MONO- AND DOUBLE-CROPPED WHEAT, SOYBEANS, AND GRAIN SORGHUM UNDER RAINFED AND IRRIGATED CONDITIONS

By

JAY DOUGLASS PRATER

Bachelor of Science

Cameron University

Lawton, Oklahoma

1979

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
May, 1987

MONO- AND DOUBLE-CROPPED WHEAT, SOYBEANS,

AND GRAIN SORGHUM UNDER RAINFED AND

IRRIGATED CONDITIONS

Thesis Approved:

Jewell Crabtree
Thesis Adviser

Richard C. Johnson

P. Larry Claypool

Francis M. Epplin

Norman N. Durham
Dean of the Graduate College

ACKNOWLEDGMENTS

I wish to express my sincere appreciation to Dr. Jewell Crabtree, for his encouragement, guidance, and assistance while working through the course of this study. I would also like to express thanks to the other graduate advisory committee members: Dr. Richard Johnson, Dr. Francis Epplin, and Dr. Larry Claypool.

Appreciation is also extended to the Agronomy Department of Oklahoma State University for providing the facilities which made this study possible.

A special appreciation is given to my mother and family for their encouragement and interest during the furthering of my education.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

In the Southern Great Plains, no-till double-cropping acreage continues to increase. Double-cropping enables farmers to increase productivity per unit land area per year, resulting in more efficient utilization of land, labor, machinery, climatic resources, and other capital investments.

In eastern Oklahoma, double-cropping wheat, followed by grain sorghum or soybeans, continues to be a viable means of crop production. In this area, interest in double-cropping remains high due to the development of new herbicides, better crop cultivars, and new or improved tillage practices and planting equipment.

Rainfall amounts and distribution during the summer months in Oklahoma are often erratic and can determine the success or failure in double-cropping. With these deficient rainfall amounts and erratic distributions, supplemental irrigation during the summer months may be profitable. The objectives of this research were: (1) to compare yields, production costs, and economic returns of mono- and double-cropped wheat under rainfed conditions; (2) to compare yields, production costs, and economic returns of mono-cropped soybeans and grain sorghum under rainfed and irrigated conditions; and (3) to compare yields, production costs, and economic returns of rainfed and irrigated double-cropped soybeans and grain sorghum, when planted no-till after wheat grain removal in eastern Oklahoma.

CHAPTER II

REVIEW OF LITERATURE

Conventional Tillage

Conventional tillage is a system of soil preparation for planting which includes plowing, disking, harrowing, and in many cases, subsequent cultivation (Larson, 1962; Baeumer and Bakermans, 1973). Some of the advantages of conventional tillage are: (1) flexibility and adaptability to a wide range of soil, crop, and weather conditions, (2) a fine seedbed for easy planting, (3) the necessary equipment readily available on most farms, and (4) results in yields as high or higher than other systems over a wide range of soil and climatic conditions (Graffis et al., 1973; Hoeft, Wedberg, and Churtleff, 1975).

Some disadvantages of conventional tillage include: (1) higher cost because of the number of tillage operations; (2) excessive tillage resulting in soil crusting and compaction; (3) small soil aggregates, which reduce the rate of water intake; (4) fine and compact soils that are subjected to water and wind erosion; (5) valuable time often lost; and (6) decreased soil moisture in the plow layer, making it less suitable for double-cropping (Graffis et al., 1973; Hoeft, Wedberg, and Churtleff, 1975).

Kamprath et al. (1979) reported that secondary tillage operations can cause recompaction of the layer below the cultivated soil, due to heavy traffic of implements. They also reported that water uptake efficiency, root proliferation, and root penetration can be reduced due to hard pans caused by cementation processes. The amount of soil damage occurring from wheel traffic is a complex and unknown variable, but it can be reduced if the amount and distribution of wheel traffic is restricted (Buntley, 1977; Soane and Pidgeon, 1975). Reducing field operations or restricting field traffic to specific zones can maintain better soil conditions for planting and seedling establishment (Unger and Stewart, 1976).

Seedbed preparation by disking and harrowing can cause a loss of soil moisture through evaporation, reducing seedling emergence and survival (Sanford, 1982). Allen et al. (1975) reported that a dense soil crust formed, due to an intense rainfall of eight cm followed by a hot dry wind four days after planting, preventing the emergence of soybean seedlings. In contrast, soybeans in no-tilled plots emerged to a near perfect stand.

No-Tillage

A concern for less pollution of lakes, streams, and reservoirs from soil erosion and runoff has prompted researchers to develop and evaluate systems that require less tillage (Sanford, Myhre, and Merwine, 1973). No-tillage has been defined as placing the crop seed into the soil by a device that opens a trench or slot through the sod or previous crop residue only sufficiently wide and deep enough to receive the seed and to provide satisfactory seed coverage (Crosson, 1981). In no-tillage systems, herbicides are used to control existing vegetation and the crop is planted directly into the soil with no plowing or other tillage operations (Clapp, 1972).

Advantages from no-tillage systems include: (1) reduced soil and moisture loss, (2) control of wind and water erosion, (3) ability to plant with higher moisture conditions, (4) reduced labor and production costs, (5) reduced soil compaction, (6) earlier planting, and (7) yields equal to or higher than those produced from conventional tillage (Graffis et al., 1973; Gregory et al., 1970; Hargrove et al., 1982; Stougaard, Kapusta, and Roskamp, 1984).

Both time and energy are conserved with no-till production systems (Allen et al., 1975). Allen et al. reported that no-till practices required only one-fifth as much time between crops to prepare and plant a second crop compared to conventional tillage; no-till reduced fuel use by 55%.

Tyler and Overton (1982) found that soybean seed quality from no-tillage systems grown in Tennessee was improved over soybeans grown in conventional tillage systems. This was primarily due to the enhanced availability of soil water under the no-tillage system during dry periods. Seed germination, weight, density, and yield were also superior under drought stress in no-tillage as compared to conventional methods.

Hargrove et al. (1982) reported that continuous no-tillage results in increased nutrient concentrations in the surface soil with a rapid decrease in depth, while conventional tillage resulted in a more homogeneous soil with respect to soil fertility status. Blevins, Thomas, and Cornelius (1977) reported that soil organic matter and organic nitrogen (N) increased significantly in the top five cm of soil for corn production under no-tillage, compared to conventional tillage systems.

Bennett, Mathias, and Lundberg (1973) reported that lower soil temperatures under mulch reduced evaporation rates considerably in no-till plots, and with reduced rainfall runoff, resulted in a significantly greater amount of available soil moisture for plant growth. Mulch also physically absorbs raindrop impact energy; thus, slaking and sealing of the soil surface is prevented or retarded. Therefore, no-tillage offers surface residues to increase infiltration and decrease erosion (Unger and Phillips, 1973).

Double-cropping soybeans or grain sorghum after small grains is often achieved with no-tillage. By using this method, both crops are planted in the small grain stubble using a no-till planter which places the seed in a slit and makes use of a press wheel to press the soil around the seed (Hinkle, 1975).

Disadvantages of no-tillage systems consist of: (1) poor stands, in some instances which may limit yields; (2) special planting equipment requirements; (3) higher incidence of insect and disease damage due to crop residues, serving as a host habitat; (4) weed control problems due to interference of crop residues with herbicides; and (5) escaped or herbicide-tolerant broadleaf weeds and grasses (Graffis et al., 1973; Gregory et al., 1970).

Weeds are the most economically important pest problem for soybean growers using reduced tillage practices (Marra and Carlson, 1983). Thompson (1981, p. 15) stated, "Competition for moisture, plant nutrients, and sunlight makes weeds the number one soybean yield robber." The objective of weed control is to reduce the competitiveness of weeds, thus preventing lower yields and/or crop quality (Erbach and Lovely, 1974). Triplett (1978) reported that for no-till cropping practices, complete reliance for control of weeds must be placed on herbicides. According to Robinson, Langdale, and Stuedemann (1984), weeds have to be controlled in no-till soybeans for 90% of the growing season to avoid yield loss.

In a study by Sanford, Myhre, and Merwine (1973), competition from weeds in no-till soybeans and grain sorghum caused significant yield reductions. In Arkansas, Hinkle (1975) showed that soybeans and grain sorghum grown under no-till conditions resulted in yields that were comparable to conventionally tilled production when conditions were favorable for good chemical weed control. However, yields were significantly reduced when little or no weed control by herbicides was used.

There are many herbicides available for use on no-till cropping systems, but when soybeans are employed in no-tillage, whether mono- or double-cropped, some weeds that are present may be quite difficult to control (Shurtleff and Coble, 1985).

Common cocklebur (Xanthium pensylvanicum), johnsongrass (Sorghum halepense), and several morning-glory species (Ipomoea spp.) are some of the most serious weed pests in the southern region of the United States. Their control is difficult, due to their herbicidal tolerance (Palmer, 1979). Numerous soil-applied herbicides control small-seeded broadleaf weed species, but control of large-seeded species such as common cocklebur and morning-glory has been less consistent. The primary factor to the herbicidal tolerance of these weeds is that seedlings will emerge from depths of up to 15 cm, which is below the zone of the herbicide-treated soil, in most instances (Chandler, Munson, and Vaughen, 1977).

Studies performed by Shurtleff and Coble (1985) showed that common cocklebur reduced soybean yields 11%, with a density of 8 weeds per 10 m of row, while a density of 16 weeds per 10 m of row for common ragweed (Ambrosia artemesiifolia), resulted in a 12% reduction in yield. McWhorter and Anderson (1981) reported that various degrees of infestations of johnsongrass reduced soybean yields by 50% or more. Black, Chen, and Brown (1969) considered johnsongrass a very competitive species, since it fixed carbon dioxide at very high rates, coupled with production of a large quantity of rhizomes and seeds. Oliver, McClelland, and Mathis (1976) reported that the competitive ability of morning-glory species is nearly equal to that of common cocklebur, which ranks as the most important and detrimental weed to soybeans grown in the United States.

With the continuous development of new and improved herbicides to control grass and weed problems, the popularity of no-tillage systems has increased in many areas in the United States (Whitwell et al., 1985). It has been predicted that 65% of the seven major annual grain crops will be grown by the no-tillage system by the year 2000 (United States Department of Agriculture, 1975).

Double-Cropping

Double-cropping is the production of two crops grown in succession on the same area of land in one year (Hovermale, Camper, and Alexander, 1979). Double-cropping achieves greater utilization of solar energy, reduction of production costs, and better land use efficiency (Hinkle, 1975).

Phillips and Young (1973) reported that the most widely-used double-cropping program in the United States is small grains and soybeans. Wheat following soybeans in a double-cropping system is efficient in much of the southeastern United States, and extends from Florida and Georgia to southern Illinois and west to Oklahoma (Crabtree and Rupp, 1980; McHarry and Kapusta, 1979; Touchton, Johnson, and Cunfer, 1980).

Sanford, Myhre, and Merwine (1973) reported that double-cropping with the use of no-tillage systems requires a high level of management and continuous supervision to anticipate unusual problems and to perform each operation at the most appropriate time. Planting time is critical if the normal maturity date of the preceding crop extends beyond the normal planting range for the succeeding crop; therefore, no-tillage planting provides the least delay in establishing a second crop (Sanford, Myhre, and Merwine, 1973). Knapp and Knapp (1978) reported that late-planted wheat produced lower grain yields because it extracted a lesser amount of water from the soil, developed a less extensive root system, fewer tillers, and resulted in fewer heads to harvest, when compared to optimal planted dates.

Climate conditions such as number of frost-free days and distribution of rainfall in midsummer play an important role in the success of double-cropping (Touchton and Johnson, 1982). Even though climatic conditions (such as number of frost-free days and distribution of rainfall) favor double-cropping systems in many areas, time lapse between harvesting one crop and planting the second crop is critical. After wheat harvest, potential soybean yield decreases each day that planting is delayed, when full season soybeans are grown (Touchton and Johnson, 1982).

McKibben and Pendleton (1968) stated that factors contributing to yield reductions of late-planted, double-cropped soybeans were the uncertainty of rainfall in late June and July for good germination and early growth, and frost before crop maturity. The yield of each crop in a double-cropping system is usually reduced, compared to the same crop in a mono-cropping system. However, despite the reduction of individual crop yields in the double-cropping system, the total grain yield of the two crops combined is usually higher than either crop grown as a mono-crop (Crabtree and Makonnen, 1981; Rogers, Thurlow, and Buchanan, 1971; Sanford, 1982).

Sanford (1982) reported that yields of wheat were higher when double-cropped after soybeans than when double-cropped after grain sorghum. He attributed the higher wheat yields following soybeans to the contribution by soybeans to the nitrogen supply and improved tilth.

Dillon and McKibben (1972) reported that perennial weeds cause more problems than annual weeds with continuous double-cropping. A major factor in the occurrence of weed problems is that herbicides with longer residual effects that can be used to effectively control weeds in one crop may cause injury to the subsequent crop and, therefore, are not suitable for use in double-cropping systems (Dillon and McKibben, 1972; Hinkle, 1975; Ndon, Harvey, and Scholl, 1982).

Residue interference can reduce crop stands in double-cropping systems, while residue removal or burning over a period of several years may reduce soil productivity, and increase soil erosion and water runoff (Malcolm, 1980; Mullins, Bell, and McCutchen, 1972). Swearingin (1973) found that using weighted fluted coulters in front of the planters helped to overcome the problem of stand establishment in residues by cutting through them and placing the seed deep enough to reach moist soil for good germination and emergence.

Other management practices that increase the chances for successful double-cropping include: (1) excellent stand of small grain to help control weeds; (2) sufficient moisture; (3) adequate fertility for both crops; and (4) planting the summer crop as soon as possible, provided sufficient moisture is present (Crabtree and Rupp, 1980; Flannery, 1977; Mederski, Jeffers, and Peters, 1973).

Irrigation

Water is the primary limiting factor to successful soybean production in the semi-arid Great Plains (Korte et al., 1983). Drought stress has been shown to reduce critical growth processes such as photosynthesis, cell enlargement, cell division, and nitrogen (N_2) fixation. Water stress at critical growth periods appears to be one of the most frequently limiting factors (Brown, Caviness, and Brown, 1985; Doss and Thurlow, 1974).

Dillon and McKibben (1972, p. 6) stated that "drought is probably the major cause of failure in nonirrigated double-cropping systems in Illinois." Yield response to irrigation varies from area to area, depending upon natural precipitation, temperature, the crop being grown, and soil properties. When rainfall is inadequate or not properly distributed throughout the growing season, irrigation will usually increase both mono- and double-crop yields (Ashley and Ethridge, 1978; Boerma and Ashley, 1982). Crabtree and Makonnen (1981) predicted that double-cropping without irrigation would be successful in eastern Oklahoma approximately 60% of the time.

Timing of irrigation appears to be quite important in determining the irrigation effects on soybean yields. Results generally are variable, but most research indicates that irrigation during pod elongation and seed enlargement results in highest seed yields (Brown, Caviness, and Brown, 1985; Reicosky and Deaton, 1979; Doss, Pearson, and Rogers, 1974).

In a study conducted by Korte et al. (1983), eight soybean cultivars were subjected to either no irrigation or one irrigation applied at three reproductive stages of growth: (1) flowering, (2) pod elongation, and (3) seed enlargement. The flowering irrigation increased yields 20 kg ha^{-1}, pod elongation irrigation increased yields 379 kg ha^{-1}, and seed enlargement irrigation increased yields 384 kg ha^{-1}, compared to nonirrigation. Shaw and Laing (1966) and Kadhem, Specht, and Williams (1985) also observed that sensitivity of soybeans to water stress was minimal during the flowering and early pod elongation stages, but that sensitivity increased to a maximum during the late pod elongation and subsequent seed enlargement stages.

Reports have shown that: (1) a moderate water supply produced about the same yield response as a high supply; (2) irrigation during the vegetative growth period is of less importance than during flowering, pod set, and pod fill stages; (3) response to irrigation varies with cultivars; and (4) plant lodging is frequently a problem when soybeans are irrigated (Ashley and Ethridge, 1978; Kadhem, Specht, and Williams, 1985).

A critical growth stage for grain sorghum is not as clearly defined as it is for soybeans, and varies with cultivar, year, and rainfall patterns (Garrity et al., 1982). Research has indicated that grain sorghum yield is reduced if water stress occurs at any time during plant growth (Lewis, Hiler, and Jordan, 1974). Since it is both drought tolerant and highly responsive to added water, it is adapted to both dryland and irrigated conditions (Eck and Musick, 1979). The greatest response to irrigation has been for irrigation during the vegetative, vegetative to heading, booting and heading, booting through bloom, and grain filling growth stages (Lewis, Hiler, and Jordan, 1974; Musick and Dusek, 1971; Salter and Goode, 1967; Stewart et al., 1975). Lewis, Hiler, and Jordan (1974) recorded yield reductions of 17%, 34%, and 10%, when the water deficit occurred during the late vegetative to boot stage, boot through bloom stage, and milk through soft dough stage, respectively. Shipley and Regier (1975) reported that water stress during booting stage causes heads to be only partially exerted from the whorl, and the part that remains in the whorl does not produce seed. Stewart et al. (1975) reported no yield response to irrigation at milk stage or later.

Management practices for higher yields such as higher plant populations, more fertilization, improved varieties, irrigation timing, and narrower rows are more feasible with irrigation, although maximum response to irrigation comes when other management practices are optimum (Jensen and Musick, 1962).

CHAPTER III

MATERIALS AND METHODS

This study was conducted at the Oklahoma Vegetable Research Station, Bixby, Oklahoma, from 1980-1985 on a Wynona silt loam soil (Cumulic Haplaquolls) with 0-1% slope. In the fall of 1979, 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 mono-cropped wheat, while one tandem disking of the soybean stubble and two tandem diskings of the grain sorghum stubble were used to prepare the seedbed for double-cropped wheat.

Each year, fall soil tests showed phosphorus (P) and potassium (K) to be between 90% and 100% sufficiency levels, as determined by the Oklahoma State University soil testing laboratory procedures and recommendations. However, in order to ensure and maintain 100% sufficiency levels of these two nutrients, maintenance P as $Ca(H_2PO_4)_2$ and K as KCl, in amounts reported by Colliver (1983) for grain removal, were bulk blended and banded when planting wheat. P and K removed in grain for wheat, grain sorghum, and soybeans in the double-cropped treatments were applied in this manner. Maintenance P and K for the mono-cropped soybean and mono-cropped grain sorghum treatments were also applied banded at planting.

Winter wheat (TAM 105) was planted on mono-cropped plots on October 18, 1979; October 20, 1980; October 15, 1981; October 21, 1982; October 14, 1983; and October 18, 1984; at a rate of 67 kg ha^{-1}. Double-cropped wheat plots were planted on November 24, 1979; November 25, 1980; December 4, 1981; November 20, 1982; November 18, 1983; and November 12, 1984; at a rate of 101 kg ha^{-1}. A hoe drill with 0.25 m row spacings was used to plant the wheat in plots of 18.3 x 18.3 m. Wheat was top-dressed by broadcasting NH_4NO_3 at a rate of 135 kg N ha^{-1} on February 28, 1980; February 25, 1981; February 25, 1982; February 26, 1983; February 21, 1984; and February 22, 1985. Wheat grain yields were obtained by harvesting a 6.1 x 18.3 m strip from the center of each plot on July 2, 1980; June 22, 1981; June 28, 1982; June 22, 1983; June 25, 1984; and June 18, 1985. Wheat yield data were analyzed using a randomized complete-block design consisting of five treatments, with four replications.

A 2 x 2 factorial arrangement was used for the second phase of the experiment. Treatment factors and their respective levels were water (rainfed and irrigated) and cropping system (mono-cropped and double-cropped grain sorghum) in a randomized complete-block design, with four replications. A 2 x 2 factorial arrangement was also used for the soybean cropping systems, with treatment factors and their respective levels being water (rainfed and irrigated) and cropping system (mono-cropped and double-cropped soybeans) in a randomized complete-block design, with four replications.

Seedbed preparation for the conventionally tilled mono-cropped grain sorghum treatments consisted of moldboard plowing and two tandem diskings, while seedbed preparation for the conventionally tilled mono-cropped soybean treatments consisted of moldboard plowing and one tandem disking.

No-till double-cropped grain sorghum and soybeans were seeded directly into standing wheat stubble. All grain sorghum plots received a broadcast application of NH_4NO_3 at 135 kg N ha^{-1} just prior to planting.

Grain sorghum (Acco BR-Y93) was planted at 5.0 kg ha^{-1}, while soybeans (Forrest, Maturity Group V) were planted at 296,000 viable seeds ha^{-1}. Both crops were planted using an eight row, no-till planted equipped with ripple coulters, double-disk openers, 40 mm depth bands, and press wheels. The planter was configurated to plant wheel traffic and nonwheel traffic rows in 0.75 and 0.50 m row spacings, respectively. Conventionally tilled mono-cropped grain sorghum and soybeans were planted on May 22, 1980; June 9, 1981; June 22, 1982; June 17, 1983; June 8, 1984; and June 14, 1985. No-till double-cropped grain sorghum and no-till, double-cropped soybeans were planted on July 2, 1980; June 22, 1981; June 30, 1982; June 29, 1983; June 25, 1984; and June 19, 1985.

Propazine [2-chloro-4,6-bis (isopropylamino)-s-triazine] was broadcast at 1.34 kg ha^{-1} in 234 L ha^{-1} water, on the conventionally tilled mono-cropped grain sorghum plots immediately after planting. Glyphosate [(N-phosphonomethyl) 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 pre-emergence application at 1.12 and 0.56 kg ha^{-1}, respectively, in 234 L ha^{-1} water. Conventionally tilled mono-cropped grain sorghum plots received one mechanical cultivation. All grain sorghum plots also received a post-emergence broadcast application of 0.84 kg ha^{-1} 2,4-Dacamine (N-Oleyl-1, 3-propylenediamine) in 234 L ha^{-1} water.

Trifluralin (a,a,a-trifluoro-2,6-dinitro-N-N-dipropyl-p-toluidine) was broadcast on the conventionally tilled mono-cropped soybean plots at 1.1 kg ha^{-1} in 234 L ha^{-1} water and incorporated with a Do-all prior to planting. All mono-cropped soybean treatments also received one mechanical cultivation. No-till double-cropped soybean treatments received 1.1 kg ha^{-1} glyphosate [N-(phosphonomethyl) glycine] broadcast in 234 L ha^{-1}

water immediately after planting. All soybean plots received a tank mix post-emergence application of bentazon (3-isopropyl-1H-2, 1, 3-benzothiadiazin-4 (3H)-one-2,2-dioxide) and acifluorfen-sodium 5-[2-chloro-4-(trifluoromethyl) phenoxy]-2-nitrobenzoate at 0.56 and 0.42 kg ha^{-1}, respectively in 234 L ha^{-1} water. A separate application of fluazifop-butyl (±)-butyl 2-[4-[(5-trifluoromethyl)-2-pyridinyl) oxy] phenoxy] propanoate at 0.19 kg ha^{-1}, along with 0.53 L surfactant in 234 L ha^{-1} water, were also applied post-emergence to all soybean treatments.

The two previously mentioned post-emergence soybean herbicide applications were necessary due to intense weed pressure from morning-glory species (Ipomoea purpurea), (Ipomoea hederacea var. jacq.), (Ipomoea hederaceae var. integriuascula), cocklebur (Xanthium pensylvanicum Wallr.), escaped within row redroot pigweed (Amaranthus retroflexus L.), common lambsquarters (Chenopodium album L.), and rhizome johnsongrass [Sorghum halepense (L.) Pers.].

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 M Pa) 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.

Grain sorghum and soybean yields were obtained by harvesting a 5.6 x 18.3 m strip from the center of each treatment plot. Harvesting dates for mono-cropped grain sorghum plots were: September 16, 1980; October 5, 1981; October 19, 1982; September 22, 1983; September 13, 1984; and October 2, 1985; and for no-till double-cropped grain sorghum plots the dates were: November 6, 1980; November 14, 1981; October 19, 1982;

November 17, 1983; October 11, 1984; and October 2, 1985. Harvesting dates for conventionally tilled mono-cropped soybean plots were: September 16, 1980; November 14, 1981; October 25, 1982; November 16, 1983; November 8, 1984; and November 6, 1985; and for no-till double-cropped soybean plots: November 7, 1980; November 14, 1981; October 25, 1982; November 16, 1983; November 8, 1984; and November 6, 1985.

CHAPTER IV

RESULTS AND DISCUSSION

Monthly rainfall amounts from January 1, 1980 to December 31, 1985 and the 30-year monthly averages (1956-1985) are given in Table I. Monthly distributions of rainfall for each year of the six-year study are given in Figure 1. Rainfall amounts and distribution for the last half of July, August, and September remain critical for summer grown crops.

Wheat-Grain Sorghum Cropping Systems

1980

Mono-cropped wheat yielded 3770, compared to 3170 and 3340 kg ha^{-1} for double-cropped wheat. The differences of 600 and 430 kg ha^{-1} were statistically significant at the 0.05 level (Table II), and may, in part, be attributed to later planting, which resulted in less tillering of the double-cropped wheat. From June 20 to August 17, precipitation amounted to only 5 mm (Figure 1). This 57-day period without rainfall represents the problem with amounts and distribution of rainfall for summer crops grown in this region. For the 1980 environment, 330 and 380 mm of supplemental water were applied during the growing season for the irrigated conventionally tilled mono-cropped and the irrigated no-till double-cropped grain sorghum, respectively (Table III). The yield of irrigated conventionally tilled mono-cropped grain sorghum was significantly higher (0.05 level) than rainfed conventionally tilled mono-cropped grain

TABLE I

RAINFALL FROM JANUARY 1, 1980 TO DECEMBER 31, 1985
AND THE 30-YEAR MONTHLY AVERAGE (1956-1985)
AT THE VEGETABLE RESEARCH STATION,
BIXBY, OKLAHOMA

	Rainfall (mm)						
Month	1980	1981	1982	1983	1984	1985	30-Year Average
January	68	17	91	65	10	21	40
February	0	34	12	71	70	102	42
March	89	50	20	48	125	118	65
April	95	108	31	85	63	123	96
May	120	141	199	177	126	74	127
June	230	96	156	69	89	181	119
July	5	76	59	26	15	69	84
August	54	104	58	7	57	57	67
September	155	100	20	41	55	118	100
October	65	166	42	260	180	237	85
November	29	81	159	78	62	144	69
December	39	4	81	13	268	33	44
Totals	924	977	928	940	1120	1277	938

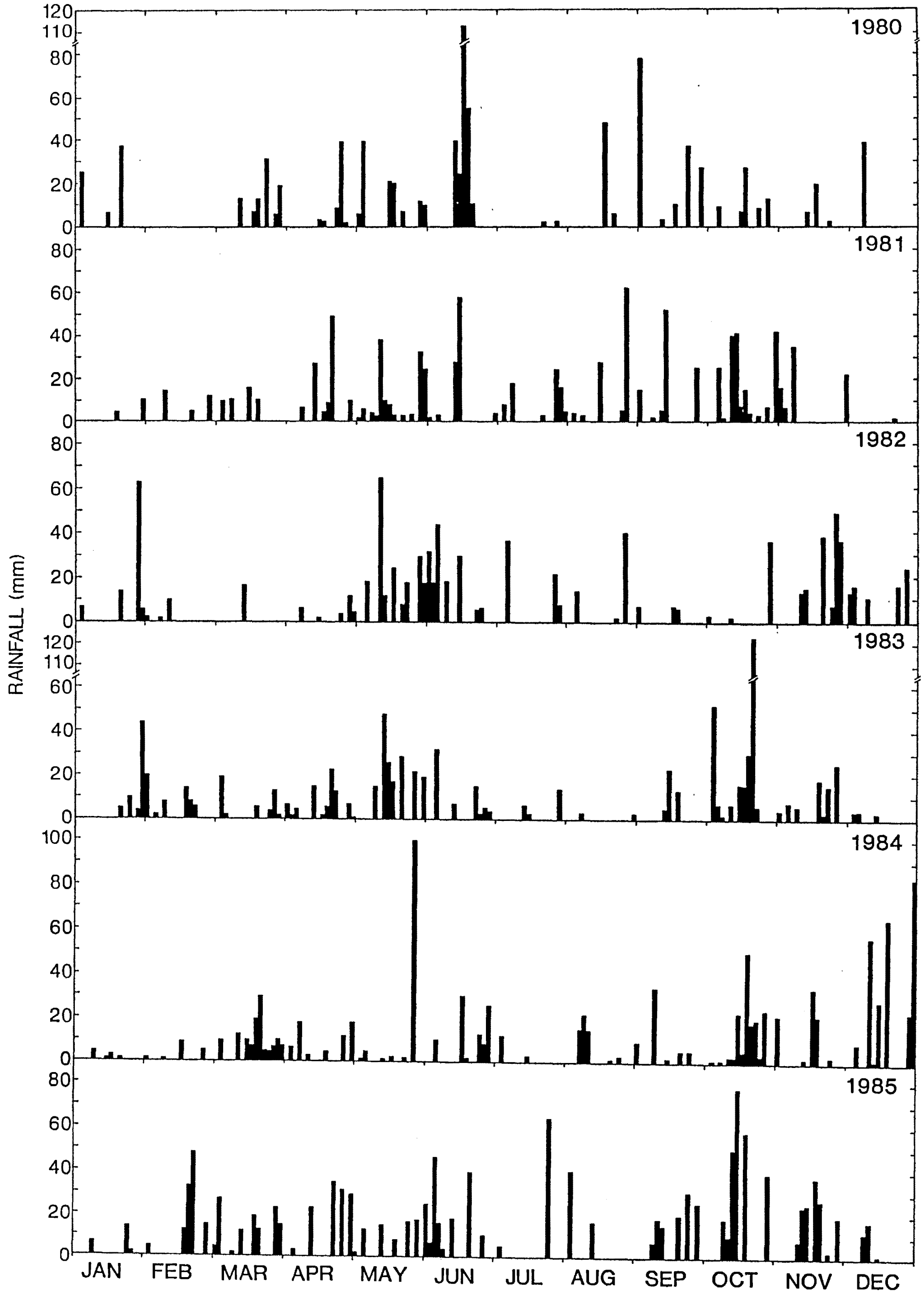

Figure 1. Rainfall Amounts and Distribution for 1980-1985 at the Vegetable Research Station, Bixby, Oklahoma

TABLE II

WHEAT YIELDS AS AFFECTED BY CROPPING SYSTEM

Cropping System	kg ha^{-1}						
	1980[a]	1981	1982	1983	1984	1985	1980-85
RFMCW[b]	3770	3730	2680	3640	3670	2780	3378
RFDCW-IDCGS	3170	3070	2240	2820	2940	2250	2748
RFDCW-RFDCGS	3340	3190	2160	2890	2660	2200	2740
LSD (0.05)	169	208	256	186	282	375	105

[a]Mean of four replications.

[b]Rainfed mono-cropped wheat (RFMCW); rainfed double-cropped wheat irrigated double-cropped grain sorghum (RFDCW-IDCGS); rainfed double-cropped wheat rainfed double-cropped grain sorghum (RFDCW-RFDCGS).

TABLE III

AMOUNT OF SUPPLEMENTAL WATER APPLIED

Cropping System	mm					
	1980	1981	1982	1983	1984	1985
MCGS[a]	330	200	160	320	120	70
MCSB	330	200	200	300	120	150
DCGS	380	260	180	360	200	70
DCSB	380	260	260	360	200	150

[a]Mono-cropped grain sorghum (MCGS); mono-cropped soybeans (MCSB): double-cropped grain sorghum (DCGS); double-cropped soybeans (DCSB).

sorghum. Irrigated no-till double-cropped grain sorghum yielded significantly more (0.05 level) than rainfed no-till double-cropped grain sorghum (Table IV).

1981

During 1981, wheat yields were similar in magnitude to 1980. Mono-cropped wheat yielded 3730, compared to 3070 and 3190 kg ha^{-1} (significant at the 0.05 level) for double-cropped wheat (see Table II). Amount and distribution of rainfall in July, August, and September were improved over the 1980 environment (see Table I and Figure 1). In 1981, 200 and 260 mm of supplemental water were applied to irrigated conventionally tilled mono-cropped and no-till double-cropped grain sorghum treatments, respectively (see Table III). Yields of both irrigated grain sorghum treatments were similar (Table IV). Rainfed no-till double-cropped grain sorghum yielded 640 kg ha^{-1} more than rainfed conventionally tilled mono-cropped grain sorghum (significant at the 0.10 level), probably due to more water stress at the boot stage of growth for the rainfed conventionally tilled mono-cropped grain sorghum. This demonstrated the erratic differences in environments that growers must contend with in growing summer crops, regardless of the cropping system in the Southern Great Plains.

1982

Yields for all wheat cropping systems were considerably lower for the 1982 environment, compared to other years. This can be attributed to an outbreak of tan spot *Pyrenophora triticirepentis*. Although tan spot decreased yields, mono-cropped wheat still yielded significantly more than (0.05 level) double-cropped wheat (see Table II). Higher than

TABLE IV

MEANS AND MEAN SQUARES FOR THE EFFECTS OF WATER AND CROPPING SYSTEMS ON THE YIELDS OF GRAIN SORGHUM

Cropping System	kg ha^{-1}						
	1980[a]	1981	1982	1983	1984	1985	1980-85[b]
ICT-MCGS[c]	4450	4570	5910	6160	7160	7630	5978
RFCT-MCGS	2960	3180	6090	4990	7110	7330	5277
INT-DCGS	4250	4670	5960	5330	4670	5240	5022
RFNT-DCGS	3400	3820	5860	3510	2690	4020	3885
LSD (0.05)	586	651	NS	448	834	416	223

Source	MS						
	1980	1981	1982	1983	1984	1985	1980-85
Water (W)	5422955[e]	5063922[e]	6778	8888178	4124038[e]	2325747[e]	20291514[e]
Cropping System (C)	59080	554843	33951	5341101	47608942[e]	32493164[e]	33170724[e]
W x C	403360	292699	81905	420977[d]	3720432[e]	834401[e]	1127700[e]
Error	134307	165544	256931	78447	271837	67773	250972
Year (Y)	--	--	--	--	--	--	14676692[e]
Error	--	--	--	--	--	--	162448
W x Y	--	--	--	--	--	--	1108221[e]
Error	--	--	--	--	--	--	200371
C x Y	--	--	--	--	--	--	10584072[e]
Error	--	--	--	--	--	--	92374
W x C x Y	--	--	--	--	--	--	925215[e]
Error	--	--	--	--	--	--	151575

[a]n = 4.

[b]n = 24.

[c]Irrigated conventional tilled mono-cropped grain sorghum (ICT-MCGS); rainfed conventional tilled mono-cropped grain sorghum (RFCT-MCGS); irrigated no-till double-cropped grain sorghum (INT-DCGS); rainfed no-till double-cropped grain sorghum (RFNT-DCGS).

[d]Significant at the 0.05 probability level.

[e]Significant at the 0.01 probability level.

normal rainfall in May and June, along with lower wheat yields, allowed subsoil to accumulate prior to planting sorghum. Cooler than normal temperatures and timely distribution and favorable amounts of rainfall during the growing season resulted in no significant yield differences between treatments, even when 160 and 180 mm of supplemental water (see Table III) were applied to conventionally tilled and no-till double-cropped grain sorghum, respectively (see Table IV).

1983

Yields of 1983 wheat were similar in magnitude to those of 1980-81. Mono-cropped wheat yielded significantly more (3640, compared to 2820 and 2890 kg ha^{-1}) than did the double-cropped wheat (see Table II). Rainfall from January 1 to June 1 was similar to the 30-year average; however, rainfall for July, August, and September was the lowest (74 mm) of the six-year study period (see Table I and Figure 1). Three-hundred twenty and 360 mm of water were applied to the conventionally tilled mono-cropped and no-till double-cropped grain sorghum treatments, respectively (see Table III). Irrigated conventionally tilled grain sorghum yielded 6160 (signifiant at the 0.05 level), compared to 4990 kg ha^{-1} for rainfed conventionally tilled mono-cropped grain sorghum. Irrigated no-till double-cropped sorghum yielded 5330, compared to 3510 kg ha^{-1} (significant at the 0.05 level) for rainfed no-till double-cropped grain sorghum (see Table IV). Unlike the three previous years, there was a significant (0.05 level) water x cropping system interaction (see Table IV), which may be attributed to the increase in yields of both cropping systems to irrigation. The increase was significantly higher for irrigated no-till double-cropped (52%) than for irrigated conventionally tilled mono-cropped grain sorghum (23%).

1984

As in the four previous years, mono-cropped wheat yielded significantly more (0.05 level) than double-cropped wheat. For the 1984 environment, mono-cropped wheat yielded 3670, compared to 2940 and 2660 kg ha^{-1} for double-cropped wheat (see Table II). Total rainfall during July, August, and September was higher than in 1983 and was similar in total amount to 1982 (see Table I). With good subsoil moisture and 55 mm of rainfall on August 8, 9, and 10, and another 34 mm on September 9, there was no significant difference in yields of irrigated conventionally tilled mono-cropped and rainfed conventionally tilled mono-cropped grain sorghum, although the irrigated conventionally tilled mono-cropped treatment had received 120 mm of supplemental water. With the addition of 200 mm of water, no-till double-cropped sorghum yielded 4670, compared to 2690 kg ha^{-1} (significant at the 0.05 level) for the rainfed no-till double-cropped grain sorghum (see Table IV). The water x cropping system interaction was significant (0.01 level) and can be attributed to the magnitude in yield difference (73.6%) between the irrigated no-till double-cropped and rainfed no-till double-cropped grain sorghum treatments.

1985

For the sixth consecutive year, mono-cropped wheat yielded significantly more (0.05 level) than did double-cropped wheat. Although rainfall from January 1 to June 15 was 130 mm above the 30-year average, mono-cropped wheat yielded only 2780, compared to 2250 and 2200 kg ha^{-1} for double-cropped wheat (see Table II). The 1985 yields were similar in magnitude when compared to the 1982 wheat yields, but unlike 1982, the lower yields can be attributed to an outbreak of leaf rust (*Puccinia recondita*).

Irrigated and rainfed conventionally tilled mono-cropped grain sorghum yielded 7630 and 7330 kg ha^{-1}, respectively (see Table IV). Although 70 mm of supplemental water were applied to both cropping systems (see Table III), the lack of response to irrigation can most likely be attributed to the build-up of subsoil moisture during January 1 to June 30, and reasonably good amounts and distribution of rainfall during July, August, and September (see Figure 1). With the addition of 70 mm of supplemental water, irrigated no-till double-cropped grain sorghum yielded 5240, compared to 4020 kg ha^{-1} (significant at the 0.05 level) for the rainfall no-till double-cropped grain sorghum (see Table IV). The water x cropping system interaction was significant (0.01 level), and can be attributed to the magnitude in yield difference (30%) between the irrigated and rainfed no-till double-cropped grain sorghum treatments (see Table IV).

1980-1985

Over the six-year study period, mono-cropped wheat yielded an average of 634 kg ha^{-1} more than did double-cropped wheat (see Table II). These results were similar to those reported by Crabtree and Makonnen (1981). For the same period, irrigated conventionally tilled mono-cropped grain sorghum averaged 5978, compared to 5277 kg ha^{-1} for rainfed conventionally tilled mono-cropped grain sorghum. Irrigated no-till double-cropped sorghum yielded an average of 5022, compared to 3885 kg ha^{-1} for rainfall no-till double-cropped sorghum (see Table IV). When the data for grain sorghum were analyzed over years, there were significant (0.01 level) water x year, crop x year, and water x crop x year interactions. The significance of the three-factor interaction implied that the two factor interaction effect of water x cropping system was not the same over six years. The largest magnitude in yield variance as a deviation from the mean occurred in 1983, 1984, and 1985.

Wheat-Soybean Cropping Systems

1980

Mono-cropped wheat yielded 3770, compared to 3400 and 3310 kg ha^{-1} for double-cropped wheat. The differences of 370 and 460 kg ha^{-1} were statistically significant at the 0.05 level (Table V), and may, in part, be attributed to later planting, which resulted in less tillering of the double-cropped wheat. From June 20 to August 17, precipitation amounted to only 0.05 mm (see Figure 1). This 57-day period without rainfall represents a classical example of the problem with precipitation amounts and distribution of rainfall for summer crops grown in this region. For the 1980 environment, 330 and 380 mm of supplemental water were applied during the growing season to the irrigated conventionally tilled mono-cropped soybeans and the irrigated no-till double-cropped soybeans, respectively (see Table III).

Irrigated mono-cropped soybeans yielded 2710, compared to 1960 kg ha^{-1} (significant at the 0.05 level) for the rainfed mono-cropped soybeans. Irrigated double-cropped soybeans yielded 2110, compared to 1910 for the rainfed double-cropped soybeans (Table VI). This small difference in yield can most likely be attributed to two significant rains in the amount of 48 and 78 mm on August 18 and September 2, respectively, when the double-cropped soybeans were flowering and initiating pod set (see Figure 1). Rainfall amounts and distribution in all of September were higher than the 30-year average (see Table I and Figure 1). These rains, coupled with nearly normal rainfall in October, apparently resulted in minimal water stress during the critical reproductive and pod filling stages of growth for double-cropped soybeans. This represents a classical example where considerable supplemental irrigation water was applied in the early vegetative stages of growth, with minimal yield benefits.

TABLE V

WHEAT YIELDS AS AFFECTED BY CROPPING SYSTEM

Cropping System	kg ha^{-1}						
	1980	1981	1982	1983	1984	1985	1980-85
RFMCW[a]	3770[b]	3730	2680	3640	3670	2780	3378
RFDCW-IDCSB	3400	3300	2020	3220	3100	2280	2887
RFDCW-RFDCSB	3310	3350	2070	3120	2890	1940	2780
LSD (0.05)	169	208	256	186	282	375	105

[a]Rainfed mono-cropped wheat (RFMCW); rainfed double-cropped wheat irrigated double-cropped soybeans (RFDCW-IDCSB); rainfed double-cropped wheat rainfed double-cropped soybeans (RFDCW-RFDCSB).

[b]Mean of four replications.

TABLE VI

MEAN AND MEAN SQUARES FOR THE EFFECTS OF WATER AND CROPPING SYSTEMS ON THE YIELDS OF SOYBEANS

Cropping System	kg ha^{-1}						
	1980[a]	1981	1982	1983	1984	1985	1980-85[b]
ICT-MCSB[c]	2710	3200	2300	3000	2800	3560	2930
RFCT-MCSB	1960	1860	1820	2610	2560	3240	2342
INT-DCSB	2110	2300	1740	2680	1530	2760	2185
RFNT-DCSB	1910	1800	1590	1170	1260	2830	1760
LSD (0.05)	427	206	370	274	328	382	122

Source	MS						
	1980	1981	1982	1983	1984	1985	1980-85
Water (W)	892683[e]	3380717[e]	398396[d]	3585563[e]	257752[d]	61974	6130453[e]
Cropping System (C)	418438[d]	922562[e]	627142[e]	3126197[e]	6684867[e]	1462761[e]	10566515[e]
W x C	318704	697304[e]	113674	1248398[e]	865	155237	161383
Error	71332	16555	53365	29309	42089	56991	59649
Year (Y)	--	--	--	--	--	--	2944082[e]
Error	--	--	--	--	--	--	53088
W x Y	--	--	--	--	--	--	489327[e]
Error	--	--	--	--	--	--	31379
C x Y	--	--	--	--	--	--	535090[e]
Error	--	--	--	--	--	--	70361
W x C x Y	--	--	--	--	--	--	474559[e]
Error	--	--	--	--	--	--	24316

[a]n = 4.

[b]n = 24.

[c]Irrigated conventional tilled mono-cropped soybeans (ICT-MCSB); rainfed conventional tilled mono-cropped soybeans (RFCT-MCSB); irrigated no-till double-cropped soybeans (INT-DCSB); rainfed no-till double-cropped soybeans (RFNT-DCSB).

[d]Significant at the 0.05 probability level.

[e]Significant at the 0.01 probability level.

1981

Wheat yields in 1981 were similar in magnitude to 1980. Mono-cropped wheat yielded 3730, compared to 3300 and 3350 kg ha^{-1} (significant at the 0.05 level) for double-cropped wheat (see Table V). Amount and distribution of rainfall in July, August, and September were improved over the 1980 environment (see Table I and Figure 1). Two hundred and 260 mm of supplemental water were applied to the irrigated mono-cropped and irrigated double-cropped soybean treatments, respectively (see Table III). There was a highly significant (0.01 level) response to irrigation by both mono- and double-cropped soybeans (see Table VI). Irrigated mono-cropped yielded 3200, compared to 1860 kg ha^{-1} for rainfed mono-cropped soybeans and irrigated double-cropped soybeans yielded 2300, compared to 1800 kg ha^{-1} for rainfed double-cropped soybeans. The water x cropping system interaction was significant (0.01 level), and can be attributed to the magnitude in increased yield response to irrigation for both mono- and double-cropped soybeans (see Table VI).

1982

Yields for all wheat cropping systems were considerably lower in magnitude for the 1982 environment, compared to other years, and can be attributed to an outbreak of tan spot Pyrenophora triticirepentis. Although tan spot decreased yields, mono-cropped wheat still significantly outyielded (0.05 level) double-cropped wheat (see Table V). Higher than normal rainfall in May and June, along with lower wheat yields, allowed subsoil water to accumulate in considerable magnitude. Nevertheless, with the addition of 200 mm of supplemental water, irrigated mono-cropped soybeans yielded 2300, compared to 1820 kg ha^{-1} (significant at the 0.05 level) for rainfed mono-cropped soybeans (see Table VI).

Despite the addition of 260 mm of supplemental water, irrigated double-cropped soybeans yielded only 1740, compared to 1590 kg ha^{-1} for rainfed double-cropped soybeans. No plausible explanation can be offered for the failure of double-cropped soybeans to respond in a more positive manner to irrigation for the 1982 environment.

1983

Yields of wheat were similar in magnitude to those of 1980-81. Mono-cropped wheat yielded significantly more (3640, compared to 3220 and 3120 kg ha^{-1} for the double-cropped wheat) (see Table V). Rainfall from January 1 to June 1 was similar to the 30-year average; however, rainfall for July, August, and September was the lowest (74 mm) of the six-year study period (see Table I and Figure 1). Three hundred and 360 mm of water were applied to the irrigated mono-cropped and irrigated double-cropped soybean treatments, respectively (see Table III). Irrigated mono-cropped soybeans yielded 3000, compared to 2610 kg ha^{-1} (significant at the 0.05 level) for rainfed mono-cropped soybeans. Irrigated double-cropped soybeans yielded 2680, compared to 1170 kg ha^{-1} (significant at the 0.05 level) for rainfed double-cropped soybeans (see Table VI). There was a significant (0.01 level) water x cropping system interaction (see Table VI), but unlike 1981, may be attributed to the magnitude of the yield response of the double-cropped soybeans to irrigation, which was much higher (129%) than for the mono-cropped soybeans (15%).

1984

For the fifth consecutive year, mono-cropped wheat yielded significantly more (0.05 level) than double-cropped wheat. For the 1984 environment, mono-cropped wheat yielded 3670, compared to 3100 and 2890 kg ha^{-1} for double-cropped wheat (Table V). Total rainfall during July, August, and September was somewhat improved over 1983 and was similar in total amount to 1982 (see Table I). With good subsoil moisture and 55 mm of rainfall on August 8, 9, and 10, and another 34 mm on September 9, there was no significant difference in yields of irrigated and rainfed mono-cropped soybeans, although the irrigated treatment had received 120 mm of supplemental water. With the addition of 200 mm of water, irrigated double-cropped soybeans yielded 1530, compared to 1260 kg ha^{-1} for the rainfed double-cropped soybeans (see Table VI). The lack of response to irrigation by both soybean cropping systems was similar to that for the 1982 environment.

1985

As in the five previous years, mono-cropped wheat yielded significantly more (0.05 level) than double-cropped wheat. Mono-cropped wheat yielded 2780, compared to 2280 and 1940 kg ha^{-1} for double-cropped wheat (see Table V). These yields were similar to the lower yields obtained in 1982, and as previously stated, can be attributed to an outbreak of leaf rust.

For the 1985 environment, there was no significant difference (0.05 level) in yields of irrigated and rainfed mono-cropped soybeans or irrigated and rainfed double-cropped soybeans (Table VI), even though 150 cm of supplemental water were applied (see Table III). This can most likely be attributed to favorable amounts and timely distribution of rainfall during the 1985 growing season (see Figure 1).

1980-1985

Over the six-year study period, mono-cropped wheat yielded an average of 3378, compared to an average of 2887 and 2780 kg ha^{-1} for no-till double-cropped wheat (see Table V). For the same period, irrigated conventionally tilled mono-cropped soybeans averaged 2930, compared to 2342 for rainfed conventionally tilled mono-cropped soybeans, and irrigated no-till double-cropped soybeans yielded an average of 2185, compared to 1760 kg ha^{-1} for rainfed no-till double-cropped soybeans (see Table VI).

When the data for soybeans were analyzed over years, there were significant (0.01 level) water x year, crop x year, and water x crop x year interactions. The significance of the three-factor interaction implied that the two-factor interaction effect of water x cropping system was not the same for yields in all six years. The largest magnitude in yield variance as a deviation from the mean occurred in 1981 and 1983.

Economic Considerations

Average annual costs for seed, fertilizer, herbicides, machine operations (Nelson and Kletke, 1984), and irrigation (Kletke, Harris, and Mapp, 1978) for the alternative production systems, are included in Tables VII and VIII. Irrigation costs are based on low-pressure center pivot, with 2.41×10^5 Pa pressure at the pivot, 48.6 ha in size (without end gun), capacity to provide a maximum water use rate of 4.7 mm day^{-1} July and August, irrigation efficiency of 65% and a water lift of 15.2 m. Electrical energy costs averaged \$0.204 mm^{-1} ha^{-1} of supplemental water pumped. The costs for the irrigation include the capital costs for the system, as well as operating costs (Kletke, Harris, and Mapp, 1978).

TABLE VII

AVERAGE ANNUAL (1980-85) WHEAT-GRAIN SORGHUM PRODUCTION COST[a]

Variable Cost	Wheat Cropping Systems			Grain Sorghum Cropping Systems			
	RFMCW[b]	RFDCW-IDCGS	RFDCW-RFDCGS	ICT-MCGS	RFCT-MCGS	INT-DCGS	RFNT-DCGS
	Dollars ha^{-1}						
Moldboard Plowing	22.88	---	---	22.88	22.88	---	---
Tandem Disking @$15.35 ha^{-1}	(2)30.70	(2)30.70	(2)30.70	(2)30.70	(2)30.70	---	---
Seed @$0.27 kg^{-1} Wh; @$1.16 kg^{-1} Gs	(67)18.14	(101)27.27	(101)27.27	(5) 5.90	(5) 5.90	(5) 5.90	(5) 5.90
Planting (w/fert. attach.)	11.98	11.98	11.98	12.50	12.50	12.50	12.50
Top Dress NH_4NO_3	5.48	5.48	5.48	---	---	---	---
135 kg N ha^{-1} @$0.53 kg^{-1} N	71.55	71.55	71.55	71.55	71.55	71.55	71.55
P (maintenance) @$1.14 k^{-1} [c]	17.90	13.97	14.03	17.66	13.76	16.93	13.67
K (maintenance) @$0.33 kg^{-1} [c]	4.39	3.82	3.58	4.90	3.82	4.70	3.54
Cultivation (mechanical)	---	---	---	7.11	7.11	---	---
Herbicides[d]	---	---	---	43.62	43.62	94.63	94.63
Spraying @$6.05 ha^{-1}	---	---	---	(2)12.10	(2)12.10	(2)12.10	(2)12.10
Irrigation	---	---	---	193.00	---	201.00	---
Harvesting	34.58	34.58	34.58	35.67	35.67	35.67	35.67
Hauling @$0.0037 kg^{-1} 24 km^{-1}	12.93	10.30	10.72	18.31	14.31	17.56	14.17
Total	230.53	209.65	209.89	475.90	273.89	472.54	263.73

[a]Cost of equipment operations based on average annual custom rates for eastern Oklahoma.

[b]Rainfed mono-cropped wheat (RFMCW); rainfed double-cropped wheat irrigated double-cropped grain sorghum (RFDCW-IDCGS); rainfed double-cropped wheat rainfed double-cropped grain sorghum (RFDCW-RFDCGS); irrigated conventional tilled mono-cropped grain sorghum (ICT-MCGS); rainfed conventional tilled mono-cropped grain sorghum (RFCT-MCGS); irrigated no-till double cropped grain sorghum (INT-DCGS); rainfed no-till double-cropped grain sorghum (RFNT-DCGS).

[c]Based on P removal in wheat and grain sorghum of 0.0044 and 0.0031 kg kg^{-1}, respectively, and K removal in wheat and grain sorghum grain of 0.00415 and 0.0030 kg kg^{-1}, respectively.

[d]Cost of Milogard, 2,4-Dacamine, Glyphosate and Linuron were $9.26 kg^{-1}, $3.56, $23.02, and $13.76 L^{-1}, respectively.

TABLE VIII

AVERAGE ANNUAL (1980-85) WHEAT-SOYBEAN PRODUCTION COST[a]

Variable Cost	Wheat Cropping Systems			Soybean Cropping Systems			
	RFMCW[b]	RFDCW-IDCSB	RFDCW-RFDCSB	ICT-MCSB	RFCT-MCSB	INT-DCSB	RFNT-DCSB
	Dollars ha^{-1}						
Moldboard Plowing	22.88	---	---	22.88	22.88	---	---
Tanden Disking @$15.35 ha^{-1}	(2)30.70	15.35	15.35	15.35	15.35	---	---
Do-all (incorp. trifluralin)	---	---	---	15.20	15.20	---	---
Seed @$0.27 kg^{-1} Wh; @$0.44 kg^{-1} Sb	(67)18.14	(101)27.27	(101)27.27	(67)29.48	(67)29.48	(101)44.22	(101)44.22
Planting (w/fert. attach.)	11.98	11.98	11.98	12.50	12.50	12.50	12.50
Top Dress NH_4NO_3	5.48	5.48	5.48	---	---	---	---
135 kg N ha^{-1} @$0.53 kg^{-1} N	71.55	71.55	71.55	---	---	---	---
P (maintenance) @$1.14 kg^{-1} [c]	17.90	14.93	14.43	20.46	13.81	15.08	10.82
K (maintenance) @$0.33 kg^{-1} [c]	4.39	4.07	3.94	19.41	13.22	14.43	10.35
Cultivation (mechanical)	---	---	---	7.11	7.11	---	---
Herbicides[d]	---	---	---	122.51	122.51	178.36	178.36
Spraying @ $6.05 ha^{-1}	---	---	---	(3)18.15	(3)18.15	(3)18.15	(3)18.15
Irrigation	---	---	---	197.00	---	207.00	---
Harvesting	34.58	34.58	34.58	39.10	39.10	39.10	39.10
Hauling @$0.0037 kg^{-1} 24 km^{-1}	12.93	11.01	10.64	11.31	7.64	8.34	5.98
Total	230.53	196.22	195.22	530.46	316.95	537.18	319.48

[a]Cost of equipment operations based on average annual custom rates for eastern Oklahoma.

[b]Rainfed mono-cropped wheat (RFMCW); rainfed double-cropped wheat irrigated double-cropped soybeans (RFDCW-IDCSB); rainfed double-cropped wheat rainfed double-cropped soybeans (RFDCW-RFDCSB); irrigated conventional tilled mono-cropped soybeans (ICT-MCSB); rainfed conventional tilled mono-cropped soybeans (RFCT-MCSB); irrigated no-till double-cropped soybeans (INT-DCSB); rainfed no-till double-cropped soybeans (RFNT-DCSB).

[c]Based on P removal in wheat and soybeans of 0.0044 and 0.0058 kg kg^{-1}, respectively and K removal in wheat and soybeans of 0.00415 and 0.020 kg kg^{-1}, respectively.

[d]Costs of Trifluralin, Glyphosate, Bentazon, Acifluorfen-sodium, and Fluazifop-butyl were $12.16, $23.02, $21.69, $20.11, and $76.72 L^{-1}, respectively.

Given the yields obtained and price relationships, irrigation for mono-cropped grain sorghum was not economical. While average mono-cropped grain sorghum yields improved by 701 kg ha^{-1}, the average addition to returns of \$70 ha^{-1} was insufficient to cover the \$193 ha^{-1} cost of the irrigation. A yield increase of over 1930 kg ha^{-1} would have been necessary to cover the cost of irrigation. Alternatively, given the actual yield increase of 701 kg ha^{-1}, the price of grain sorghum would have to increase from \$0.101 kg^{-1} to \$0.275 kg^{-1} to cover the irrigation costs. Irrigation of no-till double-cropped grain sorghum increased yields an average of 1137 kg ha^{-1}, with an average addition to returns of \$114 ha^{-1}; however, this was also insufficient to cover the \$201 ha^{-1} cost of irrigation. A yield increase of 2010 kg ha^{-1} would have been necessary to cover the cost of irrigation. Alternatively, given the actual yield increase of 1137 kg ha^{-1}, the price of grain sorghum would have to increase from \$0.101 kg^{-1} to \$0.177 kg^{-1} to cover the cost of irrigating double-cropped grain sorghum.

Given the yields obtained and price relationships, irrigation for mono-cropped soybeans was also not economical. While average mono-cropped soybean yields improved by 588 kg ha^{-1}, the average addition to returns of \$141 ha^{-1} was insufficient to cover the \$197 ha^{-1} cost of the irrigation. A yield increase of over 820 kg ha^{-1} would have been necessary to cover the cost of irrigation. Alternatively, given the actual yield increase of 588 kg ha^{-1}, the price of soybeans would have to increase from \$0.240 kg^{-1} to \$0.335 kg^{-1} to cover the irrigation costs. Irrigation of double-cropped soybeans increased yields an average of 425 kg ha^{-1}, with an average addition to returns of \$102 ha^{-1}; however, this was also insufficient to cover the \$207 ha^{-1} cost of irrigation. A yield increase of 863 kg ha^{-1} would have been necessary to cover the cost of irrigation. Alternatively, given the actual yield increase of 425 kg ha^{-1}, the price of soybeans would have to increase from \$0.240 kg^{-1} to \$0.487 kg^{-1} to cover the cost of irrigating double-cropped soybeans.

CHAPTER V

SUMMARY AND CONCLUSIONS

A six-year (1980-85) summary of economic returns to land, management, overhead, and risk, for the nine cropping systems are given in Table IX. Dollar returns ha^{-1} were highest for rainfed double-cropped wheat and rainfed no-till double cropped grain sorghum ($263); rainfed double-cropped wheat and rainfed no-till double-cropped soybeans ($259); rainfed conventionally tilled mono-cropped soybeans ($241); rainfed conventionally tilled mono-cropped grain sorghum ($237); and rainfed conventionally tilled monocropped wheat ($211) cropping systems. Dollar returns ha^{-1} were lower for rainfed double-cropped wheat and irrigated no-till double-cropped grain sorghum ($174); rainfed double-cropped wheat and irrigated no-till double-cropped soybeans ($174); irrigated conventionally tilled mono-cropped soybeans ($170); and irrigated conventionally tilled mono-cropped grain sorghum ($113) cropping systems (see Table IX).

Over the six-year period, irrigation of mono- or double-cropped grain sorghum and soybeans was not economically feasible when production costs and commodity prices for this period were considered.

TABLE IX

AVERAGE (1980-85) RETURN FOR LAND, MANAGEMENT, OVERHEAD, AND RISK[a]

Cropping System	Gross Value[b]	Production Cost	Return
	Dollars ha^{-1}		
Rainfed mono-cropped wheat	441	230	211
Rainfed conventionally tilled mono-cropped soybeans	558	317	241
Rainfed conventionally tilled mono-cropped grain sorghum	511	274	237
Irrigated conventionally tilled mono-cropped soybeans	700	530	170
Irrigated conventionally tilled mono-cropped grain sorghum	589	476	113
Rainfed double-cropped wheat rainfed no-till double-cropped soybeans	774	515	259
Rainfed double-cropped wheat rainfed no-till double-cropped grain sorghum	737	474	263
Rainfed double-cropped wheat irrigated no-till double-cropped soybeans	907	733	174
Rainfed double-cropped wheat irrigated no-till double-cropped grain sorghum	856	682	174

[a]Rounded to nearest dollar.

[b]Yearly day of harvest grain values in dollars kg^{-1} for wheat, grain sorghum, and soybeans, respectively--1980: 0.136, 0.123, 0.315; 1981: 0.140, 0.091, 0.224; 1982: 0.134, 0.086, 0.182; 1983: 0.131, 0.122, 0.309; 1984: 0.131, 0.103, 0.229; 1985: 0.105, 0.075, 0.182.

LITERATURE CITED

Allen, R. R., J. T. Musick, F. O. Wood, and D. A. Dusek. 1975. No-till seeding of irrigated sorghum double-cropped after wheat. Trans. Amer. Soc. agric. Eng., 18:1109-1113.

Ashley, D. A., and W. J. Ethridge. 1978. Irrigation effects on vegetative and reproductive development of three soybean cultivars. Agron. J., 70:467-471.

Baeumer, K., and W. A. P. Bakermans. 1973. Zero tillage. Adv. Agron., 25:78-120.

Bennett, O. L., E. L. Mathias, and P. E. Lundberg. 1973. Crop responses to no-till management practices on hilly terrain. Agron. J., 65:488-491.

Black, C. C., T. M. Chen, and R. H. Brown. 1969. Biochemical basis for plant competition. Weed Sci., 17:338-344.

Blevins, R. L., G. W. Thomas, and P. L. Cornelius. 1977. Influence of no-tillage and nitrogen fertilization on certain soil properties after five years of continuous corn. Agron. J., 69:383-386.

Boerma, H. R., and D. A. Ashley. 1982. Irrigation, row spacing, and genotype effects on late and ultra-late planted soybeans. Agron. J., 74:995-999.

Brown, E. A., C. E. Caviness, and D. A. Brown. 1985. Response of selected soybean cultivars to soil moisture deficit. Agron. J., 77:274-278.

Buntley, G. J. 1977. Plow pans and traffic pans. Univ. of Tennessee, Agric. Ext. Service Pub. no. 767, 1-36.

Chandler, J. M., R. L. Munson, and C. E. Vaughen. 1977. Purple moonflower: emergence, growth, reproduction. Weed Sci., 25:163-167.

Clapp, J. G., Jr. 1972. No-tillage soybean production. Soybean Digest, 32(7):6-9.

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

Crabtree, R. J., and G. A. Makonnen. 1981. Double and monocropped wheat and grain sorghum under different tillage and row spacings. Soil Sci., 32:213-219.

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.

Crosson, P. 1981. Conservation tillage and conventional tillage: A comparative assessment. Soil Conserv. Soc. Am., 18:16-20.

Dillon, J. E., and G. E. McKibben. 1972. Double-crop and play summer roulette. Ill. Agric. Exp. Stn., Ill. Res., 14(1):6-7.

Doss, B. D., R. W. Pearson, and H. T. Rogers. 1974. Effect of soil water stress at various growth stages on soybean yield. Agron. J., 66:297-299.

Doss, B. D., and D. L. Thurlow. 1974. Irrigation, row width, and plant population in relation to growth characteristics of two soybean varieties. Agron. J., 66:620-623.

Eck, H. U., and J. T. Musick. 1979. Plant water stress effects on irrigated grain sorghum. I. Effects on yield. Crop. Sci., 19:589-592.

Erbach, D. C., and W. G. Lovely. 1974. Weed control with conservation tillage production of corn and soybeans. J. Soil Water Conserv., 29:44-45.

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

Garrity, D. P., D. G. Watts, C. Y. Sullivan, and J. R. Gilley. 1982. Moisture deficits and grain sorghum performance: Effect of genotype and limited irrigation strategy. Agron. J., 74:808-814.

Graffis, D. W., E. L. Knake, W. D. Scott, and W. R. Oschwald. 1973. Soil management and tillage systems. Ill. Agron. Handbk., Circular 1069, 49-53.

Gregory, W. W., J. W. Herron, C. H. Gulley, and S. H. Phillips. 1970. No-tillage recommendations. Univ. Kentucky Ext. Misc. Pub. 382-A, 1-5.

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.

Hinkle, D. A. 1975. Use of no tillage in double-cropping wheat with soybeans or grain sorghum. Ark. Agric. Exp. Stn. Rep. Ser. 223, 1-11.

Hoeft, R. G., J. Wedberg, and M. C. Churtleff. 1975. Double-cropping in Illinois. Ill. Cir. 1106, 1-31.

Hovermale, C. H., H. M. Camper, and M. W. Alexander. 1979. Effects of small grain stubble height and mulch on no-tillage soybean production. Agron. J., 71:644-647.

Jensen, M. E., and J. T. Musick. 1962. Irrigating grain sorghums. U.S. Dept. of Agric., Leaflet no. 511.

Kadhem, F. A., J. E. Specht, and J. H. Williams. 1985. Soybean irrigation serially timed during stages R1 to R6. Yield Component Responses. Agron. J., 77:299-304.

Kamprath, E. J., D. K. Cassel, H. D. Gross, and D. W. Dibb. 1979. Tillage effects on biomass production and moisture utilization by soybeans on coastal plain soils. Agron. J., 71:1001-1005.

Kletke, D. D., T. R. Harris, and H. P. Mapp, Jr. 1978. Irrigation cost program users reference manual. Okla. Agri. Exp. Stn. Res. Rep., 770.

Knapp, W. R., and J. S. Knapp. 1978. Response of winter wheat to date of planting and fall fertilization. Agron. J., 70:1048-1053.

Korte, L. L., J. H. Williams, J. E. Specht, and R. C. Sorensen. 1983. Irrigation of soybean genotypes during reproductive ontogeny. I. Agronomic responses. Agron. J., 23:521-527.

Larson, W. E. 1962. Tillage requirements for corn. J. Soil Water Conserv., 17:3-7.

Lewis, R. B., E. A. Hiler, and W. R. Jordan. 1974. Susceptibility of grain sorghum to water deficit at three growth stages. Agron. J., 66:589-591.

Malcolm, K. W. 1980. Tillage, planting equipment, row spacing, and plant population effects on yields in a wheat-soybean double-cropping system. (Unpub. M.S. thesis, Oklahoma State University.)

Marra, M. C., and G. A. Carlson. 1983. An economic threshold model for weeds in soybeans. Weed Sci., 31:604-609.

McHarry, M. J., and G. Kapusta. 1979. Herbicide applications in tillered winter wheat for double crop soybean weed control. Agron. J., 71:1051-1055.

McKibben, G. E., and J. W. Pendleton. 1968. Double-cropping in Illinois. Illinois Research, 10(3):6-7.

McWhorter, C. G., and J. M. Anderson. 1981. The technical and economic effect of johnsongrass control in soybeans. Weed Sci., 29:245-253.

Mederski, H. J., D. L. Jeffers, and D. B. Peters. 1973. Water and water relations. In B. E. Caldwell (Ed.)., Soybeans: Improvement, production, and uses, 239-266. Agron. 16, Amer. Soc. Agron.

Mullins, J. A., F. F. Bell, and T. McCutchen. 1972. Tillage methods and residue management with a soybean-wheat double-cropping system. Tenn. Farm and Home Sci. Progress Report, 82:2-3.

Musick, J. T., and D. A. Dusek. 1971. Grain sorghum response to number, timing, and size of irrigations in the Southern High Plains. Trans. Amer. Soc. Agric. Eng., 14:401-405.

Ndon, B. A., R. G. Harvey, and J. M. Scholl. 1982. Weed control in double-cropped corn, grain sorghum, or soybeans minimum-till planted following canning peas. Agron. J., 74:266-269.

Nelson, T. R., and D. D. Kletke. 1984. Oklahoma farm and ranch custom rates. Okla. State Univ. Exten. Facts, No. 140.

Oliver, L. R., M. McClelland, and W. D. Mathis. 1976. Response of six morning-glory species to bentagon. Proc. South. Weed Sci. Soc., 30:37.

Palmer, R. D. 1979. Weed survey--Southern states. South. Weed Sci. Soc. Res. Rep., 32:115.

Phillips, S. H., and H. M. Young, Jr. 1973. No-tillage farming. Milwaukie, Wisc.: Reinman.

Reicosky, D. C., and D. E. Deaton. 1979. Soybean water extraction, leaf water potential, and evapotranspiration during drought. Agron. J., 71:45-50.

Robinson, E. L., G. W. Langdale, and J. A. Stuedemann. 1984. Effect of three weed control regimes on no-till and tilled soybeans. Weed. Sci., 32:17-19.

Rogers, H. T., D. L. Thurlow, and G. A. Buchanan. 1971. Cropping systems and other cultural practices. In Soybean production--Recent research findings. Auburn Univ. Agric. Exp. Stn., Bull. 413, 31-38.

Salter, P. J., and J. E. Goode. 1967. Crop responses to water at different stages of growth. Commonwealth Agric.. Bureaux, Farnham Royal, Bucks, England, 246-252.

Sanford, J. O. 1982. Straw and tillage management practices in soybean-wheat double-cropping. Agron. J., 74:1032-1035.

Sanford, J. O., D. L. Myhre, and N. C. Merwine. 1973. Double cropping systems involving no-tillage and conventional tillage. Agron. J., 65:978-982.

Shaw, R. H., and D. R. Laing. 1966. Moisture stress and plant response. In W. H. Pierre et al. (Eds.), Plant environment and efficient water use. Am. Soc. Agron., 73-94.

Shipley, J., and C. Regier. 1975. Water response in the production of irrigated grain sorghum. High Plains of Texas, Tex. Agric. Exp. Stn., 1202.

Shurtleff, J. L., and H. D. Coble. 1985. Interference of certain broadleaf weed species in soybeans. Weed Sci., 33:654-657.

Soane, B. D., and J. D. Pidgeon. 1975. Tillage requirement in relation to soil physical properties. Soil Sci., 119:376-384.

Stewart, J. I., R. D. Misra, W. O. Pruitt, and R. M. Hagan. 1975. Irrigating corn and grain sorghum with a deficient water supply. Trans. Am. Soc. Agric. Eng., 18:270-280.

Stougaard, R. N., G. Kapusta, and G. Roskamp. 1984. Early preplant herbicide applications for no-till soybean weed control. Weed Sci., 32:293-298.

Swearingin, M. L. 1973. Double-cropping in the corn belt. Better Crops With Plant Food, 57(2):20-24.

Thompson, W. R., Jr. 1981. Ten steps to higher soybeans and profits. Suppl. to Progr. Farm, 96(1):15-16.

Touchton, J. T., and J. W. Johnson. 1982. Soybean tillage and planting method effects on yield of double-cropped wheat and soybeans. Agron. J., 74:57-59.

Touchton, J. T., J. W. Johnson, and B. M. Cunfer. 1980. The relationship between phosphorus and copper concentrations in wheat. Soil Sci. and Plant An., 11:1051-1066.

Triplett, G. B., Jr. 1978. Weed control for double crop soybeans planted with the no-tillage method following small grain harvest. Agron. J., 70:577-581.

Tyler, D. D., and J. R. Overton. 1982. No-tillage advantages for soybean seed quality during drought stress. Agron. J., 74:344-347.

Unger, P. W., and R. E. Phillips. 1973. Soil water evaporation and storage. In Proc. Natl. Conf. Conserv. Tillage, SCS Am., Ankeny, Iowa, 42-54.

Unger, P. W., and B. A. Stewart. 1976. Land preparation and seedling establishment practices in multiple cropping systems. Multiple cropping. Spec. Pub. no. 27, 255-273.

United States Department of Agriculture (USDA). 1975. Minimum tillage: A preliminary technology assessment. (Part II of a report for the Committee on Agriculture and Forestry, U.S. Senate.) Washington, D.C.: U.S. Government Printing Office. (Pub. no. 57-398.)

Whitwell, T., G. Wehtje, R. H. Walker, and J. A. McGuire. 1985. Johnsongrass control in soybeans with postemergence grass herbicides applied alone and in mixtures. Weed Sci., 33:673-678.

VITA

Jay Douglass Prater

Candidate for the Degree of

Master of Science

Thesis: MONO- AND DOUBLE-CROPPED WHEAT, SOYBEANS, AND GRAIN SORGHUM UNDER RAINFED AND IRRIGATED CONDITIONS

Major Field: Agronomy

Biographical:

Personal Data: Born in Altus, Oklahoma, November 22, 1955, the son of Mr. and Mrs. J. D. Prater.

Education: Graduated from Olustee High School, Olustee, Oklahoma, May, 1974, received Bachelor of Science degree in Agriculture from Cameron University in May, 1979, completed requirements for the Master of Science degree at Oklahoma State University in May, 1987.

Professional Experience: Pest Control Operator, Altus, Oklahoma, May, 1979 to June, 1981; Cotton Scout Supervisor, Coakley Consultants, Altus, Oklahoma, July, 1981 to October, 1981; Senior Agriculturist, Department of Agronomy, Oklahoma State University, March, 1982 to present.