EFFECTS OF PHOSPHORUS AND POTASSIUM FERTILIZATION ON SOIL TEST INDICES AND YIELDS OF MONO- AND DOUBLE-CROPPED WHEAT, SOYBEAN, AND GRAIN SORGHUM UNDER RAINFED AND IRRIGATED CONDITIONS

By

SAMUEL GELETA

Bachelor of Science
Addis Ababa University
Alemaya, Ethiopia
1978

Master of Science
Addis Ababa University
Alemaya, Ethiopia
1982

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
July, 1989

EFFECTS OF PHOSPHORUS AND POTASSIUM FERTIL-
IZATION ON SOIL TEST INDICES AND YIELDS
OF MONO- AND DOUBLE-CROPPED WHEAT,
SOYBEAN, AND GRAIN SORGHUM UNDER
RAINFED AND IRRIGATED
CONDITIONS

Thesis Approved:

Jewell Crabtree
Thesis Adviser

[illegible]

Ronald W. McNew

Robert L. Westerman

Norman N. Durham
Dean of the Graduate College

ACKNOWLEDGEMENTS

I would like to express sincere appreciation to my major adviser Dr. R. Jewell Crabtree, for his friendship, guidance and understanding throughout this study. Appreciation is also extended to the members of my advisory committee, Dr. Stephen Hawkins, Dr. R.W. McNew, and Dr. R.L. Westerman for their advice and constructive criticism in the preparation of this manuscript.

Thanks are also extended to Mr. Jay Prater, for his constant assistance in conducting the experiment, and to fellow graduate students for their friendship and support which made time spent at Oklahoma State University enjoyable.

I would like to recognize the financial support provided by the Office of the International Programs, and the Department of Agronomy at Oklahoma State University, which made the work towards my Ph.D. possible.

Special thanks goes to Dr. Tesfaye Tessema, who initiated and recommended me for this program, and to Mr. Conrad Evans and his family for their friendship and support during my stay in Stillwater.

Special thanks also goes to Nomsa Mncadi for her love and understanding throughout this program, to my father Geleta Beyen, to my mother Aster Fekede, to my sisters and brothers, and to their families for their love and constant support while completing my graduate program.

TABLE OF CONTENTS

LIST OF TABLES

Table | Page

Part I

Part II

LIST OF FIGURES

Figure | Page

Part I

Part II

INTRODUCTION

Each part of this thesis is a separate manuscript to be submitted for journal publication. Both parts will be submitted to Agronomy Journal, an American Society of Agronomy Publication. Articles in this journal are peer reviewed and must report experiments repeated over time and/or space.

PART I

EFFECTS OF PHOSPHORUS AND POTASSIUM FERTILIZATION ON SOIL TEST INDICES AND YIELDS OF MONO- AND DOUBLE-CROPPED WHEAT AND SOYBEAN UNDER RAINFED AND IRRIGATED CONDITIONS.

ABSTRACT

Current soil test interpretations and fertilizer recommendations for rates of P and K applications are based on monoculture data. Producers have expressed concern as to whether these recommendations are adequate for double-cropping situations. A seven year (1982-1988) field study was conducted at the Oklahoma Vegetable Research Station, Bixby, Oklahoma on a Wynona silt loam soil (Cumulic Haplaquoll) with 0-1% slope. The objectives of the study were to determine the changes in selected soil test indices (pH, NO_3-N, extractable P, K, Ca, and Mg) and yield responses of wheat [Triticum aestivum (L.) em Thell], and soybean [Glycine max (L.) Merr.] to levels of P and K fertilization under mono- and double-cropped rainfed and irrigated conditions. Monocropped wheat produced an average of 2785 compared with 2385 kg ha^{-1} for double-cropped wheat. Irrigated, monocropped soybean yielded an average of 3094 compared with 2892 kg ha^{-1} for rainfed monocropped soybean. Irrigated double-cropped soybean yielded an average of 2281 compared with 1928 kg ha^{-1} for rainfed double-cropped soybean. Potassium fertilization increased wheat yields by 383 kg ha^{-1} and soybean yields by 234 kg ha^{-1} during the first year of application, after which the magnitude in yield response dropped for both crops. However, when yield data were pooled, the effect of K was statistically significant for wheat, but not for soybean yields.

Both wheat and soybean yields were not significantly influenced by P application. The average extractable P and K levels remained in the 100% sufficiency range for monoculture cropping as determined by the Oklahoma State University Soil Testing Laboratory procedures and recommendations. The results suggest that with routine soil testing P soil test levels that fall in the 100% sufficiency range for monoculture appears to be adequate for double-cropping practices. Although not conclusive, the wheat yield data suggest that a possible upward adjustment of soil test K levels may be required for 100% sufficiency and merits more research on the Wynona silt loam and other medium to fine textured soils in eastern Oklahoma. Soil pH did not vary with cropping systems or fertilizer treatments, but when compared with the initial levels decreased by 0.9 of a pH unit. Soil test indices at the end of the 7-yr study showed small increases of extractable Ca, Mg, and only slight increases in soil NO_3-N in the top 15 cm of a Wynona silt loam soil.

INTRODUCTION

Many growers continue to have interest in double-cropping hard red winter wheat [Triticum aestivum (L.) em. Thell] and soybean [Glycine max (L.) Merr.] in the eastern part of the Southern Great Plains. Fall, winter, and spring precipitation is usually sufficient in this region of the Great Plains to produce wheat, however, insufficient amounts and distribution of rainfall are often the major limiting factors to summer crop production whether grown mono- or double-cropped (Crabtree et al., 1987).

In this and other regions the use of supplemental irrigation has the potential for increasing yields. Application of supplemental irrigation to soybean grown on a silt loam soil in eastern Oklahoma under mono- and double-cropped systems has been shown to significantly increase yields (Crabtree, et al., 1987). Similar results were reported by Wesley et al., (1988) for a silt loam soil in Mississippi.

Double-cropping offers a number of potential advantages which include: reduced soil erosion (Campbell, 1979; Hairston et al., 1984), more efficient utilization of climatic resources, land, labor, and machinery (Crabtree and Rupp, 1980), and increased net returns (Lewis and Phillips, 1976; Sanford et al., 1986; Hariston, et al., 1987).

Despite these advantages, there are concerns about the effects that double-cropping has on nutrient supplying power of many soils, particularly when supplemental irrigation is practiced. These concerns are based on the lack of adequate research information concerning the effects of long-term double-cropping on soil test indices, fertilizer management, and crop yield levels.

Under double-cropping, in order to consistently obtain high yields and also to maintain the soil fertility level, adequate and balanced fertilization has to be made for both crops (Flannery, 1977; Swearingin, 1979; Colliver, 1983). Crop response to fertilization and soil test parameters under double-cropping are reported to vary with irrigation availability, tillage management, crop sequences, and soil type (Brown and Perkins, 1979; Touchton et al., 1982; Sharpe et al., 1984; Elwali and Gascho, 1985).

The results of a relatively short period study (3-yrs) by Brown and Perkins (1979) involving fertilization and irrigation of single and double-cropping systems of corn, grain sorghum, and small grains showed that drought restricted yield response to N, P, and K in non-irrigated plots, but under irrigation grain yield for each cropping sequence was directly related to fertilizer applied. On a deep sandy soil, Elwali and Gascho (1985) reported that applications of increasing rates of K linearly increased wheat yield, but had no significant effect on either soybean yield or on soil extractable K levels at the end of the season.

Touchton et al. (1982) reported that a single annual P application to low-P-eroded Ultisols was adequate for double-cropped wheat and soybeans. Sharpe et al. (1984) also reported that a single application of 128 kg P or more ha^{-1} to a Cecil sandy loam soil provided sufficient soil P to maintain soybean yields significantly higher than the zero P application rate over a four year period in a double-cropped wheat and soybean conservation tillage system. They also reported that P fertilization increased extractable soil P levels when wheat and soybean were double-cropped under conservation tillage management.

An Ultisol continuously double-cropped no-till to wheat and soybean increased in nutrient (Ca, Mg, P, Mn, and Zn) concentrations in the surface soil with a rapid decrease with depth, while conventionally tilled double-cropping resulted in a more homogeneous soil fertility status with depth (Hargrove et al., 1982). Wells et al. (1983) reported that over a four year period intensive double-cropping of corn and barley or oats with either no-tillage or conventional tillage did not affect the soil productivity parameters (organic matter content, pH, and extractable P and K) measured on Huntington or Pope silt loam soils.

Although the total grain yield advantage of double-cropping wheat and soybean on a Wynona silt loam soil has been established (Crabtree et al. 1987), P and K fertilizer management and the long term effect of double-cropping on selected soil test parameters has not been established for eastern Oklahoma. In 1982 soil test levels for the experimental area showed 100 percent sufficiency for P and K, and under monocropped conditions one would not expect a yield response to applications of these two nutrients (Coop. Ext. Serv., 1977). However, under double-cropped irrigated conditions, potential yield responses and changes in soil test indices are possible, especially over years. The objectives of this research were to determine the changes in selected soil test indices and yield responses of wheat and soybean to levels of P and K fertilization under mono- and double-cropped rainfed and irrigated conditions.

MATERIALS AND METHODS

This study was conducted at the Oklahoma Vegetable Research Station, Bixby, Oklahoma from 1982-1988 on a Wynona silt loam soil (Cumulic Haplaquolls) with 0 to 1% slope.

The experiment was designed as a split-plot with four replications. The five main plot treatments were: rainfed monocropped wheat, rainfed double-cropped wheat and rainfed double-cropped soybean, rainfed double-cropped wheat and irrigated double-cropped soybean, rainfed monocropped soybean, and irrigated monocropped soybean. The subplots constituted four fertility treatments that included a factorial combination of P at two levels (0 and 67 kg P ha^{-1}) in the form of $Ca(H_2PO_4)_2$, and K at two levels (0 and 135 kg K ha^{-1}) as KCl.

Fertilizer treatments were applied broadcast to the mono- and double-cropped wheat cropping systems in late winter of 1982. In late May of 1982, fertilizer materials were surface broadcast and incorporated with one tandem disking for the monocropped soybean treatments. No other P and K applications were made during the course of this study.

In the fall of 1981 the seedbed for all wheat was prepared by moldboard plowing plus two tandem diskings. In subsequent years, the same tillage operations were used to prepare the seedbed for monocropped wheat. Two tandem diskings of the double-cropped soybean stubble were used to prepare the seedbed for double-cropped wheat.

Winter wheat, 'TAM-105', was planted on monocropped plots with a range of 5 October to 21 October planting dates at a rate of 67 kg ha^{-1}. Double-cropped wheat plots were planted with a range of 6 November to 4 December planting dates at 101 kg ha^{-1}. A hoe drill with 0.25-m row spacings was used to plant the wheat. Each year wheat was topdressed by broadcasting NH_4NO_3 at a rate of 135 kg ha^{-1} during mid to late February. The experimental field plot sizes were 36.6- by 18.3-m for the main plot treatments and 9.15- by 18.3-m for the subplot treatments. Wheat grain yields were obtained by harvesting a 3.05- by 18.3-m strip from the center of each plot. Wheat yield data were analyzed using a split-plot design consisting of three main plot treatments and the four fertility treatments (2 x 2 factorial combinations of P and K) as subplots.

Seedbed preparation for the conventionally tilled monocropped soybean treatments consisted of moldboard plowing and two tandem diskings. No-till double-cropped soybean was seeded directly into standing wheat stubble. Soybean, 'Forrest', (Maturity Group V) was planted at 296 000 viable seeds ha^{-1}. Soybean was planted using an eight-row, no-till planter equipped with ripple coulters, double-disk openers, 40-mm depth bands, and press wheels. The planter was configurated to plant wheel traffic and non-wheel traffic rows in 0.75 and 0.50-m row spacings, respectively. Conventionally tilled monocropped soybean was planted with a range of 1 June to 22 June planting dates and the no-till double-cropped soybean was planted with a range of 9 June to 30 June planting dates.

Two tensiometers were placed at a depth of 0.25 m in the center and 6 m from each end of the irrigated plots on all four replications of the study. Tensiometer readings (soil water potentials of approximately - 0.1 MPa) were used to schedule irrigations. Water was metered and applied using a solid set sprinkler irrigation system designed so that all irrigated treatments could be irrigated at the same time or independent of one another.

Trifluralin (α,α,α-trifluoro-2,6-dinitro-N-N-dipropyl-p-toluidine) was broadcast on the conventionally tilled monocropped soybean plots at 1.1 kg ha^{-1} a.i. in 234 L ha^{-1} water and incorporated with a Do-all prior to planting. All monocropped soybean treatments also received one mechanical cultivation. No-till, double-cropped soybean treatments received 1.1 kg ha^{-1} a.i. glyphosphate [N-(phosphonomethyl) glycine] broadcast in 234 L water ha^{-1} water immediately after planting. All soybean plots received a tank-mixed, postemergence application of bentazon (3-isopropyl-1H-2,1, 3-benzothiadiazin-4((3H)-one-2,2-dioxide) and acifluorfen-sodium 5-[2-chloro-4-(triflurormethyl)phenoxy]-2-nitrobenzoate at 0.56 and 0.42 kg ha^{-1} a.i., respectively in 234 L water ha^{-1}. Glyphosate was used to control rhizome johnsongrass [Sorghum halepense (L.) pres.] by spot treating as needed from 1982-83. In 1984 and in the subsequent years, a separate application of fluazifop-butyl(±)-butyl 2-[4-[(5-(trifluoromethyl)-2-pyridinyl)oxy]-phenoxy] propanoate at 0.19 kg ha^{-1} a.i. along with 0.53 L surfactant in 234 L water ha^{-1} were also applied postemergence to all soybean treatments for continued johnsongrass control.

The above-mentioned postemergence herbicide applications were necessary due to intense weed pressure from morningglory species (Ipomoea purpurea), (Ipomoea hederacea var.jacq.), (Ipomoea hederaceae var. integriuascula), cocklebur (Xanthium pensylvanicum Wallr.), escaped within row redroot pigweed (<u>Amaranthus retroflexus</u> L.), common lambsquarters (<u>Chenopodium album</u> L.), and rhizome johnsongrass.

Soybean yields were obtained by harvesting a 2.92- by 18.3-m strip from the center of all mono- and double-cropped plots. Harvesting dates ranged from 21 September to 20 November and 21 October to 2 December for monocropped and double-cropped soybeans, respectively. Soybean yield data were analyzed using a split-plot design consisting of four main plot treatments which included 2 x 2 factorial combinations of cropping system (mono- and double-crop) and water (rainfed and irrigated) and four subplot fertility treatments as 2 x 2 factorial combinations of P and K.

Soil samples of the top 15 cm of the soil profile were taken from each subplot on 25 Feb. 1982 prior to any fertilizer application. On 11 Nov. 1988 surface soil samples (0 to 15-cm) were again taken from each subplot and analyzed for pH (1:1, soil/water), 0.01M $CaSO_4$ extractable NO_3-N, and neutral 1.0M ammonium acetate (NH_4OAc) extractable Ca and Mg. In 1982 samples for K were extracted with 1.0M NH_4OAc and samples for P were extracted by Bray/Kurtz extracting solutions consisting of 0.025 N HCl and 0.03 N NH_4F. In 1988 both P and K were extracted with Mehlich III extractant, at the Oklahoma State University Soil Testing Laboratory. It is assumed that both extracting procedures would result in similar soil test index values for extractable P and K for Oklahoma soils (Hanlon and Johnson, 1984). The soil test results were statistically analyzed as a split-plot with all the cropping systems as main plot and the 2 x 2 factorial combinations of P and K fertility treatments as subplots.

RESULTS AND DISCUSSION

Rainfall

Monthly rainfall from 1 Jan. 1982 to 31 Dec. 1988 and the 30-yr monthly averages (1959 to 1988) are given in Table 1. Monthly distributions of rainfall for each year of the 7-yr study are given in Fig. 1 and 2. Rainfall amounts and distribution during the last half of July, August, and September remain critical for summer grown crops.

Wheat

Monthly distributions of rainfall for 1982 through 1984 are given in Figure 1. The total amount of precipitation during the months of February, March, and April were low (63 mm) in 1982 compared with 204 and 258 mm in 1983 and 1984, respectively (Table 1, Fig. 1). In 1982 the lower magnitude in yields ran across all cropping systems (Table 2), and can be attributed to an outbreak of tan spot _Pyrenophora triticirepentis_ and to the less than average precipitation obtained during February, March, and April (Table 1). Over the 3-yr period (1982-1984) monocropped wheat yields averaged over fertilization ranged from 2700 to 3650 kg ha^{-1} compared with a range of 2168 to 3175 kg ha^{-1} for double-cropped wheat (Table 2). From 1982 through 1984, the effect of cropping systems on wheat yield was significant at the 0.01 probability level (Table 3). When averaged over fertilization, monocropped wheat yields were significantly higher compared with rainfed double-cropped wheat whether double-cropped soybeans were grown rainfed or under irrigated conditions during the 3-yr period (Table 2). In two out of three years (1982-1983) the two double-cropped wheat yields were not statistically different ($P<0.05$). In 1984, the only plausible explanation that can be given for the 275 kg ha^{-1} yield increase is that the wheat benefited from residual water from the previously irrigated (1983) double-cropped soybean treatment (Table 2).

When applied alone, P fertilization did not significantly influence wheat yields, across all the cropping system treatments for the 1982 environment (Tables 2 and 3). In 1983, wheat yield response to P varied with cropping system resulting in a significant ($P<0.01$) cropping system (CS) x P fertilization interaction (Table 3). During this year, significantly lower wheat yields were obtained under monocropping when P was applied alone and when applied in combination with K, however, under double-cropping the wheat yield response to P was not significantly affected (Table 2). In 1984, three years after application, the main effect of P fertilization was significant ($P<0.01$) across all the cropping systems (Table 3). For the 1984 environment, wheat yields for P applied treatments averaged over all the cropping systems increased by 190 kg ha^{-1} (Table 2).

Potassium fertilization alone significantly ($P<0.01$) influenced wheat yields in the 1982 and 1984 environments with an increase in yields of 383 and 108 kg ha^{-1}, respectively when averaged over cropping systems (Tables 2 and 3).

Over the next 4-yr period (1985-88) rainfall amounts and distribution were good from February through May of each year with the exception of April and May 1988, when lower than average rainfall was obtained (Table 1, Fig. 2). For the most part, wheat yields were not affected by water stress, however, in 1986 an outbreak of leaf rust (Puccinia recondita Rob. ex Desm F. sp. tritici Eriks) severely decreased the yield of wheat across all the treatments (Table 2). During 1985 and 1986, cropping systems, P, and K fertilization did not significantly affect wheat yields, however, during 1987 and 1988 cropping system and K fertilization had a significant influence on wheat yields (Table 3). In 1987 and 1988, monocropping produced significantly higher wheat yields when compared with double-cropping (Table 2).

For the 1987 environment, the interaction CS x P x K was significant ($P<0.01$). Under rainfed monocropped wheat, and rainfed double-cropped wheat and rainfed double-cropped soybean cropping systems, significantly lower wheat yields were obtained when combined P and K fertilizers were applied. However, under the rainfed double-cropped wheat and irrigated double-cropped soybean treatment the P x K interaction was not significant (Table 2). In 1988 the main effect of K on wheat yields was significant ($P<0.05$). When averaged over cropping systems, K in combination with P produced an even higher yield of 230 kg ha^{-1} when compared with the check treatment (Table 2).

Over the 7-yr period, the main effects (year, cropping system, and K fertilization) were significant at probability levels <0.01 (Table 3). During this period, when averaged over fertilization the mono-cropped wheat treatment produced significantly ($P<0.01$) higher wheat yields ranging from 1863 to 3650 kg ha^{-1} with an average yield of 2785 kg ha^{-1} compared with wheat yields ranging from 1845 to 3175 kg ha^{-1}

with an average yield of 2385 kg ha^{-1} for the double-cropped treatments (Table 2).

The higher yields under monocropping were expected as monocropped wheat is planted around the first to third week of October and benefits from more fall growth and tillering compared with early November to early December planting and less tillering of the double-cropped wheat. Similar results have been reported by Crabtree et al. (1986) and Crabtree and Rupp (1980).

Over the 7-yr period supplemental irrigation of the preceding soybean crop, in the double-cropping system, did not affect the yields of the following years wheat crop. This was also expected since the total amount of rainfall during the wheat growing period was near or above the long term average during the 7-yr period (Table 1). When wheat yield data were pooled over the 7-yr period, K fertilization significantly ($P<0.01$) increased wheat yields (Table 3). The largest yield increase (383 kg ha^{-1}) for the applied K alone treatment was obtained during the first year of application (Table 2). During the subsequent years, the yield response was of lower magnitude and also varied from not being significant in 1983-85-86 to significant ($P<0.05$) in 1988 and to significant ($P<0.01$) in 1982-84-87 (Table 3). The interaction effects (CS x Y, P x Y, and K x Y) were all significant at the 0.01 probability level (Table 3). These significant interactions can be attributed to wide variations in yearly amounts and distribution of rainfall in the southern Great Plains (Table 1, Fig. 1 and 2).

Soybean

Rainfall amounts and distribution during the last half of July, August, and September remain critical for soybean production. During this three month period, irrigated soybean treatments received supplemental water in the amounts given in Table 4.

From 1982 through 1984 (the first 3-yrs of the experiment), yearly yields of higher magnitude were obtained under both rainfed and irrigated monocropped conditions compared with rainfed and irrigated double-cropped soybean treatments, respectively (Table 5). However, during the 3-yr period, the effect of supplemental irrigation on soybean yields varied with cropping system resulting in yearly significant CS x W interactions (Table 6). When averaged over all fertility treatments, the application of supplemental water increased soybean yields by 387, 408, and 150 kg ha^{-1} when monocropped and by 175, 1410, and 447 kg ha^{-1} when double-cropped during 1982, 1983, and 1984, respectively. The exceptionally higher yield increase due to irrigation during 1983 for double-cropped soybean can be attributed to the low amount of precipitation received during the months of July, August, and September (Fig. 1, Table 1).

Soybean yield response to P application was not statistically significant during the 3-yr period (Table 6). In 1982, the first year of K application, soybean yields averaged over cropping systems significantly increased by 234 kg ha^{-1} ($P<0.01$) compared with soybean yields that received no K, however, this trend did not occur again for the duration of the experiment (Tables 5 and 6). The significant interaction effects of W x P x K ($P<0.05$) and CS x W x K ($P<0.01$) in

1983 can most likely be attributed to environmental factors for that specific year since they were not significant again for the duration of the study period (Table 6).

During the following four year period (1985 to 1988) when averaged over fertilization, monocropped soybean yields ranged from 2958 to 3538 kg ha^{-1} compared to a range of 718 to 3350 kg ha^{-1} for double-cropped soybean (Table 5). In three out of this four year period, monocropped soybean yielded significantly more ($P<0.05$) than the double-cropped soybean by 545, 893, and 2228 kg ha^{-1} during 1985, 1987, and 1988, respectively. The large yield differences between mono- and double-cropping in 1988 was due to failure in establishing a good stand of double-cropped soybean because of a severe shortage of rainfall during the months of May and June (Table 1, Fig 1).

In 1986, no statistically significant yield differences were obtained, however, the soybean yields were in general high under both mono- and double-cropping systems. The 1986 environment represents a classic example where no significant yield response to early irrigation was achieved because of adequate rainfall in late August during which time Maturity Group V soybean was in early bloom and pod set. This situation coupled with continued adequate rainfall in September when soybean was in the pod fill stage of growth further explains why no response to irrigation was achieved (Table 1, Fig. 2). During this 4-yr period, soybean yields did not significantly respond to supplemental irrigation, except in 1988 when the water build up in the soil profile might have been lower due to the less than average rainfall amount received during the months of May, June, and July (Table 1, Fig. 2).

From 1985 through 1988, soybean yield response to P, K, and the P x K interaction was not significant under mono- and double-cropped systems with or without irrigation (Tables 5 and 6).

During the 7-yr period (1982 to 1988), rainfed monocropped soybean yields averaged over fertilization ranged from 1978 to 3450 with an average yield of 2892 kg ha^{-1}, and irrigated monocropped soybean yields ranged 2365 to 3538 with an average yield of 3094 kg ha^{-1} (Table 5). When averaged over fertilization during the same 7-yr period, rainfed double-cropped soybean yields ranged from 718 to 3350 with an average of 1928 kg ha^{-1} and irrigated double-cropped soybean ranged from 948 to 3328 with an average yield of 2281 kg ha^{-1} (Table 5).

When soybean yield data were pooled and analyzed over the 7-yr period (1982-88), the main effects of cropping systems (CS), water (W), and year (Y) along with CS x W, Y x CS, Y x W, Y x CS x W, and Y x K interactions were significant (Table 6). When compared with rainfed conditions the application of supplemental irrigation consistently increased soybean yields under monocropping. Under double-cropping, irrigation increased yields in five out of seven years. These results are most likely responsible for the significant interaction effects of Y x CS x W (Tables 5 and 6).

When yield data were pooled and analyzed over the 7-yr period, P and K fertilization did not have significant influence on soybean yields, however, the occurrence of the significant main effect of K applied alone during the first year (1983) may have been the reason for the significant Y x K interaction (Table 6).

Soil Indices

Over the 7-yr cropping period (1982-88), surface soil (0-15 cm) pH values decreased from an overall average of 6.6 in 1982 to 5.7 in 1988 when measured in a 1:1 soil-water ratio (Table 7). This decrease appears not to be due to different cropping systems or P and K fertilization, but is most likely due to the duration of the cropping period and seasonal variances associated with soil sampling and the decomposition stages of organic matter.

At the end of 7-yrs of cropping, the soil NO_3-N in the upper 0-15 cm of soil profile did not vary with mono- or double-cropping under both rainfed and irrigated condition. However, when compared to the initial year (1982), the NO_3-N increased only slightly from an average of 0.5 to 3 mg kg^{-1} of soil at the final year (1988). The slight increase in NO_3-N during the course of the study was probably due to fertilization of the wheat with NH_4NO_3 and decomposition and mineralization of organic residues.

After 7-yrs of cropping, the average extractable soil P significantly ($P<0.01$) declined by about 25% from an average of 54 mg P kg^{-1} soil in 1982 to 41 mg P kg^{-1} soil in 1988 (Tables 7 and 8). However, these soil test levels were still in the range of 100% sufficiency levels ($\geq$ 32.5 mg P kg^{-1} soil) as determined by the Oklahoma State University Soil Testing Laboratory procedures and recommendations.

At the end of 7-yrs of mono- and double-cropping, there was a statistically significant ($P<0.05$) difference in the extractable K level as influenced by cropping system (Table 8). When averaged over fertilization, the extractable soil K levels of 149 mg kg^{-1} soil was obtained under the rainfed double-cropped wheat and irrigated double-cropped soybean treatment. This was significantly higher than the average extractable soil K levels of 127 and 128 mg kg^{-1} soil obtained under irrigated monocropped soybean, and rainfed double-cropped wheat and rainfed double-cropped soybean treatments, respectively (Table 7). When averaged over cropping systems and fertilization, the extractable K levels of 136 mg kg^{-1} of soil at the beginning of the experiment remained virtually unchanged after seven years. The results of this experiment indicate that the Wynona silt loam soil had sufficient supplying power and quantity/intensity properties to maintain extractable K levels in the 100% sufficiency range ($\geq$ 125 mg K kg^{-1} soil) as determined by the Oklahoma State University Soil Testing Laboratory procedures and recommendations (Tables 7 and 8).

Initial soil test values showed levels of extractable Ca that ranged from 1035 to 1166 mg kg^{-1} soil and extractable Mg that ranged from 108 to 124 mg kg^{-1} soil across all plots. In general, over the 7-yr period the extractable Ca and Mg levels showed a slight increase in the surface (0-15 cm) soil across all the cropping system treatments (Table 7). Extractable Ca levels were not significantly influenced by cropping systems, whereas the extractable Mg was significantly ($P<0.05$) influenced by the cropping system treatments applied over the 7-yr period (Table 8). Statistically Mg levels were significantly lower (magnitude of only 12 mg Mg kg^{-1} soil) under the rainfed monocropped wheat compared with the rainfed double-cropped wheat and irrigated double-cropped soybean treatment (Table 7).

SUMMARY AND CONCLUSIONS

During the 7-yr (1982-1988) period, mono-cropped wheat produced an average of 2785 compared with 2385 kg ha^{-1} for double-cropped wheat. During this period, wheat yields from the double-cropping practices were not significantly influenced by the supplemental water applied to the preceding soybean crop.

When data were pooled over the 7-yr period, K fertilization increased wheat yields. In 1982, K applied alone significantly increased wheat yields across all cropping systems and when K was applied in combination with P, yields for both double-cropped wheat treatments were also significantly increased. After the first year of application, the yield response to K was of a lower magnitude, varied from year to year resulting in a significant Y x K interaction, and showed a somewhat higher yield trend for the double-cropped wheat treatments.

During the first year of application, the effect of P alone on wheat yields was not significant, however, wheat yield in response to K was significantly increased by an average of 383 kg ha^{-1}. In 1983, wheat yield response to P varied with cropping system, while in 1984, the third year after application, P alone or when applied in combination with K, significantly increased wheat yields, followed with no effect for the subsequent years.

Irrigated monocropped soybean yielded an average of 3094 compared with 2892 kg ha^{-1} for rainfed monocropped soybean. Irrigated double-cropped soybean yielded an average of 2281 compared with 1928 kg ha^{-1} for rainfed double-cropped soybean.

Potassium fertilization increased soybean yields by an average of 234 kg ha^{-1} during the first year of application with a higher magnitude of yield increase under double-cropping compared with monocropping. The effect of K fertilization on soybean yields was not significant during the subsequent years and when the yield data were pooled over 7-yrs, no statistically significant yield response to K fertilization was obtained.

Soil pH and extractable P levels did not vary with the cropping system, application of supplemental water, and with P, or K fertilization over the 7-yr period. However, compared to the initial levels, the soil pH decreased by 0.9 of a pH unit and the extractable P level declined by nearly 25%. The decline in pH can probably be attrituted to seasonal variations in soil sampling and to decomposition stages of organic residues in the top 0-15 cm of the soil profile since there was no major change in measured extractable levels of Ca and Mg. The extractable K levels showed some variation with cropping system, nevertheless, the K level remained virtually unchanged after 7-yrs of cropping, indicating that the Wynona silt loam soil has the supplying power and quantity/intensity properties to maintain extractable K levels at the 100% sufficiency level as determined by the Oklahoma State University Soil Testing Laboratory procedures and recommendations. Soil NO_3-N levels ranged from 0.5 in 1982 to 3.0 mg kg^{-1} soil in 1987 for only a slight increase in the top 0-15 cm of the soil profile.

LITERATURE CITED

Brown, A.R., and H.F. Perkins. 1979. Single vs. double cropping under two levels of fertilization with and without irrigation. Commun. In Soil Sci. Plant Anal. 10(10):1279-1289.

Campbell, R.B., T.A. Matheny, P.G. Hunt, and S.C. Gupta. 1979. Crop residue requirements for water erosion control in six southern states. J. Soil Water Conserv. 34:83-85.

Cooperative Extension Service. 1977. Oklahoma Soil Fertility Handbook. 1st Ed. Okla. Agric. Ext. Serv. and Okla. Plant Food Educational Soc., Inc.

Crabtree, R.J., R.G. Greenland, J.D. Prater, J.O. Adesina, and P.L. Claypool. 1987. Mono- and double-cropped wheat and soybeans under rainfed and irrigated conditions. Soil Science. 144:53-60.

Crabtree, R.J., and R.N. Rupp. 1980. Double and monocropped wheat and soybeans under different tillage and row spacings. Agron. J. 72:445-448.

Colliver, G.W. 1983. Fertilizers as an investment. Crops Soils 36(1):12-14.

Elwali, A.M.O., and G.J. Gascho. 1985. Timing and rate of K application for wheat-soybean double cropping on a sandy soil. Agron. J. 77:145-149.

Flannery, R.L. 1977. Make double cropping pay off. Better Crops with Plant Food. 61(1):28-31.

Hairston, J.E., J.O. Sanford, J.C. Hayes, and L.L. Reinschmiedt. 1984. Crop yield, soil erosion, and net returns from five tillage systems in the Mississippi Blackland Prairie. J. Soil Water Conserv. 39:391-395.

Hairston, J.E., J.O. Sanford, D.F. Pope, and D.A. Horneck. 1987. Soybean-wheat double cropping: Implications from straw management and supplemental nitrogen. Agron. J. 79:281-86.

Hanlon, E.A., and G.V. Johnson. 1984. Bray/Kurtz, Mehlich III, AB/D and ammonium acetate extractions of P, K and Mg in four Oklahoma Soils. Commun. in Soil Sci. Plant Anal. 15(3):277-294.

Hargrove, W.L., J.T. Reid, J.T. Touchton, and R.N. Gallaher. 1982. Influence of tillage practices on the fertility status of an acid soil double-cropped to wheat and soybeans. Agron. J. 74:684-687.

Lewis, W.M., and J.A. Phillips. 1976. Double cropping in the eastern United States. p. 41-50. In R.I. Papendick, P.A. Sanchez, and G.B. Triplett (ed.) Multiple Cropping. ASA Spec. Pub. 27. ASA, CSSA, and SSSA, Madison, WI.

Sanford, J.O., B.R. Eddleman, S.R. Spurlock, and J.E. Hairston. 1986. Evaluating ten cropping alternatives for the Midsouth. Agron. J. 78:875-880.

Sharpe, R.R., J.T. Touchton, F.C. Boxwell, and W.L. Hargrove. 1984. Effect of applied and residual P on double cropped wheat and soybean under conservation tillage management. Agron. J. 76:31-35.

Swearingin, M.L. 1979. Doublecropping winter wheat and soybeans in Indiana. Ext. Publ. ID-96. Purdue Univ., West Lafayette, Ind.

Touchton, J.T., W.L. Hargrove, R.R. Sharpe, and F.C. Boxwell. 1982. Time, rate, and method of phosphorus application for continuously double-cropped wheat and soybeans. Soil Sci. Am. J. 46:861-864.

Wells, K.L., L.W. Murdock, and W.W. Frye. 1983. Intensive cropping effects on physical and chemical conditions of two soils in Kentucky. Commun. In Soil Sci. Plant Anal. 14(4):297-307.

Wesley, R.A., L.G. Heatherly, H.C. Pringle, III and G.R. Tupper. 1988. Seedbed tillage and irrigation effects on yield of mono- and doublecrop soybean and wheat on a silt loam. Agron. J. 80:139-143.

Table 1. Rainfall from 1 Jan. 1982 to 31 Dec. 1988 and the 30-yr monthly average (1959-1988) at the Vegetable Research Station, Bixby, Oklahoma.

	Rainfall							
Month	1982	1983	1984	1985	1986	1987	1988	30-yr avg.
	mm							
January	91	65	10	21	00	77	26	39
February	12	71	70	102	31	136	35	44
March	20	48	125	118	49	56	162	65
April	31	85	63	123	114	17	45	96
May	199	177	126	74	204	210	30	126
June	156	69	89	170	56	67	27	114
July	59	26	15	69	12	72	135	86
August	58	7	57	57	88	65	22	67
September	20	41	55	118	264	78	133	103
October	42	260	180	237	178	32	23	85
November	159	78	62	144	81	90	148	74
December	81	13	268	33	27	177	71	48
Totals	928	940	1120	1266	1104	1077	867	947

Table 2. Wheat yields as affected by cropping system and fertilization under wheat-soybean mono- and double-cropping.

Fertilization†	1982	1983	1984	1985	1986	1987	1988	7-yr avg.
	kg ha^{-1}							
	Rainfed monocropped wheat							
Check	2570	3490	3510	1910	2190	2480	3310	2780
P	2500	3260	3720	1970	2130	2480	3200	2751
K	2990	3550	3610	1780	2150	2420	3260	2823
PK	2740	3280	3760	1790	2210	2320	3400	2786
Cropping System Mean	2700	3395	3650	1863	2170	2425	3293	2785
	Rainfed double-cropped wheat and rainfed double-cropped soybean							
Check	1980	2990	2760	1860	1900	1920	2560	2281
P	1990	2960	2970	1940	1930	1880	2670	2334
K	2420	3020	2860	1880	1990	1930	2750	2407
PK	2280	3070	3010	2060	2050	1770	2960	2457
Cropping System Mean	2168	3010	2900	1935	1968	1875	2735	2370
	Rainfed double-cropped wheat and irrigated double-cropped soybean							
Check	1940	3080	2970	2190	1820	1930	2600	2361
P	1970	3060	3190	1980	1900	1860	2550	2359
K	2480	3010	3160	2020	1750	1750	2480	2379
PK	2340	3120	3380	2030	1910	1930	2770	2497
Cropping System Mean	2183	3068	3175	2055	1845	1868	2600	2399
	Over cropping system							
Check, P	2158	3140	3188	1973	1978	2092	2814	
K, PK	2541	3175	3296	1926	2009	2019	2938	
LSD (0.05)‡	321	225	160	NS	NS	200	160	
LSD (0.05)§	108	NS	68	NS	NS	53	126	

†Check (no P or K); P (67 kg ha^{-1}); K (135 kg ha^{-1}); PK (67 and 135 kg ha^{-1}, respectively).

‡For comparisons between cropping system means averaged over fertilization.

§For comparisons between K means averaged over cropping system and P fertilization.

Table 3. Mean squares for the effects of cropping system and fertilization on wheat yields under wheat-soybean mono- and double-cropping.

Source	df	1982	1983	1984	1985	1986	1987	1988	1982-88
		Mean Square ($x10^4$)							
Blocks	3	16.1	1.0	5.6	10.2	15.8	9.8	22.4	21.8
Cropping System (CS)	2	145.6**	68.8**	231.2**	15.4	43.7	163.2**	216.3**	601.0**
Block x CS Error (a)	6	13.8	6.8	3.4	14.4	19.8	5.4	3.5	16.1
P	1	10.8	5.3	42.7**	0.6	3.4	1.2	12.0	5.0
K	1	175.3**	1.4	14.0**	2.8	1.2	6.5**	18.3*	53.3**
P x K	1	8.6	0.9	0.5	2.0	2.1	0.1	16.4	2.8
CS x P	2	1.4	10.8**	0.2	5.5	1.3	2.4	2.4	7.4
CS x K	2	1.7	0.6	2.0	4.9	2.0	0.4	3.9	4.8
CS x P x K	2	0.01	0.8	0.1	1.8	0.2	4.1**	1.5	3.8
Block x CS x P x K Error (b)	27	3.3	1.6	1.3	3.3	1.9	0.8	4.5	2.8
Year (Y)	6	-	-	-	-	-	-	-	1520.9**
Block x Y Error(c)	18	-	-	-	-	-	-	-	9.8
CS x Y	12	-	-	-	-	-	-	-	47.2**
Block x CS x Y Error (d)	36	-	-	-	-	-	-	-	8.5
P x Y	6	-	-	-	-	-	-	-	11.8**
K x Y	6	-	-	-	-	-	-	-	27.7**
P x K x Y	6	-	-	-	-	-	-	-	4.6
CS x P x K x Y	36	-	-	-	-	-	-	-	1.8
BlockxCSxPxKxY (Error)	162	-	-	-	-	-	-	-	2.3

*,** significant at the 0.05 and 0.01 probability levels, respectively.

Table 4. Supplemental water applied to mono- and double-cropped soybean.

	Year						
Cropping system	1982	1983	1984	1985	1986	1987	1988
	mm						
Irrigated monocropped soybean	200	300	120	150	120	110	150
Irrigated double-cropped soybean	260	360	200	150	120	110	150

Table 5. Soybean yields as affected by cropping system, water, and fertilization.

Fertilization†	1982	1983	1984	1985	1986	1987	1988	7-yr avg.
	kg ha^{-1}							
	Rainfed monocropped soybean							
Check	1820	2620	2560	3240	3440	3380	2860	2846
P	1840	2680	2530	3380	3270	3450	2920	2867
K	2090	2600	2540	3370	3480	3500	3070	2950
PK	2160	2480	2500	3330	3420	3470	2980	2906
Cropping system mean	1978	2595	2533	3330	3403	3450	2958	2892
	Irrigated monocropped soybean							
Check	2310	3000	2800	3560	3450	3430	3150	3100
P	2340	2950	2570	3650	3430	3550	3100	3084
K	2340	3000	2690	3560	3440	3420	3310	3109
PK	2470	3060	2670	3380	3400	3490	3100	3081
Cropping system mean	2365	3003	2683	3538	3430	3473	3165	3094
	Rainfed double-cropped soybean							
Check	1590	980	1260	2840	3410	2560	850	1930
P	1940	1000	1100	2900	3360	2410	610	1900
K	1900	1280	1110	2940	3260	2400	750	1950
PK	1970	1140	1080	3050	3370	2270	660	1930
Cropping system mean	1850	1100	1138	2933	3350	2410	718	1928
	Irrigated double-cropped soybean							
Check	1740	2680	1530	2760	3390	2640	980	2246
P	1930	2520	1560	2990	3260	2790	950	2286
K	2140	2300	1740	2740	3300	2790	890	2270
PK	2290	2540	1510	2890	3360	2690	970	2320
Cropping system mean	2025	2510	1585	2845	3328	2728	948	2281
	Over cropping system-water							
Check, P	1937	2304	1988	3164	3375	3027	1929	
K, PK	2171	2301	1978	3157	3378	3003	1964	
LSD (0.05)‡	120	220	200	304	NS	320	230	
LSD (0.05)§	149	NS	NS	NS	NS	NS	NS	

†Check (no P or K); P(67 kg ha^{-1}); K(135 kg ha^{-1}); PK (67 and 135 kg ha^{-1}, respectively).

‡For comparisons between cropping system - water means averaged over fertilization.

§For comparisons between K means averaged over cropping system - water.

Table 6. Mean squares for the effects of cropping system, water, and fertilization on soybean yields.

Sources	df	1982	1983	1984	1985	1986	1987	1988	1982-88
		Mean square($\times 10^4$)							
Block	3	6.6	5.0	2.6	9.7	0.9	9.0	6.6	3.1
Cropping system (CS)	1	86.9**	1579.2**	2491.4**	479.6**	9.7	1276.6**	7951.9**	8849.8**
Water (W)	1	126.0**	1325.4**	140.7**	6.1	0.02	46.4	77.3**	863.0**
CSxW	1	17.2*	400.7**	35.1*	33.9	1.1	35.2	0.3	65.4**
BlockxCSxW Error (a)	9	2.1	7.6	6.2	14.5	2.1	15.7	8.3	7.9
P	1	25.3	0.1	12.5	7.1	2.0	0.0001	8.0	0.03
K	1	87.3**	0.01	0.2	0.1	0.01	0.9	2.0	12.0
P x K	1	0.5	0.7	0.2	5.4	5.0	3.5	0.03	0.4
CS x P	1	6.3	0.01	0.1	7.2	1.6	5.3	0.01	2.4
CS x K	1	2.7	1.0	0.1	2.6	1.9	2.8	7.1	0.2
CS x P x K	1	5.5	2.4	3.0	4.0	1.8	0.2	7.9	1.5
W x P	1	0.002	1.6	1.0	0.01	0.01	5.4	0.5	1.8
W x K	1	0.008	5.6	3.5	13.1	0.2	0.4	0.4	3.0
W x P x K	1	2.0	18.4*	0.7	1.0	0.3	1.1	0.02	0.6
CS x W x P	1	0.7	0.5	0.6	3.6	2.2	0.8	9.4	3.7
CS x W x K	1	18.3	32.5**	2.2	0.01	3.9	8.4	0.2	4.1
CS x W x P x K	1	0.8	1.6	9.5	0.1	0.6	2.8	0.01	0.7
BlockxCSxWxPxK Error(b)	36	8.6	4.0	3.5	5.7	1.6	4.5	4.2	5.5
Year (y)	6	-	-	-	-	-	-	-	2417.1**
BlockxY Error(c)	18	-	-	-	-	-	-	-	6.2
Y x CS	6	-	-	-	-	-	-	-	837.6**
Y x W	6	-	-	-	-	-	-	-	143.1**
Y x CS x W	6	-	-	-	-	-	-	-	76.3**
BlockxYxCSxW Error(d)	54	-	-	-	-	-	-	-	8.1
Y x P	6	-	-	-	-	-	-	-	9.2
Y x K	6	-	-	-	-	-	-	-	13.1**
Y x P x K	6	-	-	-	-	-	-	-	2.5
Y x CS x W x P x K	54	-	-	-	-	-	-	-	3.7
BlockxYxCSxWxPxK(Error)	216	-	-	-	-	-	-	-	4.4

*,** significant at the 0.05 and 0.01 probability levels, respectively.

Table 7. Means for the effects of wheat-soybean cropping systems and fertilization on soil pH, extractable P, K, Ca, and Mg.

Fertilization*	pH		P		K		Ca		Mg	
	1982‡	1988	1982	1988	1982	1988	1982	1988	1982	1988
	—pH unit—		—mg kg^{-1}—							
				Rainfed monocropped wheat						
Check	6.6	5.6	57	47	137	134	1062	1090	110	108
P	6.6	5.6	61	46	131	140	1059	1130	108	110
K	6.6	5.6	57	41	126	134	1052	1078	110	107
PK	6.5	5.9	63	44	148	139	1089	1121	118	113
Cropping System Mean	6.6	5.7	59	45	135	137	1065	1105	112	110
		Rainfed double-cropped wheat and rainfed double-cropped soybean								
Check	6.6	5.7	55	43	140	138	1045	1191	126	126
P	6.6	5.7	57	31	137	121	1046	1190	111	124
K	6.6	5.8	57	32	135	121	1117	1196	110	119
PK	6.6	5.7	58	41	142	133	1047	1163	108	119
Cropping System Mean	6.6	5.7	57	37	139	128	1064	1185	114	122
		Rainfed double-cropped wheat and irrigated double-cropped soybean								
Check	6.5	5.8	52	38	133	147	1070	1257	113	137
P	6.6	5.4	53	44	127	140	1083	1283	119	138
K	6.5	5.5	55	39	127	145	1107	1259	118	136
PK	6.6	5.5	51	44	137	162	1035	1235	110	131
Cropping System Mean	6.6	5.5	53	41	131	149	1074	1259	115	135
				Rainfed monocropped soybean						
Check	6.6	5.7	55	44	130	142	1070	1179	112	124
P	6.6	5.6	55	49	149	142	1093	1203	114	129
K	6.6	5.6	56	45	144	140	1091	1206	113	124
PK	6.5	5.6	53	43	134	138	1102	1201	114	125
Cropping System Mean	6.6	5.6	55	45	139	141	1089	1197	113	125
				Irrigated monocropped soybean						
Check	6.6	5.7	46	34	136	133	1106	1229	123	134
P	6.6	6.0	50	40	144	126	1148	1294	119	132
K	6.7	5.7	46	33	141	130	1139	1253	124	135
PK	6.7	6.0	43	34	136	120	1166	1285	119	130
Cropping System Mean	6.6	5.9	46	35	139	127	1140	1265	121	132
					Over cropping system					
Check	6.6	5.7	53	41	135	139	1071	1189	117	126
P	6.6	5.6	55	42	138	134	1086	1220	114	127
K	6.6	5.7	54	38	135	134	1101	1199	115	124
PK	6.6	5.7	54	41	139	138	1088	1201	114	124
LSD (0.05)§	NS	NS	NS	NS	NS	14	NS	99	NS	12

*Check (no P or K); P(67 kg ha^{-1}); K(135 kg ha^{-1}); PK(67 and 135 kg ha^{-1}, respectively).
‡Soil test values for samples taken before any treatments were applied.
§For comparisons between cropping system means averaged over fertilization.

Table 8. Mean squares for the effects of cropping system and fertilization on the differences between 1982 and 1988 soil pH, extractable P, K, Ca, and Mg under wheat-soybean mono- and double-cropping.

Source	df	pH	P	K	Ca	Mg
Year (Y)	1	67.7**	14298**	12	1076248**	7990**
Block x Y Error (a)	3	0.9	311	2870	26470	120
CS x Y	4	0.2	279	2193*	43270	1042*
Block x CS x Y Error (b)	12	0.4	602	664	17708	268
P x Y	1	0.1	41	302	4898	79
K x Y	1	0.2	83	12	8818	29
P x K x Y	1	0.1	150	257	1	34
CS x P x K x Y	12	0.1	66	207	1052	44
BlockxCSxPxKxY Error	45	0.1	75	350	2996	64

, significant at the 0.05 and 0.01 probability levels, respectively.

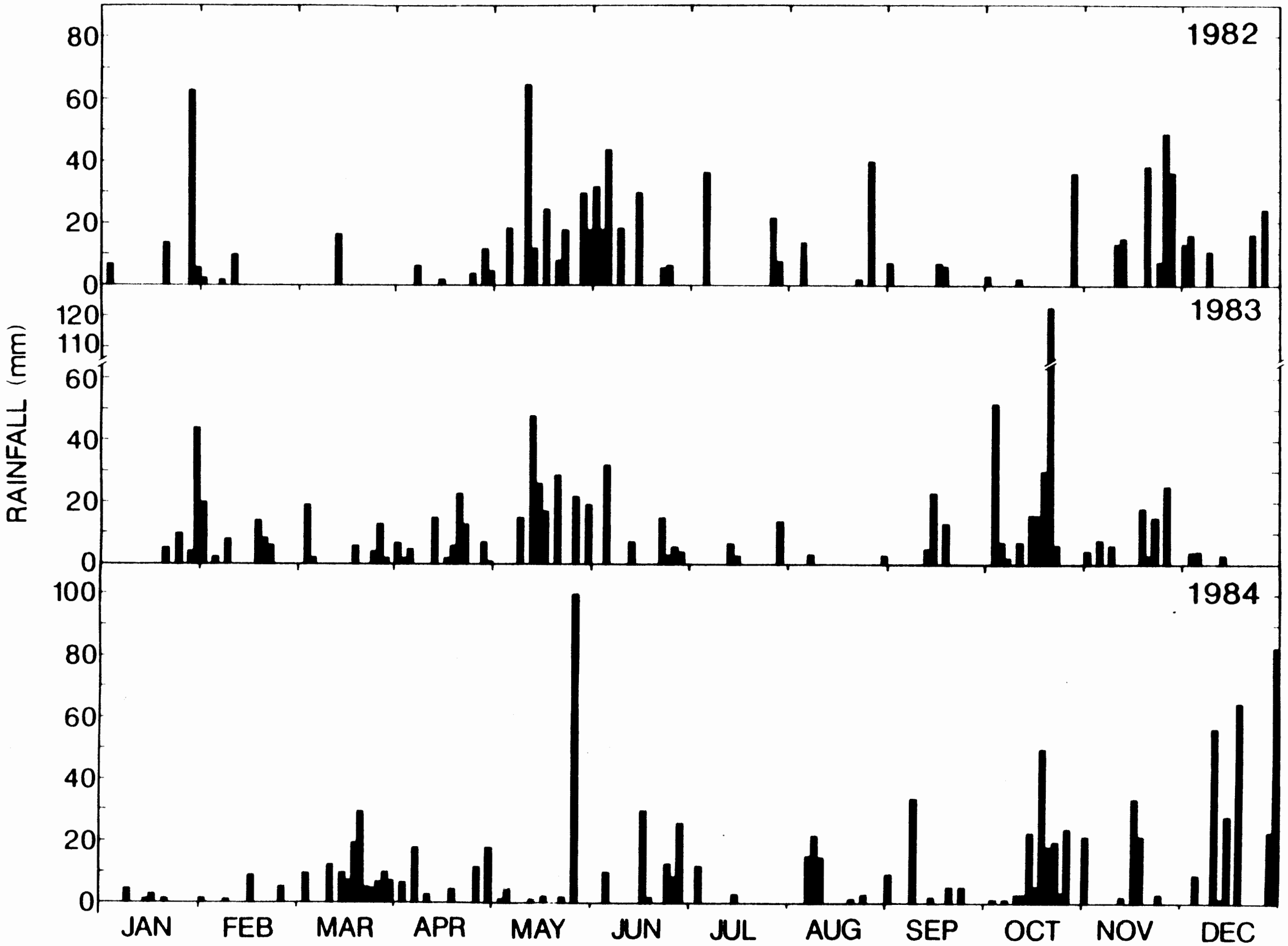

Fig. 1. Rainfall amounts and distribution for 1982-1984 at the Vegetable Research Station, Bixby, Oklahoma.

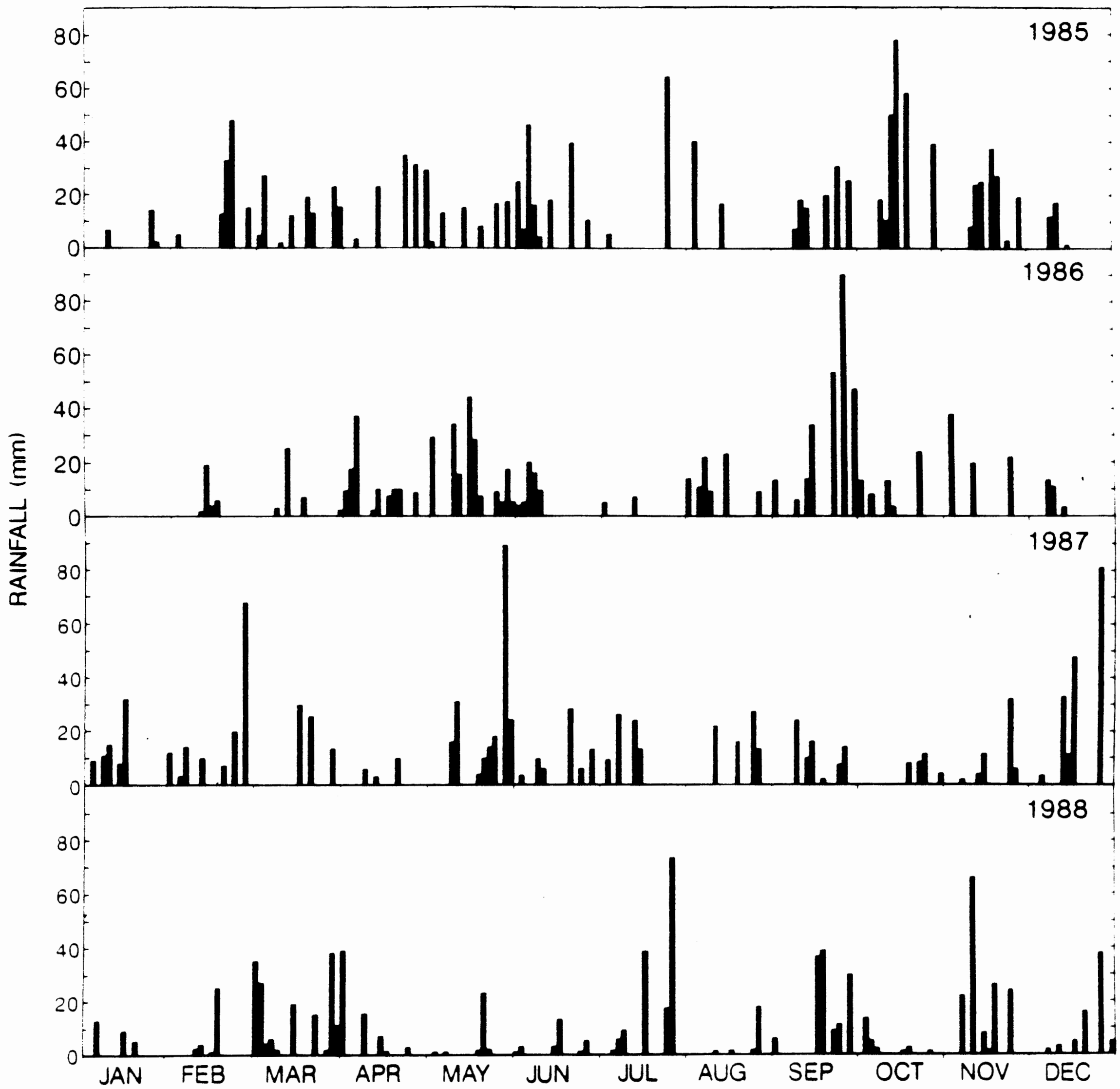

Fig. 2. Rainfall amounts and distribution for 1985-1988 at the Vegetable Research Station, Bixby, Oklahoma.

PART II

EFFECTS OF PHOSPHORUS AND POTASSIUM FERTILIZATION ON SOIL TEST INDICES AND YIELDS OF MONO- AND DOUBLE-CROPPED WHEAT AND GRAIN SORGHUM UNDER RAINFED AND IRRIGATED CONDITIONS.

ABSTRACT

Current soil test interpretations and fertilizer recommendations for rates of P and K applications are based on monoculture data. Producers have expressed concern as to whether these recommendations are adequate for double-cropping situations. A seven year (1982-1988) field study was conducted at the Oklahoma Vegetable Research Station, Bixby, Oklahoma, on a Wynona silt loam soil (Cumulic Haplaquoll) with 0-1% slope. The objectives of the study were to determine the changes in selected soil test indices (pH, NO_3-N, extractable P, K, Ca, and Mg) and yield responses of wheat [Triticum aestivum (L.) em. Thell], and grain sorghum [Sorghum bicolor (L.) Moench], to levels of P and K fertilization under mono- and double-cropped rainfed and irrigated conditions. Monocropped wheat yielded an average of 2785 compared with 2358 kg ha^{-1} for double-cropped wheat. Irrigated monocropped grain sorghum yielded an average of 6477 compared with 6328 kg ha^{-1} for rainfed monocropped grain sorghum. Irrigated double-cropped grain sorghum yielded an average of 5391 compared with 4404 kg ha^{-1} for rainfed double-cropped grain sorghum. Potassium fertilization increased wheat yields by 318 kg ha^{-1} the first year of application, after which the magnitude in yield response declined in subsequent years. When yield data were pooled, the effect of K was statistically significant for wheat yields. Grain sorghum yields were not influenced by K or P fertilization. The average extractable P and K

levels for the Wynona silt loam soil remained in the 100% sufficiency range for all cropping system treatments except for rainfed mono-cropped grain sorghum. Under this treatemnt the K level declined to 93% of sufficiency as determined by the Oklahoma State University Soil Testing Laboratory procedures and recommendations. Although not conclusive, the wheat yield data suggest that a possible upward adjustment of soil test K levels may be required for 100% sufficiency and merits more research on the Wynona silt loam and other medium to fine textured soil in the eastern Oklahoma. Soil pH did not vary with cropping systems or fertilizer treatments, but when compared with the initial level decreased by 0.8 of a pH unit. Soil test indices at the end of the 7-yr study also showed no statistically significant change in extractable Ca and Mg, but a slight increase of soil NO_3-N in the top 15 cm of a Wynona silt loam soil.

INTRODUCTION

Many growers continue to have interest in double-cropping hard red winter wheat [Triticum aestivum (L.) em. Thell] and grain sorghum [Sorghum bicolor (L.) Moench] in the eastern part of the Southern Great Plains. Fall, winter, and spring precipitation is usually sufficient in this region of the Great Plains to produce wheat, however, insufficient amounts and distribution of rainfall are often the major limiting factors to summer crop production whether grown mono- or double-cropped (Crabtree et al., 1986).

In this and other regions the use of supplemental irrigation has the potential for increasing yields. Crabtree et al. (1986) reported that the application of supplemental irrigation to grain sorghum grown on a silt loam soil in eastern Oklahoma under mono- and double-cropped systems significantly increase yields. Production of irrigated grain sorghum under double-cropping has been successful in the Southern High Plains (Allen et al. 1975), and as far north as Wisconsin (Okoli, et al. 1984).

Double-cropping offers a number of potential advantages which include: reduced soil erosion (Campbell, 1979; Hairston et al., 1984), more efficient utilization of climatic resources, land, labor and machinery (Crabtree and Rupp, 1980), and increased net returns (Lewis and Phillips, 1976; Sanford et al., 1986; Hairston, et al., 1987).

Despite these advantages, there are concerns about the effects double-cropping has on nutrient supplying power of many soils when supplemental irrigation is practiced. These concerns are based on the lack of adequate research information concerning the effects of long-term double-cropping on soil test indices, fertilizer management, and crop yield levels.

Under double-cropping, in order to obtain consistently high yields and also to maintain the soil fertility level, adequate and balanced fertilization has to be made for both crops (Flannery, 1977; Swearingin, 1979; Colliver, 1983). Crop response to fertilization and soil test parameters under double-cropping are reported to vary with irrigation availability, tillage management, crop sequences, and soil type (Brown and Perkins, 1979; Wells et al., 1983).

The results of a relatively short period study (3-yrs) by Brown and Perkins (1979) involving fertilization and irrigation of single and double-cropping systems of corn, grain sorghum, and small grains showed that drought restricted yield response to N, P, and K in non-irrigated plots, but under irrigation grain yields for each cropping sequence was directly related to fertilizer applied. Wells et al. (1983) reported that over a 4-yr period intensive double-cropping of corn and barley or oat with either no-tillage or conventional tillage did not affect the soil productivity parameters (organic matter content, pH, and extractable P and K) measured on Huntington or Pope silt loam soils. However, earlier reports by Murdock and Wells (1978) indicate the removal of large amounts of nutrients, particularly K, by the small grain component of the double-crop system.

Although the total grain yield advantage of double-cropping wheat and grain sorghum on a Wynona silt loam soil has been established (Crabtree and Makonnen, 1981, Crabtree et al., 1986), P and K fertilizer management and the long term effect of double-cropping on selected soil test parameters has not been established for eastern Oklahoma. In 1982, soil test levels for the experimental area showed 100 percent sufficiency for P and K, and under monocropped conditions one would not expect a yield response to applications of these two nutrients (Coop. Ext. Serv., 1977). However, under double-cropped irrigated conditions, potential yield responses and changes in soil test indices are possible, especially over years. The objectives of this research were to determine the changes in selected soil test indices and yield responses of wheat and grain sorghum to levels of P and K fertilization under mono- and double-cropped rainfed and irrigated conditions.

MATERIALS AND METHODS

This study was conducted at the Oklahoma Vegetable Research Station, Bixby, Oklahoma from 1982-1988 on a Wynona silt loam soil (Cumulic Haplaquolls) with 0 to 1% slope.

The experiment was designed as a split-plot with four replications. The five main plot treatments were: rainfed monocropped wheat, rainfed double-cropped wheat and rainfed double-cropped grain sorghum, rainfed double-cropped wheat and irrigated double-cropped grain sorghum, rainfed monocropped grain sorghum, and irrigated monocropped grain sorghum. The subplots constituted four fertility treatments that included a factorial combination of P at two levels (0 and 67 kg P ha^{-1}) in the form of $Ca(H_2PO_4)_2$, and K at two levels (0 and 135 kg K ha^{-1}) as KCl.

Fertilizer treatments were applied broadcast to the mono- and double-cropped wheat cropping systems in late winter of 1982. In late May of 1982, fertilizer materials were surface broadcast and incorporated with one tandem disking for the monocropped grain sorghum treatments. No other P and K applications were made during the course of this study.

In the fall of 1981 the seedbed for all wheat was prepared by moldboard plowing plus two tandem diskings. In subsequent years, the same tillage operations were used to prepare the seedbed for monocropped wheat. Two tandem diskings of the double-cropped grain sorghum stubble were used to prepare the seedbed for double-cropped wheat. Winter wheat, 'TAM-105', was planted on monocropped plots with a range of 5 October to 21 October planting dates at a rate of 67 kg ha^{-1}. Double-cropped wheat plots were planted with a range of 6 November to 4 December planting dates at 101 kg ha^{-1}. A hoe drill with 0.25-m row spacings was used to plant the wheat. Each year wheat was topdressed by broadcasting NH_4NO_3 at a rate of 135 kg N ha^{-1} during mid to late February. The experimental field plot sizes were 36.6- by 18.3-m for the main plot treatments and 9.15- by 18.3-m for the subplot treatments. Wheat grain yields were obtained by harvesting a 3.05- by 18.3-m strip from the center of each plot. Wheat yield data were analyzed using a split-plot design consisting of three mainplot treatments and the four fertility treatments (2 x 2 factorial combination of P and K) as subplots.

Seedbed preparation for the conventionally tilled monocropped grain sorghum treatments consisted of moldboard plowing and two tandem diskings. No-till double-cropped grain sorghum was planted directly into standing wheat stubble. All grain sorghum plots received an additional broadcast application of NH_4NO_3 at a rate of 135 kg N ha^{-1} just prior to planting each year.

Grain sorghum, 'Paymaster BR-Y90', was planted at 6.8 kg ha^{-1} using an eight-row, no-till planter equipped with ripple coulters, double-disk openers, 40 mm depth bands, and press wheels. The planter was configurated to plant wheel traffic and non- wheel traffic rows in 0.75 and 0.50 m row spacings, respectively. Conventionally tilled monocropped grain sorghum was planted with a range of 1 June to 22 June planting dates.

Two tensiometers were placed at a depth of 0.25 m in the center and 6 m from each end of the irrigated plots on all four replications of the study. Tensiometer readings (soil water potentials of approximately - 0.1 MPa) were used to schedule irrigations. Water was metered and applied using a solid-set sprinkler irrigation system designed so that all irrigated treatments could be irrigated at the same time or independent of one another.

Propazine [2-chloro-4,6-bis(isopropylamino)-S-triazine] was broadcast at 1.34 kg ha^{-1} a.i. in 234 L water ha^{-1} on the conventionally tilled monocropped grain sorghum plots immediately after planting. Glyphosphate [(N-phosphomethyl) glycine] and linuron [3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea] were broadcast on the no-till, double-cropped grain sorghum plots as a tank-mix, preemergence application at 1.12 and 0.56 kg ha^{-1} a.i., respectively in 234 L water ha^{-1}.

Conventionally tilled, monocropped grain sorghum plots received one mechanical cultivation. All grain sorghum plots also received a postemergence broadcast application of 0.84 kg ha^{-1} a.i. 2,4-Dacamine-(N-oleyl-1,3-propylenediamine) in 234 L water ha^{-1}.

Grain sorghum yields were obtained by harvesting a 2.92- by 18.3 m strip from the center of all mono- and double-cropped plots. Harvesting dates ranged from 13 September to 30 October and 24 September to 17 November for monocropped and double-cropped grain sorghum, respectively.

Grain sorghum yield data were analyzed using a split-plot design consisting of four main plot treatments which included a 2 x 2 factorial combination of cropping system (mono- and double-crop) and water (rainfed and irrigated) and four subplot fertility treatments as 2 x 2 factorial combinations of P and K.

Soil samples of the top 15 cm of the soil profile were taken from each subplot on 25 Feb. 1982 prior to any fertilizer application. On 11 November 1988 surface soil samples (0-15 cm) were again taken from each subplot and were analyzed for pH (1:1, soil/water), 0.01M $CaSO_4$ extractable NO_3-N, and neutral 1.0M ammonium acetate (NH_4OAc) extractable Ca and Mg. In 1982 samples for K were extracted with 1.0M NH_4OAc and samples for P were extracted by Bray/Kurtz extracting solutions consisting of 0.025 N HCl and 0.03 N NH_4F. In 1988 both P and K were extracted with Mehlich III extractant, at the Oklahoma State University Soil Testing Laboratory. It is assumed that both extracting procedures would result in similar soil test index values for extractable P and K for Oklahoma soils (Hanlon and Johnson, 1984). The soil test results were statistically analyzed as a split-plot with all the cropping systems as main plots and the 2 x 2 factorial combination of P and K fertility treatments as subplots.

RESULTS AND DISCUSSION

Rainfall

Monthly rainfall from 1 Jan. 1982 to 31 Dec. 1988 and the 30-yr. monthly averages (1959 to 1988) are given in Table 1. Monthly distributions of rainfall for each year of the 7-yr study are given in Fig. 1 and 2. Rainfall amounts and distribution during the last half of July, August, and September remain critical for summer grown crops.

Wheat

During the first 3-yrs (1982-1985), monocropped wheat yields averaged over fertilization ranged from 2700 to 3650 compared with a range of 2230 to 2943 kg ha^{-1} for double-cropped wheat (Table 2). During this period, the yields of monocropped wheat were significantly higher ($P<0.05$) than that of the double-cropped wheat, and in two out of the three years (1982 and 1983), there were no significant differences between the two double-cropped wheat yields. In 1984, a 233 kg ha^{-1} higher wheat yield was produced when the preceding grain sorghum crop was irrigated compared with the yield of wheat obtained when the preceding grain sorghum was rainfed (Table 2). The only plausible explanation that can be offered for the higher yield is that the wheat benefitted from residual irrigation water added to the double-cropped grain sorghum in 1983.

Soil test values of 32.5 and 125 mg kg^{-1} soil for P and K, respectively, are considered to be at the 100% sufficiency level as determined by the Oklahoma State University Soil Testing Laboratory procedures and recommendations (Coop. Ext. Serv., 1977). Under the conditions of this experiment, initial P soil test values ranged from 46 to 61 mg kg^{-1} soil and the initial K soil test values ranged from 130-148 mg kg^{-1} soil.

The effect of P fertilization on wheat yields varied from one year to the other during this 3-yr period. When wheat yields were averaged over cropping systems in 1982 and 1983, reduced yields were obtained in response to P fertilization and the reduction was statistically significant in 1983. However, in 1984 (third year after P application) P significantly increased wheat yields by an average of 193 kg ha^{-1} across all the cropping systems (Tables 2 and 3).

The K applied in 1982, had a significant influence on wheat yields during 1982 and 1983 (Table 3). In 1982, the increase in wheat yields in response to K applied alone averaged 318 kg ha^{-1} across all the cropping systems, while in 1983 the increase was of lower magnitude averaging 106 kg ha^{-1}, and further declined to a point of nonsignificance under the 1984 environment (Table 2).

During the last four year period (1985-88) of the experiment, monocropped wheat yields ranged from 1863 to 3293 compared with the double-cropped yields that ranged from 1743 to 2870 kg ha^{-1} (Table 2). In three out of the four years, the monocropped yields were statistically higher compared with yields of double-cropped wheat (Table 2).

During the 4-yr period, wheat yields were not significantly influenced by the residual P from the 1982 P fertilization. In three out of four years (1986-87-88), the effect of K fertilization was not statistically significant (Tables 2 and 3). In 1985 lower wheat yields were obtained from K applied alone to two cropping system treatments. The rainfed monocropped wheat, and rainfed double-cropped wheat and rainfed double-cropped grain sorghum treatments were lower compared with an increase in wheat yields when K alone was applied to the rainfed double-cropped wheat and irrigated double-cropped grain sorghum treatment (Table 2). This most likely resulted in the significant ($P<0.05$) cropping system (CS) x K interaction, which occurred only for the 1985 environment (Table 3).

When wheat yield data were pooled over the 7-yr period, the main effects (year, cropping system, and K fertilization) were significant ($P<0.01$). In addition to yield differences due to environmental conditions it should be noted that the wheat yields during the years 1982 and 1986, were also affected across all treatments by tan spot (pyrenophora triticirepentis), and by leaf rust (Puccinia recondita Rob. ex Besm F. sp. tritici Eriks), respectively (Table 2). During the 7-yr period when averaged over fertilization, rainfed monocropped wheat ranged from 1863 to 3650 with an average yield of 2785 kg ha^{-1}. Double-cropped wheat ranged from 1743 to 2865 with an average yield of 2296 kg ha^{-1} when the preceding sorghum crop was rainfed, and from a range of 1835 to 2943 with an average of 2419 kg ha^{-1} when the preceding sorghum received supplemental irrigation (Table 2). In six out of seven years, monocropped wheat yielded significantly higher when compared with double-cropped wheat. The higher yields under monocropped was expected as monocropped wheat is planted around the first to third week of October and benefits from more fall growth and tillering compared with early November to early December planting and less tillering of the double-cropped wheat. Similar results have been reported by Crabtree and Makonnen (1981) for eastern Oklahoma. In five out of seven years, double-cropped wheat yields were not significantly affected by the supplemental water applied to the preceding grain sorghum crop.

When wheat yield data were pooled over the 7-yr period, K significantly ($P<0.01$) increased wheat yields, however, the yield increase varied from one year to the other. Significant positive yield responses were obtained in 1982-83 with a significant negative response in 1985 with no significant responses for the other four years of the experiment. These results most likely contributed to the significant year (Y) x K interaction effect (Tables 2 and 3). The effect of P alone was not significant over the seven years, nevertheless, during the course of the experiment the effect of P on wheat yields varied from year to year resulting in a significant ($P<0.01$) Y x P interaction effect (Table 3).

Grain sorghum

From 1982 through 1984 regardless of fertilization a higher magnitude in yields was obtained when supplemental water (Table 4) was applied to mono- and double-cropped grain sorghum compared with rainfed mono- and double-cropped grain sorghum yields (Table 5).

During this 3-yr period, when averaged over fertilization, rainfed monocropped grain sorghum yields ranged from 4998 to 7103 compared with a range of 5893 to 7255 kg ha^{-1} when supplemental irrigation was applied (Table 5). Rainfed double-cropped grain sorghum ranged from 2700 to 5755 and from 4670 to 6183 kg ha^{-1} with supplemental irrigation (Table 5). In 1982, yield differences due to cropping system or irrigation were not statistically significant, however, in 1983 and 1984, grain sorghum yields were significantly ($P<0.01$) influenced by cropping system, supplemental water, and by CS x Water (W) interaction effects (Table 6). The irrigation of monocropped grain sorghum, increased yields by 895 and 152 compared with 1850 and 1970 kg ha^{-1} for double-cropped grain sorghum in 1983-84, respectively (Table 6). The larger yield increase under double-cropped conditions can be attributed to less than average amounts and poor distribution of precipitation from mid-June to mid-September of 1983 and 1984 (Table 1, Fig. 1).

In 1982, during the first year of fertilizer application, the effects of P, K, and their interactions effects on grain sorghum yields were not significant. However, during both 1983 and 1984 the effect of K on grain sorghum yields varied with P and the application of supplemental water, resulting in a significant W x P x K interaction (Tables 5 and 6).

During the last four years (1985-1988) of the experiment, rainfed monocropped grain sorghum yields averaged over fertilization ranged from 5805 to 7360 compared with 5828 to 7433 kg ha^{-1} under irrigated monocropped conditions (Table 5). Rainfed double-cropped grain sorghum yields ranged from 2663 to 6550 compared with 3390 to 6848 kg ha^{-1} when irrigated (Table 5). In 1988, lower yields can be attributed to difficulty of establishing a good stand of double-cropped grain sorghum because of the severe moisture shortage during the months of May and June (Table 1, Fig. 2). In three out of the 4-yr period (1985, 86, and 88) monocropped yields were significantly higher than the double-cropped grain sorghum yields (Table 5). In 1985, similar to the previous two years, the effects of supplemental irrigation varied significantly ($P<0.01$) with mono- and double-cropping systems. Under double-cropping, supplemental irrigation significantly increased grain sorghum yields by 1292 compared with an increase of only 73 kg ha^{-1} under the monocropped system (Table 5).

Grain sorghum response to supplemental water (50 mm) under the 1987 environment varied with cropping system treatments. Under monocropped irrigated conditions, a lower yield was obtained when compared with the rainfed monocropped treatment. In contrast, an increased yield response was obtained under irrigated double-cropped conditions when compared with the rainfed double-cropped treatment (Table 5). This variation in yield response to supplemental water under mono- and double-cropping, although statistically not significant, most likely contributed to the significant ($P<0.05$) CS x W interaction effect in 1987 (Table 6).

Over the 7-yr period monocropped grain sorghum yields, when averaged over fertilization, ranged from 4998 to 7360 with an average of 6328 kg ha^{-1} under rainfed conditions, and from 5828 to 7433 with an average of 6477 kg ha^{-1} when irrigated. When averaged over fertilization, rainfed double-cropped grain sorghum yields ranged from 2663 to 6550 with an average of 4404 kg ha^{-1} and from 3390 to 6848 with an average of 5391 kg ha^{-1} when irrigated (Table 5). In six out of seven years, supplemental irrigation did not significantly increase grain sorghum yields when monocropped (Table 5). In contrast, irrigation of double-cropped grain sorghum significantly increased yields six out of seven years (Table 5). When the grain sorghum yield data were pooled over the 7-yr period there was a significant ($P<0.01$) CS x W interaction (Table 6), which can most likely be attributed to the contrasting yield differences between rainfed and irrigated treatments.

The main effect and interaction effects of P and K fertilization on grain sorghum yields were not significant when yield data were pooled over the 7-yr period, however, when averaged over seven years somewhat lower grain sorghum yields were obtained in response to P fertilization under rainfed compared to irrigated condition (Table 5). These variations in grain sorghum yield response to P fertilization under rainfed and irrigated conditions most likely contributed to the significant ($P<0.05$) W x P interaction effect (Table 6). Pooling of the yield data over years also resulted in significant ($P<0.01$) Y, Y x CS, Y x W, and a significant ($P<0.05$) Y x CS x W interaction (Table 6). These interaction effects were not unexpected in the southern Great Plains due to wide variation in amounts and distributions of rainfall during the 7-yr period (Table 1, Fig. 1 and 2).

Soil Indices

Soil test results for the Wynona silt loam soil are given in Table 7. After seven years of continuous mono- and double-cropping under rainfed and irrigated conditions, pH values were significantly ($P<0.01$) decreased from an overall average of 6.6 in 1982 to 5.8 in 1988 when measured in a 1:1 soil-water ratio (Table 7). This decrease appears not to be due to different cropping systems or P and K fertilization (Table 8), but is most likely due to the duration of the cropping period and seasonal variances associated with soil sampling and the decomposition stages of organic matter.

Regardless of cropping systems and P fertilization, the average extractable P level significantly ($P<0.01$) declined by about 25% of the original 53 mg P kg^{-1} of soil in 1982 to 42 mg P kg^{-1} of soil in 1988 when no K was applied. When K fertilizer was applied, the extractable P level showed even further decline from the original 56 to 40 mg P kg^{-1} soil after seven years of cropping, resulting in a significant ($P<0.05$) K x Y interaction effect for extractable soil P levels (Tables 7 and 8). Despite this decline, after seven years of mono- and double-cropping, the extractable P level of the Wynona silt loam soil still remained at or above the 100% sufficiency level ($\geq$32.5 mg P kg^{-1} soil) as determined by Oklahoma State University Soil Testing Laboratory procedures and recommendations across all the cropping system treatments (Table 7). Moreover, the one time application of the 67 kg P ha^{-1} did not differ from the check treatment in influencing the soil extractable P level after seven years.

During the seven years of cropping, extractable K levels were not significantly influenced by neither cropping system treatments nor by P or K fertilization (Table 8). At the end of the 7-yr period extractable K levels across all cropping systems, except under the rainfed monocropped grain sorghum treatment, remained near or above the 100% sufficiency level ($\geq$125 mg K Kg^{-1} soil) as determined by the Oklahoma State University Soil Testing Laboratory procedures and recommendations. The rainfed monocropped grain sorghum treatment had soil test levels of 93% sufficiency at the end of seven years.

Extractable Ca and Mg levels at the end of the 7-yr cropping period show little change (Table 7 and 8). However, over the 7-yr period, the extractable Mg level showed a slight increase under irrigated mono- and double-cropped grain sorghum and a slight decrease under both the rainfed monocropped wheat and rainfed grain sorghum treatments, resulting in a significant ($P<0.05$) CS x Y interaction (Tables 7 and 8). The NO_3-N in the surface (0-15 cm) soil increased from an overall average of 0.6 mg kg^{-1} soil at the beginning of the experiment to an overall average of 3.2 mg kg^{-1} soil after seven years of cropping. The slight increase in the NO_3-N level can probably be attributed to the NH_4NO_3 fertilizers applied annually to both wheat and grain sorghum and mineralization of organic matter.

SUMMARY AND CONCLUSIONS

During the 7-yr period (1982-88), monocropped wheat yielded an average of 2785 compared with 2358 kg ha^{-1} for double-cropped wheat. Rainfed monocropped grain sorghum yielded an average of 6328 compared with 4404 kg ha^{-1} for rainfed double-cropped grain sorghum. Irrigated monocropped grain sorghum yielded an average of 6477 compared with 5391 kg ha^{-1} for irrigated double-cropped grain sorghum.

Potassium fertilization increased wheat yields by 318 kg ha^{-1} during the first year after which the magnitude in response dropped sharply. Phosphorus applied alone or in combination with K did not significantly influence wheat yields during the first year of application and also when wheat yield data were pooled over the 7-yr period. A statistically significant wheat yield response to P application occurred in 1983 and 1984, however, these yield responses were negative for 1983 and positive for 1984. These contrasting responses can most likely be attributed to variations in growing condition from year to year. When yield data were pooled over the 7-yr period, P and K fertilization did not significantly influence grain sorghum yields.

The soil pH and extractable P levels did not vary significantly with mono- and double-cropping systems or with the application of supplemental water. The soil pH was also not influenced by either P or K fertilization whereas the soil extractable P level showed a declining trend in the presence of K fertilization. When compared with the initial year, the soil pH decreased by 0.8 of a pH unit and the extractable P level declined by an average of 25%. The decline in pH can probably be attributed to seasonal variations in soil sampling and to the decomposition stages and mineralization of organic residues in the top 0-15 cm of the soil profile since the extractable Ca and Mg remained at or above the initial levels.

Despite the declining trend observed at the end of the 7-yr period, extractable P levels remained near or above the 100% sufficiency level (32.5 mg P kg^{-1} soil) as determined by the Oklahoma State University Soil Testing Laboratory procedures and recommendations. The 100% sufficiency level of extractable P was substantiated by the absence of wheat and grain sorghum yield responses over the 7-yr period. Under most of the treatments the extractable K levels also remained close to or above the 125 mg kg^{-1} soil set as the 100% sufficiency level, the only exception being the rainfed monocropped grain sorghum where the extractable K declined to 93% sufficiency level.

The soil NO_3-N level in the top 0-15 cm of the soil profile showed a slight increase from an average of 0.6 mg kg^{-1} soil in 1982 to 3.2 mg kg^{-1} soil in 1988. This increase can probably be attributed to the NH_4NO_3 fertilizer applied over the 7-yr period and mineralization of organic matter.

LITERATURE CITED

Allen, R.R., J.T. Musick, F.O. Wood, D.A. Dusek. 1975. No-tillage seeding of irrigated sorghum double-cropped after wheat. Trans. ASAE. 18:1109-113.

Brown, A.R. and H.F. Perkins. 1979. Single vs. double cropping under two levels of fertilization with and without irrigation. Commun. in Soil Sci. and Plant Anal. 10(10):1279-1289.

Campbell, R.B., T.A. Matheny, P.G. Hunt, and S.C. Gupta. 1979. Crop residue requirements for water erosion control in six southern states. J. Soil Water Conserv. 34(2):83-85.

Cooperative Extension Service. 1977. Oklahoma Soil Fertility Handbook. 1st Ed. Oklahoma Agricultural Ext. Serv. and Okla. Plant Food Educational Soc., Inc.

Crabtree, R.J., R.G. Greenland, S.O. Mehdawi, and P.L. Claypool. 1986. Mono- and double-cropped wheat and grain sorghum under rainfed and irrigated conditions. Agron. J. 78:986-990.

Crabtree, R.J. and Girma A. Makonnen. 1981. Double and monocropped wheat and grain sorghum under different tillage and row spacings. Soil Science 132:213-219.

Crabtree, R.J. and R.N. Rupp. 1980. Double and monocropped wheat and soybeans under different tillage and row spacings. Agron. J. 72:445-448.

Colliver, G.W. 1983. Fertilizers as an investment. Crop Soils 36(1):12-14.

Flannery, R.L. 1977. Make double cropping pay off. Better Crops with Plant Food. 61(1):28-31.

Hairston, J.E., J.O. Sanford, J.C. Hayes, and L.L. Reinschmiedt. 1984. Crop yield, soil erosion, and net returns from five tillage systems in the Mississippi Blackland Prairie. J. Soil Water Conserv. 39:391-395.

Hairston, J.E., J.O. Sanford, D.F. Pope, and D.A. Horneck. 1987. Soybean-wheat double cropping: Implications from straw management and supplemental nitrogen. Agron. J. 79:281-86.

Hanlon, E.A., and G.V. Johnson. 1984. Bray/Kurtz, Mehlich III, AB/D and ammonium acetate extractions of P, K, and Mg in for Oklahoma Soils. Commun. in Soil Sci. Plant Anal. 15(3):277-294.

Lewis, W.M., and J.A. Phillips. 1976. Double cropping in the eastern United States. p. 41-50. In R.I. Papendick, P.A. Sanchez, and G.B. Triplett (ed.) Multiple Cropping. ASA Spec. Pub. 27. ASA, CSSA, and SSSA, Madison, WI.

Murdock, L.W. and K.L. Wells. 1978. Yields, nutrient removal, and nutrient concentrations of double cropped corn and small grain silage. Agron. J. 70:573-576.

Okoli, P.S.O., P.N. Drolsom, and J.M. Scholl. 1984. Forage production and weed control in a double-cropping program. Agron. J. 76:363-366.

Sanford, J.O., B.R. Eddleman, S.R. Spurlock, and J.E. Hairston. 1986. Evaluating ten cropping alternatives for the Midsouth. Agron. J. 78:875-880.

Swearingin, M.L. 1979. Double-cropping winter wheat and soybeans in Indiana. Ext. Publ. ID-96. Purdue Univ., West Lafayette, Ind.

Wells, K.L., L.W. Murdock, and W.W. Frye. 1983. Intensive cropping effects on physical and chemical conditions of two soils in Kentucky. Commun. In Soil Sci. Plant Anal. 14(4):297-307.

Table 1. Rainfall from 1 Jan. 1982 to 31 Dec. 1988 and the 30-yr monthly average (1959-1988) at the Vegetable Research Station, Bixby, Oklahoma.

	Rainfall							
Month	1982	1983	1984	1985	1986	1987	1988	30-yr avg.
	mm							
January	91	65	10	21	00	77	26	39
February	12	71	70	102	31	136	35	44
March	20	48	125	118	49	56	162	65
April	31	85	63	123	114	17	45	96
May	199	177	126	74	204	210	30	126
June	156	69	89	170	56	67	27	114
July	59	26	15	69	12	72	135	86
August	58	7	57	57	88	65	22	67
September	20	41	55	118	264	78	133	103
October	42	260	180	237	178	32	23	85
November	159	78	62	144	81	90	148	74
December	81	13	268	33	27	177	71	48
Totals	928	940	1120	1266	1104	1077	867	947

Table 2. Wheat yields as affected by cropping system and fertilization under wheat-grain sorghum mono- and double-cropping.

Fertilization†	1982	1983	1984	1985	1986	1987	1988	7-yr avg.
	kg ha^{-1}							
	Rainfed monocropped wheat							
Check	2570	3490	3510	1910	2190	2480	3310	2780
P	2500	3260	3720	1970	2130	2480	3200	2751
K	2990	3550	3610	1780	2150	2420	3260	2823
PK	2740	3280	3760	1790	2210	2320	3400	2786
Cropping System Mean	2700	3395	3650	1863	2170	2425	3293	2785
	Rainfed double-cropped wheat and rainfed double-cropped grain sorghum							
Check	2070	2770	2550	2100	1870	1670	2920	2279
P	2090	2710	2780	2100	1770	1740	2860	2293
K	2430	2850	2650	1700	1830	1630	2820	2273
PK	2330	2790	2860	1730	1870	1930	2860	2339
Cropping System Mean	2230	2780	2710	1908	1835	1743	2865	2296
	Rainfed double-cropped wheat and irrigated double-cropped grain sorghum							
Check	2150	2700	2820	2150	1850	1740	2760	2310
P	2240	2710	3040	2420	1870	1860	2970	2444
K	2590	2910	2880	2230	1900	1900	2860	2467
PK	2430	2890	3030	2250	1840	1840	2890	2453
Cropping System Mean	2353	2803	2943	2263	1865	1835	2870	2419
	Over cropping system							
Check, K	2465	3046	3004	1979	1964	1973	2987	
P, PK	2386	2937	3197	2043	1946	2028	3030	
Check, P	2266	2939	3070	2109	1945	1993	3002	
K, PK	2584	3045	3132	1912	1965	2008	3015	
LSD (0.05)‡	314	171	230	162	235	306	215	
LSD (0.05)§	97	106	74	106	NS	NS	NS	

†Check (no P or K); P(67 kg ha^{-1}; K(135 kg ha^{-1}); PK(67 and 135 kg ha^{-1}, respectively).

‡For comparisons between cropping system means averaged over fertilization.

§For comparisons between K or P means averaged over cropping system.

Table 3. Mean squares for the effects of cropping system and fertilization on wheat yields under wheat-grain sorghum mono- and double-cropping.

Source	df	1982	1983	1984	1985	1986	1987	1988	1982-88
		Mean Square (x10^{4})							
Blocks	3	19.8	21.7	0.9	1.7	11.4	3.3	5.0	1.0
Cropping System (CS)	2	94.3*	195.0**	383.9**	78.0**	56.2*	218.7**	97.3**	726.5**
Block x CS Error(a)	6	13.2	3.9	7.1	3.5	7.4	12.5	6.2	13.2
P	1	7.4	14.4*	44.6**	4.9	0.4	3.7	2.2	3.8
K	1	121.1**	13.4*	4.7	46.5**	0.5	0.2	0.2	19.3**
P x K	1	10.4	0.2	0.6	2.5	1.2	0.03	1.1	2.4
CS x P	2	2.1	6.7	0.2	2.0	0.2	5.8	2.1	6.8
CS x K	2	0.1	2.6	0.4	12.1*	0.03	4.8	1.8	2.9
CS x P x K	2	0.4	0.03	0.1	2.2	1.6	4.5	4.8	7.3
Block x CS x P x K Error(b)	27	2.7	3.2	1.5	3.2	2.5	4.9	5.3	2.3
Year (Y)	6	-	-	-	-	-	-	-	1321.9**
Block x Y Error(c)	18	-	-	-	-	-	-	-	10.6
CS x Y	12	-	-	-	-	-	-	-	66.1**
Block x CS x Y Error (d)	36	-	-	-	-	-	-	-	6.8
P x Y	6	-	-	-	-	-	-	-	12.3**
K x Y	6	-	-	-	-	-	-	-	27.9**
P x K x Y	6	-	-	-	-	-	-	-	2.3
CS x P x K x Y	36	-	-	-	-	-	-	-	2.1
Block x CS x P x K x Y (Error)	162	-	-	-	-	-	-	-	4.0

*,** significant at the 0.05 and 0.01 probability levels, respectively.

Table 4. Supplemental water applied to mono- and double-cropped grain sorghum.

Cropping System	Year						
	1982	1983	1984	1985	1986	1987	1988
	mm						
Irrigated monocropped grain sorghum	160	320	120	70	120	50	150
Irrigated double-cropped grain sorghum	180	360	200	70	120	50	150

Table 5. Grain sorghum yields as affected by cropping system, water, and fertilization.

Fertilization[+]	1982	1983	1984	1985	1986	1987	1988	7-yr avg
	kg ha^{-1}							
	Rainfed monocropped grain sorghum							
Check	6090	5000	7110	7370	6530	6980	5860	6420
P	5440	4730	7290	7420	6270	6750	5590	6213
K	5660	5620	6990	7260	6470	6970	5800	6396
PK	5860	4640	7020	7390	6310	6780	5970	6281
Cropping System Mean	5763	4998	7103	7360	6395	6870	5805	6328
	Irrigated monocropped grain sorghum							
Check	5910	6160	7170	7390	6230	6420	5660	6420
P	5740	5770	6880	7350	6360	7140	5960	6457
K	5810	5740	7300	7330	6750	6560	5810	6471
PK	6120	5900	7670	7660	6530	6160	5880	6560
Cropping System Mean	5895	5893	7255	7433	6468	6570	5828	6477
	Rainfed double-cropped grain sorghum							
Check	5860	3520	2700	4180	5370	7000	2590	4460
P	5560	3390	3060	4190	5470	6470	2530	4381
K	5760	3630	2950	4260	5310	6510	2620	4434
PK	5840	3220	2090	4280	5820	6220	2910	4340
Cropping System Mean	5755	3440	2700	4228	5493	6550	2663	4404
	Irrigated double-cropped grain sorghum							
Check	5960	5330	4670	5240	5950	7070	3300	5360
P	6110	5220	4240	5380	5810	6680	3520	5280
K	6170	5370	4740	5600	5860	6810	3150	5386
PK	6490	5240	5030	5860	5730	6830	3590	5539
Cropping System Mean	6183	5290	4670	5520	5838	6848	3390	5391
	Over cropping system-water							
Check, K	5901	5046	5454	6078	6058	6792	4348	
P, PK	5894	4764	5410	6190	6039	6628	4493	
LSD (0.05)‡	NS	201	526	104	237	NS	474	
LSD (0.05)§	NS	172	NS	NS	NS	NS	134	

[+]Check (no P or K); P(67 kg ha^{-1}); K(135 kg ha^{-1}); PK(67 and 135 kg ha^{-1}, respectively).

‡For comparisons between cropping system-water means averaged over fertilization.

§For comparisons between P means averaged over cropping system-water.

Table 6. Mean squares for the effects of cropping system, water, and fertilization on grain sorghum yields.

Sources	df	1982	1983	1984	1985	1986	1987	1988	1982-88
		Mean square ($x10^6$)							
Block	3	103.3	3.2	104.9	4.1	39.9	272.5	15.2	288.2
Cropping System (CS)	1	30.1	1865.4**	19509.3**	10182.2**	940.2**	0.8	12468.0**	25381.2**
Water (W)	1	128.0	3017.7**	1812.4**	740.5**	70.1	.0003	226.4	3631.0**
CS x W	1	34.4	363.1**	1324.7**	591.0**	30.8	143.5*	202.9	1968.8**
Block x CS x W Error(a)	9	76.0	12.7	86.6	3.4	17.5	21.1	70.5	38.7
P	1	0.1	127.5**	3.1	20.0	0.6	43.1	33.6*	15.5
K	1	27.6	1.5	11.3	31.9	16.2	70.7	13.7	31.1
PK	1	88.2	5.8	0.002	8.1	0.9	5.2	15.8	22.3
CS x P	1	7.9	12.7	21.0	0.1	18.4	29.9	9.7	1.7
CS x K	1	6.3	1.6	3.5	20.0	7.9	.01	0.1	0.1
CS x P x K	1	14.9	0.5	26.5	2.3	11.1	75.1	2.9	0.9
W x P	1	41.9	42.1	1.2	5.8	7.3	35.5	20.6	84.1*
W x K	1	12.6	12.3	208.5**	28.2	1.5	1.3	13.8	37.3
W x P x K	1	8.6	59.1*	188.1**	4.3	18.1	24.6	16.2	7.6
CS x W x P	1	0.2	12.9	6.2	1.6	35.5	2.1	0.1	7.0
CS x W x K	1	0.3	21.2	1.8	1.6	35.1	54.3	1.4	9.2
CS x W x P x K	1	0.8	25.6	32.0	0.8	0.1	44.2	7.3	14.8
Block x CS x W x P x K Error(b)	36	25.6	11.6	24.8	8.8	13.6	24.9	6.9	17.5
Year (Y)	6	-	-	-	-	-	-	-	3937.3**
Block x Y Error(c)	18	-	-	-	-	-	-	-	42.5
Y x CS	6	-	-	-	-	-	-	-	3269.1**
Y x W	6	-	-	-	-	-	-	-	394.0**
Y x CS x W	6	-	-	-	-	-	-	-	120.3*
Block x Y x CS x W Error(d)	54	-	-	-	-	-	-	-	41.5
Y x P	6	-	-	-	-	-	-	-	35.4
Y x K	6	-	-	-	-	-	-	-	23.6
Y x P x K	6	-	-	-	-	-	-	-	16.9
Y x CS x P x K	54	-	-	-	-	-	-	-	21.2
Block x Y x CS x P x K (Error)	216	-	-	-	-	-	-	-	164.3

*,** significant at the 0.05 and 0.01 probability levels, respectively.

Table 7. Means for the effects of wheat-grain sorghum cropping systems and fertilization on soil pH, extractable P, K, Ca, and Mg.

	pH		P		K		Ca		Mg	
Fertilization†	1982‡	1988	1982	1988	1982	1988	1982	1988	1982	1988
	—pH unit—		mg kg^{-1}							
				Rainfed monocropped wheat						
Check	6.6	5.6	57	47	137	134	1062	1090	110	108
P	6.5	5.6	61	46	131	139	1058	1130	108	110
K	6.6	5.6	57	41	126	134	1052	1088	110	107
PK	6.5	5.9	63	44	148	139	1089	1121	118	113
Cropping System Mean	6.6	5.7	59	45	136	137	1065	1107	112	110
	Rainfed double-cropped wheat and rainfed double-cropped grain sorghum									
Check	6.6	5.8	53	35	138	123	1116	1201	118	117
P	6.5	6.0	62	36	144	130	1142	1165	127	125
K	6.4	5.9	66	43	145	128	1168	1178	124	124
PK	6.5	6.0	62	33	141	124	1112	1204	123	125
Cropping System Mean	6.5	5.9	61	37	142	126	1134	1187	123	123
	Rainfed double-cropped wheat and irrigated double-cropped grain sorghum									
Check	6.6	5.9	58	45	153	148	1134	1237	111	118
P	6.5	5.7	54	47	144	148	1194	1286	114	125
K	6.6	6.1	63	45	151	130	1218	1249	124	122
PK	6.6	5.7	57	43	142	140	1203	1249	117	123
Cropping System Mean	6.6	5.9	58	45	148	142	1187	1255	117	122
				Rainfed monocropped grain sorghum						
Check	6.5	5.6	51	37	140	122	1098	1110	120	114
P	6.6	6.0	50	33	129	113	1121	1091	116	114
K	6.6	5.9	48	33	135	111	1074	1069	109	105
PK	6.6	5.9	50	31	135	116	1102	1125	115	114
Cropping System Mean	6.6	5.9	50	34	135	116	1099	1099	115	112
				Irrigated monocropped grain sorghum						
Check	6.6	5.4	45	48	128	141	1092	1185	120	129
P	6.6	5.5	44	46	128	131	1138	1234	114	129
K	6.6	5.5	49	47	133	134	1112	1183	120	130
PK	6.6	5.7	45	41	131	123	1115	1167	117	129
Cropping System Mean	6.6	5.5	46	46	130	132	1114	1192	118	129
				Over cropping system						
Check, P	6.6	5.7	53	42	137	133	1115	1173	116	121
K, PK	6.6	5.8	56	40	139	127	1125	1163	118	119
LSD (0.05)§	NS	NS	NS	NS	NS	NS	NS	NS	NS	14
LSD (0.05)¶	NS	NS	NS	NS	NS	5	NS	NS	NS	NS

†Check (no P or K); P (67 kg ha^{-1}); K (135 kg ha^{-1}); PK (67 and 135 kg ha^{-1}), respectively.
‡Soil test for samples taken before any treatments were applied.
§For comparisons between cropping system means averaged over fertilization.
¶For comparisons between K means averaged over cropping system.

Table 8. Mean squares for the effects of cropping system and fertilization on the differences between 1982 and 1988 soil pH, extractable P, K, Ca, and Mg under wheat-grain sorghum mono- and double-cropping.

Source	df	pH	P	K	Ca	Mg
Year (Y)	1	51.7**	14864*	4388	184848	928
Block x Y Error (a)	3	0.9	716	862	28710	330
CS x Y	4	0.6	1224	1486	14398	610*
Block x CS x Y Error (b)	12	0.8	778	2016	7214	136
P x Y	1	0.1	72	28	200	2
K x Y	1	0.3	408*	894	6872	346
P x K x Y	1	0.1	1	36	5636	104
CS x P x K x Y	12	0.1	32	198	3306	160
Block x CS x P x K x Y Error	45	0.1	94	290	2344	144

*,** significant at the 0.05 and 0.01 probability levels, respectively.

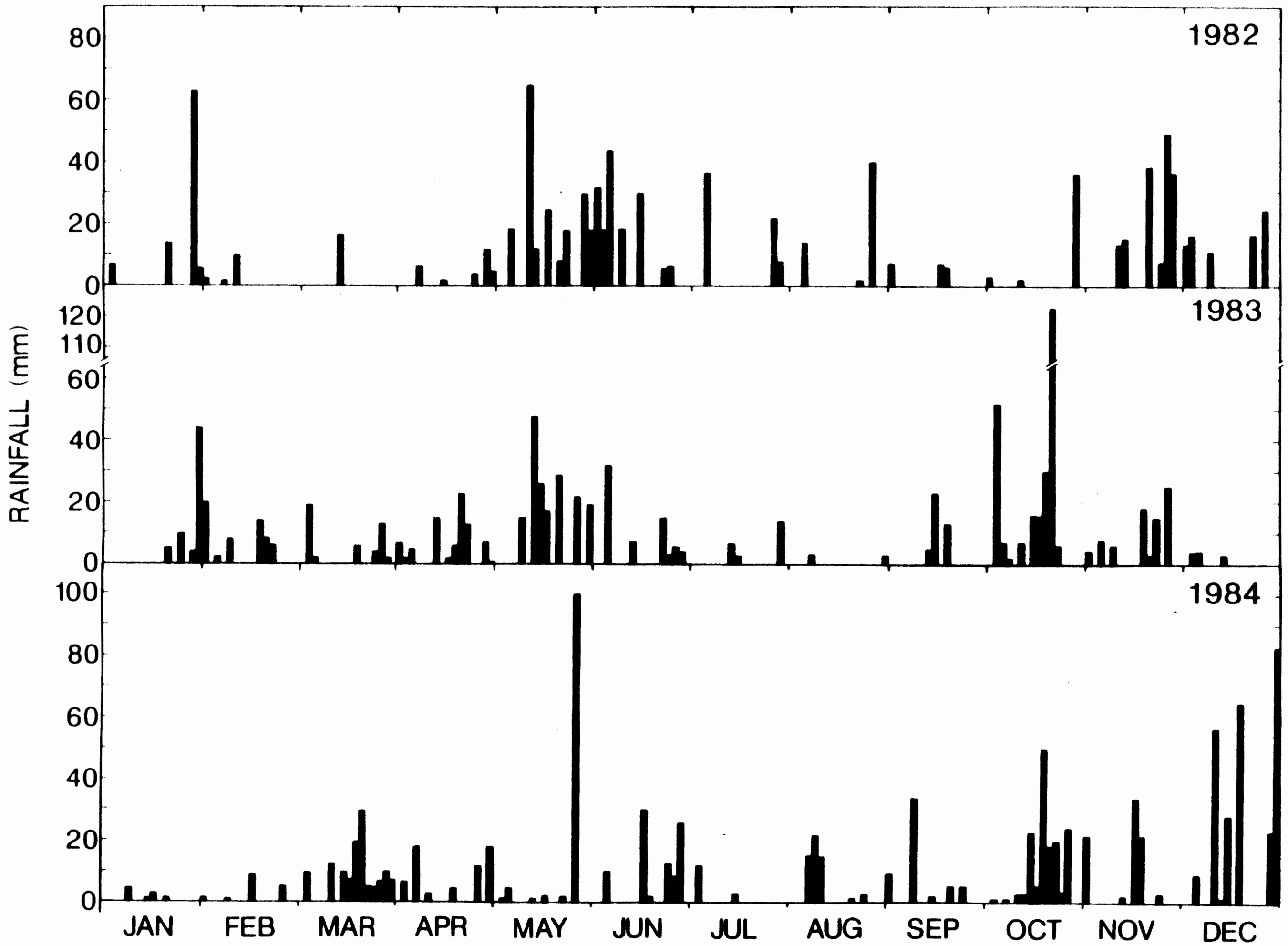

Fig. 1. Rainfall amounts and distribution for 1982-1984 at the Vegetable Research Station, Bixby, Oklahoma.

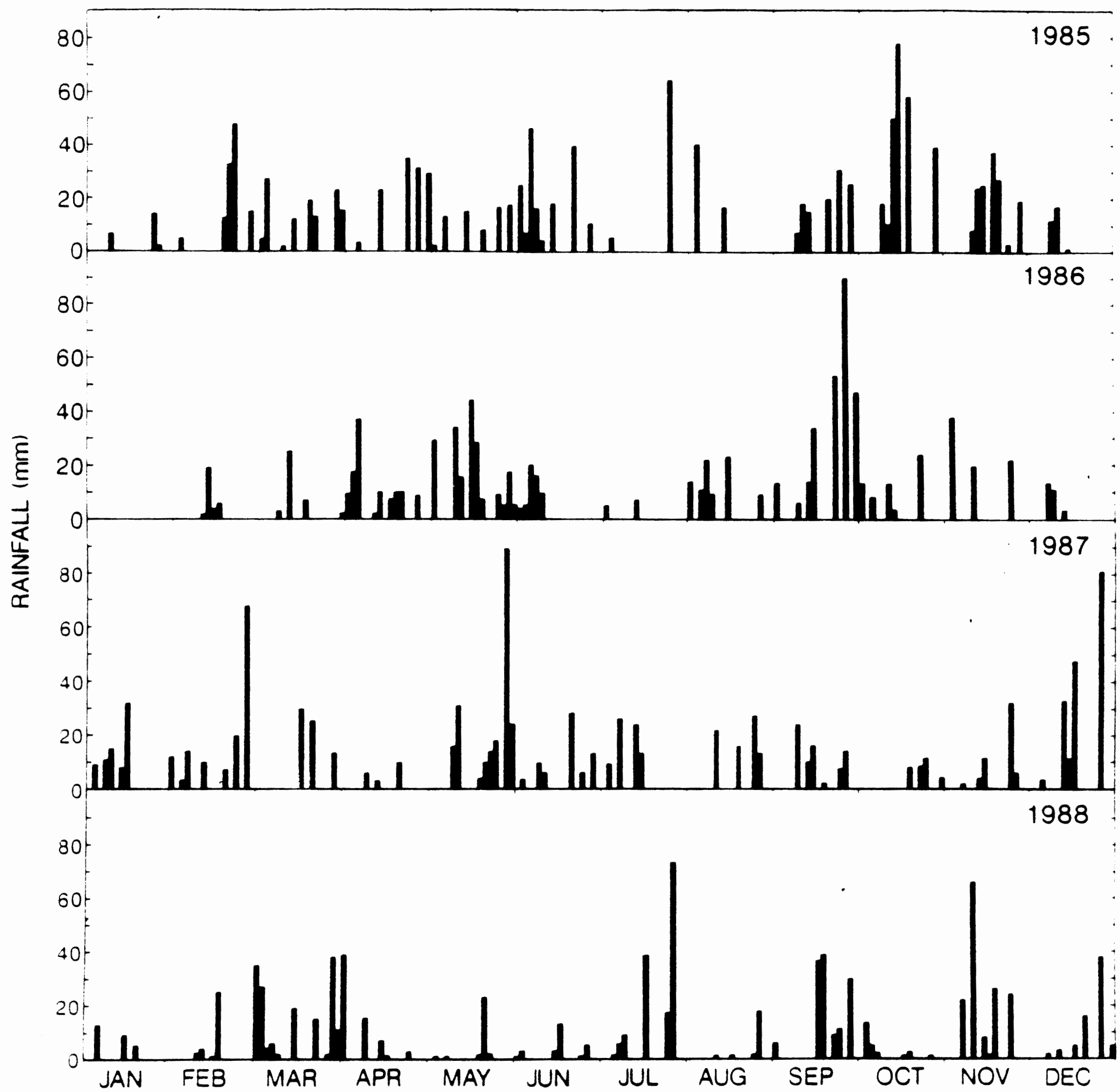

Fig. 2. Rainfall amounts and distribution for 1985-1988 at the Vegetable Research Station, Bixby, Oklahoma.

VITA

SAMUEL GELETA

Candidate for the Degree of

Doctor of Philosophy

Thesis: EFFECTS OF PHOSPHORUS AND POTASSIUM FERTILIZATION ON SOIL TEST INDICES AND YIELDS OF MONO- AND DOUBLE-CROPPED WHEAT, SOYBEAN, AND GRAIN SORGHUM UNDER RAINFED AND IRRIGATED CONDITIONS.

Major Field: Soil Science

Biographical:

Personal Data: Born in Ghimbie, Wollega, Ethiopia on Sept. 5, 1952, the son of Geleta Beyen and Aster Fekede.

Education: High school certificate from Ethiopian Advantist College, Shashemane, Ethiopia, 1972; Bachelor of Science degree in Plant Sciences in July 1978 and Master of Science in Agronomy in July 1982, from Alemaya College of Agriculture, Addis Ababa University, Ethiopia; completed requirements for the Doctor of Philosophy degree from Oklahoma State University at Stillwater in July, 1989.

Professional Experience: Graduate Assistant, Addis Ababa University, Debre Zeit Junior Agricultural College and Research Center, Ethiopia from 1978-1979; Assistant Lecturer and graduate student, Addis Ababa University, College of Agriculture, Alemaya, Ethiopia, from 1979 to 1982; Lecturer of Soil science and head of soil science research section, Debre Zeit Agricultural Research Center, Addis Ababa University, Ethiopia, from 1982 to 1985; Graduate research assistant, Oklahoma State University, 1986 to June, 1989.

Professional Memberships: American Society of Agronomy, Soil Science Society of America.