narrow rows of soybeans during the later half of the season had 24% greater water infiltration and 35% less soil loss than wide rows. Timmons and Thompson (119) found no difference in evapotranspiration measured over a variety of row spacings and plant populations but they did find that the highest water use efficiency was obtained from high populations in 8-inch rows. Gates and Hanks (39) reported that evaporation from most bare soils decreased rapidly at one or two days after an irrigation or rain. The rapid rate of water evaporation from the soil surface brings about formation of a dry soil layer which greatly reduces or even prevents evaporation. Thus, water conserved in the soil can be used for plant transpiration. Mederski and Jeffers (75) maintaining the irrigated plots at specific moisture tensions found that if lodging was not present to any appreciable degree, narrow spacing still maintained a significant yield advantage over wider spacing under condition of equal soil moisture. Aubertin and Peters (5) concluded that if moisture was limited, a lower population with moderately spaced rows would produce higher yield from available moisture. Thompson (116), and Mederski and Jeffers (75) found that increased moisture tension during flowering and pod setting may result in abortion of the flowers or of the young pods causing yield differences.

Dry Matter

Several workers have reported that dry matter production was progressive in soybeans reaching a maximum during the beginning of bean formation (46, 56, 58, 85). Two changes took place in dry matter accumulation during the season: (a) highest rate of dry matter accumulation occurred at approximately the same time that plants reached their maximum height, and (b) dry weight dropped at the end of the season because of leaf drop.

Nitrogen

Hanway and Weber (54) reported that the percent N in soybean plants decreased from the seedling stage until pod fill began and then increased until bean harvest. Harper (56) found that percent N decreased from the first of the season until midbloom and then leveled off until bean harvest. Hammond, Black and Norman (46), and Henderson and Kamprath (58) reported that percent N was initially high but decreased throughout the season.

Nitrogen accumulation has been reported to increase until harvest (14, 54, 58). The peak period of uptake coincided with the period of pod set and initial filling (56). The accumulation of N was also reported by Henderson and Kamprath (58) to continue after the pods and seeds were formed, which indicated that the plant continued to fix nitrogen during that period.

Phosphorus

Phosphorus uptake patterns were similar to N uptake over the season with peak uptake occurring during the period of pod set and initial pod fill (54). Henderson and Kamprath (58) stated that this peak uptake of P during podding indicated a rapid accumulation of P in the seeds. The percent P in the plant has been reported to increase initially, then decrease slowly until early bloom and then increase until maturity (14, 54, 56, 58).

Potassium

Hanway and Weber (54) and Henderson and Kamprath (58) published results showing the percent K in the whole plant was the highest at the first of the season after which time there was a continuous decrease in the vegetative portion except for a brief increase about the start of leaf fall. Although the accumulation of K was not as uniform as other elements, it was very similar to N and P, the period of greatest uptake being during the pod filling stage. The K accumulation, however, did decline during the last growth stages (54, 56).

Calcium

The percent Ca increased sharply for the first 30 days, then decreased rapidly to a relatively constant value till the plant reached maturity (54, 56, 58). Hammond, Black, and Norman (46) reported the accumulation of Ca to increase at relatively constant rates until pod fill began and after this a small decrease in Ca occurred. Other workers also reported the same trends (14, 54, 56).

Magnesium

The percentage of Mg has been reported to decrease slightly in the first 70 days after planting and remained almost constant through the later part of the season (46, 56, 58). Accumulation of Mg has been reported to continue until maturity with an increasing rate of accumulation occurring from 45 days after emergence to the end of the season (46, 56, 58).

III. Factors Affecting Root Development

Mechanical Impedance

Mechanical impedance increased with bulk density and with increased moisture tension. Lack of aeration at low matric potential and soil moisture stress both restricted root growth in a low density soil. But mechanical impedance becomes more important as the bulk density increases above 1.4 and/or the matric potential increases above 100 cm of water (10, 44). Root penetration was inversely correlated with mechanical impedance (7, 10, 35, 44, 69, 99, 123) in such a way that an increase in bulk density reduced root growth. Bertrand and Kohnke (12) have shown that 5-week old corn roots did not freely penetrate subsoil which had a bulk density of 1.5 g/cm^3 and 5.4% air capacity, but they grew profusely in subsoil with a bulk density of 1.2 g/cm^3 and 14.6% air capacity. This barrier was not entirely mechanical but it was also caused by lack of oxygen. On the other hand, it has been shown that when any soil restriction prevents penetration of roots downward, the lateral roots branch more profusely and enhanced lateral elongation makes up for the roots that could not develop (8, 35).

Water

Water affected the growth and function of roots directly, and indirectly affected aeration, mechanical impedance, soil temperature and nutrient movement (10, 12, 44, 65, 99). Water and nutrient movement as well as gas flow in the soil was definitely related to soil porosity, and nutrient movement to the plant was greatest when the soil water film was thick. This condition restricted gas exchange (10, 44).

Root Density and Nutrient Absorption

Barley (8) reported that root density L_v (length per volume of soil) tended to have an overriding influence on the rate at which the soil was depleted of immobile nutrient elements even though there was no definite correlation between L_v and the quantity of element absorbed. Different nutrients were absorbed in amounts and proportions that varied with the stage of growth (8, 98). Their relative availability may differ widely with depth. Comforth (24) has shown that uptake of N was independent of root density while P and K uptake per unit of soil decrease as the root density decreased.

It has been shown that in fertilized plots, corn plants derived only 7 to 11% of their P from below 12 inches (25 cm) and that root density within the top soil under well-established corn and pasture was adequate for large P uptake (8).

Root System and Yield

Although the root dry weight decreased as the mechanical impedance measured by bulk density increased, as previously described, there was no positive correlation between yield and total root weight (34). This was due to the fact that configuration of the root systems and its function depended considerably on the interaction of the factors that make up the soil environment for root growth. Rosemberg (99) found a parabolic relationship between bulk density, plant response and the maximum yield obtained. The porosity at which it occurred could not be characterized by a quantitative relationship.

Aeration

The aeration requirements for growth of different species vary considerably. Due to biological activity in the soil, the important feature seemed to be the continuous rate of oxygen supply (10, 44, 65). There was a close correlation between oxygen diffusion rate and growth of the plant in a compact soil. Root elongation was restricted when the diffusion rate was below a certain minimum which is considered to be 20 to 30 x 10^{-8} g/cm^2/min (12, 44, 65, 99).

Soil is generally well aerated for plant growth if it has aeration porosity of 10% or more (10, 65). Minimum oxygen diffusion has occurred when aeration porosity was around 10% and was virtually zero at porosity below 10%. Therefore, aeration porosity of 10% is a dangerously low level for plant growth (124). In addition, gas flow through the soil was affected by the soil water content. The gas flow tended to decrease as the moisture content increased (10, 12, 44).

Fertility

The fertility status of the soil affects root development. Roots grow vigorously at high fertility levels provided other factors are satisfactory. But lack of fertility prevented root development with sufficient vigor to penetrate the subsoil intensively (10, 36, 68).

CHAPTER III

MATERIAL AND METHODS

I. General

The experiments were conducted at the Plant Science Farm, near Knoxville, Tennessee, on a Sequatchie loam with 0-2% slope, for two consecutive years, starting in 1972.

A complete randomized block experimental design was employed with each crop using three row arrangements and four replications. Each plot was 35 feet long by 36 feet wide and was divided in half lengthwise with one end used for soil and plant sampling and the other harvested for yield.

Two, four, and six central rows of each half plot in treatment, 36, 12-24, and 12, respectively, were harvested for yield in each crop each year. The soybean seeds and corn ears were weighed and sampled for moisture content. These data were converted to weights at 15.5% and 13% moisture for corn and soybeans, respectively.

Results of soil analyses showed pH varying from 6.2 to 6.7; therefore, application of lime was not necessary. The soil level of P and K varied from low to medium. For both seasons, N, P_2O_5, K_2O were surface-applied and incorporated as fertilizer mixtures at the rate of 500 pounds per acre. A 6-12-12 fertilizer was applied on the corn plots and a 0-20-20 fertilizer was applied on the soybean plots.

Ammonium nitrate was sidedressed at the rate of 400 pounds per acre when corn plants were about 30 days old.

Corn hybrid Tenn 606 was planted in 1972, and Pioneer brand 3369A was planted in 1973. York soybeans were planted both seasons. In 1972, corn was seeded on May 18 and due to irregular germination and bird damage it was thinned to 17,424 plants per acre in order to have the same population for all treatments. The germination of corn planted on May 17, 1973, was excellent and the plant population was thinned to 20,380 plants per acre. The thinning operation was performed when the corn plants were about 30 days old.

Soybean germination was impaired by presence of a soil crust. In 1972, seeds planted on May 18 did not germinate satisfactorily and the experiment was replanted on June 2. In 1973, despite the fact that the soil was wet, seeds planted on May 17 and replanted on May 25 did not germinate well, therefore a third planting was made on June 8. The germination of the soybean seeds in the second planting in 1972 and in the third planting in 1973 was reduced in spite of irrigation after the replanting operations. The plant population was still not uniform for both seasons but was generally adequate for valid yields.

II. Row Arrangements

Three row arrangements were selected in order to have a constant population but different plant distribution for each arrangement. The first arrangement consisted of all rows placed at 36-inch intervals; in the second arrangement two rows were placed 12 inches apart from each other leaving a 24-inch interval between two sets of two rows. In the third arrangement all rows were at 12-inch intervals. These arrangements are hereafter denoted as 36", 12-24", and 12", respectively, and are shown in Figure 1. The plant distribution within the rows varied with row arrangement for corn but not for soybeans. Corn seeds were planted thick but thinned to 9-, 17- and 26-inch intervals for the three row arrangements while soybean seed distribution rates were 8 to 12 seeds per foot of row for all row arrangements. Therefore, the 12-24" and 12" row arrangement had half and one-third as many corn plants per row as the 36" row arrangement but twice and three times as many soybean plants per unit area as the 36" row arrangement.

III. Weed Control

In order to avoid competition with the crops, the plots were kept almost weed free. This also avoided the problem of separating corn and soybean roots from weed roots. Atrazine 80 (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) at two pounds per acre applied pre-emerge gave good control of most weed species in corn in both seasons. Those weeds that survived were removed by hoeing as they germinated. For soybean plots, dinoseb (2-sec-butyl-4,6-dinitrophenol) at 1 1/2 pounds per acre applied when the seeds were sprouting was not effective in controlling the weeds in the 1972 season. Three hand hoeings were required before the canopy closed and two more later as the weeds germinated. In 1973, the same herbicide pre-emerge applied at four pounds per acre gave good control of most of the weed species. Those

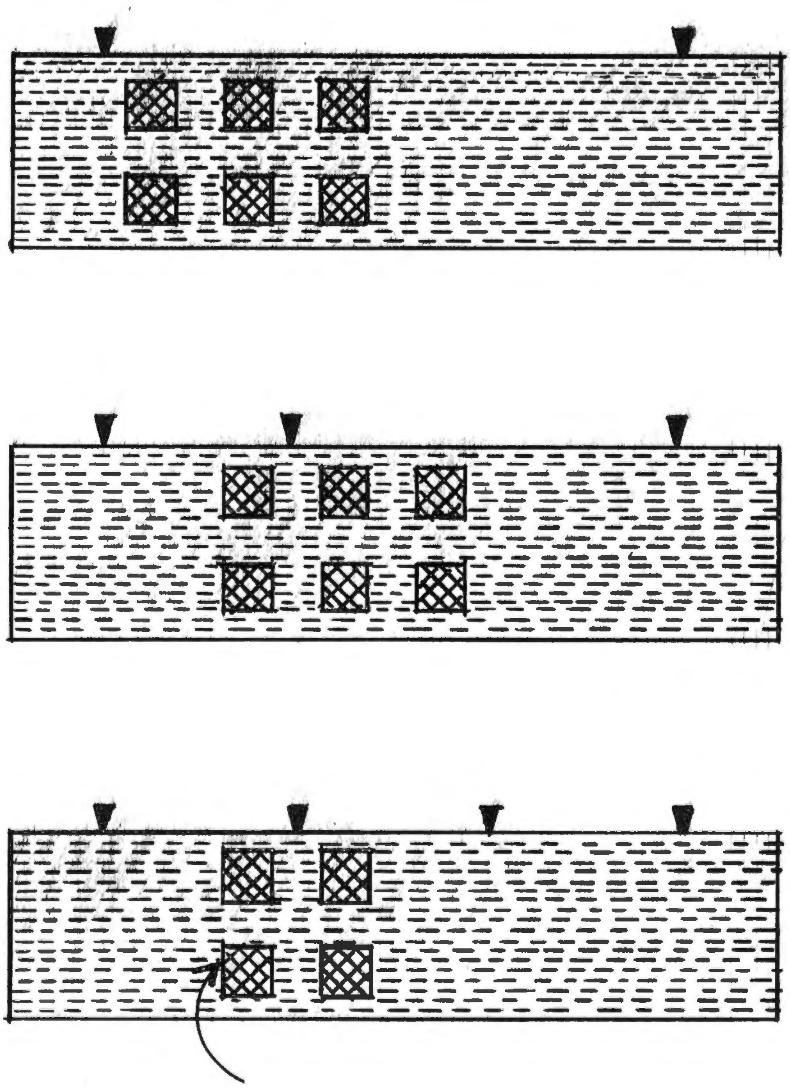

Figure 1. Location of three-inch by three-inch soil core samples relative to row in each of the three row arrangements.

weeds not affected by the herbicide were removed by hoeing as they germinated.

IV. Sampling Procedures

Soil Sampling

Three by three-inch core samples were obtained in the 0-6" and 6-12" depth using Uhland's method (120). In sampling the 0-6" depth of the surface soil about one inch of soil was removed and the soil sampler driven into the soil vertically. The soil was then removed to a depth of seven inches with a hoe, the surface smoothed and the sampler driven vertically into the subsoil to sample the 6-12" depth. The samples were taken in each plot wherever the plant population was considered well distributed, and at different distances from the row toward the row center at six-inch intervals according to row arrangements. In the 36" row arrangement, core samples were taken at 0-6", 6-12", and 12-18" intervals. In the 12-24" arrangement, core samples were taken at 0-6" between the two rows planted 12" apart and at 0-6", and 6-12" intervals in the 24-inch row spacing. In the 12" arrangement, core samples were taken beside the reference row at 0-6" intervals. A fallow plot adjacent to each crop was used for control.

Figure 1 shows the three row arrangements, and sites at which the samples were taken. The soil sample was roughly trimmed in the field and the core samples checked for any damage of irregularity before being brought into the laboratory for study.

Plant Sampling

The plant sampling procedure varied with crop. For both crops, two samples per plot were taken wherever the plants were considered well distributed within the rows, and the plants were cut close to the ground with a sharp knife.

The corn sample consisted of three whole above ground plants, while the soybean samples consisted of all plants within a three-foot row length.

All plants were washed to eliminate any possible source of soil contamination, placed in labeled cloth bags and dried in a forced-air oven at 70°C. The dried plants were ground in a Wiley Mill using a two millimeter screen, thoroughly mixed and a sample of the total plant samples stored in glass bottles until analyzed.

V. Laboratory Procedure and Analysis

Soil Analysis

1. Sample preparation. The core samples which had been roughly trimmed in the field were trimmed flush with the cylinder with a sharp knife. A piece of cotton broadcloth was placed around the bottom, a metal ring was put on the top of the cylinder, and both were held in place by rubber bands. The soil samples were soaked overnight under a mild vacuum to saturate and remove air trapped in the soil.

2. Large pore space determination. The saturated soil samples were drained of free water, weighed and transferred to a tension table to determine the large pore space at 50 centimeters tension. After 15

hours, they were removed from the tension table and weighed. The weight difference in grams converted to millimeters gave the large pore space volume.

3. Root separation. The soil samples were soaked, then placed on a number 20 metal screen which in turn was inside a plastic bucket. The soil was washed off and the roots that remained on the screen were carefully picked up and kept wet to avoid alteration in their volume.

4. Root measurement. The roots, after adsorbed water was removed by blotters, were inserted into a graduate cylinder with a known volume of water to determine their volume. The difference between the initial and final readings was taken as the volume of the roots in milliliter per core sample which was converted to milliliter per liter of soil. The roots were dried at 70°C and weighed.

5. Bulk density determination. After the roots had been separated from the soil, and all the soil washed from the screen, the contents of the bucket were then transferred to a preweighed can for drying to determine the weight of the soil. The dry weight of the soil plus the roots' dry weight divided by the volume of the core sample gave the bulk density in grams per cubic centimeter.

Plant Tissue Analysis

Plant samples for N analysis were digested with H_2SO_4 and H_2O_2 as described in Appendix A. Portions of the digestate were analyzed for N by the procedure of Gehrke, Ussary and Kaiser (40) as modified by Ashburn and Parks (4) for the Technicon Autoanalyzer. This procedure is outlined in Appendixes B and C.

A modification of the wet oxidation procedure by Gieseking, Snider, and Getz (41) was used to digest all tissue samples for K, Ca, Mg, and P determinations. These procedures are outlined in Appendix D.

Pottassium, Ca, Mg, and P concentrations were determined on the digestate using the Technicon Autoanalyzer. These procedures, as modified from that of Steckel and Flannery (111), are outlined in Appendixes E, F, G, and H. Potassium and Ca were determined by flame, while P and Mg were determined colorimetrically.

All laboratory analyses were converted to percentage plant content for each element.

VI. Data Comparisons

Root volume in milliliters per liter of soil, bulk density in grams per cubic centimeter (gm/cc), and large pore space in percent by volume, collected from samples taken at comparable distance from the reference rows to the different row arrangements were compared by sampling dates each year in the following manner: (1) data from samples taken at 0-6-inches interval from the row in all row arrangements were compared; (2) data from samples taken at the 6-12-inch interval in 36" row arrangement were compared with data from samples taken at the same distance in the 12-24 inch arrangement; (3) data from samples taken at the 0-6-inch interval between the two rows in 12-24" arrangement were compared with data from samples taken at the 0-6-inch interval in arrangement 12" for both corn and soybeans. Hereafter these comparisons will be designated comparison I, comparison II, and comparison III, respectively.

VII. Statistical Analyses

The data for the three comparisons of bulk density, large pore space and root volume as well as the nutrient content data were analyzed using the Nesting procedure (10). The yield data were analyzed by simple analysis of variance. The 0.05 level of probability was used to determine significant differences. When differences were detected, significant means were separated by Duncan's Multiple Range Test.

CHAPTER IV

RESULTS AND DISCUSSION

I. Climate

Data for monthly precipitation, mean air temperature and mean cloud coverage during the two years of the experiments are presented in Appendix I.

The data show that temperature was slightly higher during the 1973 season than during the 1972 season. Precipitation was generally higher in 1972 than in 1973. The cloud coverage which reduced the total incoming solar radiation was slightly higher in 1973 than in 1972 in June and July and slightly lower in 1973 than in 1972 during May, August and September. The two later months coincide with the tasseling and filling stage.

II. Corn

Bulk Density of Soil

The means for the bulk density determinations in grams per cubic centimeter are shown in Tables 1 and 2. The bulk density of the surface soil (0-6-inch depth) varied from 1.22 to 1.45 in 1972 and from 1.27 to 1.50 in 1973. The surface soil was more compact in 1973 as most of the bulk density measurements were almost equally divided between the 1.30 to 1.39 and the 1.40 to 1.49 range while in 1972 they were almost equally

Table 1. Bulk Density of Soil Samples Taken at Different Places and Times Within Three Row Arrangements of Corn Planted on May 18, 1972

Row Spacing	Distance From Row	Days After Planting 29	35	42	48	62	69	76	83	92	97
		Grams per cubic centimeter									
		Surface Soil (0-6")									
36"	0-6"	1.33*	1.40	1.35	1.42	1.34	1.33	1.27	1.28	1.24	1.42
	6-12"	1.35	1.38	1.35	1.29	1.44	1.39	1.35	1.25	1.29	1.37
	12-18"	1.33	1.40	1.28	1.31	1.40	1.41	1.38	1.39	1.45	1.39
12-24"	0-6"	1.30	1.42	1.30	1.27	1.23	1.36	1.35	1.33	1.30	1.28
	6-12"	1.27	1.39	1.32	1.31	1.22	1.37	1.35	1.40	1.21	1.23
12"	0-6"	1.35	1.23	1.28	1.27	1.33	1.28	1.27	1.32	1.35	1.31
12-24"	0-6"**	1.29	1.29	1.29	1.38	1.23	1.25	1.35	1.33	1.35	1.28
Barren soil check		1.38	1.23	1.20	1.43	1.27	1.40	1.48	1.36	1.50	1.48
		Sub soil (6-12")									
36"	0-6"	1.51	1.56	1.50	1.50	1.49	1.49	1.55	1.52	1.56	1.53
	6-12"	1.53	1.56	1.53	1.50	1.57	1.37	1.52	1.53	1.43	1.44
	12-18"	1.56	1.53	1.52	1.40	1.52	1.54	1.53	1.48	1.48	1.50
12-24"	0-6"	1.47	1.47	1.49	1.41	1.35	1.46	1.40	1.51	1.45	1.39
	6-12"	1.49	1.45	1.45	1.42	1.51	1.43	1.49	1.52	1.47	1.43
12"	0-6"	1.48	1.48	1.52	1.43	1.47	1.52	1.47	1.47	1.49	1.46
12-24"	0-6"**	1.52	1.49	1.46	1.40	1.44	1.42	1.45	1.43	1.46	1.51
Barren soil check		1.54	1.55	1.48	1.54	1.38	1.55	1.55	1.53	1.56	1.49

*All figures represent an average of two replications.

**From samples taken between the two twelve-inch rows.

Table 2. Bulk Density of Soil Samples Taken at Different Places and Times Within Three Row Arrangements of Corn Planted on May 17, 1973

Row Spacing	Distance From Row	Days After Planting 32	40	46	53	60	67	74	81	97	102
		Grams per cubic centimeter									
		Surface soil (0-6")									
36"	0-6"	1.35*	1.37	1.35	1.34	1.40	1.40	1.32	1.27	1.34	1.40
	6-12"	1.40	1.42	1.40	1.43	1.47	1.41	1.37	1.43	1.39	1.41
	12-18"	1.29	1.47	1.48	1.33	1.47	1.39	1.42	1.29	1.41	1.38
12-24"	0-6"	1.38	1.43	1.40	1.36	1.46	1.30	1.31	1.34	1.41	1.44
	6-12"	1.43	1.40	1.39	1.39	1.44	1.42	1.44	1.44	1.45	1.40
12"	0-6"	1.50	1.48	1.40	1.50	1.47	1.38	1.33	1.36	1.41	1.35
12-24"	0-6"**	1.45	1.39	1.46	1.43	1.36	1.39	1.38	1.38	1.38	1.41
Barren soil check		1.45	1.44	1.42	1.40	1.46	1.33	1.45	1.42	1.29	1.40
		Sub soil (6-12")									
36"	0-6"	1.49	1.53	1.51	1.59	1.56	1.54	1.54	1.54	1.56	1.56
	6-12"	1.47	1.31	1.48	1.37	1.60	1.51	1.62	1.49	1.49	1.52
	12-18"	1.47	1.54	1.54	1.53	1.41	1.52	1.50	1.52	1.53	1.53
12-24"	0-6"	1.50	1.52	1.55	1.55	1.50	1.46	1.45	1.54	1.48	1.56
	6-12"	1.50	1.52	1.35	1.54	1.50	1.57	1.60	1.58	1.50	1.57
12"	0-6"	1.54	1.54	1.43	1.51	1.46	1.38	1.45	1.49	1.51	1.49
12-24"	0-6"**	1.57	1.46	1.53	1.55	1.45	1.48	1.50	1.56	1.45	1.55
Barren soil check		1.57	1.53	1.62	1.51	1.57	1.52	1.53	1.57	1.56	1.62

*All figures represent an average of two replications.

**From samples taken between the two twelve-inch rows.

divided between the 1.20 to 1.29 and 1.30 and 1.39 range. Generally no pattern of the bulk density increasing or decreasing as the growing season progressed was observed in the surface soil.

The subsoil (6-12-inch depth) bulk density ranged from 1.37 to 1.56 in 1972 and from 1.31 to 1.62 in 1973. No pattern of changes in bulk density as the growing season progressed was observed.

The few samples that fell much below this range probably had cavities which remained from decayed organic material or were burrows or holes caused by other biological life.

Large Pore Space

The mean from the large pore space determinations are shown in Tables 3 and 4. The large pore space in the surface soil ranged from 9.7% to 18.1% in 1972 and from 7.4% to 17.6% in 1973. The values show a decline in large pore space as the growing season progressed in 1972 but not for 1973. No general seasonal relationships were observed. The large pore space was generally lower in 1973 than in 1972 but this would be expected as the bulk density measurements showed the surface soil to be more dense in 1973.

The subsoil values were generally lower than corresponding values for the surface soil. Such a trend was expected but some of the values reached 5% or less and these are too low for very much root development. Generally values of 10% or more are necessary to maintain adequate oxygen supply to the root system and other soil biological activity (10, 12, 44, 65, 124).

Table 3. Large Pore Space of Soil Samples Taken at Different Places and Times Within Three Row Arrangements of Corn Planted on May 18, 1972

Row Spacing	Distance From Row	Days After Planting 29	35	42	48	62	69	76	83	92	97
		Percent by volume									
		Surface soil (0-6")									
36"	0-6"	11.5*	13.6	13.9	13.3	12.7	17.5	14.6	12.4	15.1	10.3
	6-12"	14.6	13.0	14.8	15.9	10.3	16.6	12.3	13.0	13.7	14.0
	12-18"	11.7	16.9	15.6	12.8	11.2	12.0	12.3	10.1	10.6	11.1
12-24"	0-6"	13.0	10.3	12.8	16.8	15.7	13.7	11.4	13.6	13.2	14.2
	6-12"	12.2	12.0	11.1	16.7	16.2	13.8	9.9	10.8	14.1	16.0
12"	0-6"	13.4	16.6	16.4	16.0	13.3	17.0	17.5	15.9	12.1	13.4
12-24"	0-6"**	15.7	15.2	14.5	13.8	15.2	17.1	11.9	13.1	12.1	14.8
Barren soil check		12.1	16.2	18.1	9.7	13.0	12.8	8.1	12.8	5.0	8.9
		Sub soil (6-12")									
36"	0-6"	10.6	9.9	11.3	10.7	9.5	11.9	6.7	6.8	6.4	8.5
	6-12"	10.2	8.7	10.5	11.1	5.8	15.1	8.0	7.6	11.7	11.7
	12-18"	8.6	10.1	9.5	10.8	9.6	11.4	8.2	8.0	9.4	9.5
12-24"	0-6"	10.9	9.3	8.4	13.2	8.7	11.4	10.8	7.2	9.0	11.7
	6-12"	9.9	9.2	10.0	10.6	7.5	12.9	7.5	7.3	9.3	9.8
12"	0-6"	9.9	10.2	10.0	11.8	10.2	10.2	10.0	10.6	7.3	9.2
12-24"	0-6"**	9.4	10.0	9.5	12.7	9.9	12.5	9.2	10.4	8.2	7.7
Barren soil check		5.8	9.8	10.9	9.5	12.1	7.2	5.8	9.0	8.7	9.2

*All figures represent an average of two replications.

**From samples taken between the two twelve-inch rows.

Table 4. Large Pore Space of Soil Samples Taken at Different Places and Times Within Three Row Arrangements of Corn Planted on May 17, 1973

Row Spacing	Distance From Row	Days After Planting 32	40	46	53	60	67	74	81	97	102
		Percent by volume									
		Surface soil (0-6")									
36"	0-6"	13.7*	11.4	12.8	11.0	12.3	11.2	14.3	17.6	14.1	13.2
	6-12"	11.7	10.3	12.1	11.2	9.3	11.2	12.8	15.3	11.8	10.4
	12-18"	15.7	8.2	8.6	13.6	9.0	11.9	11.1	16.2	12.5	11.8
12-24"	0-6"	12.3	8.3	11.4	11.6	9.8	13.5	14.2	16.1	9.6	10.4
	6-12"	11.3	11.1	13.1	11.8	12.2	8.2	12.0	12.6	8.3	13.3
12"	0-6"	8.3	10.0	12.3	7.4	10.0	12.0	14.5	15.7	11.2	12.9
12-24"	0-6"**	9.4	12.2	7.9	9.5	12.1	11.1	13.0	17.7	11.2	12.0
Barren soil check		10.1	9.0	10.1	10.0	9.1	12.4	9.7	11.2	10.1	11.7
		Sub soil (6-12")									
36"	0-6"	8.5	7.7	9.9	6.5	6.5	7.3	8.3	8.7	6.4	7.2
	6-12"	8.4	12.2	8.5	10.5	4.8	8.7	4.8	10.4	7.1	7.8
	12-18"	7.9	4.4	6.8	7.9	10.8	8.6	8.4	10.0	9.8	7.6
12-24"	0-6"	12.3	7.3	7.5	13.5	9.4	8.1	11.7	11.3	8.2	8.2
	6-12"	10.7	5.2	12.4	7.0	10.2	12.7	5.9	9.3	8.6	7.8
12"	0-6"	8.8	4.1	7.3	7.7	9.6	12.8	10.2	11.9	7.1	7.8
12-24"	0-6"**	5.8	9.1	6.6	7.2	9.6	8.6	10.0	10.3	12.9	8.4
Barren soil check		5.7	6.6	3.9	3.7	6.4	6.8	6.5	7.0	5.3	5.2

*All figures represent an average of two replications.

**From samples taken between the two twelve-inch rows.

Root Volume

The mean values from the root volume determinations are shown in Tables 5 and 6. The volume of roots measured at each sample site tended to increase each year as the season progressed until approximately 80 days after planting and then decreased. Generally the volume of roots measured was not great as perhaps many of the finer roots were lost in the separation process. The highest root volume occurred each year at the sample site near the 36-inch row arrangement. This was expected since this row arrangement provided the greatest plant density within each row.

The root volume in the subsoil was much lower in 1973 than in 1972 and this was probably due to the more dense surface soil in 1973.

III. Nutrient Content

The percent of N, P, K, Ca, and Mg in the plants at different days after planting for 1972 and 1973 are shown in Tables 7 and 8. respectively.

Nitrogen

Only for the sampling days 43, 51, and 58 days after planting when the nitrogen content for the 12-inch row arrangement was significantly lower were there any significant differences in the nitrogen content of the plants in any of the row arrangements. Generally, the percentage of nitrogen was higher at the beginning of the season and gradually decreased as the season progressed. The values were slightly higher

Table 5. Root Volume of Soil Samples Taken at Different Places and Times Within Three Row Arrangements of Corn Planted on May 18, 1972

Row Spacing	Distance From Row	Days After Planting 29	35	42	48	62	69	76	83	92	97
		Milliliters per liter of soil									
		Surface soil (0-6")									
36"	0-6"	3.3*	5.8	3.2	3.2	3.5	13.0	6.6	8.2	9.7	8.4
	6-12"	1.4	6.3	1.7	3.5	2.2	5.2	3.2	4.6	3.0	1.7
	12-18"	.6	2.0	2.9	2.9	2.3	2.6	2.0	1.9	1.3	1.6
12-24"	0-6"	1.4	3.5	6.3	4.3	3.5	2.7	3.3	3.3	2.7	2.3
	6-12"	.9	3.5	2.6	4.3	3.5	4.0	3.2	2.3	1.7	2.2
12"	0-6"	2.7	3.5	4.0	2.9	3.3	2.7	3.3	2.5	2.2	1.2
12-24"	0-6"**	2.0	5.5	3.9	5.2	2.3	3.5	2.7	4.3	2.0	2.7
		Sub soil (6-12")									
36"	0-6"	.9	2.0	2.9	3.5	2.6	3.5	3.5	3.5	2.2	2.0
	6-12"	.6	2.0	2.6	2.3	1.0	4.6	1.5	5.2	3.7	2.3
	12-18"	.0	.6	3.9	2.5	1.9	3.6	1.7	3.7	1.3	1.6
12-24"	0-6"	.9	.9	7.2	3.7	2.2	2.6	4.9	3.5	3.0	2.7
	6-12"	.7	3.2	3.5	4.9	5.3	4.9	5.5	2.3	1.2	1.4
12"	0-6"	2.2	2.9	2.3	5.8	4.9	4.5	3.7	2.3	.9	1.6
12-24"	0-6"**	1.3	2.3	2.9	2.6	2.6	3.7	3.7	3.0	1.2	1.3

*All figures represent an average of two replications.

**From samples taken between the two twelve-inch rows.

Table 6. Root Volume of Soil Samples Taken at Different Places and Times Within Three Row Arrangements of Corn Planted on May 17, 1973

Row Spacing	Distance From Row	Days After Planting 32	40	46	53	60	67	74	81	97	102
		Milliliters per liter of soil									
		Surface soil (0-6")									
36"	0-6"	2.7*	1.7	3.2	3.3	3.9	11.8	7.1	9.5	8.5	4.6
	6-12"	1.0	1.7	2.9	2.5	1.6	3.0	1.7	3.5	1.4	1.3
	12-18"	.7	1.0	2.7	2.6	2.6	2.6	1.6	3.6	2.5	1.0
12-24"	0-6"	.7	1.6	2.2	2.5	2.0	2.3	3.0	5.0	2.8	1.3
	6-12"	-	2.0	2.7	1.9	2.2	3.5	2.2	4.2	1.7	1.7
12"	0-6"	.4	1.6	2.3	2.6	1.4	2.6	1.4	3.2	1.7	.9
12-24"	0-6"**	1.5	2.0	3.6	1.4	4.8	3.5	3.0	2.3	2.7	1.3
		Sub soil (6-12")									
36"	0-6"	.4	.7	1.3	1.7	2.0	1.9	1.7	4.0	2.3	1.4
	6-12"	.7	2.0	1.0	1.9	2.6	.7	1.0	1.6	.7	1.4
	12-18"	-	2.6	4.8	1.3	2.2	1.0	1.2	1.3	.7	1.2
12-24"	0-6"	.9	1.6	1.9	2.2	1.4	1.4	1.4	2.2	1.7	1.2
	0-12"	.3	1.2	1.4	1.4	.9	1.4	.7	1.7	1.2	.9
12"	0-6"	.1	.9	2.2	.7	1.7	4.2	1.6	2.0	1.0	.7
12-24"	0-6"**	.1	1.6	1.6	.4	2.0	.9	2.0	1.4	1.6	1.2

*All figures represent an average of two replications

**From samples taken between the two twelve-inch rows.

Table 7. Percent N, P, K, Ca, and Mg in the Above Ground Plant for Samples Taken at Different Times Within Three Row Arrangements of Corn Planted on May 18, 1972

Nutrient	Row Spacing	Days After Planting 21	36	43	51	58	65	76	91	105
N	36"	2.98*	2.75	2.40	2.04	1.84	1.59	1.31	1.29	1.23
	12-24"	3.25	2.77	2.38	2.03	1.69	1.62	1.51	1.27	1.15
	12"	3.28	2.85	1.84	1.63	1.48	1.37	1.28	1.23	1.11
P	36"	.22	.21	.22	.21	.20	.20	.19	.26	.16
	12-24"	.20	.19	.20	.18	.17	.23	.25	.28	.19
	12"	.23	.22	.21	.19	.18	.23	.23	.26	.17
K	36"	2.32	2.19	2.31	1.80	1.36	1.41	1.09	.86	.75
	12-24"	2.63	2.31	2.18	1.75	1.48	1.71	1.43	.73	.76
	12"	2.71	2.37	1.96	1.64	1.39	1.33	1.09	.77	.62
Ca	36"	.41	.45	.47	.39	.30	.29	.24	.22	.16
	12-24"	.43	.40	.40	.39	.29	.34	.27	.19	.19
	12"	.44	.43	.41	.38	.32	.32	.27	.24	.15
Mg	36"	.39	.35	.39	.33	.28	.27	.21	.19	.16
	12-24"	.33	.33	.29	.28	.22	.26	.29	.28	.19
	12"	.32	.39	.41	.37	.35	.29	.28	.23	.20

*All figures represent an average of sixteen replications.

Table 8. Percent N, P, K, Ca, and Mg in the Above Ground Plant for Samples Taken at Different Times Within Three Row Arrangements of Corn Planted on May 17, 1973

Nutrient	Row Spacing	Days After Planting									
		40	46	53	60	67	74	81	88	97	102
N	36"	2.78*	2.54	2.02	1.77	1.26	1.30	1.04	1.22	1.01	1.03
	12-24"	2.68	2.61	2.06	1.65	1.32	1.20	1.25	1.34	1.11	1.07
	12"	2.80	2.73	2.09	1.82	1.49	1.21	1.26	1.11	1.08	1.08
P	36"	.31	.28	.26	.24	.20	.21	.17	.21	.21	.20
	12-24"	.31	.28	.26	.22	.23	.20	.20	.20	.19	.18
	12"	.31	.29	.26	.21	.23	.21	.21	.21	.21	.21
K	36"	3.20	3.11	2.88	1.93	1.59	1.49	1.20	1.24	1.25	1.10
	12-24"	3.38	2.96	2.67	2.00	1.79	1.41	1.31	1.35	1.19	.92
	12"	3.16	3.19	2.55	1.93	1.70	1.42	1.39	1.36	1.25	1.08
Ca	36"	.45	.46	.38	.33	.23	.20	.17	.20	.16	.12
	12-24"	.47	.44	.40	.29	.28	.20	.19	.19	.14	.12
	12"	.46	.44	.40	.29	.25	.19	.19	.19	.14	.13
Mg	36"	.52	.47	.38	.40	.31	.31	.25	.29	.24	.23
	12-24"	.47	.45	.40	.37	.34	.29	.27	.27	.19	.23
	12"	.49	.43	.42	.34	.32	.28	.28	.26	.22	.23

*All figures represent an average of four replications.

in 1972 than in 1973 and this may have been due to the lower plant population in 1972 as the nitrogen fertilization rate was the same during both years.

Phosphorus

The percentage of P in the plants was highest during the early stages of growth in 1973, gradually decreased for about the first sixty days and then leveled off. The values in 1973 were generally higher than those in 1972 and this was probably due to higher soil phosphorus levels during the second year of the experiment.

Potassium

The percentage of K of the plants was highest in the early stages of growth and gradually decreased as the season progressed. As was true with the phosphorus values, potassium content in the plants was higher in 1973 and this was also probably due to fertilizer carryover as the fertilization rates were the same during both years.

Calcium

During both years, the calcium content of the plants remained at 0.40% or above for about the first 50 days and then gradually decreased. The higher potassium values in 1973 did not seem to depress the calcium values.

Magnesium

The magnesium values followed somewhat the same pattern as the calcium values except that they were generally higher in 1973 than in 1972.

Nutrient Accumulation

The pounds per acre accumulation of N, P, K, Ca, and Mg in the above ground parts of corn plants grown in three row arrangements in 1972 and 1973 are shown in Tables 9 and 10. A gradual increase in plant content of the five nutrients up to the tasseling stage (about 70 days) was observed. Following tasseling stage the amounts of N, P, and K greatly increased during the ear development and filling stages of growth while the amounts of Ca and Mg increased only a small amount. The values for nitrogen were higher in 1972 than in 1973. The values for N, P, and K reported are in agreement with equivalent values reported by other research workers (43, 50).

Dry Matter Accumulation

Dry matter accumulation for the above ground parts of corn plants grown in 1972 and 1973 are shown in Table 11. A gradual increase in dry matter was found in the first half of the growing season and it increased more rapidly during the period of ear formation and filling. Dry matter production was greater in 1972 than in 1973.

Corn Yields

Corn yield for the two years are presented in Table 12. A significant difference in yields among the different row arrangement occurred in 1972. The 12-24" row arrangement yielded more than 12" row arrangement which in turn yielded more than the 36" row arrangement. In 1973, the corn yields were much higher than in 1972, but there were no differences among yields for the different row arrangements.

Table 9. N, P, K, Ca, and Mg Accumulation in the Above Ground Plant for Samples Taken at Different Times Within Three Row Arrangements of Corn Planted May 18, 1972

Nutrient	Row Spacing	Days After Planting 21	36	43	51	58	65	76	91	105
		Pounds per acre								
N	36"	15.0*	78.9	97.2	115.2	139.6	146.1	157.2	224.1	250.5
	12-24"	11.1	75.9	89.4	120.9	119.7	140.1	175.5	210.0	219.2
	12"	16.2	78.0	74.1	110.4	102.0	122.4	150.0	197.7	196.5
P	36"	1.2	6.0	8.7	12.0	15.3	18.3	22.5	45.3	32.9
	12-24"	0.9	5.4	7.8	10.8	12.0	20.1	29.1	46.5	36.2
	12"	0.9	6.0	8.4	12.9	12.3	20.4	27.0	41.7	30.0
K	36"	12.0	63.0	93.3	101.7	103.2	129.6	130.8	149.4	152.7
	12-24"	9.3	63.3	81.6	104.4	105.0	147.6	166.2	120.6	144.9
	12"	13.5	64.8	78.6	111.3	96.0	118.5	127.8	123.6	109.8
Ca	36"	1.8	12.9	19.2	21.9	22.5	26.4	28.8	38.4	32.7
	12-24"	1.5	11.1	15.0	23.4	20.7	29.4	31.5	31.5	36.6
	12"	2.4	12.0	16.5	25.8	22.2	28.5	31.8	38.4	26.4
Mg	36"	1.8	9.9	15.6	18.9	21.0	24.9	25.2	33.0	32.7
	12-24"	1.2	9.3	10.8	16.5	15.6	22.5	33.9	46.5	36.6
	12"	1.5	10.8	16.5	24.9	24.3	25.8	33.0	36.9	35.4

*Figures represent an average of sixteen replications.

Table 10. N, P, K, Ca, and Mg Accumulation in the Above Ground Plant for Samples Taken at Different Times Within Three Row Arrangements of Corn Planted May 17, 1973

	Row	Days After Planting									
Nutrient	Spacing	40	46	53	60	67	74	81	88	97	102
		Pounds per acre									
N	36"	64.5*	76.5	87.8	101.3	96.5	142.4	162.3	180.7	167.9	178.3
	12-24"	50.9	77.3	95.2	100.5	102.8	140.2	200.5	159.9	160.4	182.8
	12"	60.7	88.6	94.4	114.3	138.7	157.8	215.1	162.8	179.4	209.9
P	36"	7.0	8.4	11.2	13.5	15.1	23.0	26.6	31.0	35.2	34.6
	12-24"	5.8	8.4	12.0	13.5	18.6	23.6	32.5	26.9	27.8	31.3
	12"	6.7	9.6	11.8	14.2	21.1	27.8	36.4	31.0	34.3	41.4
K	36"	72.0	93.1	124.8	110.4	121.5	155.3	186.1	182.7	205.3	190.9
	12-24"	63.9	44.1	124.3	120.3	140.0	168.9	212.3	184.6	172.2	155.9
	12"	68.7	103.2	118.6	122.1	156.0	185.4	238.2	199.4	209.1	209.1
Ca	36"	10.5	13.8	16.6	18.7	17.5	22.3	25.9	28.9	27.1	20.9
	12-24"	8.5	12.9	19.5	17.5	22.9	23.3	30.5	26.3	19.5	18.9
	12"	10.2	14.4	18.3	18.0	23.3	24.7	31.6	27.2	25.1	25.3
Mg	36"	11.8	14.1	16.9	22.6	23.6	34.3	34.9	42.8	39.5	39.2
	12-24"	8.7	13.0	18.4	22.3	27.7	33.4	43.1	36.4	27.5	38.8
	12"	10.8	14.1	19.5	21.5	29.3	35.9	47.0	38.0	35.8	44.4

*Figures represent an average of four replications.

Table 11. Dry Matter Accumulation in the Above Ground Plant for Samples Taken at Different Times Within Three Row Arrangements of Corn Planted on May 18, 1972 and May 17, 1973

Row Spacing	1972 Days After Planting								
	21	36	43	51	58	65	76	91	105
	Pounds per acre								
36"	510*	2874	4044	5660	7601	9186	11995	17374	20382
12-24"	345	2736	3753	5959	7095	8641	10114	16522	19085
12"	491	2736	4013	6788	6903	8925	11726	16062	17685

Row Spacing	1973 Days After Planting									
	40	46	53	60	67	74	81	88	97	102
	Pounds per acre									
36"	2274**	2992	4368	5715	7645	10981	15573	14870	16635	17249
12-24"	1900	2947	4623	6119	7779	11609	16232	13748	14421	17099
12"	2184	3261	4578	6298	9230	13060	18969	14691	16725	19493

*Figures represent an average of sixteen replications.

**Figures represent an average of four replications.

Table 12. Yield of Corn Planted in Three Row Arrangements on May 18, 1972 and May 17, 1973

Treatment	1972	1973
	Bushels per acre	
36"	132.0 a*	190.6 a**
12-24"	148.5 c	189.2 a
12"	141.2 b	189.0 a

*All figures represent an average of four replications.

**Values followed by the same letters are not significantly different at the 0.05 level of probability.

In the 1972 experiment, the soil physical characteristics expressed by bulk density and large pore space generally did not contribute to any difference among the means of root volume for all comparisons. Root volume probably could not account for the corn yield differences in 1972. The nutrient contents of the whole plants were generally higher in the 12-24" row arrangement in the period from tasseling to filling stage. According to earlier studies, maximum yield depends on an adequate and balanced supply of essential nutrients (49, 106, 124, 125). Therefore, the higher nutrient content at the tasseling and filling stage may have contributed to the yield differences among the row arrangements in 1972. In addition, 17,424 plants per acre is a relatively low plant population, and the distribution of plants may have contributed to a better light interception, moisture utilization and subsequent higher yield production in 12-24" and 12" row arrangements as compared with the 36" treatment.

In 1973, the soil physical characteristics expressed as bulk density and large pore space did not contribute to significant differences among the means of root volume of the different row arrangements. The nutrient contents of the whole plant were similar for all row arrangements. At comparable plant age, the nutrient contents of the whole plant were generally higher in 1973 than in 1972 for the early stage of growth which may explain the more vigorous corn growth in 1973 and the subsequent higher yield. Even though some nutrients were lower in the late stage of growth in the 1973 corn crop, the means were very close to each other and apparently in sufficient concentration for high yields. This lower percentage of some nutrients may be due to the dilution effect caused by higher dry matter production in 1973. The plant population was 20,380 plants per acre in all row arrangements and it appeared that at this high population the plant distribution did not have any effect on sunlight interception. According to Brown (16) corn yield is a product of grain per plant and plant population. Therefore the higher plant population in 1973, the use of a different corn hybrid, and better weather conditions which prevailed during the 1973 season, as shown in Appendix I, may account for the yields being higher in 1973 than in 1972.

IV. Soybeans

Bulk Density

The means for the bulk density determinations expressed in grams per cubic centimeter are presented in Tables 13 and 14. The bulk densities of the surface soils ranged from 1.20 to 1.49 in 1972 and from 1.36 to 1.52 in 1973. As was true in the corn experiments, the surface soil densities were greater in 1973 than in 1972 as most of the density measurements were in the 1.40 to 1.49 range in 1973 and in the 1.30 to 1.39 range in 1972. No clear cut patterns of increasing bulk density as the growing season progressed was observed.

Most of the subsoil density measurements were in the 1.50 to 1.59 range during both years even though a slight increase in density measurements was observed in 1973.

Large Pore Space

The values from the large pore space measurements shown in Tables 15 and 16 were slightly greater in 1972 than in 1973 as might be

Table 13. Bulk Density of Soil Samples Taken at Different Places and Times Within Three Row Arrangements of Soybeans Planted on June 2, 1972

Row Spacing	Distance From Row	Days After Planting 36	44	51	64	74	78	85	94	99	104
		Grams per cubic centimeter									
		Surface soil (0-6")									
36"	0-6"	1.29*	1.27	1.28	1.31	1.34	1.29	1.34	1.33	1.38	1.44
	6-12"	1.41	1.32	1.35	1.38	1.33	1.40	1.33	1.36	1.28	1.42
	12-18"	1.47	1.33	1.32	1.39	1.26	1.38	1.35	1.42	1.40	1.45
12-24"	0-6"	1.26	1.29	1.21	1.49	1.32	1.32	1.30	1.30	1.30	1.33
	6-12"	1.30	1.36	1.32	1.33	1.39	1.32	1.33	1.29	1.31	1.36
12"	0-6"	1.25	1.20	1.34	1.35	1.26	1.25	1.37	1.29	1.41	1.42
12-24"	0-6"**	1.35	1.31	1.31	1.32	1.29	1.44	1.25	1.36	1.33	1.37
Barren soil check		1.31	1.33	1.28	1.37	1.31	1.43	1.39	1.30	1.34	1.36
		Sub soil (6-12")									
36"	0-6"	1.47	1.47	1.53	1.57	1.51	1.51	1.49	1.53	1.55	1.47
	6-12"	1.50	1.50	1.48	1.51	1.47	1.52	1.55	1.50	1.47	1.42
	12-18"	1.56	1.45	1.47	1.56	1.41	1.52	1.51	1.53	1.47	1.52
12-24"	0-6"	1.58	1.52	1.48	1.51	1.41	1.48	1.52	1.47	1.49	1.52
	6-12"	1.50	1.49	1.47	1.43	1.51	1.36	1.50	1.50	1.53	1.40
12"	0-6"	1.51	1.45	1.44	1.57	1.40	1.45	1.48	1.39	1.53	1.48
12-24"	0-6"**	1.50	1.45	1.54	1.48	1.52	1.52	1.49	1.47	1.45	1.49
Barren soil check		1.45	1.52	1.49	1.51	1.50	1.54	1.50	1.53	1.49	1.48

*All figures represent an average of two replications.

**From samples taken between the two twelve-inch rows.

Table 14. Bulk Density of Soil Samples Taken at Different Places and Times Within Three Row Arrangements of Soybeans Planted on June 8, 1973

Row Spacing	Distance From Row	Days After Planting								
		28	34	41	48	55	76	84	91	99
		Grams per cubic centimeter								
		Surface soil (0-6")								
36"	0-6"	1.37*	1.37	1.38	1.40	1.41	1.44	1.39	1.45	1.41
	6-12"	1.37	1.37	1.48	1.38	1.39	1.52	1.42	1.44	1.46
	12-18"	1.45	1.45	1.48	1.46	1.43	1.43	1.44	1.46	1.44
12-24"	0-6"	1.40	1.40	1.40	1.42	1.37	1.42	1.38	1.38	1.42
	6-12"	1.46	1.46	1.42	1.40	1.43	1.43	1.41	1.41	1.46
12"	0-6"	1.45	1.45	1.42	1.42	1.41	1.44	1.43	1.50	1.46
12-24"	0-6"**	1.43	1.43	1.40	1.40	1.36	1.37	1.44	1.36	1.42
Barren soil	check	1.47	1.38	1.47	1.52	1.44	1.41	1.41	1.38	1.45
		Sub soil (6-12")								
36"	0-6"	1.50	1.50	1.56	1.55	1.51	1.47	1.56	1.56	1.63
	6-12"	1.51	1.51	1.46	1.56	1.53	1.54	1.44	1.57	1.51
	12-18"	1.53	1.53	1.52	1.51	1.50	1.59	1.51	1.57	1.55
12-24"	0-6"	1.53	1.53	1.47	1.55	1.45	1.55	1.53	1.48	1.56
	6-12"	1.59	1.59	1.46	1.54	1.55	1.57	1.41	1.60	1.58
12"	0-6"	1.60	1.60	1.52	1.59	1.51	1.55	1.46	1.57	1.53
12-24"	0-6"**	1.44	1.44	1.49	1.51	1.52	1.52	1.43	1.54	1.54
Barren soil	check	1.58	1.52	1.56	1.60	1.54	1.52	1.57	1.51	1.54

*All figures represent an average of two replications.

**From samples taken between the two twelve-inch rows.

Table 15. Large Pore Space of Soil Samples Taken at Different Places and Times Within Three Row Arrangements of Soybeans Planted on June 2, 1972.

Row Spacing	Distance From Row	Days After Planting 36	44	51	64	71	78	85	94	99	104
		Percent by volume									
		Surface soil (0-6")									
36"	0-6"	16.0*	12.9	13.5	12.8	11.8	13.0	11.2	10.2	8.9	10.0
	6-12"	13.8	13.3	13.1	11.9	11.1	11.1	10.2	10.4	14.5	11.5
	12-18"	10.7	11.9	11.7	9.2	12.8	9.1	11.9	10.9	12.6	10.5
12-24"	0-6"	14.2	12.9	15.9	13.9	12.0	11.7	13.0	10.2	12.9	13.3
	6-12"	13.1	14.7	14.2	13.9	12.2	11.9	11.4	9.8	14.5	13.1
12"	0-6"	13.8	14.3	12.9	13.0	14.0	13.9	11.7	11.4	10.8	11.7
12-24"	0-6"**	13.0	14.1	12.7	13.8	11.2	10.1	14.6	12.2	13.2	14.1
Barren soil	check	13.8	15.5	13.6	11.5	11.8	10.2	10.8	12.1	12.6	14.5
		Sub soil (6-12")									
36"	0-6"	11.8	11.0	9.2	7.6	7.5	7.2	8.6	8.1	6.3	10.0
	6-12"	13.7	9.6	10.0	9.5	7.8	7.5	6.4	8.7	10.1	11.8
	12-18"	9.5	8.8	10.3	7.5	10.4	7.9	8.1	8.4	9.7	6.4
12-24"	0-6"	7.8	9.2	9.9	8.3	8.7	8.2	8.0	8.5	9.2	7.8
	6-12"	10.2	11.2	12.5	12.6	7.3	7.7	8.1	7.7	9.7	13.5
12"	0-6"	9.5	10.2	10.2	7.3	10.6	9.9	8.6	10.4	8.1	11.1
12-24"	0-6"**	9.4	10.4	7.8	9.6	4.2	7.4	6.8	9.7	10.3	9.5
Barren soil	check	10.9	9.1	9.0	7.4	9.0	6.6	10.4	5.9	8.7	8.7

*All figures represent an average of two replications.

**From samples taken between the two twelve-inch rows.

Table 16. Large Pore Space of Soil Samples Taken at Different Places and Times Within Three Row Arrangements of Soybeans Planted on June 8, 1973

Row Spacing	Distance From Row	Days After Planting 28	34	41	48	55	76	84	91	99
		Percent by volume								
		Surface soil (0-6")								
36"	0-6"	11.2*	13.9	11.7	11.2	12.6	11.1	12.0	9.0	11.4
	6-12"	11.1	13.1	8.8	12.7	11.3	6.3	10.3	9.9	10.3
	12-18"	10.1	10.8	8.4	12.5	10.9	11.1	10.9	8.9	10.0
12-24"	0-6"	9.2	11.0	11.5	10.2	14.5	10.2	11.2	12.7	10.5
	6-12"	4.4	11.0	10.4	11.0	12.8	11.2	10.3	12.2	9.7
12"	0-6"	13.0	11.2	10.2	10.7	11.9	9.9	9.0	8.0	11.1
12-24"	0-6"**	12.8	10.2	12.5	10.7	14.8	12.7	8.6	13.0	11.8
Barren soil	check	7.8	10.9	8.4	9.1	12.9	8.9	10.3	10.6	8.2
		Sub soil (6-12")								
36"	0-6"	8.1	10.2	3.1	8.5	8.7	9.2	9.6	7.6	12.3
	6-12"	8.9	10.3	9.5	7.1	8.8	7.7	10.8	7.6	8.4
	12-18"	9.5	8.8	8.4	6.8	10.0	6.6	9.0	7.9	8.3
12-24"	0-6"	9.2	11.6	8.4	8.0	12.4	9.1	9.1	10.6	9.1
	6-12"	9.3	8.0	9.2	9.0	13.3	4.1	11.5	12.2	12.6
12"	0-6"	9.0	7.7	8.2	5.9	9.8	6.2	9.1	7.0	10.1
12-24"	0-6"**	7.2	9.6	7.6	7.5	11.1	9.7	11.3	8.2	9.5
Barren soil	check	7.7	8.7	6.4	6.9	10.6	6.8	11.3	8.8	7.7

*All figures represent an average of two replications.

**From samples taken between the two twelve-inch rows.

expected in view of the increased soil densities in 1973. The values were mostly in the 10 to 14% range in 1972 and in the 10 to 12% range in 1973.

The percentage of large pore space in the subsoils was much less than that of the surface soils with many of the values being in the 6 to 9% range. These values will permit limited root penetration but during periods of high moisture, oxygen supply to the roots will be greatly reduced (10, 65, 124).

Root Volume

The results from the root volume measurements are shown in Tables 17 and 18. Generally the root volume increased as the growing season progressed although the last two sampling periods showed a decrease in some cases. The greatest volume of roots in the surface soil occurred near the row and generally decreased as the distance from the row increased.

Only a small number of roots penetrated the subsoil and most of this occurred 50 days or more after planting.

V. Nutrient Content

The percent N, P, K, Ca, and Mg in the above ground plant samples taken at different times after planting are shown in Tables 19 and 20.

Nitrogen

The nitrogen content of the soybeans was highest during the early stages of growth. It gradually decreased for about 70 to 80 days after

Table 17. Root Volume of Soil Samples Taken at Different Places and Times Within Three Row Arrangements of Soybeans Planted on June 2, 1972.

Row Spacing	Distance From Row	Days After Planting 36	44	51	64	71	78	85	94	99	104
		Milliliters per liter of soil									
		Surface soil (0-6")									
36"	0-6"	.9	2.0	2.2	2.3	3.2	3.3	4.3	3.7	4.5	3.8
	6-12"	-	.6	1.2	1.3	2.3	1.6	2.3	3.5	1.4	1.7
	12-18"	-	.6	.4	.7	1.9	1.2	1.4	2.3	3.5	1.0
12-24"	0-6"	.9	2.7	3.0	2.3	1.9	3.9	2.9	2.2	2.5	2.0
	6-12"	.3	2.2	1.2	1.4	2.3	3.5	2.3	1.7	1.7	2.2
12"	0-6"	1.2	2.0	1.7	3.0	3.5	2.3	2.5	1.7	2.0	2.7
12-24"	0-6"**	.7	1.3	1.9	2.6	2.3	3.6	2.9	1.7	2.3	1.9
		Sub soil (6-12")									
36"	0-6"	-	.1	.9	.4	.6	.7	.7	.4	.6	1.4
	6-12"	-	.3	0	.6	1.9	.3	.3	.6	1.2	1.0
	12-18"	-	0	.3	.4	.7	.9	.7	.4	.6	.7
12-24"	0-6"	-	0	.4	.6	.7	.3	.4	.7	.7	.4
	6-12"	-	0	0	.3	0	.7	.1	.6	.3	.4
12"	0-6"	.14	.3	.4	.1	.6	.7	.3	1.0	.4	.7
12-24"	0-6"**	-	.1	.1	.6	.3	.4	.7	.6	.4	.6

*All figures represent an average of two replications.

**From samples taken between the two twelve-inch rows.

Table 18. Root Volume of Soil Samples Taken at Different Places and Times Within Three Row Arrangements of Soybeans Planted on June 8, 1973

Row Spacing	Distance From Row	Days After Planting 28	34	41	48	55	76	84	91	99
		Milliliter per liter of soil								
		Surface soil (0-6")								
36"	0-6"	1.2*	.6	2.0	1.4	3.5	2.2	3.3	4.2	1.9
	6-12"	.1	.1	1.3	.7	1.6	1.7	2.7	1.4	1.3
	12-18"	-	.1	.9	.3	1.7	2.6	1.6	.9	1.4
12-24"	0-6"	.9	.7	1.2	1.6	2.3	2.7	2.7	3.5	1.7
	6-12"	.4	.2	.7	.7	1.0	1.0	1.4	3.2	.6
12"	0-6"	1.4	1.2	2.3	2.2	2.2	2.2	4.0	1.5	1.6
12-24"	0-6"**	1.2	.9	1.4	1.7	2.0	2.5	1.6	2.9	1.6
		Sub soil (6-12"								
36"	0-6"	.4	.3	.4	.7	1.0	1.0	.4	.7	.1
	6-12"	-	.1	.3	.3	.2	1.0	1.6	.8	.4
	12-18"	.1	-	.1	.1	.6	.4	1.8	.2	.6
12-24"	0-6"	.3	.1	.7	.3	.6	.7	.6	.2	.2
	6-12"	.3	-	.1	.3	.2	.5	.8	.2	.1
12"	0-6"	0	.3	.9	.3	.4	.4	1.5	.4	.4
12-24"	0-6"**	.4	.4	.1	.6	.4	.4	2.5	3.2	.2

*All figures represent an average of two replications.

**From samples taken between the two twelve-inch rows.

Table 19. Percent N, P, K, Ca, and Mg in the Above Ground Plant for Samples Taken at Different Times Within Three Row Arrangements of Soybeans Planted on June 2, 1972

Nutrient	Row Spacing	Days After Planting							
		38	44	52	59	69	77	92	110
N	36"	3.92*	3.80	3.21	2.76	2.34	1.68	2.05	2.41
	12-24"	3.83	3.29	2.57	2.00	1.46	1.23	1.60	2.82
	12"	3.32	2.98	2.91	2.42	2.06	2.31	2.32	2.70
P	36"	.23	.25	.25	.19	.20	.17	.19	.20
	12-24"	.23	.24	.24	.21	.20	.20	.21	.22
	12"	.24	.28	.24	.22	.20	.24	.25	.26
K	36"	2.12	1.94	1.93	1.86	1.90	1.52	1.66	1.51
	12-24"	2.62	2.16	2.17	2.15	1.97	2.21	1.88	1.86
	12"	2.44	2.35	2.05	1.91	2.02	1.95	1.73	1.69
Ca	36"	1.52	1.78	1.84	1.31	1.38	1.07	1.08	1.08
	12-24"	1.62	1.53	1.64	1.39	1.24	1.28	1.21	1.20
	12"	1.78	2.10	1.78	1.46	1.39	1.30	1.06	1.22
Mg	36"	.57	.75	.96	.71	.61	.43	.43	.45
	12-24"	.73	.74	.78	.61	.48	.50	.49	.49
	12"	.75	.74	.77	.53	.48	.48	.44	.46

*All figures represent an average of sixteen replications.

Table 20. Percent of N, P, K, Ca, and Mg in the Above Ground Plant for Samples Taken at Different Times Within Three Row Arrangements of Soybeans Planted on June 8, 1973

Nutrient	Row Spacing	Days After Planting 28	34	41	48	55	62	69	76	84	91	99
N	36"	3.67*	3.32	3.10	2.90	2.68	3.92	2.68	2.84	2.89	3.09	3.02
	12-24"	3.35	3.38	2.88	2.83	2.71	2.95	2.96	2.63	2.91	2.97	3.19
	12"	3.38	3.27	3.12	2.59	2.64	2.90	2.73	2.76	2.89	2.93	3.02
P	36"	.33	.30	.25	.26	.27	.27	.26	.26	.28	.28	.32
	12-24"	.30	.32	.25	.28	.28	.30	.24	.27	.26	.22	.27
	12"	.31	.30	.26	.23	.28	.26	.25	.25	.25	.25	.29
K	36"	2.68	2.27	2.25	2.23	2.25	2.30	2.22	2.01	1.97	1.87	1.99
	12-24"	2.28	2.53	2.00	2.49	2.51	2.48	2.01	2.11	2.06	1.78	1.89
	12"	2.51	2.29	2.33	2.14	2.65	2.22	2.08	2.18	2.04	1.83	2.02
Ca	36"	1.53	1.47	1.43	1.44	1.53	1.37	1.38	1.37	1.41	1.18	1.14
	12-24"	1.44	1.42	1.29	1.33	1.37	1.42	1.23	1.33	1.27	1.24	1.04
	12"	1.38	1.42	1.45	1.22	1.41	1.32	1.48	1.28	1.23	1.16	1.01
Mg	36"	.72	.76	.68	.72	.60	.58	.47	.61	.58	.53	.46
	12-24"	.68	.63	.61	.62	.59	.60	.49	.54	.51	.49	.49
	12"	.64	.70	.63	.55	.61	.56	.56	.54	.49	.52	.43

*All figures represent an average of four replications.

planting and then increased slightly during the last few sampling periods near maturity. The values in 1973 were generally higher than in 1972.

Phosphorus

The phosphorus content generally decreased as the season progressed but showed a small increase in both years during the last few sampling dates near maturity. The values in 1973 were generally higher than those in 1972 as was true in the corn experiment.

Potassium

The percent potassium was highest during the early stages of growth and generally decreased as the season progressed. The values were slightly higher in 1973 than in 1972.

Calcium

The percent calcium in the plants decreased early in the season, tended to level off as the season progressed and then decreased again in the final sampling periods.

Magnesium

The percent magnesium in the plants decreased in the early part of the season and then leveled off in the later stages of growth.

Nutrient Accumulation

The pounds per acre accumulation of N, P, K, Ca and Mg in the above ground parts of soybeans grown in three row arrangements in 1972 and 1973 are shown in Tables 21 and 22. The amount of N and K increased gradually for about the first 70 days in all treatments. After this, a

Table 21. N, P, K, Ca, and Mg Accumulation in the Above Ground Plant for Samples Taken at Different Times Within Three Row Arrangements of Soybeans Planted on June 2, 1972

Nutrient	Row Spacing	Days After Planting							
		38	44	52	59	69	77	92	110
		Pounds per acre							
N	36"	10.1*	14.2	27.4	43.5	57.5	67.6	122.5	195.4
	12-24"	19.0	25.2	39.9	58.4	59.9	62.3	124.3	288.0
	12"	29.7	41.3	75.2	76.8	110.3	162.1	218.4	312.4
P	36"	.6	1.0	2.1	3.0	4.9	6.8	11.3	16.2
	12-24"	1.1	1.9	3.6	6.2	8.3	10.0	16.4	22.4
	12"	2.2	3.8	6.1	7.0	10.9	17.0	23.7	30.1
K	36"	5.4	7.3	16.5	29.3	46.7	61.2	99.1	122.4
	12-24"	13.0	16.4	33.7	62.9	80.8	111.7	140.7	190.0
	12"	21.8	32.3	53.1	60.5	108.4	136.9	162.8	195.7
Ca	36"	3.9	6.6	15.7	20.7	33.9	43.1	64.5	87.5
	12-24"	8.1	11.7	25.4	40.7	51.0	64.6	94.0	122.6
	12"	16.0	29.1	46.1	46.4	74.5	91.1	99.8	141.4
Mg	36"	1.5	2.8	8.2	11.2	14.9	17.3	25.7	36.5
	12-24"	3.6	5.5	12.2	17.9	19.6	25.4	38.2	50.1
	12"	6.7	10.2	19.8	16.6	25.6	33.6	46.1	53.4

*All figures represent an average of sixteen replications.

Table 22. N, P, K, Ca, and Mg Accumulation in the Above Ground Plant for Samples Taken at Different Times Within Three Row Arrangements of Soybeans Planted on June 8, 1973

Nutrient	Row Spacing	Days After Planting 28	34	41	48	55	62	69	76	84	91	99
		Pounds per acre										
N	36"	53.8*	60.7	62.4	70.8	66.1	114.0	112.7	147.3	184.2	220.0	225.0
	12-24"	135.6	105.5	132.8	125.2	123.0	233.2	217.7	284.0	307.2	436.2	498.0
	12"	178.1	129.2	134.3	184.5	177.8	392.4	334.2	435.6	472.7	577.9	735.9
P	36"	4.6	5.5	5.1	6.4	6.6	10.2	11.0	13.6	17.6	19.6	23.9
	12-24"	11.9	9.8	11.3	12.4	12.8	23.5	17.3	29.4	27.3	38.4	41.6
	12"	16.0	11.8	12.1	16.3	18.6	35.5	30.7	39.0	41.9	48.0	71.6
K	36"	39.3	41.6	45.9	34.8	55.9	88.1	92.6	105.5	126.2	133.0	147.4
	12-24"	91.3	78.1	103.0	62.0	116.0	196.1	143.7	229.8	217.5	268.0	291.0
	12"	131.4	88.6	107.1	86.7	179.4	300.0	256.8	338.7	339.3	355.9	498.6
Ca	36"	22.4	26.7	28.7	54.7	38.0	53.0	57.5	71.1	88.9	84.4	84.5
	12-24"	58.6	44.1	59.3	110.0	61.8	111.9	89.3	143.7	134.5	180.2	162.3
	12"	72.6	56.9	64.3	152.9	94.7	176.9	181.3	204.4	202.4	229.6	249.1
Mg	36"	10.6	13.9	13.4	17.9	14.7	22.5	19.5	31.8	36.1	38.0	34.0
	12-24"	28.1	19.6	28.1	27.5	26.7	47.3	36.2	58.4	53.5	73.1	75.9
	12"	60.1	27.8	30.7	39.0	40.6	74.8	67.5	84.8	79.6	102.7	104.6

*All figures represent an average of four replications.

large increase in the content of these two nutrients was observed. The amount of P, Ca and Mg followed the same trends during the first 70 days but the increase after this was not as pronounced as was the case for N and K.

In all cases, as the number of rows per unit area increased, an increase in nutrient accumulation was observed. This was due to a higher number of plants per unit area in the closer row spacings. The least number of plants per acre and thus the lowest nutrient accumulation occurred in the 36-inch row arrangement.

Dry Matter Accumulation

Dry matter accumulation for 1972 and 1973 is shown in Table 23. Dry matter accumulation almost paralleled that of nutrient accumulation in that a gradual increase was observed for about the first 70 days followed by a marked increase during the next 30 to 40 days.

As was true with nutrient accumulation, the dry matter accumulation was greatest in the row arrangements having the greatest number of rows per unit area and thus more plants per acre.

Dry matter accumulation was much greater in 1973 than in 1972. It more than doubled in the 12-inch row arrangement and exceeded that of corn in that row arrangement. However, in the standard 36-inch row arrangement, dry matter production in corn was 2 1/2 to almost 3 times that of the soybeans.

Soybean Lodging and Yield

Soybean plants began lodging in the middle of the season when the plants had just covered the ground. The high number of plants per acre

Table 23. Dry Matter Accumulation for Three Row Arrangements in Soybeans Planted on June 2, 1972 and June 8, 1973

Row Spacing	1972 Days After Planting							
	38	44	52	59	69	77	92	110
	Pounds per acre							
36"	2580*	3730	8540	1576	2456	4024	5972	8106
12-24"	4960	7620	1551	2924	4107	5053	7774	10218
12"	8920	1379	2586	3166	5360	7020	9410	11577

Row Spacing	1973 Days After Planting										
	28	34	41	48	55	62	69	76	84	91	99
	Pounds per acre										
36"	1471**	1833	2015	2505	2473	3902	4200	4968	6364	7131	7430
12-24"	4093	3113	4605	4435	4541	7888	7377	10831	10575	14753	15585
12"	5277	3997	4701	7100	6716	13527	12312	15766	16502	19764	24433

*Figures represent an average of sixteen replications.

**Figures represent an average of four replications.

caused the soybean plants to grow taller and with a thinner stem than normal made the soybean plant more susceptible to lodging according to previous research results (2, 67, 130). In addition, weekly irrigations, applied in order to allow adequate moisture for soil core sampling, contributed a great deal to the lodging of soybean plants. The plants in 12" row arrangement lodged more than those in the 12-24" row arrangement which in turn lodged more than plants in 36" row arrangement. It was estimated that the percentage of lodging was around 70, 50, and 10% for 12", 12-24", and 36" row arrangements, respectively, in 1972. However, the lodging was more severe in 1973 and was estimated to be about 90, 70, and 20%, respectively.

The yield of soybeans for the two years is shown in Table 24. Although the yield of the 36" row arrangement was the lowest for each year, the differences were not significant at the 5% probability level. The yield was slightly higher in 1973 than in 1972.

The percentage of nutrients in the late stage of growth, the dry matter and nutrient accumulation were lower in 1972 than in 1973. These conditions, which may have been brought about by lower air temperatures, lower total incoming solar radiation and higher precipitation in 1972 as compared with the 1973 season, may explain the lower soybean yields in 1972. The irregular plant distribution and the larger proportion of lodging occurring in 12-24" and 12" row arrangements may have also reduced yields of these treatments.

Table 24. Yield of Soybeans Planted in Three Row Arrangements on June 2, 1972 and June 8, 1973

Treatment	1972	1973
	Bushels per acre	
36"	39.4 a*	45.6 a**
12-24"	42.4 a	49.8 a
12"	40.1 a	48.9 a

*All figures represent an average of four replications.

**Values followed by the same letter are not significantly different at the 0.05 level of probability.

VI. Crop Comparisons

Soil physical characteristics expressed as bulk density and large pore space did not contribute to differences in root volume for corn but did result in a significantly lower root volume in the subsoil for soybeans. Generally, the surface soil was more compact and the root volume was smaller in 1973 than in 1972. However, the smaller root volume observed for both corn and soybeans did not significantly reduce nutrient absorption as sufficient nutrients were absorbed in 1973 to produce higher yields of soybeans and corn than in 1972.

The nitrogen content of both crops was high in the early stages of growth. Nitrogen in corn gradually decreased throughout the growing season but in soybeans it also gradually decreased until maturity and gradually increased during the bean maturation period. This was probably due to the higher protein content of the soybeans. The phosphorus values showed a similar relationship.

The percentage of K, Ca and Mg in the plant was generally highest early in the season and gradually decreased during the season for both crops except that the Ca and Mg values for soybeans tended to level off during the latter part of the growing season.

The nutrient accumulation was highest in the 12-inch row arrangement for soybeans. Generally the corn accumulated more phosphorus and much less calcium than the soybeans. The N and K accumulation was higher in the corn than soybeans in the 36-inch row arrangement but the reverse was true for the 12-24-inch row arrangements. The Mg values were about the same for both crops in the 36-inch row arrangements but were higher in the soybeans for the other two row arrangements.

Dry matter accumulation for corn was over double that for soybeans in the standard 36-inch row arrangement. Corn dry matter accumulation was almost double that of soybeans for the 12-24-inch row arrangement in 1972 but just slightly more in 1973. In the 12-inch row arrangement, corn dry matter exceeded that of soybeans by slightly more than 50% in 1972 but soybean dry matter exceeded that for corn by 25% in 1973.

Corn grain yields were 3.5 times greater than soybean yields in 1972 and about 3.8 times greater in 1973.

CHAPTER V

SUMMARY

I. Corn

The soil physical characteristics expressed by bulk density and large pore space generally did not contribute to differences in root volume when measured a comparable distance from the reference row for both seasons, or to differences in root volume in the top soil or subsoil at each sampling site. The root volume of each site tended to increase until approximately 80 days after planting and then to decrease. The root volumes were not greatly different among the row arrangements in 1972.

The percentage of N in the corn plants was higher in 1972 while the percentage of Ca was about the same each year, but the percentage of P, K, and Mg in the plants were generally higher in 1973 than in 1972. The N, K, Ca, and Mg percentages were higher in the early stage of growth and gradually decreased as the season progressed. The P percentage decreased for about 60 days in both seasons. After 60 days the P values leveled off in 1972 while in 1973 they increased to higher than the original levels. Generally the nutrient percentage of the 12-24" row arrangement were higher than the nutrient levels of the other row arrangements from tasseling to filling stage in 1972.

The pounds per acre accumulation of N, P, K, Ca, and Mg gradually increased up to about 70 days (tasseling stage). The amount of N, P, and K greatly increased during the ear development and filling stage of growth, while the amount of Ca and Mg increased only a small amount following the tasseling stage. Root volume differences were not great among the row arrangements in 1972. The higher nutrient content of the 12-24" row arrangement during the tasseling to filling stage of growth may at least partially explain the yield differences among the means of the different row arrangements. In addition, at the population of 17,424 plants per acre, the distribution of plants may have contributed to a better light interception and moisture utilization and subsequent higher yield in 12-24" and 12" row arrangements as compared with the 36" treatments.

In 1973 the plant population was higher and the nutrient accumulation was lower but in amounts sufficient to support high yields. At the population of 20,380 plants per acre, yield for all row arrangements was almost the same.

II. Soybeans

Bulk density and large pore space generally did not affect root volume means in different row arrangements for samples taken at comparable distances from the reference row. The bulk density was lower, the large pore space higher, and the root volume was higher in the 0-6-inch than in the 6-12-inch depth. The greatest volume of roots in the surface soil occurred near the row and gradually decreased as the distance from the row increased.

Percentage of N and P gradually decreased for about the first 70 to 80 days after planting and then increased slightly while the percent of

K decreased as the season progressed. Ca and Mg decreased early in the season and tended to level off at a later stage of growth. The values for P and K were higher in 1973 than in 1972.

The amount of N, P, K, Ca, and Mg accumulated in the above ground soybean plants increased gradually for about 70 days. After this period, a large increase in the content of N and K was observed while the increase of P, Ca and Mg was less pronounced. The nutrient uptake values were higher in 1973 than in 1972. Severe lodging occurred in both seasons. The amount of lodging was estimated to be 70, 50, and 10% in 1972; and 90, 70, and 20% in 1973 for the 12", 12-24", and 36" row arrangements, respectively.

The percentage of nutrients in the late stage of growth, the dry matter and nutrient accumulation were lower in 1972 than in 1973. These conditions which may have been brought about by lower air temperatures, lower total incoming solar radiation and higher precipitation in 1972 as compared with the 1973 season, may explain the lower soybean yields in 1972. The irregular plant distribution and the larger proportion of lodging occurring in 12-24" and 12" row arrangements may have also reduced yields of these treatments.

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APPENDIXES

APPENDIX A

PROCEDURE FOR THE DIGESTION OF PLANT TISSUE FOR THE DETERMINATION OF NITROGEN

1. Dry plant tissue at 70°C, grind into fine particles (2 mesh screen), and store in air tight bottles.

2. Weigh a 0.2000 gram sample and place in a 125 ml Erlenmeyer flask.

3. Add 10 ml of concentrated H_2SO_4 to each flask and allow to predigest for four hours or more at room temperature.

4. After predigesting, set the flasks on a hot plate and heat to 200-225°C for 1.5 to 2 hours, or until the volume is reduced by about 50%.

5. Remove flasks from the hot plate and allow to cool.

6. After sufficient cooling, add 15 ml of 35% H_2O_2 to each flask and place back on the hot plate and heat at 200-225°C for 45 minutes after clearing.

7. Remove clear samples from hot plate, cool, and transfer to 250 ml volumetric flasks.

8. Take to volume in distilled water, shake thoroughly, and allow samples to equilibrate.

APPENDIX B

AUTOMATED COLORIMETRIC DETERMINATION OF N IN WET DIGESTED PLANT TISSUE SAMPLES

1. The instrumentation for the Technicon Autoanalyzer used consisted of seven separate modules as follows: small automatic sampler equipped with a liquid wash system; one positive displacement proportioning pump; one water bath; one colorimeter equipped with a continuous tubular flow cell; one recorder; one voltage stabilizer; and one range expander.

2. The sample stream goes through two dilutions:

(a) One part sample diluted with two parts water,

(b) One part diluted sample diluted with 6.5 parts of 0.4 N NaOH.

3. The diluted sample stream is then joined by a stream of alkaline phenol (250 grams phenol and 108 grams NaOH made to 1 liter).

4. After mixing, the stream is then joined by a stream of sodium hypochlorite (commercial grade "Clorox") and is mixed further.

5. The stream then passes into a 85°C (± 5°C) heating bath for 5 minutes and, after cooling, enters the colorimeter containing a 10 mm flow cell where the percent transmittance is measured at 610 mμ.

6. The N concentration of samples is determined by comparing with the semilog plot of percent transmittance vs. ppm N of a group of standards containing 0, 5, 10, 20, 30, 40, and 45 ppm N as NH_4^+.

7. The proportioning pump manifold designed to supply the correct volumes of sample, water, NaOH, alkaline phenol, and sodium hypochlorite to the colorimeter is shown in Appendix E.

APPENDIX C

NITROGEN MANIFOLD

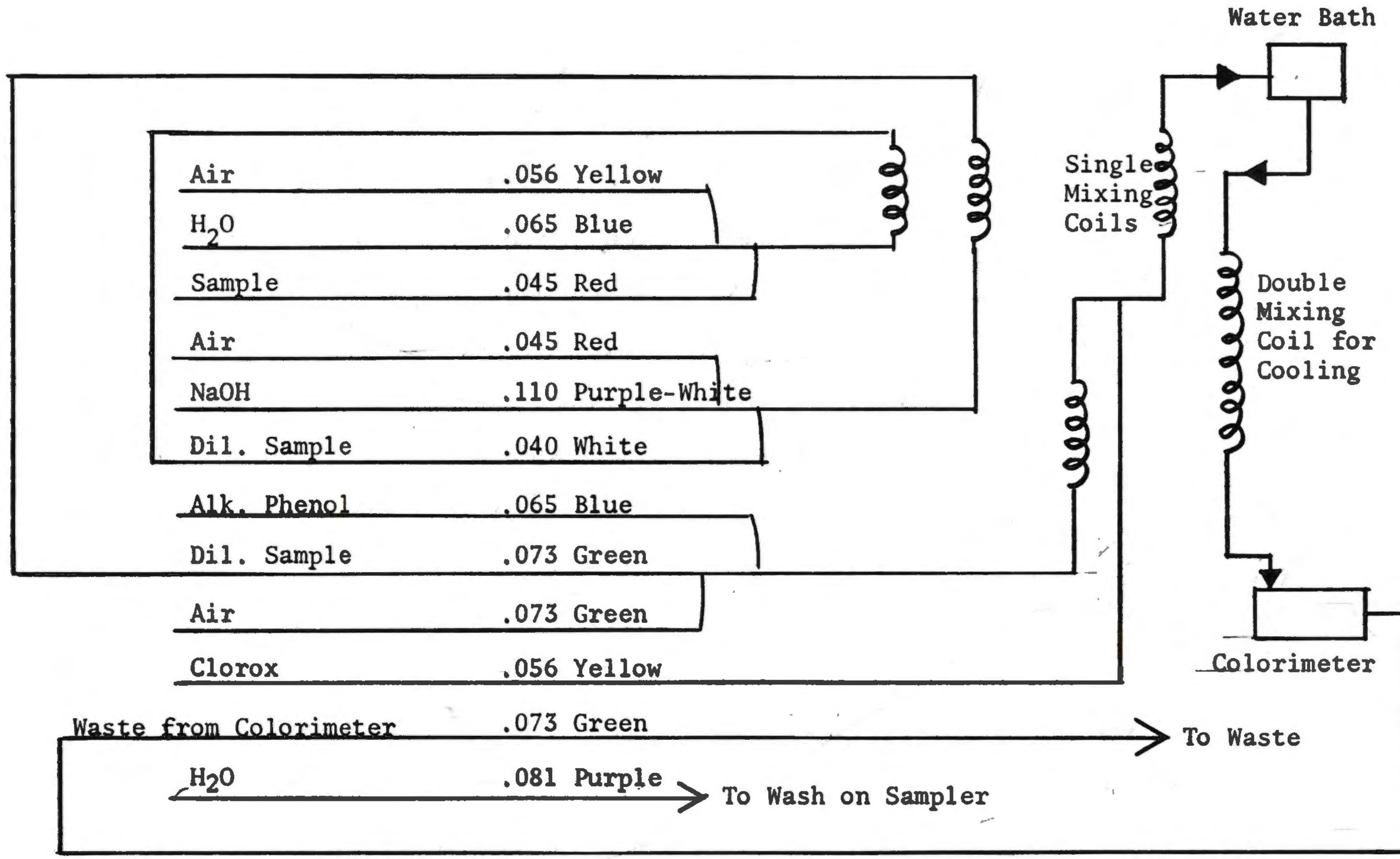

Figure 2. Nitrogen manifold.

APPENDIX D

PROCEDURE FOR THE WET ASHING BY THE ALUMINUM HEATING BLOCK METHOD FOR ANALYSES OF PLANT SAMPLES

1. Dry plant tissue at 70°C, grind into fine particles, and store in air tight bottles.

2. Weigh a 0.5000 gram portion of each sample and place into a 50 ml tube.

3. Add 2 small glass beads, and 3 ml of concentrated nitric acid to each sample. Place a small funnel in the mouth of each tube to act as a condenser.

4. Place tubes into the aluminum heating block, and let the sample digest at room temperature overnight.

5. Place block on hotplate and raise the temperature to 150°C. Digest at this temperature for 1 hour.

6. Add 2 ml of 60 to 70% perchloric acid to each tube and digest at 235°C for 2 hours. The liquid in each sample should be clear at this point. If not, continue digestion until clear.

7. Cool the block to room temperature and add 1 ml of concentrated hydrochloric acid. Digest at 150°C for 15 to 20 minutes.

8. Transfer cooled samples into 100 ml volumetric flasks and make to volume with distilled water.

9. Shake the flask thoroughly and let stand overnight.

10. At this point the samples are ready for analysis on the Technicon Autoanalyzer.

APPENDIX E

SIMULTANEOUS DETERMINATION OF Ca, K, Mg, AND P CONCENTRATIONS BY AUTOANALYSIS

1. The instrumentation for the Technicron Autoanalyzer employed here consisted of 14 separate modules as follows: small automatic sampler equipped with a liquid wash system; three positive displacement proportioning pumps; two colorimeters equipped with continuous tubular flow cells; one dual-channel flame photometer; two 2-pen recorders; two voltage stabilizers; one time-delay coil; and two range expanders.

2. Calcium and potassium determinations were made by using the Technicon III dual-channel flame photometer. Lithium nitrate (.525 g in 1 liter of water) is used as an internal standard and lanthanum chloride (5 g in 1 liter of water) is used to increase the calcium flame response. The proportioning-pump manifold designed to supply the correct volume of sample, $LiNO_3$, and $LaCl_3$ to the dual-channel flame photometer is shown in Appendix F.

3. Magnesium concentrations were determined in a colorimeter by a modified lake procedure in which $Mg(OH)_2$ is precipitated in an alkaline solution and Magnesium Blue dye (.02%) is adsorbed on the $Mg(OH)_2$ in the presence of a detergent (.05% Brij 35 in water) and a suspending material (2 g EGTA and 2 g polyvinyl alcohol in 1 liter H_2O). The proportioning-pump manifold designed to supply the correct volumes of sample, PVA-EGTA, Magnesium Blue, and NaOH (2N) to the flow cell of the colorimeter is shown in Appendix G. The colorimeter used in this procedure was equipped with a 630 mμ filter.

4. Phosphorus determinations were made using a colorimeter. The sample is first diluted with .05 N HCl. The diluted sample stream is

then joined by a stream of ammonium vanadate (25 g ammonium molybdate in 400 ml of H_2O mixed with an equal volume of a solution of 1.25 g ammonium metavanadate in 300 ml of water with a few drops of concentrated NH_4OH and 250 ml of concentrated HNO_3). The stream then passes through the colorimeter, equipped with a 420 mμ filter, where phosphorus is determined as PO_4^{-3}. The proportioning-pump manifold designed to supply the correct volumes of sample, HCl, and ammonium vanadate to the colorimeter is shown in Appendix H.

APPENDIX F

POTASSIUM-CALCIUM MANIFOLD

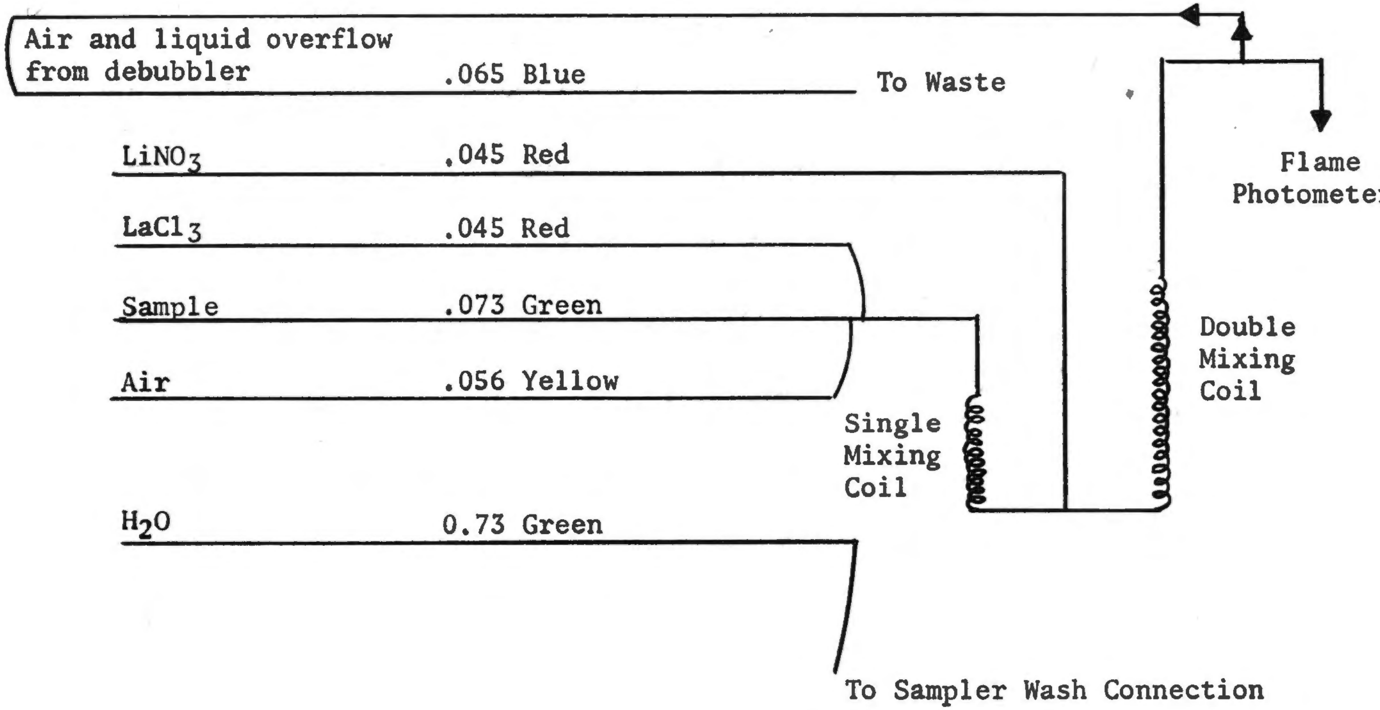

Figure 3. Potassium-calcium manifold.

APPENDIX G

MAGNESIUM MANIFOLD

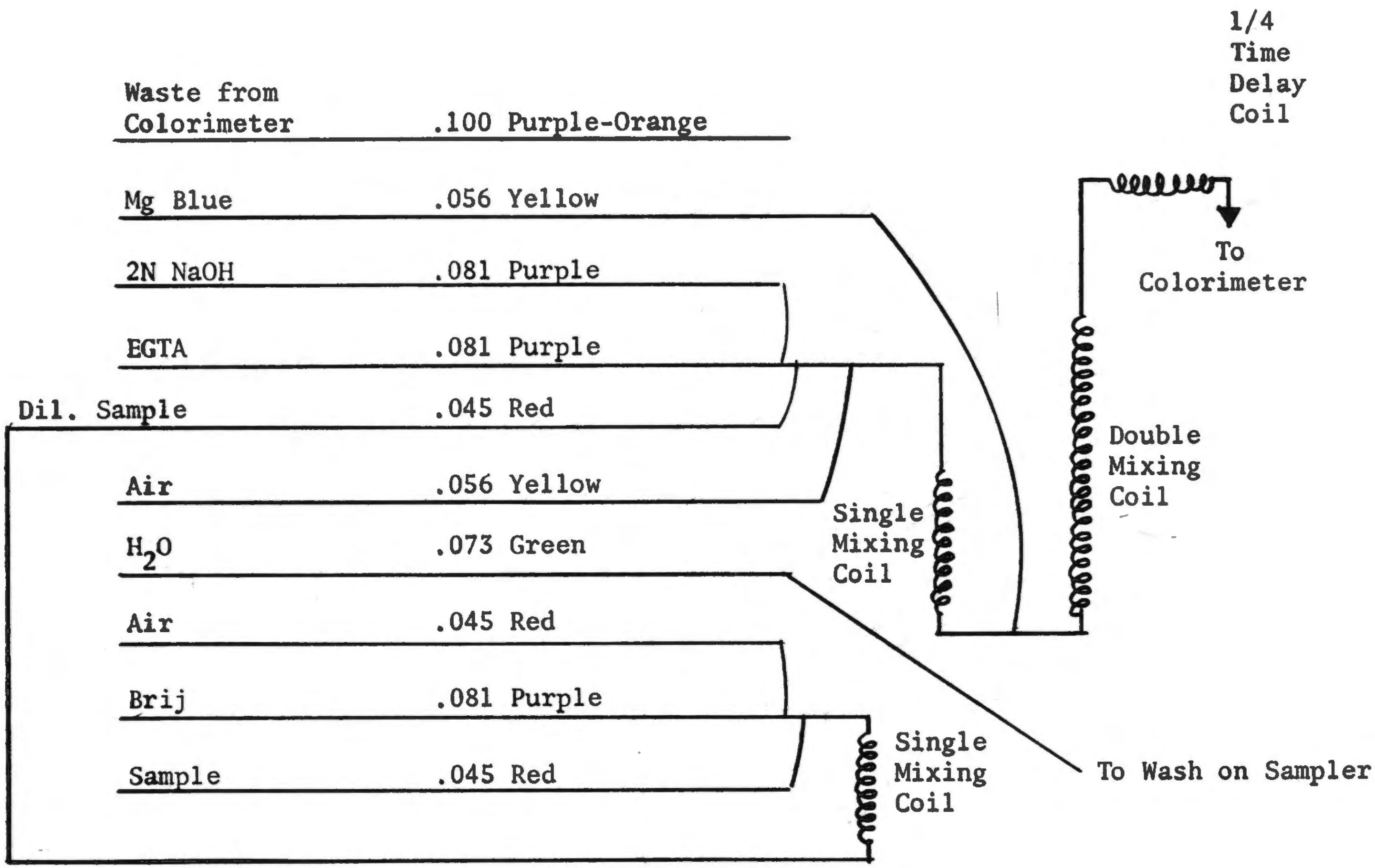

Figure 4. Magnesium manifold.

APPENDIX H

PHOSPHORUS MANIFOLD

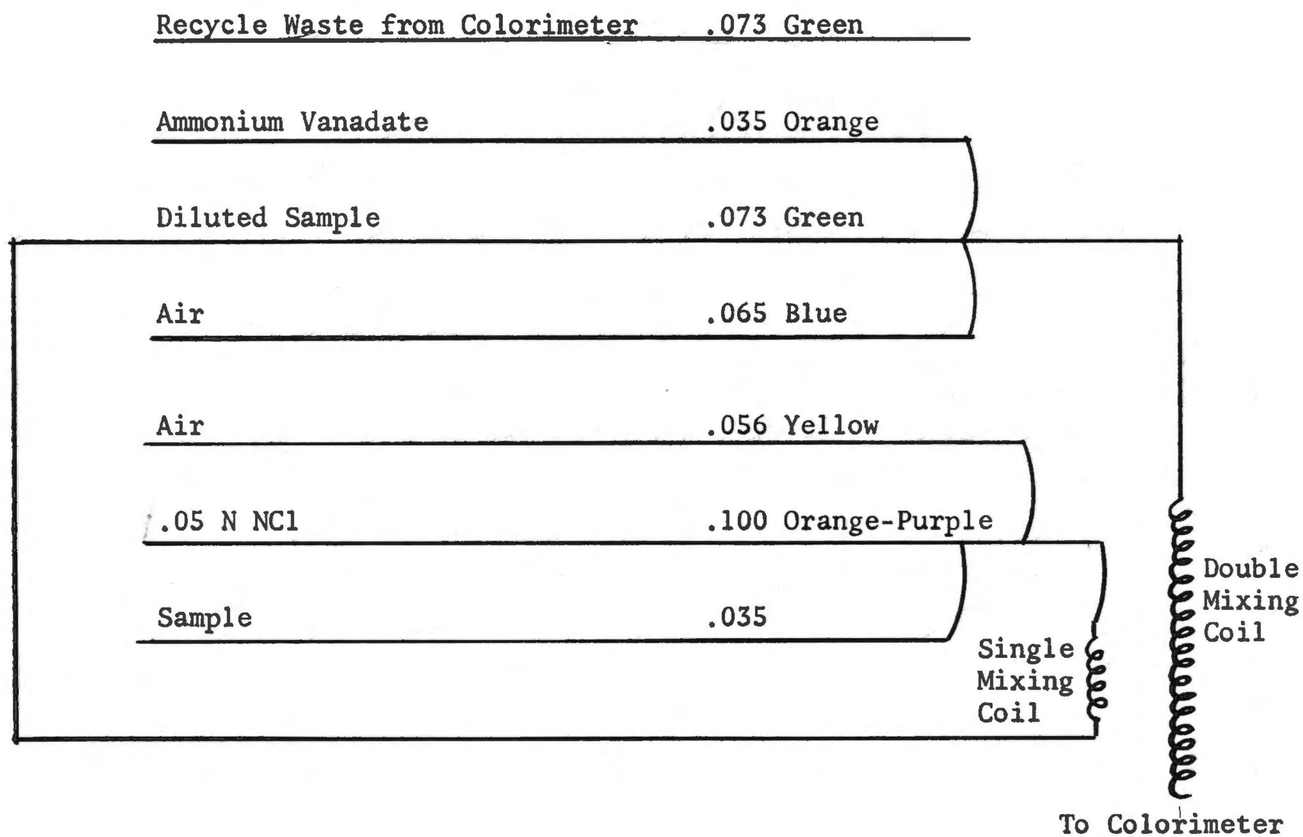

Figure 5. Phosphorus manifold.

APPENDIX I

WEATHER INFORMATION FOR THE PERIOD FROM MAY THROUGH SEPTEMBER OF 1972 AND 1973

Table 25. Monthly Precipitation, Mean Air Temperature, and Average Sky Cover from Knoxville WSD AP Station and Knoxville Experiment Station During the Period from May Through September of 1972 and 1973

Month	Mean Temperature		Total Monthly Precipitation		Mean Cloud Coverage Sunrise to Sunset	
	1972	1973	1972	1973	1972	1973
	Degrees		Inches			
May	64.9	63.5	6.17	7.28	7.4	6.5
June	70.8	74.8	7.73	5.26	5.6	6.8
July	75.5	76.7	7.06	4.38	6.5	7.2
August	75.9	76.2	2.32	2.31	5.5	5.2
September	71.9	73.8	5.17	3.49	6.5	6.2

VITA

Matosinho de Souza Figueiredo was born on November 17, 1931, in Divinolandia de Minas, Minas Gerais, Brasil. He graduated from high school in 1955. In 1957 he entered the Universidade Rural do Estado de Minas Gerais currently Universidade Federal de Viçosa where he received his Bachelor of Science degree in Agronomy, in 1961. He worked for a private company from January 1962 through December 1964. Since January 1965, he has been a staff member of the Universidade Federal de Viçosa where he currently is assistant professor. Concurrently he entered the Graduate School at the Universidade Federal de Viçosa working toward a Master of Science degree. He received his degree in 1969. In January 1971, he began study toward the Doctor of Philosophy degree with a major in Plant and Soil Science at the University of Tennessee in Knoxville which he received in March 1975. He is married to the former Maria Francisca Araujo. They have two children, Maria Cristina, age 9, and Sergio, age 8.