EFFECTS OF IRRIGATION, PHOSPHORUS AND POTASSIUM FERTILIZATION, AND MONO AND DOUBLE CROPPING SYSTEMS ON YIELDS AND GRAIN ELEMENTAL COMPOSITION OF WHEAT, SOYBEANS AND GRAIN SORGHUM

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PREFACE

This thesis summarizes a three year (1980-1982) experiment at the Vegetable Research Station near Bixby, Oklahoma. In the first two years the effects of irrigation and double cropping on yields of soybeans and grain sorghum were examined. In the third year the effects of phosphorus and potassium fertilization on yields of wheat, soybeans and grain sorghum were also studied. Chemical composition of the grains of soybeans, wheat and grain sorghum, and soil test value changes with the imposed treatments were also examined in 1982.

I express thanks to Dr. R. Jewell Crabtree, my major advisor and good friend, for his guidance, assistance, and encouragement while I worked on my doctoral degree at Oklahoma State University. I would also like to express thanks to the other committee members, Dr. Lawrence Morrill, Dr. Lewis Edwards, and Dr. Ronald McNew, for their help in preparation of this dissertation and for other instructions given. I would like to recognize the financial support given by Oklahoma State University for research and schooling.

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CHAPTER I

INTRODUCTION

In eastern Oklahoma, mono and double crop soybean and grain sorghum production is often limited by inadequate moisture caused by erratic precipitation patterns. Some years yield reductions due to drought are small, but in other years severe reductions in yields of these crops occur. Supplemental irrigation has the potential for increasing yields almost every year. However, irrigation systems are generally expensive and if yield increases from irrigation are not large enough to cover the costs of acquisition and operation of the irrigation system, it would not be economically feasible to irrigate. Crop removal of soil nutrients will be greater under double cropping and irrigation than under monocropping and rainfed conditions. Irrigation may also increase crop response to added fertilizers. Presently, sufficient data are not available for eastern Oklahoma to accurately estimate yield increases or to determine the economic feasibility of irrigating mono and double cropped soybeans and grain sorghum. Information is also needed to more accurately estimate the responses of wheat, soybeans, and grain sorghum to fertilization under irrigation and double cropping.

The objective of this experiment was to obtain experimental data on potential yield responses of mono and double cropped wheat, soybeans, and grain sorghum to irrigation and to phosphorus (P) and potassium (K) fertilizer applications. Changes in soil test values and grain elemental composition with irrigation and P and K applications under mono and double cropping conditions were also studied.

CHAPTER II

REVIEW OF LITERATURE

Double Cropping

Double cropping, the growing of two successive crops on the same land in one year, makes better use of climatic resources (39, 137) and has the potential for reducing production costs per crop while increasing net income and land use efficiency (75). It has been shown to be profitable under favorable climatic conditions and proper management (28, 54, 164).

The yield of each crop in a double cropping system is usually reduced as compared to the same crop in a monocropping system (39, 132, 136). Late planting of the double crop due to late harvesting of the first crop can be a major factor causing this yield reduction because it reduces the time a plant has to develop, carry on photosynthesis, and produce full size seeds (19, 28, 77, 115, 117, 122, 144, 150, 156). Jeffers et al. (79) found soybean yield reductions of a bushel/acre (67 kg/ha) per day for each day past the optimum planting date. Beatty et al. (11) and Boerma and Ashley (20) reported a 50% and Beaver and Johnson (12) reported a 33% soybean yield reduction for plantings from one to two months late. However, delaying planting can increase yields if by doing so the soybeans enter the pod set and pod fill stages of growth under more favorable moisture conditions (59). In soybeans, late planting reduces percent harvestable seed (seeds above 10 cm) (12), and, except for dry seasons, increases lodging (115, 119). Parker et al. (117) found soybean seed quality decreased for late plantings but Green et al. (62) showed seed quality was more dependent on weather conditions during seed maturation than on planting date. Late planted soybeans often had lower seed quality because they matured seed during hot, dry weather, but if seeds matured during cooler, more humid weather, late planted soybeans had equivalent or better seed quality. When compared to wheat planted near the optimal planting date, late planted wheat has lower grain yields because it extracts less water from the soil, develops a less extensive root system, tillers less, produces fewer heads, accumulates less dry weight before winter (which can reduce winter survival rates) and uses nitrogen (N) less effectively (48, 53, 56, 83, 84, 159). Alhagi (3) indicated that increasing wheat seeding rate may compensate for late planting. In Australia, Millington et al. (105) reported that grain yields varied little with date of planting, however, other researchers have found that planting after the optimal planting date usually reduces yields due to a shorter seed maturation period which reduces seed size (19, 72, 77, 150). Martin et al. (93) reported better control of chinch bugs and sorghum midge with early plantings. When the double crop is planted at the same time as the monocrop the yield comparisons are variable and depend more on other growth factors including weather and tillage practices (5, 38, 39, 132).

Grain yields also depend on the combination of crops grown in the double cropping system. Rupp (134) reported greater wheat yields after an earlier maturing soybean variety than a late maturing variety and Sanford et al. (137) found higher wheat yields after soybeans than after sorghum, partially because the soybeans left the soil more friable and higher in N than did the grain sorghum. Sorghum usually produces well after small grains and is more drought resistant than many crops, making it a good double crop choice for possible water deficient areas. However, sorghum often retards growth and reduces yields of crops planted after harvesting sorghum (93).

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 monocrop (24, 38, 39, 174). This increased total grain yield usually more than compensates for the higher total production costs of a double cropping system, resulting in a greater net income from a double cropping system as compared to a monocropping system (136, 174). However, grain yields and production costs vary greatly depending on the geographic region and the management practices used (136, 138).

Weed control is very critical in double cropping. Continuous double cropping over several years often leads to weed control problems, with perennial weeds usually causing more problems than annual weeds (42, 63, 74, 79). One reason these weed problems occur is that herbicides with longer residual effects that can be used to effectively control weeds in one crop may injure the subsequent crop and, therefore, are not suitable for use in double cropping systems (112, 127). Weed control in double cropping has been acheived by the use of a contact herbicide, such as glyphosate [*N*-(phosphonomethyl) glycine] or paraquat (1,1'-dimethyl-4,4'-bipyridinium ion), plus a residual herbicide, such as linuron [3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea] or metribuzin [4-amino-6-*tert*-butyl-3-(methylthio)-*as*-triazine-5(4*H*)one] (depending on the weed species present) (32, 112, 163). Narrow rows often reduce weed competition because of rapid canopy development which shades the ground and retards the growth of weeds (26, 27, 121). However, growth of vigorously growing weeds such as johnsongrass (Sorghum halepense) amd cockleburr (Xanthium pensylvanicum) does not seem to be reduced by narrow rows (119), nor do narrow rows effectively control weeds if early weed control measures are unsatisfactory (173).

The use of narrow rows for increasing yields has attracted much attention over the last few years (12, 26, 35, 37, 39, 42, 51, 59, 74, 79, 100, 117, 120, 153, 174). Planting soybeans and grain sorghum in narrow rows makes more effective use of space by forming a more complete canopy which provides more photosynthetic area and produces greater yields (11, 20, 72, 74, 119, 161, 164). Boerma and Ashley (20) noted that although narrow rows did not seem to increase yields very much in monocrop soybeans in the Southeast, there was a definite yield advantage to narrow rows for late-planted soybeans such as in double cropping systems. In their study, the late-planted soybeans, with a shorter growth period, did not grow as much vegetatively and did not canopy over in wide rows. In areas of the far South where the growing period is longer and plants grown in wide rows are able to canopy over the rows, Smith (144) found no yield response to narrow rows for late-planted soybeans. Soybeans planted in narrow rows may not increase yield if soil moisture is inadequate (2, 134, 157).

Proper selection of varieties is an important management consideration in double cropping. Carter and Boerma (29) reported that soybean varieties with highest yields under early-wide row conditions did not necessarily yield the most under late-narrow row conditions. They suggested using an earlier maturing variety planted in narrow rows to obtain the highest yields in double cropping. Rupp (134) found a late-maturing soybean variety produced more than an early-maturing variety when planted as a double crop. Pendleton and Hartwig (119) stated that using a late-maturing variety for double cropping resulted in more harvestable yield (seeds above 10 cm) than using an early-maturing variety. Use of the earlier maturing variety should, however, increase yields of the wheat crop following soybeans (122, 134).

Establishment of a good stand in double cropping is often difficult due to residue interference and low soil moisture (39, 91, 108, 134). Residues can be removed either by gathering or burning. However, straw removal over a period of several years may reduce soil productivity and burning the straw will pollute the air (136). Swearingin (156) found that using weighted fluted coulters in front of the planters helped overcome the problem of stand establishment in residues. Planting the seed deep enough to reach moist soil may provide the seed with sufficient moisture to germinate, emerge and grow, but planting too deep could reduce emergence (52, 119, 153). A compromise solution given by Stucky (153) is to plant the seed deep enough to be in moist soil, then scrape off some of the soil over the seed with a cultivator sweep.

Disease and insect control in double cropping will depend on the type of pathogen or insect, amount of moisture, temperature, health and development of the plant, and effect of double cropping on biological controls (115). For some diseases and insects the double crop acts as a rotation and breaks the disease or insect's life cycle, thus reducing disease occurrence and insect populations (155). Other diseases and insect populations are enhanced by double cropping because each crop is a host or carrier of the disease or supports the insect's life cycle (25).

Additional and special equipment may be needed for double cropping, especially if planted no-till (61). However, Ewen et al. (51) reported intrarow skips of up to 46 cm did not reduce double crop soybean yields significantly, indicating that special equipment that would distribute the seeds evenly in the row was not essential for double cropping.

Other management practices that increase the chances for successful double cropping are (1) an excellent stand of small grain to control weeds, (2) sufficient moisture, (3) adequate fertility for both crops, and (4) planting the summer crop as soon as possible after removal of the small grain crop (provided sufficient moisture is present) (39, 54, 100, 156).

Tillage

No-till, planting directly into stubble, and minimum tillage, using the minimum number of tillage operations needed to prepare a seedbed under the existing soil and climatic conditions, are commonly used when double cropping. This is done principally because of the short time usually available for tillage operations between successive crops. Allen et al. (5) reported no-till required only one fifth the time conventional tillage required. McKibben and Oldham (100) stated that no-till increased the chances for successful double cropping because of timeliness of operations and water conservation. No and minimum tillage also help prevent wind and water erosion (16, 57, 85, 98, 99, 119). Fewer trips over the field produce a savings in fuel, machine and labor costs (5, 16, 57, 61, 119). Herbicide costs are usually higher for no and minimum tillage systems (57) and additional and special equipment can increase production costs (61, 119). However, Malcom (91) showed a slightly modified drill planter could be used in no-till planting to reduce costs. Wendte and Nave (174) reported no difference in net income for no-till vs. conventional tillage.

Yield comparisons between no and minimum tillage vs. conventional tillage vary depending on weed control, precipitation, soil and microclimate temperatures, stand establishment, and disease and insect control. The degree of weed control in no and minimum tillage systems is a major cause of yield differences. Weeds are generally more difficult to control with no-till than with conventional tillage, especially after the first or second year, because weeds resistant to the herbicides used in no-till systems go largely unchecked, whereas in conventional tillage these weeds are controlled through cultivation (132, 168). Perennial weeds cause the most problems in no-till systems, but glyphosate shows promise for helping to control them (168). Allen et al. (5) reported weed control was better in no-till grain sorghum because of a rougher interrow seedbed and quicker shading of the soil by sorghum. When weeds are not controlled, yields for no-till sorghum and soybeans are lower than for conventional tillage systems (137).

Soil moisture is usually greater under no and minimum tillage than under conventional tillage because of decreased runoff, increased infiltration, and decreased surface evaporation (5, 16, 18, 31, 85, 99, 119, 151, 164, 165, 167). This is especially true for sloping fields and soils with slow infiltration rates. Crabtree et al. (38, 39) found no significant differences in soil moisture under no-till vs. conventional tillage treatments on fields of 0 to 1% slopes. When seasonal rainfall is inadequate, no-till yields are often superior to conventional tillage yields because of the additional soil moisture under no-till (18, 79, 113, 164, 167). This additional soil moisture improves seed quality by reducing purple stain and wrinkled seed coats of soybeans (165). The lower evaporation rate and lower temperatures under no-till also reduce soil crusting (5, 16).

Maintaining the moisture content of a soil maintains a higher heat capacity, thus making the soil more resistant to temperature change. This effect, along with shading of the soil by crop residues, causes fields under no-till to be cooler in the spring and summer and warmer during the winter (5, 16, 61, 119, 166). Where growing seasons are short and crops are planted early in the season, the cooler temperatures slow crop growth, increase weed problems (since the smaller plants cannot compete as well with the weeds), and ultimately reduce yields (16, 145). In the South where high spring and summer temperatures are of more concern than frosts, the lower soil temperatures under no-till protect the seedlings from desiccation and in many cases produce better emergence, faster growth, less leaf loss, earlier maturity and higher yields (5, 166, 168). Lower soil temperatures also influence N mineralization rate and reduce nitrate accumulation in the soil (16), and can reduce percent Mn and Zn in plant tissue (49, 87).

Residues and stubble left on the field with no and minimum tillage often reduce stand and yield by interfering with planting and fertilizer application, and by decreasing seedling emergence (31, 61, 108, 119, 136, 156, 168). Using a fluted coulter in front of the planting unit (especially in heavy residues) and moving the residues away from the planting row helps overcome these problems (5, 31, 156). Sanford et al. (137) found that no-till reduced soybean stands as compared to conventional tillage if planting was followed by a light rain, but stands were improved by no-till if planting was followed by a heavy rain because the stubble prevented the soil from crusting.

Residues can provide a habitat for insects and diseases harmful to crops (25, 61, 119, 155) and may produce phytotoxins which predispose plants to diseases (31, 155). Burns (25) states that although theoretically no-till could lead to large increases in diseases and insects, it probably will not, due to pesticides, resistant varieties, and other treatments available.

If weeds, diseases and insects can be controlled, and with similar stands, yields with no-till are usually as good as, or better than, with conventional tillage (5, 16, 18, 31, 38, 39, 74, 79, 113, 134, 137, 164, 167, 168, 174). However, Van Doren et al. (169) found yield reductions with comparable stands of no-till soybeans when weeds and diseases were controlled. They attributed the yield reductions to a greater bulk density and reduced soil penetrability under no-till as compared to conventional tillage. Concentration of nutrients near the top of the soil profile, greater aggregate stability, improved soil structure and higher organic matter content of soils under no-till may also affect yields (16, 69, 136, 169). Estes (50) found lower plant tissue concentrations of Ca, Mg, Zn, molybdenum (Mo), boron (B) and Al, higher plant concentrations of K, and no effect on plant concentrations of P, Fe and Mn in corn grown no-till as compared to corn grown with conventional tillage.

Irrigation

In a review of double cropping in Illinois, Dillon and McKibben (42) state that "drought is probably the major cause of failure in many non-irrigated double cropping systems", and in a review of soybean management, Pendleton and Hartwig (119) called soil moisture the key to double cropping. Malcom (91) and Greenland (63) reported drought caused complete crop failure in one of two and two of three years, respectively, for double cropped soybeans and grain sorghum in eastern Oklahoma. Crabtree and Makonnen (38) predicted that double cropping without irrigation would be successful in eastern Oklahoma only 60% of the time. In Indiana, Swearingin (156) reported that 90% of the double crops that were planted in soil too dry for germination and emergence failed.

Whenever rainfall is inadequate or not properly distributed throughout the growing season, irrigation will usually increase both mono and double crop yields. Yield response to irrigation varies from area to area depending on natural precipitation, temperature, the crop(s) grown, and soil properties. Craigmiles and Wood (40) and McCauley (97) reported that soybeans did not respond to irrigation in the Texas Gulf Coast Prairie. Rogers and Thurlow (131) reported yield response of soybeans to irrigation in only one of three years in Alabama. In northeast and east central Arkansas and in Tennessee, soybean yields were significantly increased by irrigation 60% or more of the time (30, 60, 116, 147). Reports from most of the Great Plains and areas of similar or drier climates showed soybean yield response to irrigation except in unusually wet years with well distributed rainfall (4, 6, 7, 8, 20, 22, 78, 88, 90, 94, 100, 102, 103, 107, 128, 154).

Sorghum grain yields usually increased as the amount of water applied increased (14, 58, 64, 110, 111, 113, 130). Often one or more timely irrigations, or allowing greater soil water depletion before irrigation, gives yields equal to full season irrigation while requiring only a fraction of the irrigation water (6, 7, 33, 44, 47, 58, 80, 94).

For soybeans, rainfall distribution is usually more important than the amount. Runge and Odell (133) examined 49 years of Illinois data and determined that maximum soybean yields occurred in years when above average rains came during the late vegetative, bloom and pod-fill growth stages. In Alabama, yield increases were more highly correlated with rains during pod-fill (131). Pod-fill is the most critical growth stage for occurrence of water stress, and irrigation during pod-fill usually increases yields more than irrigation at any other time (6, 33, 43, 47, 97, 119, 135, 143, 160). Water stress during pod-fill reduces seed size and weight, number of seeds per pod, and may reduce pod number (7, 47, 107, 139, 143). Water stress during pod-set (especially late pod-set) also decreases yield by reducing the number of pods (7, 47, 107, 139, 143) and sometimes by reducing seed weight and number of seeds per pod (143). The flowering period is usually less critical for water stress occurrence than pod-fill or pod-set (6, 97) since a soybean plant has many flowers and will normally abort over half of them under good conditions (23). Even when the flower abortion rate is higher than normal, the number of pods may be reduced but the soybean plant often compensates by putting more beans per pod or by developing bigger beans (6, 107, 126, 139, 143). However, if too many flowers are aborted the plant cannot compensate completely and yield reductions occur (7, 26, 47, 97, 135, 146). The least critical growth stage for water stress is the vegetative stage (6, 43, 97). Although moisture stress during this period may reduce vegetative growth, most researchers have reported that the grain yield is not affected unless the drought is severe (4, 6, 7, 8, 71, 147). However, in many of the reported experiments, lower evaporative demand, higher rainfall amounts, and pre-irrigation of treatment plots may not have allowed water stress to develop as much during the vegetative stage as in later growth stages. Yield reductions and crop failures have been observed when drought occurs during germination and emergence, but since most experiments in yield reductions due to drought start with an established stand or are pre-irrigated, little information is available on yield reduction due to water stress during the establishment stages (91, 156). A graphical summary from Shaw and Laing (139) of yield reduction (expressed as a percentage of potential yield) if water stress occurs during critical physiological growth stages is given in Figure 1. Even though some growth stages are more critical than others, severe drought during any growth stage can reduce grain yields (43, 143).

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 (58, 140, 152). The greatest response to irrigation has been reported for irrigation during the vegetative (14), vegetative to heading (149), booting and heading (135), booting through bloom (86), and grain filling (110) growth stages. If moisture is inadequate, the initial moisture present is used to produce vegetative growth, leaving little moisture for grain development (80). Irrigation that ends severe drought before heading causes undesireable sucker growth, and late season drought causes spindly stalks, fewer heads, unfilled heads, and lodging (80). Drought during booting stage causes heads to be only partially exerted from the whorl, and that part that remains in the whorl does not produce seed (140). No yield response to irrigation was reported for irrigation at milk stage or later (80, 111, 149). On the other hand, many researchers have reported that grain sorghum yield is reduced if water stress occurs at anytime during plant growth (14, 64, 86, 110, 140, 152).

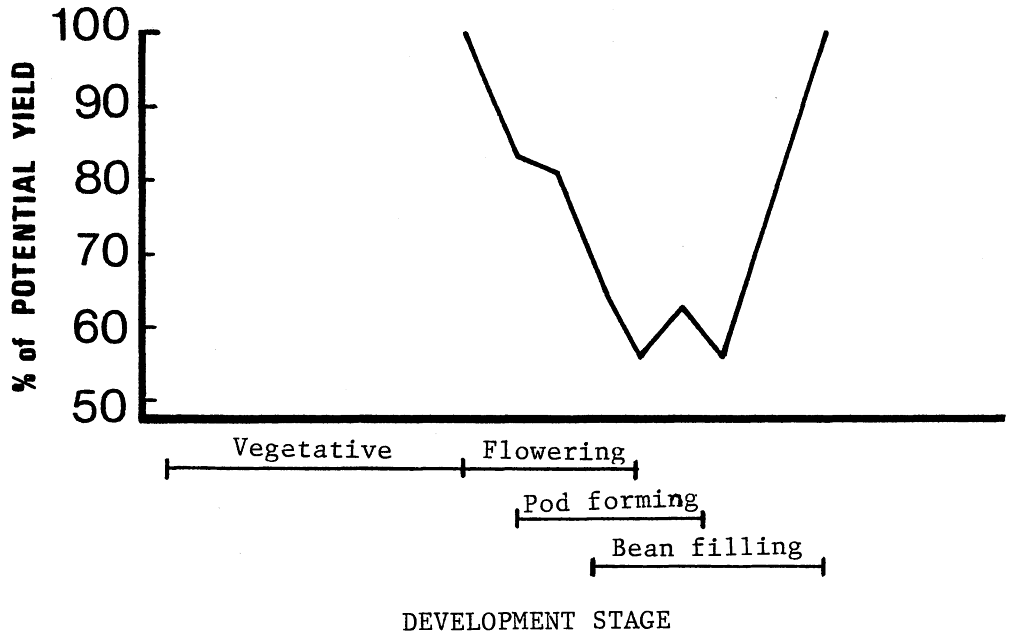

Figure 1. Yield reduction (expressed as a percentage of potential yield) if water stress occurs at certain critical growth stages. Adapted from Shaw and Laing (139).

Irrigation of soybeans and grain sorghum increases plant root growth in the upper part of the soil profile (82, 95, 96) and increases dry matter production (4, 7, 8, 71, 82). In soybean production it has been reported that irrigation increases lodging (which decreases yields) (22, 34, 96, 116, 154), delays maturity (4, 96, 160), increases water use (44, 92), reduces canopy temperature (which favors higher yields since temperatures above 35° C have been shown to reduce yield) 128, 133, 154), and helps increase rhizobia populations (89). Irrigation usually does not lower (and may increase) nutrient concentrations in soybean leaves and seeds (4, 8, 102, 103). Bielorai et al. (14) reported higher yields and lower percent protein in grain sorghum at high irrigation rates. Management practices for higher yields such as narrower rows, higher plant populations, more fertilization, better varietal selection, and better rhizobia inoculation (for soybeans) are more feasible with irrigation (14, 24, 60, 64, 90, 100, 101, 111, 130). On the other hand, maximum response to irrigation comes when other management practices are optimum (6, 80).

Even though irrigation may increase yields it may not be economical if the costs for installation, operation and financing are too high. Among the things to be considered for determining costs are initial price of the system, energy requirements, labor, seed, fertilizer, pesticides, land costs, inflation, financing arrangements, depreciation, repair costs, taxes (or tax breaks), and learning costs (since irrigation will probably not be applied as effectively the first few years because the farmer is learning how to use the system) (60, 138). In Arkansas and the Great Plains irrigation should be profitable (6, 60), but in Alabama and the Texas Gulf Prairie irrigation may not be profitable (40, 97, 131).

Phosphorus and Potassium Fertilization

Phosphorus and potassium are used extensively in agriculture to increase yields and quality of most crops, including soybeans, wheat and grain sorghum (124, 125). Grain and dry matter yield responses of wheat, soybeans and grain sorghum to P and K are usually inversely proportional to the available P and exchangeable K in the soil, with larger responses at low P and K availabilities and little or no yield response at high P and K availabilities (10, 13, 41, 54, 55, 65, 67, 104, 129, 141, 172). Plants respond more to either P or K depending on which one is the most limiting (21, 41, 104). Drought, disease, pests, low soil temperatures, poor soil aeration, low nutrient availability (other than P and K) and other yield reducing factors usually reduce yield response to P and K fertilizer applications (13, 66). In Georgia, Brown and Perkins (24) found little yield response of mono and double cropped grain sorghum, corn and small grains to P and K fertilization under rainfed conditions but a good response to P and K applications under irrigated conditions. However, Reneau et al. (129) reported a greater response to K applications in years of lower rainfall. They explained that during times of limited moisture, water films around and between soil particles become thinner resulting in less soil K movement and reduced plant uptake of K, resulting in lower yields. When K is applied, distances K must move in the soil (or plant roots need to grow to get K) decrease, resulting in more K uptake by plants and increased yields. During severe droughts water becomes the limiting factor and no amount of fertilizer will increase yields.

Different crops and varieties differ in their response to P and K fertilization, with soybeans usually responding less to P and K than do corn, sorghum and wheat (41, 66). Wheat, corn and sorghum respond more to direct P and K applications, whereas soybeans usually respond as well to residual P and K as to direct applications (10, 41, 66). This is advantageous in a wheat-soybean double cropping system since P and K can be applied once a year to the wheat in quantities sufficient for both crops (162).

Boswell and Anderson (21) reported that soybeans continued to respond to yearly P and K applications because previous applications had been immobilized, but low soil pH (5.4) may have lowered P and K availability. Hanway and Weber (67) and others (41, 45, 129, 162) found low soybean yield response to P and K applications, with response to only the first increment (each year) or to the first year of P and K fertilization, after which little or no yield response was obtained. As management practices and varieties improve, yield responses to P and K become greater and more consistent (124, 125).

Fertilizer applications of P and K will increase soil availability of these nutrients, but applications may not be effective if they are applied broadcast without incorporation (as is often done in no-till systems) and the surface remains dry (54, 66, 76). However, with sufficient moisture on a wheat-soybean double crop, Touchton et al. (162) found that broadcast, unincorporated P applications were just as effective as broadcast, incorporated P applications.

Applications of P or K usually increase the concentration of that element in plant tissue and seed, especially when growing conditions are good and when the initial soil availability of the applied nutrient is low (55, 65, 68). Bhangoo and Albritton (13) reported that P applications did not increase P concentrations in soybeans under limited moisture conditions.

Soil P (either native or applied) affects the availability and plant uptake of many other nutrients. Harper and Paulsen (70) reported that wheat seedling N concentrations were reduced by low P availability. Generally, if P applications produce yield increases in wheat, sorghum and corn, it will also reduce percent N in the plant through a dilution effect (123, 158). Reneau et al. (129) reported an exception to this and attributed it to greater root proliferation with added P. Bhangoo and Albritton (13) and Hanway and Weber (68) found no difference in percent N in soybean grain from P applications even when yields increased. The plant K concentration response to P is similiar to that for N, with dilution of K concentration for wheat, corn and sorghum, and little K concentration change for soybeans when P additions produce a yield increase (13, 68, 129, 162). No difference in availability of soil K at different P rates was found by Touchton et al. (162) and Adams (1).

Phosphorus additions have decreased Ca and Mg concentrations in soybeans (13) and have increased Ca and Mg concentrations in wheat and sorghum (129, 162). Touchton et al. (162) reported no effect on soil Ca and Mg availability with P applications, but Adams (1) stated that soil available Ca was reduced by P applications.

Badanur and Venkata Rao (9), Hulagur et al. (76), and Singh and Swarup (142) reported reduced availability of Zn, copper (Cu) and Mn with high and/or continued P applications. This may have been due to either an increase in soil pH or interaction of the micronutrients with the applied phosphates. In pot experiments, Bingham and Garber (15) found that P applied in many different forms increased soil available Zn, Cu and Mn. Pauli et al. (118) reported similar results for Zn except when applied with calcium carbonate, in which case P reduced available Zn. In a field experiment with P applications ranging from 0 to 128 kg/ha (which were lower rates than used in the experiments mentioned previously) no effects of P on soil available Zn, Cu and Mn were found (162).

The effect of P on soil availability of Zn, Cu and Mn, and its effect on plant uptake of these micronutrients are not necessarily related (1, 15, 109). Although P application generally reduces percent Zn, Cu, and Fe in plants, contradictions and theories abound in the literature as to why and how much P affects many of the micronutrients, especially Zn (1, 49, 109, 162, 172). One area receiving much attention is the effect of soil pH on plant micronutrient uptake at different soil P levels. At a pH of around 5 to 6 or above, P applications reduce plant uptake of Zn, Cu, Mn, Fe and Mo, but increase uptake of B. At low pH, P applications increase plant uptake of Mn and Mo but may reduce Al, B, Zn, and Fe uptake (1, 15, 109, 171). Crop response to P also influences the effect of P on plant micronutrient concentrations. Hilka (73) reported a dilution effect for Cu when yields increased due to P applications, but Shukla and Singh (141) reported P increased Cu concentrations in wheat until wheat no longer gave a yield response to P, after which P applications reduced plant Cu concentrations. An important point made by Murphy et al. (109) and confirmed by others (1, 49, 172) is that even though P may effect the micronutrient concentrations in plants, yields are not usually affected unless P is excessive and micronutrient(s) are low or are at toxic levels.

Potassium helps increase N absorption by plants (17, 70, 106) but wheat, sorghum and corn N concentrations may not increase or may decrease due to dilution if there is a yield response to K (123, 129). Soybeans did not show a N dilution effect when yields were increased by K applications (13, 68). Bhangoo and Albritton (13) and Reneau et al. (129) found that K did not affect P concentrations in soybeans and grain sorghum, but Miller et al. (104) reported that percent P in soybeans decreased with added K if soil P was low, and increased with added K if soil P was high. Plant Ca and Mg concentrations are usually reduced and percent B and Mo in plants may be reduced by K applications (13, 125, 129).

CHAPTER III

MATERIALS AND METHODS

A field study to determine irrigation and cropping system effects on yield of soybeans and grain sorghum was conducted at the Vegetable Research Station near Bixby, Oklahoma in 1980 and 1981. Cropping systems used were monocrop-conventional tillage and double crop (after wheat-grain harvest)-no tillage. The soil is a Wynona silty clay loam (Cumulic Haplaquolls) with 0 to 1% slope. The experiment was expanded in 1982 to include the effects of two phosphorus (P) and two potassium (K) fertility levels on the yield and nutrient uptake of soybeans, grain sorghum and double crop wheat. The effects of P and K fertilization on several soil test values were also evaluated. The experimental design used for the first two years was a 4 x 2 (cropping system (S) by irrigation (I)) factorial arranged in a randomized, complete block design with four replications. In 1982 a split plot design was used with the S x I treatments as the main plots and a 2 x 2 factorial arrangement of P and K fertilizer rates as the subplots.

Adjacent areas with the same soil type (both of which had been cropped to soybeans previous to planting double crop wheat) were used in 1980 and 1981. 'TAM W-101' winter wheat was planted on 24 Nov. 1979 and 25 Nov. 1980 on the plots which would later be planted to double crop soybeans (DCSB), double crop grain sorghum

(DCGS), or left in summer fallow. The wheat plots received a broadcast application of 135 kg N/ha as ammonium nitrate (NH_4NO_3) on 28 Feb. 1980 and 26 Feb. 1981, and were harvested on 2 July 1980 and 22 June 1981. Monocrop soybean and grain sorghum plots were winter fallowed, then plowed and tandem disced in the spring. Plots to be planted to grain sorghum received a broadcast application of 155 kg N/ha as NH_4NO_3 just before planting each year.

Trifluralin (a,a,a-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine) at 1.1 kg active ingredient (AI)/ha and propazine [2-chloro-4,6-bis(isopropylamino)-s-triazine] at 2.2 kg AI/ha were applied to monocrop soybean (MCSB) plots and monocrop grain sorghum (MCGS) plots, respectively, for weed control. Herbicides were incorporated with two additional tandem discings prior to planting. Chemical weed control for the DCSB plots consisted of glyphosate [N-(phosphonomethyl) glycine] at 1.1 kg AI/ha, oryzalin (3,5-dinitro-N^4,N^4-dipropyl-sulfanilamide) at 1.1 kg AI/ha, and metribuzin [4-amino-6-tert-butyl-3-(methylthio)-as-triazine-5(4H)one] at 0.4 kg AI/ha. DCGS received glyphosate at 1.1 kg AI/ha and linuron [3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea] at 0.8 kg AI/ha. Additional weed control measures used during the growing season included mechanical cultivation (monocrop only), hand hoeing, and 'wiping' with glyphosate.

On 22 May 1980 and 9 June 1981, MCSB and MCGS were planted at a rate of 370,000 and 180,000 viable seeds/ha, respectively. Row widths of 50 and 75 cm were used in 1980 and 1981, respectively. Varieties used were 'Forrest' (Maturity Group V) soybeans and 'Paymaster BR-Y93' grain sorghum. Plot size was 18.3 x 18.3 m. Plots were planted with a no-till planter equipped with 5-cm fluted coulters, double-disk openers, 4-cm depth bands, and press wheels. DCSB and DCGS were planted into wheat stubble on 2 July 1980 and 22 June 1981 using the same varieties, rates, row spacings and planter as for the monocrop plots. Yields were determined by harvesting an 18.3 x 6 m section from the center of each plot with a Gleaner Model "A" combine. MCGS, MCSB, DCGS, and DCSB were harvested on 16 Sept., 30 Oct., 6 Nov., and 7 Nov., respectively, in 1980. In 1981, MCGS was harvested on Oct. 5 and MCSB, DCGS, and DCSB were harvested on Nov. 14.

In 1982 the experiment was moved back to the original (1980) site which had been cropped to soybeans in 1981. Plot size was reduced to 18.3 x 9.1 m. 'TAM W-101' winter wheat was planted on 4 Dec. 1981 on those plots which would later be planted to DCSB, DCGS, or left in summer fallow. Soil samples of the top 15 cm of the soil profile were taken from each subplot on 25 Feb. 1982 prior to any fertilizer applications. Two levels of P (0 and 67 kg/ha as concentrated superphosphate) and two levels of K (0 and 135 kg/ha as muriate of potash (KCl)) were applied broadcast without incorporation in a 2 x 2 factorial arrangement to the four subplots in each of the main plots. A broadcast application of 155 kg N/ha as NH_4NO_3 was also applied to the wheat on 25 Feb. 1982. An 18.3 x 3 m section from the center of each plot was harvested for wheat grain yields on 28 June 1982 with a Gleaner Model "A" combine.

Soybeans and grain sorghum were planted in 75-cm rows on 22 June and 28 June 1982 for monocrops and double crops, respectively, using the same varieties, weed control measures, seeding rates, planter and tillage methods as in 1980 and 1981. The late planting date for monocrop plots was due to wet fields and heavy rains in May and early

June. Grain yields were determined by harvesting the center 4 rows (3 m) of each plot with a Gleaner Model "A" combine. All grain sorghum plots were harvested on 19 Oct. 1982 and all soybean plots were harvested on 25 Oct. 1982.

At their respective harvest times, grain samples of wheat, soybeans and grain sorghum from each plot were collected for nutrient analysis. After drying and grinding, total N was determined by the micro Kjeldahl method, and P, K, Ca, Mg, Mn, Fe, Al, B, Cu and Zn concentrations were determined by the use of a direct reading emmission arc spectrograph. On 26 Feb. 1983 soil samples were again taken from each subplot and analyzed for nitrate nitrogen, pH, P, K, Ca, and Mg at the Oklahoma State University soil testing laboratory.

Irrigated plots were sprinkler irrigated as required to avoid stress. From 5 to 7 cm of water were applied at each irrigation. Total irrigation water applied is shown in Table 1.

Table 1. Irrigation water applied to soybeans and grain sorghum.

Treatment	1980	1981	1982	Average
	cm			
Monocrop	45	30	35	37
Double crop	40	30	35	35

CHAPTER IV

RESULTS AND DISCUSSION

Irrigation and Cropping System Effects on Yields

Since a different area (same soil type) was used each year and because of the difficulty in irrigating the wheat plots, no irrigation or cropping system treatments were applied to the wheat during this three year experiment. All wheat was planted into soybean stubble and would be considered double cropped wheat (DCWH). Wheat was established to set up the plots for planting of DCSB and DCGS into wheat stubble. Average wheat yields for 1980 and 1981 were 2250 and 3040 kg/ha, respectively.

Soybeans

Soybean grain yields are given in Table 2. The yields given for 1982 (when the experiment was expanded to include P and K fertility treatments) include only those treatments receiving no P and K additions. A significant interaction occurred between irrigation and cropping system treatments (see analysis of variance table (AOV), Table 21, appendix). Irrigation significantly increased MCSB yield each year with the average increase being 556 kg/ha. DCSB did not respond to irrigation in 1980 and 1981, but a small, 147 kg/ha yield increase was obtained in 1982. There are several reasons why an interaction between irrigation and cropping system treatments may have occurred. Since DCSB are preceded by a wheat crop, the amount of available water at planting is usually less for DCSB than for MCSB, and indicates that DCSB should respond more to irrigation than MCSB. However, Crabtree and Rupp (39) (on the same site) showed that although soil water for MCSB was significantly greater than for DCSB at planting, by the time the plants reached the reproductive growth stages, differences in soil water content were small and generally not significant. The additional soil water for MCSB was probably used to increase vegetative growth, resulting in more transpiration and greater water use. This may have caused a greater response to irrigation later in the growing season when rainfall was inadequate.

Table 2. Soybean yield response to irrigation and cropping system.

Treatment	1980	1981	1982	3 Year Average
		kg/ha		
Monocrop Irrigated	2713	2291	2306	2436
Monocrop Rainfed	1959	1865	1817	1880
Double Crop Irrigated	1932	1843	1738	1838
Double Crop Rainfed	1910	1798	1591	1767
LSD (0.05)	382	382	382	216

Explanation of the yield results can also be approached by looking at water stress during critical physiological growth stages. MCSB were planted six, two and one week(s) before DCSB in 1980, 1981 and 1982, respectively. Therefore, MCSB and DCSB entered their critical water stress periods at different times. Since rainfall distribution was not uniform throughout the season, MCSB and DCSB could have been stressed differently during their critical growth periods, resulting in a difference in response to irrigation. Figures 2, 3 and 4 show daily rainfall amounts each year together with a graph (from Shaw and Laing, see Figure 1) showing when each crop entered its critical stage and the percentage of potential yield that could be expected if water stress occurred during that period. The rainfall data is indicative of when water stress occurred, although other factors such as differences in stand density, previous water storage, evaporation, and transpiration may create more stress for one cropping system than for the other. The rainfall distribution data (Fig. 2) indicate more water stress occurred during the critical period for MCSB than for DCSB in 1980, but the rainfall distribution pattern induced water stress appears to have been similar for both crops in 1981 and also in 1982 (Fig. 3 and 4). With normal planting time, MCSB (Maturity Group V) usually enter their critical water stress period in late August, whereas DCSB (Group V) enter their critical water stress period in early to mid September. Examination of the 25-year monthly precipitation pattern at Bixby (Fig. 5) shows lower amounts of rainfall in August and higher amounts in September. Therefore, given other factors are equal, MCSB should have a higher average yield response to irrigation than DCSB. Lack of rainfall during critical times may explain part of the difference in MCSB and DCSB yield responses to irrigation, but does not completely explain the magnitude of the differences observed. DCSB appeared to lack sufficient rainfall during their critical period all three years and should have responded

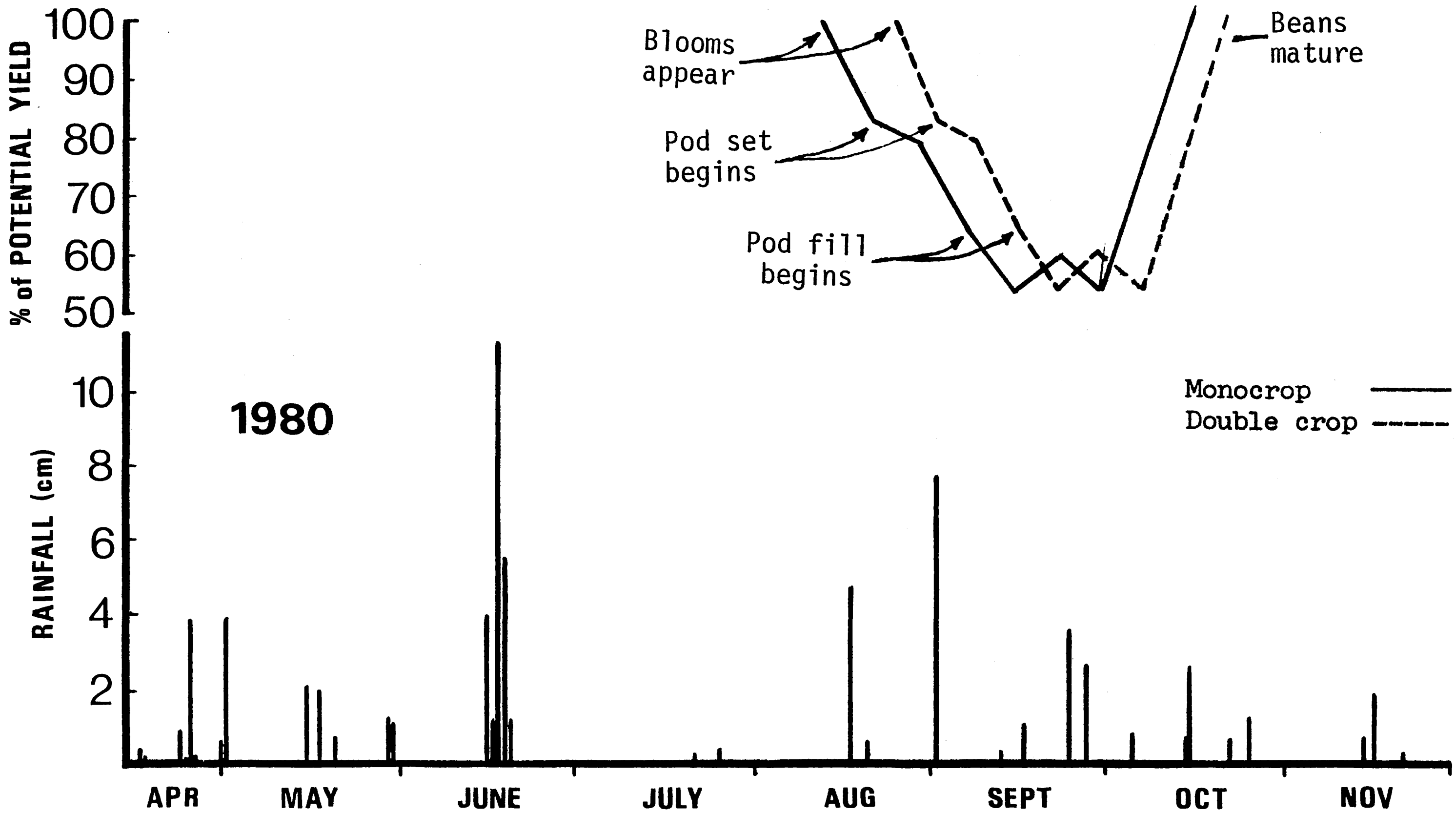

Figure 2. Rainfall, 1980, compared with possible yield reductions if drought occurs during critical physiological growth stages of mono- and double crop soybeans. Graph is placed to show when critical growth stages occurred during 1980.

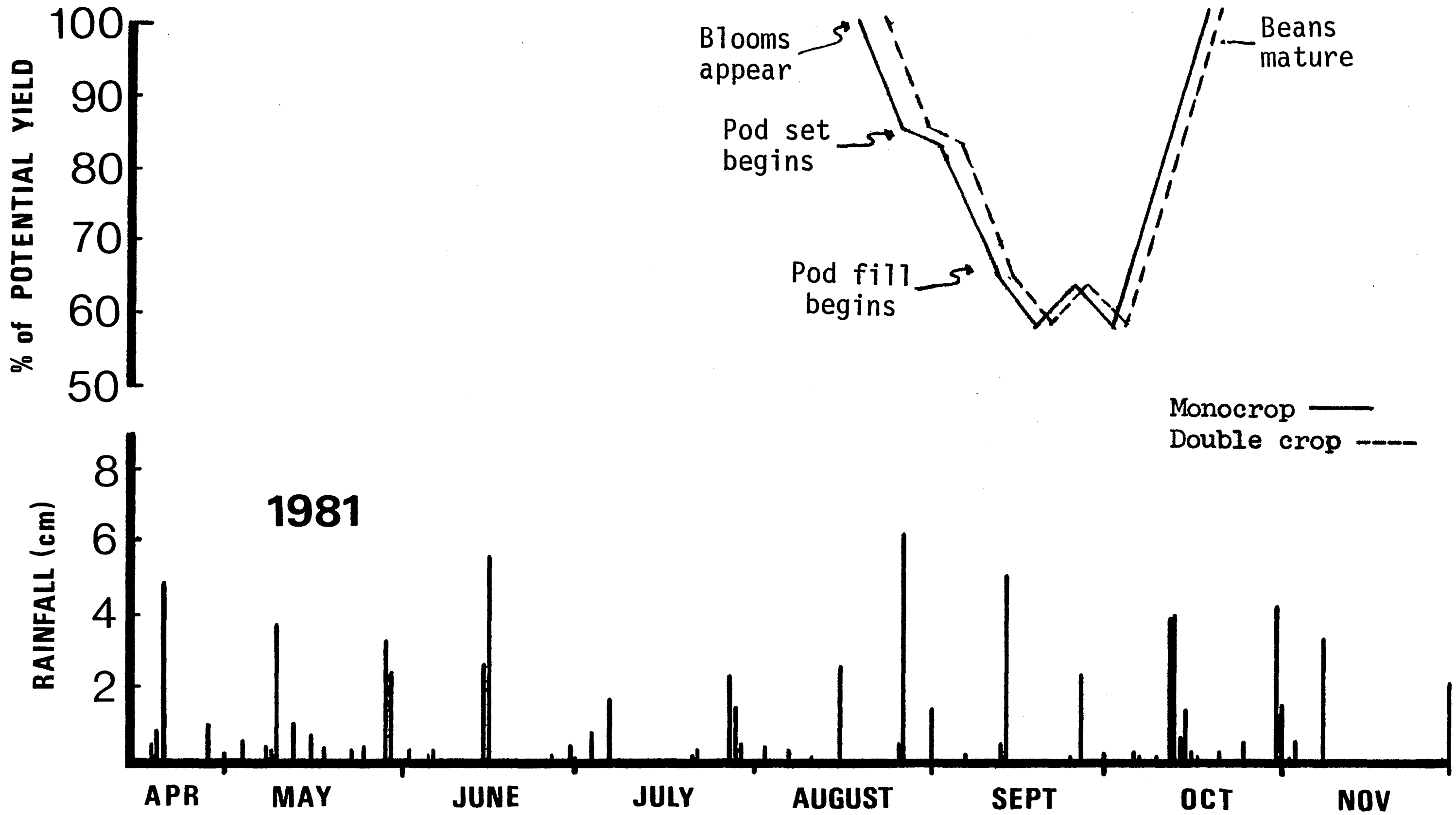

Figure 3. Rainfall, 1981, compared with possible yield reductions if drought occurs during critical physiological growth stages of mono- and double crop soybeans. Graph is placed to show when critical growth stages occurred during 1981.

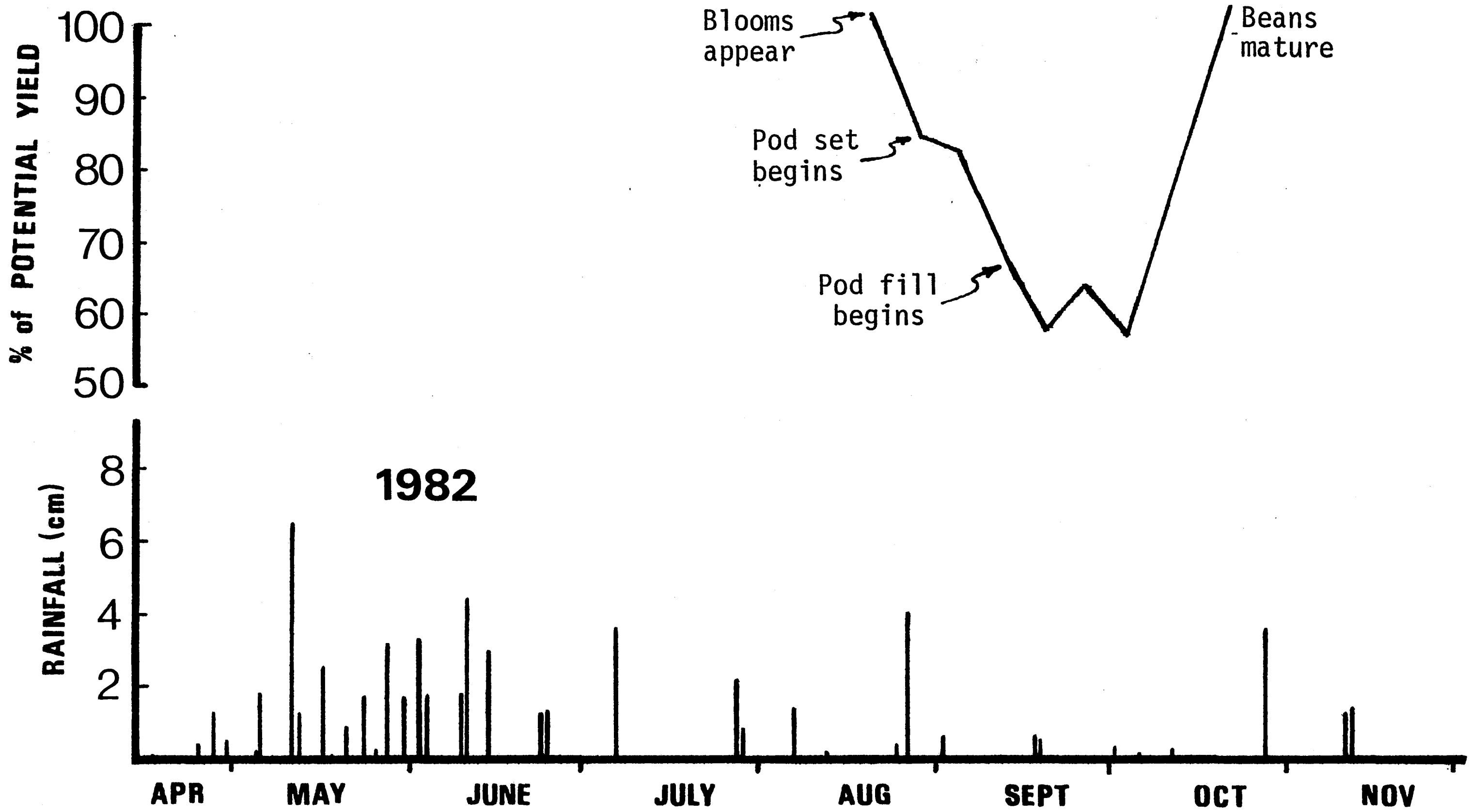

Figure 4. Rainfall, 1982, compared with possible yield reductions if drought occurs during critical physiological growth stages of mono- and double crop soybeans. Graph represents both mono- and double crop soybeans. The graph is placed to show when critical growth stages occurred during 1982.

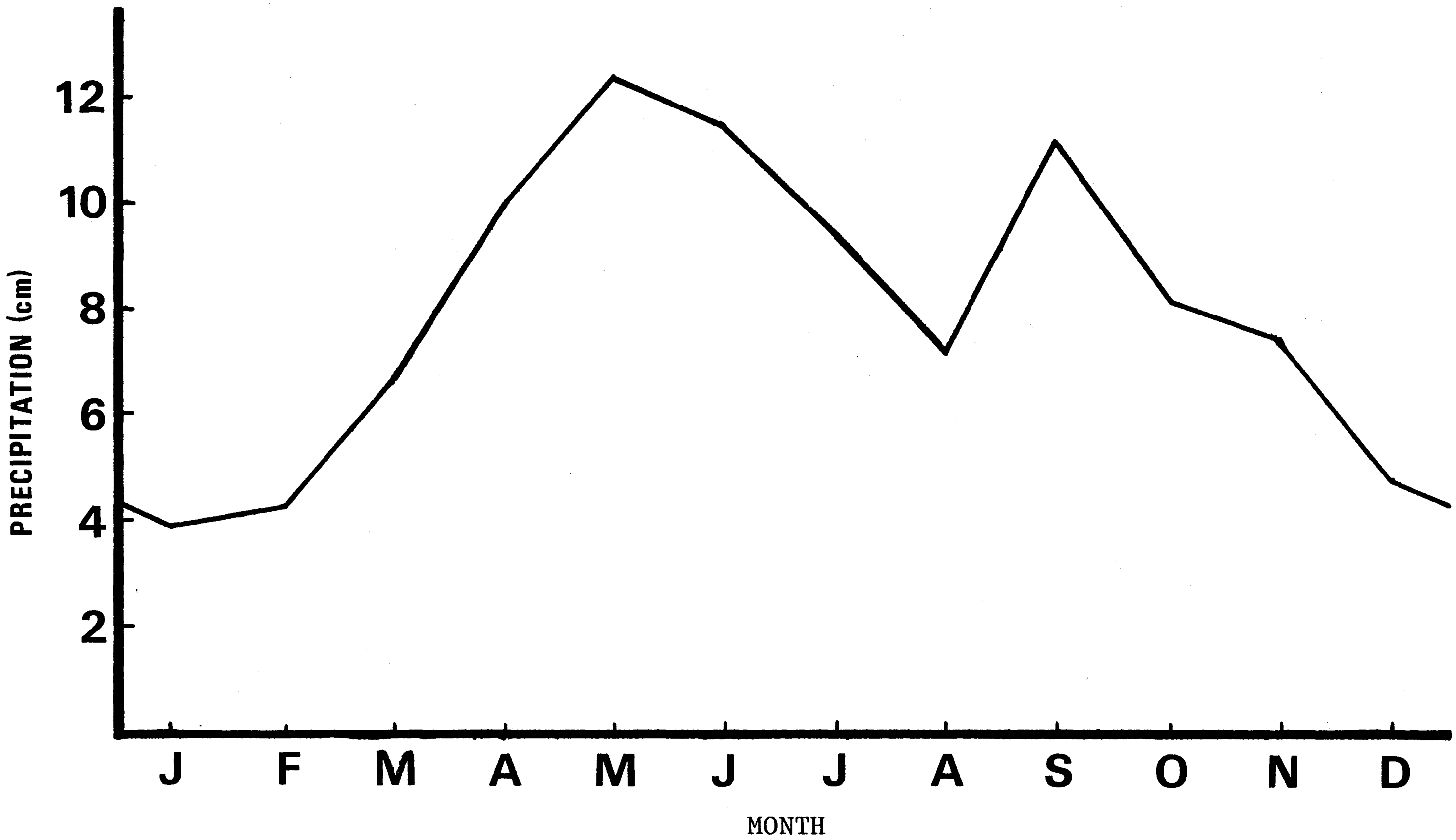

Figure 5. Average monthly precipitation at Bixby, Oklahoma (1950-1975).

to irrigation in 1980 and 1981, and should have responded more to irrigation in 1982.

Lower stand densities were noted for DCSB and were similar for the three years of the study. The number of plants per meter of row in 1981 was 14.9 and 8.7 for MCSB and DCSB, respectively (148). Straw interfered with planting and emergence of soybeans by preventing the planter from placing the seed properly in the soil. The result was a reduced and uneven stand of soybeans in DCSB plots. With a lower plant density, plants have a greater soil volume per plant from which to draw water and would, therefore, have more water available per plant, resulting in less response to irrigation than a soybean crop with a higher plant density.

Although DCSB may have responded less to irrigation because they were planted no-till, which has been shown by some researchers to increase available water by increasing infiltration and reducing evaporation, this is probably not the case in this experiment since Crabtree and Rupp (39) showed no significant difference in water storage between no-till and conventional tillage on this site. A greater yield potential because of a longer time for growth and development may have allowed MCSB to respond more to irrigation than DCSB.

Under irrigation, MCSB produced significantly higher yields each year than DCSB, but MCSB and DCSB yields were not significantly different under rainfed conditions (Table 2). This indicates that MCSB yields under rainfed conditions were limited by water stress, but yields of DCSB, on the other hand, were limited by something other than moisture stress. Low and uneven plant populations were the most likely limitation. If stand density and uniformity could be increased, a greater yield response to irrigation would be expected. Additional research on planter modification, straw management, seeding rates, and other management practices is needed to produce a better stand of soybeans in soybeans planted no-till into grain stubble.

Grain Sorghum

Yield responses of grain sorghum to irrigation and cropping systems are shown in Table 3 (also see AOV, Table 22, appendix). Irrigation increased yields of both MCGS and DCGS in 1980 and 1981 but did not significantly affect MCGS yields in 1982. A dry period from July to mid August of 1980, and only light intermittent rains in late June through mid August of 1981 reduced yields of rainfed grain sorghum. In 1982, a soil profile well supplied with moisture from May and June rains and intermittent rains in July and August provided MCGS with sufficient water for good yields without irrigation.

Grain sorghum responded more to irrigation in 1981 than in 1980, even though 1980 was a drier year. There are several possible reasons for this. In 1980, grain sorghum started out the season with the soil profile well supplied with water. As the soil dried out, the sorghum possibly put down deeper roots and was able to obtain soil-stored moisture. In 1981, lighter spring rains did not fill the soil profile and light intermittent rains probably kept the roots closer to the soil surface and more subject to yield reduction from water stress periods.

Weed competition played a major part in causing yield response differences to irrigation by reducing the yield potential of the 1980 grain sorghum. The field used in 1980 was infested with rhizome johnsongrass (Sorghum halepense) and had some tall morning glory (Ipomoea purpurea), whereas the field used in 1981 was nearly free of these two weeds. Other weed species were successfully controlled by herbicides or tillage. The control of johnsongrass in grain sorghum remains one of the most difficult management problems, especially with DCGS and/or no tillage. At the present time, crop rotation with a crop such a MCSB where johnsongrass can be controlled through chemicals and cultivation appears to be the best solution. Black bird damage is also a serious problem in grain sorghum production and caused reduced harvestable yield in 1980.

Table 3. Grain sorghum yield response to irrigation and cropping systems.

Treatment	1980	1981	1982	2 year[‡] Average
	kg/ha			
Irrigation[§]				
Irrigated	3847	5133	5859[#]	4490
Rainfed	3178	3506	5751[#]	3342
LSD (0.05)	602	602	NS	426
Cropping system[¶]				
Monocrop	3202	3883	5805	3542
Double crop	3823	4756	--	4289
LSD (0.05)	602	602		426

[‡]Does not include 1982 data.

[§]Averaged over cropping system treatments.

[¶]Averaged over irrigation treatments.

[#]Does not include double crop, but does include all P x K monocropped treatments.

In this study grain sorghum yield did not seem to be affected by drought disproportionally more during any particular "critical growth stage". The large separation in planting dates between MCGS and DCGS in 1980 caused these crops to enter "critical growth stages" at different times but no significant difference in yield response of MCGS and DCGS to irrigation was observed (Table 22, appendix). In 1981, the DCGS and MCGS were planted close enough together that no difference in response to irrigation due to "critical periods" could be detected. There was a higher water stress during boot stage in 1980 than in 1981 but grain sorghum responded more to irrigation in 1981, indicating that the boot stage (which has been identified by some researchers as the most critical growth stage) may not be so critical in this environment. Heavy spring rains that filled the soil profile seemed to have the greatest single influence on grain sorghum yield response to irrigation. For this three year study, the more spring precipitation received, the less the yield response to irrigation. Additional years of data are needed to better define any relationship that might exist between rainfall distribution patterns and grain sorghum yield response to irrigation.

DCGS produced significantly higher yields than MCGS except in 1982 when the DCGS failed due to johnsongrass infestation (Table 3). The DCGS was planted no-till which may have increased yield by reducing microclimate temperatures and improving moisture conditions during the early summer (as reported by Allen et al. (5)). Stand density did not appear to be a problem for either MCGS or DCGS. The grain sorghum variety used is a mid season variety. It is usually planted in eastern Oklahoma in mid to late June. Planting it earlier than this date, as was done for MCGS in 1980 and 1981, may have reduced MCGS yield and been one of the reasons DCGS produced more than MCGS.

DCGS consistently had more johnsongrass problems than did MCGS and johnsongrass caused DCGS failure in 1982. Unless johnsongrass can be better controlled, DCGS production in this area would not be recommended.

Effects of Irrigation, Cropping System, P, and K Treatments under the 1982 Environment

In 1982 the experiment was expanded to include P and K fertilization treatments (applied to plots in Feb. 1982) in addition to the irrigation and cropping system treatments applied in 1980 and 1981. Data for soil fertility levels and grain nutrient elemental concentrations were evaluated along with grain yields. Since DCWH for the 1981-82 season received P and K treatments, DCWH yield and grain nutrient elemental concentration responses to P and K were included in these analyses. Responses of wheat, soybeans and grain sorghum to the treatments applied depend on environmental conditions. Since these data represent only one year's results, they should be interpreted with caution, realizing that results in other years and under different environments may be different.

Soil Fertility

Applications of 0 and 67 kg P/ha and 0 and 135 kg K/ha were applied in a 2 x 2 factorial arrangement on each main plot on 25 Feb. 1982 after taking soil samples from the top 15 cm in each subplot. Test values of the soil samples taken just prior to P and K applications are included in Tables 4 through 7 and give a reference point for this and future studies. Soil samples were taken again one year later (Feb. 1983) to evaluate the effects of irrigation, cropping system, P, and K treatments on soil pH and soil nutrient levels.

Soil test K increased when K was applied (Table 4; also see AOV, Table 23, appendix). This increase was expected since more K was applied than was harvested in the grain of the various crops grown. Soil test K was higher for irrigated DCGS than for any other cropping system x irrigation treatment (Table 4). Most of the irrigated DCGS plots were not harvested in 1982 because of weeds and herbicide damage, so no K was removed in grain sorghum harvest. Soil samples taken before P and K applications in Feb. 1982 showed that irrigated DCGS plots had higher soil test K than other plots. These two factors combined resulted in higher soil test K for irrigated DCGS than for the other treatments.

Phosphorus applications increased soil test P (Table 5; also see AOV, Table 24, appendix). Phosphorus applications also significantly increased soil test Ca (by 44 kg/ha) (Table 5; also see AOV, Table 25, appendix). Applications of P and K did not affect soil nitrate-N, soil Mg, or soil pH, and K applications did not affect soil Ca (Table 6; also see AOVs, Tables 25-28, appendix). The amount of N, Ca and Mg uptake by the crops increased when K was applied (due to increased yields), but the increase in uptake was small compared to the amount of these nutrients in the soil and did not significantly affect the amounts of soil test N, Ca and Mg.

The soil pH was affected by both cropping systems and irrigation. DCGS and DCWH had the lowest soil pH and MCSB had the highest soil pH

Table 4. The effects of irrigation, cropping system and K application on soil test K.

Treatments		Soil test K‡ 1982§	1983¶
		kg/ha	
K application rate			
0 kg K/ha		305	290
135 kg K/ha		308	330
LSD (0.05)			9
Irrigation x Cropping system#			
Irrigated	DCGS	344	360
Irrigated	DCSB	311	305
Irrigated	MCGS	292	286
Irrigated	MCSB	311	283
Rainfed	DCWH	296	316
Rainfed	DCGS	305	313
Rainfed	DCSB	300	320
Rainfed	MCGS	300	304
Rainfed	MCSB	306	296
LSD (0.01)			35

‡1.0 N neutral NH_4OAc extractable.

§Soil test values for samples taken Feb. 1982 before any treatments were applied. These values are given as a reference point for this and future studies.

¶Test values for soil samples taken Feb. 1983 after one year of treatments.

#Double cropped grain sorghum after wheat (DCGS); Double cropped soybeans after wheat (DCSB); Monocropped grain sorghum (MCGS); Monocropped soybeans (MCSB); and Double cropped wheat after soybeans (DCWH).

Note: A soil test value of 280 kg K/ha is considered to be 100% sufficient according to the Oklahoma Soil Fertility handbook.

Table 5. The effects of P applications on soil test P and soil test Ca.

	Soil test P		Soil test Ca	
Treatment	1982	1983	1982	1983
	kg/ha			
0 kg P/ha	117	92	2478	2294
67 kg P/ha	120	121	2490	2335
LSD (0.05)		4		37

§Soil test values for samples taken Feb. 1982 before any treatments were applied. These values are given as a reference point for this and future studies.

¶Test values for soil samples taken Feb. 1983 after one year of treatments.

Note: A soil test value of 73 kg P/ha is considered to be 100% sufficient according to the Oklahoma Soil Fertility handbook.

Table 6. Means of measured soil parameters not responding to irrigation, cropping system, P, or K treatments.

	Mean‡	
Soil parameter	1982§	1983¶
	kg/ha	
Soil test nitrate-N	1.43	5.93
Soil test Mg	262	277

‡Mean averaged over all treatments.

§Soil test values for samples taken Feb. 1982 before any treatments were applied. These values are given as a reference point for this and future studies.

¶Test values for soil samples taken Feb. 1983 after one year of treatments.

Table 7. The effects of irrigation and cropping system treatments on soil pH.

Treatment	Soil pH 1982[‡]	1983[§]
Irrigation		
Irrigated	6.6	6.7
Rainfed	6.6	6.5
LSD (0.05)		0.1
Cropping system[¶]		
DCWH	6.6	6.5
MCSB	6.6	6.9
MCGS	6.6	6.6
DCSB	6.6	6.7
DCGS	6.6	6.5
LSD (0.05)		0.1

[‡]Soil test values for samples taken Feb. 1982 before any treatments were applied. These values are given as a reference point for this and future studies.

[§]Test values for soil samples taken Feb. 1983 after one year of treatments.

[¶]Double cropped wheat after soybeans (DCWH); Monocropped soybeans (MCSB); Monocropped grain sorghum (MCGS); Double cropped soybeans after wheat (DCSB); and Double cropped grain sorghum after wheat (DCGS).

(Table 7; also see AOV, Table 28, appendix). The lower pH values may have been due to nitrification of ammonium nitrate applications to the wheat and grain sorghum. As the ammonium ion undergoes nitrification, hydrogen ions are released, which lowers soil pH. Soil nitrate-N was not significantly greater in plots receiving ammonium nitrate applications (see AOV, Table 26, appendix). Total soil N was not measured and may have been higher in plots receiving N fertilization. Irrigation water was never applied in sufficient amounts to cause leaching or runoff. This could cause some salt buildup (from salts in the irrigation water) with a parallel rise in soil pH. A small increase in pH was observed with irrigation (Table 7; also see AOV, Table 28, appendix). Soil test Ca and Mg were numerically, but not significantly, greater under irrigation and soil test sodium was not measured. Some effort may be needed to monitor, and if necessary correct, salt buildup under irrigated conditions. When winter and spring rains are sufficient to leach excess salts from the top soil, no corrective action is necessary.

Wheat

All the wheat planted for the 1981-1982 growing season was planted into soybean stubble and would be considered DCWH. In eastern Oklahoma, monocropped wheat (MCWH) usually has higher grain yields than DCWH (38, 39). Therefore, MCWH and DCWH yield responses to P and K applications may differ.

DCWH grain yield responses to P and K applications for 1982 are shown in Table 8 (also see AOV, Table 29, appendix). Potassium increased grain yields 448 kg/ha when applied alone and 321 kg/ha when applied in combination with P despite the fact that soil tests showed K was at least 95% sufficient in all plots and over 100% sufficient in most plots (according to the Oklahoma Soil Fertility handbook (36)). The 1982 wheat crop received above average rainfall and, therefore, the response to added fertilizers may have been greater than in most years. However, for maximum profits applications of fertilizer should be sufficient that the nutrient applied does not limit crop production during years of above average conditions (36). Additional research is needed to determine if the accepted K sufficiency levels are high enough for maximum production in eastern Oklahoma with new and better varieties, irrigation and more intensive management practices (such as in double cropping).

Table 8. Wheat grain yield response to P and K applications.

Treatments		
P	K	Wheat Grain Yield
— kg/ha —		kg/ha
0	0	2109
0	135	2557
67	0	2135
67	135	2430
LSD (0.05)		99

A significant interaction occurred between P and K in that P did not effect yield at low K but decreased yield at high K (Table 8; also see AOV, Table 29, appendix). A positive response to P applications would not be expected since soil test values showed P was well above the 100% sufficiency level. On plots not receiving K applications, it appears K was a limiting nutrient affecting yield under the 1982 environment and the negative effect of P was not observed. When K was applied, P produced an effect that reduced grain production. Soil P level was not high enough to produce P toxicity, but this high level of soil P, P applications, and an associated soil pH of 6.6 has been shown to reduce uptake of several micronutrients (46, 109). If micronutrient level(s) in the plant fall below critical level(s) when P is applied, a yield reduction could occur. However, much more information is needed to determine if micronutrient deficiency(ies) caused the yield reductions observed.

The effect of P and K on grain elemental concentrations and on total nutrients removed in grain harvest (elemental concentration x grain yield) are shown in Tables 9, 10 and 11 (also see AOVs, Tables 30-51, appendix). Since K increased yield, a dilution of some of the elements with applied K would be expected, but such was the case only for B. Potassium applications decreased percent B in the grain but total B was not changed (Tables 9 and 10; also see AOVs, Tables 38 and 49, appendix). Percent N, K, Ca, Fe, and Al in the grain were not significantly affected by either P or K applications (Table 10; also see AOVs, Tables 30, 32, 33, 36 and 37, appendix), and percent P and Mg were not affected by applications of K (Tables 31 and 34, appendix). When soil nutrient availability is high, the dilution effect is often minimized, which appears to be what happened in this experiment. Since the K applications increased yields and did not cause a nutrient dilution effect (except for B), the total amount of

Table 9. Wheat grain parameters responding to K fertilization.

	Grain Nutrient Concentration		Total Nutrients Removed in Grain Harvest									
Treatment	Mn	B	TN†	TP	TK	TCa	TMg	TMn	TFe	TAl	TCu	TZn
	ppm		kg/ha					g/ha				
0 kg K/ha	55.2	1.81	53.9	15.1	18.1	2.24	4.53	118	113	8.8	7.99	120
135 kg K/ha	58.7	1.46	63.6	17.6	21.1	2.53	5.17	146	137	10.2	9.36	141
LSD (0.05)	2.4	0.30	1.8	0.7	0.8	0.16	0.19	7	7	1.0	0.56	5

†TN is total N removed in grain harvest; TP is for total P removed in grain harvest; etc.

Table 10. Means of wheat grain parameters not responding to P or K fertilization treatments.

Parameter	Mean†
% N in wheat grain	2.5 %
% K in wheat grain	0.8 %
% Ca in wheat grain	0.1 %
% Fe in wheat grain	54 ppm
% Al in wheat grain	4.1 ppm
Total B removed in grain harvest	3.7 g/ha

†Averaged over all treatments.

Table 11. Wheat grain parameters responding to P fertilization.

	Grain Nutrient Concentration				Total Nutrients	
Treatment	P	Mg	Cu	Zn	TCu†	TZn
	—— % ——		—— ppm ——		—— g/ha ——	
0 kg P/ha	0.69	0.207	4.03	57.7	9.32	135
67 kg P/ha	0.72	0.213	3.57	54.8	8.02	125
LSD (0.05)	0.02	0.005	0.20	1.2	0.56	5

†TCu and TZn are total Cu and total Zn, respectively, removed in wheat grain harvest.

nutrients removed in grain harvest was greater when K was applied (Table 9; also see AOVs, Tables 41-51, appendix).

When P was applied, percent P and Mg in wheat grain increased and concentrations of Cu and Zn decreased (Table 11; also see AOVs, Tables 31, 34, 39 and 40, appendix). The increase in grain P concentration was expected since applied P did not increase yields. Increases in Mg with applied P have been shown by others (129, 162), and are probably due to the anion phosphate and cation Mg^{++} creating a synergistic effect on plant uptake of both nutrients. The antagonistic effect of P on plant Cu and Zn concentrations has been well documented, especially at high P levels and pH values observed in this experiment (109). In a review of plant tissue analysis, Jones (81) and the Oklahoma Soil Fertility handbook (36) give general sufficiency ranges for micronutrient concentrations in plants. These ranges are mostly for plant tissue and not for mature seed, but an indication of possible nutrient deficiencies may be gained by comparison with the values reported. Using the values Jones and the Oklahoma Soil Fertility handbook give, Zn and Mn would be sufficient, Cu and Fe would be borderline, and B would be very deficient. No Cu deficiencies have been reported in Oklahoma, B deficiencies have been reported only on alfalfa and peanuts, and lime induced Fe deficiencies are sometimes found (36). Whether these concentrations of B, Fe, and Cu limited yield or whether the reduction of Cu concentration with applied P was the reason yields were reduced with P applications at high K fertility can not be verified with this experiment. More information is needed (possibly from plant leaf tissue analyses) to determine if these concentrations found in the grain represent deficiencies, and if so, what effect they have on yield.

The total amount of Cu and Zn removed in grain harvest was reduced by P applications because of the large reduction in wheat grain concentrations of these elements with applied P (Table 11; also see AOVs, Tables 50 and 51, appendix). Phosphorus applications did not increase the total amount of P and Mg removed in grain harvest even though grain concentrations of these elements were increased with P applications (Tables 42 and 45, appendix). This was due to reduced grain yields with P applications at high K fertilization.

Soybeans

In 1982 soybean yields were increased by irrigation, monocrop and K application treatments (Table 12; also see AOV, Table 52, appendix). There was no significant soybean grain yield response to P applications. Yield responses to irrigation or fertilization treatments are often greater if other management practices are optimum (6). However, in this experiment, yield response to irrigation was not improved with applied K or P, nor was yield response to K applications greater under irrigated (vs. rainfed) conditions. Under the rainfed treatment, low soil moisture conditions may occur. When this happens, thin water films around and between soil particles reduce K movement (through diffusion and mass flow) to the plant root. The crop's uptake of K is limited which may reduce yields. Applications of K increase K concentrations in the soil solution, increase plant K uptake, and may increase yields (129). Potassium applications may also increase root growth, allowing the plant to absorb more water and nutrients from the soil profile (125). Under irrigated conditions, increased plant growth caused K to be a limiting factor. Potassium applications corrected this limitation and increased yields. Soil test values indicated little or no response should be expected from K applications to soybeans (36). Data from 1982 indicate that accepted sufficiency level values for K may need to be reevaluated for soybean production on some soil types in eastern Oklahoma.

Table 12. Soybean grain yield response in 1982 to irrigation, cropping system (monocrop vs. double crop), and K application treatments.

Treatment	Soybean grain yield
Irrigation	
Rainfed	1909
Irrigated	2190
LSD (0.05)‡	135
Cropping system	
Double crop soybeans	1932
Monocrop soybeans	2167
LSD (0.05)‡	135
Potassium application	
0 kg K/ha	1934
135 kg K/ha	2165
LSD (0.05)‡	135

‡LSD calculated using error (pooled).

For the 1982 environment, the total amount of most elements in soybean grain increased under irrigation, MCSB and K application treatments (Tables 13, 14, and 15; also see AOVs, Tables 64-74, appendix). This increase occurred since these treatments increased yields and because little or no dilution of grain nutrient concentrations occurred with increased yields. Grain nutrient concentration dilution effects when yield increased were observed only with grain Ca concentrations (Tables 13, 14, and 15; also see AOV, Table 56, appendix). However, the percent increase in yield due to K applications was much greater than the percent decrease in the grain Ca concentration, resulting in an increase in total Ca when K was applied (Table 14; also see AOV, Table 67, appendix).

Irrigation increased Mn concentrations in soybean grain (Table 13; also see AOV, Table 58, appendix). If soil Mn was low, irrigation may have made it more available to plants either by increasing Mn movement in the soil or by increasing root growth. The increase in pH observed with irrigation would tend to decrease soil Mn availability, but this effect was not manifest in this year of this experiment, which can probably be attributed to the small increase in soil pH.

Potassium applications did not increase K concentrations in soybean grain but did increase total K removed in grain harvest (Table 15; also see AOVs, Tables 55 and 66, appendix). This was due to yield increases with applied K. Phosphorus applications did not affect grain P concentrations or total P in soybean grain (Table 16; also see Tables 54 and 65, appendix). When P is applied and no yield increase is obtained, luxury consumption often occurs resulting in higher plant P concentrations and greater total P uptake by the plant (68). In this experiment, high levels of soil P may have precluded a detect-

Table 13. Soybean parameters showing response to irrigation treatments.

	Grain Nutrient Concentration		Total Nutrients Removed in Grain Harvest†									
Treatment	Ca	Mn	TN	TP	TK	TMg	TB	TMn	TAl	TFe	TCu	TZn
	%	ppm	kg/ha				g/ha					
Irrigated	0.29	23.2	120	13.1	40.7	4.66	72.5	50.1	21.5	313	22.3	83.1
Rainfed	0.30	22.3	104	11.4	35.4	4.24	64.7	42.5	14.0	258	19.3	73.5
LSD (0.05)	0.01	0.7	6	1.0	1.8	0.38	5.2	2.9	6.1	31	1.7	4.0

†TN is total N removed in grain harvest; TP is for total P removed in grain harvest; etc.

Table 14. Soybean parameters showing response to cropping system treatments.

	Grain Nutrient Concentration		Total Nutrients Removed in Grain Harvest†					
Treatment	Ca	Cu	TN	TP	TK	TMg	TMn	TB
	%	ppm	kg/ha				g/ha	
Monocrop	0.28	9.5	119	13.0	40.6	4.66	49.0	73.0
Doublecrop	0.31	10.8	104	11.5	35.4	4.24	43.7	64.2
LSD (0.05)	0.01	0.6	6	1.0	1.8	0.38	2.9	5.2

†TN is total N removed in grain harvest; TP is for total P removed in grain harvest; etc.

Table 15. Soybean parameters showing response to K applications.

Treatment	Grain Nutrient Concentration		Total Nutrients Removed in Grain Harvest[†]								
	Ca	K	TN	TP	TK	TCa	TMg	TMn	TCu	TZn	TB
	%		kg/ha					g/ha			
0 kg K/ha	0.299	1.87	106	11.7	36.2	5.75	4.18	44.0	19.5	72.6	63.4
135 kg K/ha	0.292	1.86	118	12.8	39.8	6.25	4.72	48.7	22.1	84.0	73.8
LSD (0.05)	0.006	NS	9	1.0	2.7	0.44	0.35	3.3	1.8	6.5	5.6

[†] TN is total N removed in grain harvest; TP is total P removed in grain harvest; etc.

Table 16. Soybean parameters showing response to P applications.

Treatment	Grain Nutrient Concentration		Total Nutrients[†]
	P	Cu	TP
	%	ppm	kg/ha
0 kg P/ha	0.59	10.5	11.8
67 kg P/ha	0.61	9.9	12.7
LSD (0.05)	NS	0.4	NS

[†] TP is total P removed in grain harvest.

able percent grain P increase from occurring. Concentrations of P in the grain decreased with K applications under irrigated conditions, but K did not significantly affect grain P concentrations under rainfed conditions (Table 17; also see Table 54, appendix). Potassium applications increased Mg and decreased Fe concentrations in soybean grain under rainfed conditions but did not affect Mg or Fe concentrations under irrigated conditions (Table 17; also see AOVs, Tables 57-59, appendix). Reduction of Mg at high K levels when soil Mg was low has been reported (125), but the soil test values for Mg for this experiment were more than double the 100% sufficiency level (according to the Oklahoma Soil Fertility handbook (36)). Table 17 shows that Fe concentrations decreased when P concentrations increased, although some of the differences were not statistically significant. This indicates a possible P antagonism to Fe. Reduction of plant Fe uptake by P applications has been found by other researchers (1, 109, 114).

Antagonistic effects of P applications on Cu and Zn grain concentrations were evident as P applications decreased the Cu and Zn concentrations of soybean grain (Tables 16 and 18; also see AOVs, Tables 62 and 63, appendix). Applications of K overcame P induced reductions in Zn grain concentrations, but did not increase grain Cu concentrations. A similar response of plant Zn to P and K has been reported (125).

Grain concentrations of Cu were lower under MCSB than with DCSB (Table 14, also see AOV, Table 62, appendix). A possible reason for this is that the wheat removed some of the applied P, leaving less in the soil to affect plant Cu uptake in DCSB. Reduction of Zn concentrations for MCSB as compared to DCSB was not statistically

Table 17. Soybean parameters showing irrigation by K application interaction.

Treatments		Grain Nutrient Concentrations		
Irrigation	K application	P	Mg	Fe
	kg/ha	%		ppm
Irrigated	0	0.623	0.219	134
Irrigated	135	0.585	0.212	149
Rainfed	0	0.579	0.214	147
Rainfed	135	0.612	0.229	124
LSD (0.01)‡		0.037	0.014	23
LSD (0.01)§		0.047	0.018	30

‡For comparing responses to K treatments in the same irrigation treatment.

§For other pairwise comparisons.

Table 18. Response of Zn concentration in soybean grain to cropping system, irrigation, P, and K treatments.

Treatments		Grain Zn Concentration
		ppm
Irrigation x cropping system		
Irrigated	monocrop	35.7
Irrigated	double crop	40.4
Rainfed	monocrop	38.6
Rainfed	double crop	38.5
LSD (0.01)‡		2.4
Phosphorus x potassium		
0 kg P/ha	0 kg K/ha	39.4
0 kg P/ha	135 kg K/ha	38.7
67 kg P/ha	0 kg K/ha	36.3
67 kg P/ha	135 kg K/ha	38.9
LSD (0.01)‡		2.4

‡LSD Calculated using error (pooled).

significant under rainfed conditions but under irrigated conditions, MCSB grain had less Zn than DCSB grain (Table 18; also see AOV, Table 63, appendix). Residual P induced reduction of grain Zn concentration was more noticeable under irrigated conditions because of increased grain yield.

For the 1982 environment, grain B concentrations increased only when MCSB, rainfed and K application treatments were applied together (Table 19; also see AOV, Table 61, appendix). This finding is contrary to what has been observed by others. Irrigation usually increases soil B availability (170) and K may decrease B uptake by plants (125). More data are needed to definitely determine if B concentration is increased under this combination of treatments.

Table 19. Soybean grain parameters showing cropping system by irrigation by K application interaction.

	Treatments		
Cropping system	Irrigation	K application	Grain B Concentration
		kg/ha	ppm
Double crop	Irrigated	0	31.64
Double crop	Irrigated	135	33.75
Double crop	Rainfed	0	32.57
Double crop	Rainfed	135	32.96
Monocrop	Irrigated	0	33.11
Monocrop	Irrigated	135	32.17
Monocrop	Rainfed	0	33.52
Monocrop	Rainfed	135	36.09
LSD (0.01)[†]			2.50

[†]Calculated using error (pooled).

Grain sorghum

In 1982 grain sorghum yield did not respond to irrigation and its response to double cropping was not known since the DCGS was not harvested due to weeds (Table 3). MCGS yield was reduced when P was applied alone but was not affected by any other P and K treatments (Table 20; also see Table 75, appendix). This reduction was similar to that reported for wheat and reasons for the decrease are probably similar.

Percent N was the only grain nutrient concentration evaluated for grain sorghum. Nitrogen did not respond to irrigation, P or K treatments (see Aov, Table 76, appendix). This was probably due to high soil plus applied N levels and little or no yield response to the treatments applied. Total N removed in grain harvest was not affected by any of the applied treatments (see AOV, Table 77, appendix).

Table 20. Grain sorghum grain yield response in 1982 to P and K applications.

Treatment		
P	K	Grain sorghum grain yield
——— kg/ha	———	kg/ha
0	0	5990
0	135	5723
67	0	5529
67	135	5979
LSD (0.05)		433

CHAPTER V

SUMMARY AND CONCLUSIONS

A three year (1980-1982) field experiment was conducted at the Oklahoma State Vegetable Research Station near Bixby, Oklahoma. In 1980 and 1981 the grain yield response of mono- and double cropped soybeans and grain sorghum to supplemental full season irrigation was examined. In 1982, yield, grain elemental composition and soil test value responses to irrigation and to P and K applications on wheat, soybeans and grain sorghum under mono- and double crop conditions were determined.

Irrigation increased MCSB yields an average of 556 kg/ha per year, but DCSB yields were not affected by irrigation except in 1982 when only a small increase was recorded. A lower stand density in DCSB was probably the major cause for differences in yield response to irrigation between MCSB and DCSB, although time of precipitation as compared to each crop's critical period and differences in evapotranspiration rates and in initial soil moisture may have also contributed to the differences in yield response to irrigation. Yields of MCSB averaged 356 kg/ha more per year than DCSB yields, mostly due to large increases in MCSB yields when irrigated.

Both mono- and double cropped grain sorghum yields were much greater when irrigated. Yields of DCGS were greater than MCGS yields in 1980 and 1981. No yield comparison was possible in 1982 because

DCGS failed due to weeds.

Wheat yields were increased 372 kg/ha, soybean yields were increased 232 kg/ha, but MCGS yields were not affected when K was applied. Potassium applications increased yields under both irrigated and rainfed conditions and in both MCSB and DCSB. Neither soybeans nor grain sorghum responded more to irrigation if K was also applied, and response to K was not enhanced by irrigation. Applications of P did not increase yields of any crop tested.

Applications of K increased soil test K, and P applications increased soil test P and slightly increased soil test Ca. Other measured soil nutrients and soil pH were not affected by either P or K applications. Soil pH was slightly higher under irrigation, possibly due to salt buildup from the irrigation water, and lower in cropping systems receiving ammonium nitrate applications.

Removal of most soil nutrients was greater under double cropping and with irrigation and K applications, mostly because of greater total grain yield under these treatments. Some dilution effects as yields increased were seen with B in wheat and Ca in soybeans. Antagonism of P with grain Cu and Zn concentrations in wheat, and with grain Cu, Zn and Fe concentrations in soybeans was evident but its effect on grain yields was uncertain.

This study covered three years for irrigation effects and one year for P and K effects. More data are needed to better understand and document yield, grain elemental composition and soil test value responses to irrigation and to P and K applications under mono- and double cropped conditions.

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APPENDIX

Table 21. Analysis of variance table for soybean grain yield response to irrigationand cropping system (monocrop vs. double crop) for 1980-1982.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	46	7276285			
Year	2	584418	292209	1.96	0.197
Error (a)	9	1342270	149141		
System (S)	1	1553872	1553872	22.47	0.0001
Irrigation (I)	1	1206914	1206914	17.45	0.0003
S X I	1	692744	692744	10.02	0.004
Y X S	2	59341	29671	0.43	0.656
Y X I	2	47670	23835	0.34	0.712
Y X S X I	2	90770	45385	0.66	0.527
Error (b)	26	1797962	69152		

Note: Although plot size in 1982 was reduced to half the size used in 1980, the variance did not change significantly.

Table 22. Analysis of variance table for grain sorghum grain yield response to irrigation and cropping system (monocrop vs. double crop) for 1980 and 1981.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	30	35218795			
Year	1	3984175	3984175	3.68	0.104
Error (a)	6	6500381	1083397		
System (S)	1	4238967	4238967	13.03	0.002
Irrigation (I)	1	10324450	10324450	31.73	0.0001
S X I	1	291810	291810	0.90	0.357
Y X S	1	117922	117922	0.36	0.555
Y X I	1	1733834	1733834	5.33	0.034
Y X S X I	1	7062	7062	0.02	0.885
Error (b)	17	5530987	325452		

Table 23. Analysis of variance table for soil test K, February 1983.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	153	309821.75			
Rep	3	42757.96	14252.75	11.16	0.0001
Among main units					
Irrigation (I)	1	1549.99	1549.99	1.21	0.280
Crop System (S)	4	45446.38	11371.60	8.89	0.0001
S x I	4	27056.80	6764.20	5.29	0.003
Error (a)	27	34492.42	1277.50		
Within main units					
Phosphorus (P)	1	771.36	771.36	0.87	0.353
Potassium (K)	1	61200.28	61200.28	69.15	0.0001
P X K	1	96.51	96.51	0.11	0.742
I X P	1	497.63	497.63	0.56	0.455
I X K	1	281.25	281.25	0.32	0.574
I X P X K	1	1822.69	1822.69	2.06	0.155
S X P	4	3674.25	918.56	1.04	0.393
S X K	4	5387.08	1346.77	1.52	0.203
S X P X K	4	3085.96	771.49	0.87	0.485
S X I X P	4	1709.54	427.39	0.48	0.748
S X I X K	4	3788.89	947.22	1.07	0.376
S X I X P X K	4	1778.86	444.72	0.50	0.734
Error (b)	84	74343.35	885.04	0.	

Table 24. Analysis of variance table for soil test P, February 1983.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	152	95918.08			
Rep	3	14898.11	4966.12	6.26	0.002
Among main units					
Irrigation (I)	1	37.82	37.82	0.05	0.829
Crop System (S)	4	5256.07	1314.02	1.66	0.189
S x I	4	6325.43	1581.36	1.99	0.124
Error (a)	27	21415.99	793.18		
Within main units					
Phosphorus (P)	1	30902.58	30902.58	207.17	0.0001
Potassium (K)	1	5.76	5.76	0.04	0.845
P X K	1	504.81	504.81	3.38	0.069
I X P	1	650.94	650.94	4.36	0.040
I X K	1	92.80	92.80	0.62	0.433
I X P X K	1	1.29	1.29	0.01	0.926
S X P	4	1380.35	345.09	2.31	0.064
S X K	4	645.86	161.47	1.08	0.371
S X P X K	4	411.35	102.84	0.69	0.601
S X I X P	4	506.24	126.56	0.85	0.499
S X I X K	4	117.02	29.26	0.20	0.940
S X I X P X K	4	109.78	27.45	0.18	0.946
Error (b)	83	12381.02	149.17		

Table 25. Analysis of variance table for soil test Ca, February 1983.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	159	7137204			
Rep	3	1141099	380366	3.01	0.047
Among main units					
Irrigation (I)	1	242359	242359	1.92	0.177
Crop System (S)	4	553022	138256	1.10	0.379
S x I	4	95873	23978	0.19	0.942
Error	27	3406953	126183		
Within main units					
Phosphorus (P)	1	64648	64648	4.66	0.034
Potassium (K)	1	20842	20842	1.50	0.224
P X K	1	2231	2231	0.16	0.689
I X P	1	979	979	0.07	0.791
I X K	1	24301	24301	1.75	0.189
I X P X K	1	6576	6576	0.47	0.493
S X P	4	93219	23305	1.68	0.162
S X K	4	20480	5120	0.37	0.830
S X P X K	4	44271	11068	0.80	0.530
S X I X P	4	97537	24384	1.76	0.145
S X I X K	4	48752	12188	0.88	0.480
S X I X P X K	4	25181	6295	0.45	0.770
Error (b)	90	1248882	13876		

Table 26. Analysis of variance table for soil test nitrate-N, February 1983.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	159	762.4983			
Rep	3	25.2899	8.4300	1.37	0.274
Among main units					
Irrigation (I)	1	7.0686	7.0686	1.15	0.294
Crop System (S)	4	46.0559	11.5140	1.87	0.145
S x I	4	46.3386	11.5847	1.88	0.143
Error (a)	27	166.5049	6.1668		
Within main units					
Phosphorus (P)	1	2.5447	2.5447	0.57	0.454
Potassium (K)	1	1.5394	1.5394	0.34	0.560
P X K	1	0.7854	0.7854	0.17	0.677
I X P	1	1.5394	1.5394	0.34	0.560
I X K	1	1.5394	1.5394	0.34	0.560
I X P X K	1	1.5394	1.5394	0.34	0.560
S X P	4	3.4243	0.8561	0.19	0.943
S X K	4	18.2527	4.5632	1.02	0.404
S X P X K	4	13.5089	3.3772	0.75	0.560
S X I X P	4	2.7018	0.6755	0.15	0.962
S X I X K	4	15.5823	3.8956	0.87	0.487
S X I X P X K	4	3.8013	0.9503	0.21	0.932
Error (b)	90	404.4813	4.4942		

Table 27. Analysis of variance table for soil test Mg, February 1983.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	159	110140.9			
Rep	3	15353.6	5117.9	2.97	0.049
Among main units					
Irrigation (I)	1	3176.91	3176.91	1.84	0.986
Crop System (S)	4	7906.52	1976.63	1.15	0.356
S x I	4	7689.97	1922.49	1.12	0.369
Error	27	46502.38	1722.31		
Within main units					
Phosphorus (P)	1	380.13	380.13	1.63	0.205
Potassium (K)	1	320.47	320.47	1.38	0.244
P X K	1	0.79	0.79	0.00	0.954
I X P	1	422.73	422.73	1.81	0.181
I X K	1	132.73	132.73	0.57	0.452
I X P X K	1	63.62	63.62	0.27	0.603
S X P	4	1637.32	409.33	1.76	0.144
S X K	4	1248.21	312.05	1.34	0.261
S X P X K	4	881.46	220.37	0.95	0.441
S X I X P	4	1529.54	382.39	1.64	0.171
S X I X K	4	981.83	245.46	1.05	0.384
S X I X P X K	4	949.16	237.29	1.02	0.402
Error (b)	90	20963.60	232.93		

Table 28. Analysis of variance table for soil pH, February 1983.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	159	7.9640			
Rep	3	1.1970	0.3990	12.06	0.0001
Among main units					
Irrigation (I)	1	1.2960	1.2960	39.18	0.0001
Crop System (S)	4	3.3678	0.8420	25.46	0.0001
S x I	4	0.1553	0.0388	1.17	0.345
Error (a)	27	0.8930	0.0331		
Within main units					
Phosphorus (P)	1	0.0090	0.0090	0.98	0.326
Potassium (K)	1	0.0040	0.0040	0.43	0.5118
P X K	1	0.0040	0.0040	0.43	0.5118
I X P	1	0.0250	0.0250	2.71	0.103
I X K	1	0.0010	0.0010	0.11	0.743
I X P X K	1	0.0010	0.0010	0.11	0.743
S X P	4	0.0235	0.0059	0.64	0.637
S X K	4	0.0060	0.0015	0.16	0.957
S X P X K	4	0.0298	0.0075	0.81	0.524
S X I X P	4	0.0175	0.0044	0.47	0.754
S X I X K	4	0.0465	0.0116	1.26	0.291
S X I X P X K	4	0.0578	0.0145	1.57	0.190
Error (b)	90	0.8300	0.0092		

Table 29. Analysis of variance table for wheat grain yield response to P and K applications.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	95	9354795			
Rep	23	3801826	165297	5.61	0.0001
Phosphorus (P)	1	61705	61705	2.10	0.152
Potassium (K)	1	3319364	3319364	112.74	0.0001
P x K	1	140388	140388	4.77	0.032
Error	69	2031512	29442		

Table 30. Analysis of variance table for N concentrations in wheat grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	95	0.5396			
Rep	23	0.1846	0.0080	1.69	0.050
Phosphorus (P)	1	0.0150	0.0150	3.16	0.080
Potassium (K)	1	0.0017	0.0017	0.35	0.556
P x K	1	0.0104	0.0104	2.19	0.143
Error	69	0.3279	0.0048		

Table 31. Analysis of variance table for P concentrations in wheat grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	90	0.2108			
Rep	23	0.0965	0.0042	2.87	0.0005
Phosphorus (P)	1	0.0204	0.0204	13.93	0.0004
Potassium (K)	1	0.0001	0.0001	0.04	0.842
P x K	1	0.0007	0.0007	0.47	0.494
Error	64	0.0936	0.0015		

Table 32. Analysis of variance table for K concentrations in wheat grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	90	0.3242			
Rep	23	0.1017			
Phosphorus (P)	1	0.0047	0.10047	1.44	0.235
Potassium (K)	1	0.0010	0.0010	0.31	0.578
P x K	1	0.0064	0.0064	1.97	0.165
Error	64	0.2077	0.0032		

Table 33. Analysis of variance table for Ca concentrations in wheat grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	89	0.0210			
Rep	23	0.0074	0.0003	1.59	0.075
Phosphorus (P)	1	0.0002	0.0002	0.94	0.335
Potassium (K)	1	0.0005	0.0005	2.43	0.124
P x K	1	0.0003	0.0003	1.41	0.239
Error	63	0.0127	0.0002		

Table 34. Analysis of variance table for Mg concentrations in wheat grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	90	0.0182			
Rep	23	0.0072	0.0003	2.14	0.009
Phosphorus (P)	1	0.0010	0.0010	6.91	0.011
Potassium (K)	1	0.0005	0.0005	3.32	0.073
P x K	1	0.0000	0.0000	0.03	0.866
Error	64	0.0093	0.0001		

Table 35. Analysis of variance table for Mn concentrations in wheat grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	89	4605			
Rep	23	2109	92	2.64	0.001
Phosphorus (P)	1	6	6	0.16	0.691
Potassium (K)	1	265	265	7.62	0.008
P x K	1	2	2	0.05	0.829
Error	63	2192	35		

Table 36. Analysis of variance table for Fe concentrations in wheat grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	90	3399			
Rep	23	1516	66	2.35	0.004
Phosphorus (P)	1	22	22	0.79	0.377
Potassium (K)	1	49	49	1.75	0.190
P x K	1	44	44	1.58	0.213
Error	64	1797	28		

Table 37. Analysis of variance table for Al concentrations in wheat grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	90	95.0144			
Rep	23	29.7086	1.2917	1.31	0.200
Phosphorus (P)	1	0.7102	0.7102	0.72	0.400
Potassium (K)	1	0.0885	0.0885	0.09	0.766
P x K	1	0.9623	0.9623	0.97	0.328
Error	64	63.3261	0.9895		

Table 38. Analysis of variance table for B concentrations in wheat grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	92	59.5021			
Rep	23	20.1219	0.8749	1.66	0.0571
Phosphorus (P)	1	1.8979	1.8979	3.60	0.0622
Potassium (K)	1	2.8794	2.8794	5.46	0.0225
P x K	1	0.0313	0.0313	0.06	0.8083
Error	66	34.8115	0.5274		

Table 39. Analysis of variance table for Cu concentrations in wheat grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	92	90.6424			
Rep	23	72.0831	3.1340	13.31	0.0001
Phosphorus (P)	1	4.8739	4.8739	20.70	0.0001
Potassium (K)	1	0.0329	0.0329	0.14	0.7099
P x K	1	0.0260	0.0260	0.11	0.7405
Error	66	15.5369	0.2354		

Table 40. Analysis of variance table for Zn concentrations in wheat grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	90	1021.43			
Rep	23	294.31	12.80	1.47	0.114
Phosphorus (P)	1	188.58	188.58	21.70	0.0001
Potassium (K)	1	1.03	1.03	0.12	0.732
P x K	1	0.84	0.84	0.10	0.757
Error	64	556.09	8.69		

Table 41. Analysis of variance table for total N removed in wheat grain harvest (grain N concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	95	5974.84			
Rep	23	2204.06	95.83	4.83	0.0001
Phosphorus (P)	1	14.19	14.19	0.71	0.401
Potassium (K)	1	2254.13	2254.13	113.54	0.0001
P x K	1	132.63	132.63	6.68	0.012
Error	69	1369.83	19.85		

Table 42. Analysis of variance table for total P removed in wheat grain harvest (grain P concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	90	640.86			
Rep	23	307.41	13.37	5.19	0.0001
Phosphorus (P)	1	3.96	3.96	1.54	0.220
Potassium (K)	1	149.16	149.16	57.97	0.0001
P x K	1	5.00	5.00	1.94	0.168
Error	64	164.68	2.57		

Table 43. Analysis of variance table for total K removed in wheat grain harvest (grain K concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	90	611.899			
Rep	23	130.175	5.660	1.36	0.170
Phosphorus (P)	1	0.154	0.154	0.04	0.848
Potassium (K)	1	194.849	194.849	46.65	0.0001
P x K	1	2.868	2.868	0.69	0.410
Error	64	267.297	4.177		

Table 44. Analysis of variance table for total Ca removed in wheat grain harvest (grain Ca concentration x grain yield)

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	89	18.3291			
Rep	23	7.1228	0.3097	2.06	0.013
Phosphorus (P)	1	0.0108	0.0108	0.07	0.790
Potassium (K)	1	1.6124	1.6124	10.72	0.002
P x K	1	0.0036	0.0036	0.02	0.877
Error	63	9.4719	0.1503		

Table 45. Analysis of variance table for total Mg removed in wheat grain harvest (grain Mg concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	90	44.8044			
Rep	23	20.3434	0.8845	4.12	0.0001
Phosphorus (P)	1	0.0818	0.0818	0.38	0.539
Potassium (K)	1	9.5114	9.5114	44.26	0.0001
P x K	1	0.6591	0.6591	3.07	0.085
Error	64	13.7538	0.2149		

Table 46. Analysis of variance table for total Mn removed in wheat grain harvest (grain Mn concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	89	72836.0			
Rep	23	32351.9	1406.6	4.68	0.0001
Phosphorus (P)	1	378.6	378.6	1.26	0.266
Potassium (K)	1	17969.8	17969.8	59.81	0.0001
P x K	1	1007.3	1007.3	3.35	0.072
Error	63	18928.2	300.4		

Table 47. Analysis of variance table for total Fe removed in wheat grain harvest (grain Fe concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ration	OSL
Total	90	46652.8			
Rep	23	16510.8	717.9	2.63	0.001
Phosphorus (P)	1	0.0	0.0	0.00	0.993
Potassium (K)	1	12448.0	12448.0	45.67	0.0001
P x K	1	21.2	21.2	0.08	0.781
Error	64	17442.4	272.5		

Table 48. Analysis of variance table for total Al removed in wheat grain harvest (grain Al concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	90	565.365			
Rep	23	122.552	5.328	0.87	0.631
Phosphorus (P)	1	0.904	0.904	0.15	0.702
Potassium (K)	1	46.320	46.320	7.59	0.008
P x K	1	0.553	0.553	0.09	0.764
Error	64	390.505	6.102		

Table 49. Analysis of variance table for total B removed in wheat grain harvest (grain B concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	92	307.026			
Rep	23	110.181	4.791	1.68	0.053
Phosphorus (P)	1	7.337	7.337	2.57	0.114
Potassium (K)	1	1.286	1.286	0.45	0.504
P x K	1	0.795	0.795	0.28	0.599
Error	66	188.261	2.852		

Table 50. Analysis of variance table for total Cu removed in wheat grain harvest (grain Cu concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	92	531.856			
Rep	23	330.174	14.355	7.56	0.0001
Phosphorus (P)	1	38.737	38.737	20.39	0.0001
Potassium (K)	1	45.248	45.248	23.82	0.0001
P x K	1	6.513	6.513	3.43	0.069
Error	66	125.374	1.900		

Table 51. Analysis of variance table for total Zn removed in wheat grain harvest (grain Zn concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	90	33656.2			
Rep	23	8844.9	384.6	2.15	0.009
Phosphorus (P)	1	1902.0	1902.0	10.64	0.002
Potassium (K)	1	10075.4	10075.4	56.34	0.0001
P x K	1	621.2	621.2	3.47	0.067
Error	64	11446.1	178.8		

Table 52. Analysis of variance table for soybean grain yield, 1982.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL	OSL‡
Total	63	7267813				
Rep	3	199048	66349			
Among main units						
Irrigation (I)	1	1266424	1266424	59.89	0.0001	0.0001
Crop System (S)	1	880097	880097	41.62	0.0001	0.001
I x S	1	167310	167310	7.91	0.020	0.137
Error (a)	9	190310	21146			
Within main units						
Phosphorus (P)	1	242527	242527	2.83	0.101	0.075
Potassium (K)	1	861110	861110	10.04	0.003	0.001
P x K	1	5073	5073	0.06	0.809	0.793
I x P	1	66	66	0.00	0.978	0.976
I x K	1	17	17	0.00	0.989	0.988
I x P x K	1	22069	22069	0.26	0.615	0.585
S x P	1	61638	61638	0.72	0.402	0.362
S x K	1	26504	26504	0.31	0.582	0.549
S x P x K	1	56689	56689	0.66	0.422	0.382
S x I x P	1	5367	5367	0.06	0.804	0.787
S x I x K	1	189652	189652	2.21	0.146	0.114
S x I x P x K	1	7657	7657	0.09	0.767	0.747
Error (b)	36	3086256	85729			
Error (pooled)	45	3276566	72813			

‡OSL using error (pooled) as denominator in calculating F ratio.

Table 53. Analysis of variance table for N concentrations in soybean grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	63	4.8798			
Rep	3	0.4067	0.1356	1.26	0.346
Among main units					
Irrigation (I)	1	0.0077	0.0077	0.07	0.796
Cropping System (S)	1	0.1502	0.1502	1.39	0.268
S x I	1	0.0977	0.0977	0.91	0.366
Error (a)	9	0.9702	0.1078		
Within main units					
Phosphorus (P)	1	0.0002	0.0002	0.00	0.963
Potassium (K)	1	0.0014	0.0014	0.02	0.889
P X K	1	0.0264	0.0264	0.37	0.547
I X P	1	0.2139	0.2139	3.00	0.092
I X K	1	0.0564	0.0564	0.79	0.380
I X P X K	1	0.0977	0.0977	1.37	0.250
S X P	1	0.1502	0.1502	2.10	0.156
S X K	1	0.0689	0.0689	0.96	0.333
S X P X K	1	0.0564	0.0564	0.79	0.380
S X I X P	1	0.0014	0.0014	0.02	0.889
S X I X K	1	0.0039	0.0039	0.05	0.816
S X I X P X K	1	0.0002	0.0002	0.00	0.963
Error (b)	36	2.5706	0.0714		

Table 54. Analysis of variance table for P concentrations in soybean grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	62	0.1312			
Rep	3	0.0032	0.0011	0.31	0.819
Among main units					
Irrigation (I)	1	0.0015	0.0015	0.43	0.530
Crop System (S)	1	0.0003	0.0003	0.08	0.783
S x I	1	0.0006	0.0006	0.18	0.677
Error (a)	9	0.0314	0.0035		
Within main units					
Phosphorus (P)	1	0.0026	0.0026	1.67	0.205
Potassium (K)	1	0.0001	0.0001	0.07	0.795
P X K	1	0.0002	0.0002	0.16	0.696
I X P	1	0.0004	0.0004	0.28	0.601
I X K	1	0.0201	0.0201	13.12	0.001
I X P X K	1	0.0006	0.0006	0.37	0.545
S X P	1	0.0004	0.0004	0.26	0.615
S X K	1	0.0068	0.0068	4.43	0.043
S X P X K	1	0.0045	0.0045	2.91	0.097
S X I X P	1	0.0003	0.0003	0.22	0.640
S X I X K	1	0.0048	0.0048	3.12	0.086
S X I X P X K	1	0.0001	0.0001	0.06	0.802
Error (b)	35	0.0537	0.0015		

Table 55. Analysis of variance table for K concentrations in soybean grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL	OSL‡
Total	62	0.3958				
Rep	3	0.0496	0.0165	3.83	0.051	
Among main units						
Irrigation (I)	1	0.0114	0.0114	2.64	0.138	0.167
Crop System (S)	1	0.0032	0.0032	0.74	0.411	0.460
S x I	1	0.0045	0.0045	1.03	0.336	0.384
Error (a)	9	0.0389	0.0043			
Within main units						
Phosphorus (P)	1	0.0000	0.0000	0.00	0.961	0.953
Potassium (K)	1	0.0007	0.0007	0.11	0.738	0.799
P x K	1	0.0021	0.0021	0.34	0.564	0.630
I x P	1	0.0011	0.0011	0.18	0.677	0.586
I x K	1	0.0332	0.0332	5.39	0.026	0.027
I x P x K	1	0.0066	0.0066	1.07	0.307	0.242
S x P	1	0.0001	0.0001	0.02	0.890	0.796
S x K	1	0.0087	0.0087	1.42	0.241	0.269
S x P x K	1	0.0063	0.0063	1.03	0.317	0.252
S x I x P	1	0.0006	0.0006	0.10	0.756	0.665
S x I x K	1	0.0004	0.0004	0.06	0.809	0.717
S x I x P x K	1	0.0124	0.0124	2.01	0.165	0.123
Error (b)	35	0.2153	0.0062			
Error (pooled)	44	0.2542	0.0058			

‡OSL using error (pooled) as denominator in calculating F ratio.

Table 56. Analysis of variance table for Ca concentrations in soybean grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	62	0.0240			
Rep	3	0.0009	0.0003	0.99	0.439
Among main units					
Irrigation (I)	1	0.0045	0.9945	14.78	0.004
Crop System (S)	1	0.0081	0.0081	26.60	0.001
S x I	1	0.0004	0.0004	1.40	0.266
Error (a)	9	0.0027	0.0003		
Within main units					
Phosphorus (P)	1	0.0000	0.0000	0.01	0.905
Potassium (K)	1	0.0008	0.0008	5.24	0.028
P X K	1	0.0002	0.0002	1.39	0.246
I X P	1	0.0000	0.0000	0.08	0.780
I X K	1	0.0003	0.0003	2.17	0.150
I X P X K	1	0.0000	0.0000	0.18	0.671
S X P	1	0.0001	0.0001	0.43	0.518
S X K	1	0.0000	0.0000	0.26	0.613
S X P X K	1	0.0000	0.0000	0.23	0.633
S X I X P	1	0.0000	0.0000	0.03	0.854
S X I X K	1	0.0002	0.0002	1.19	0.283
S X I X P X K	1	0.0000	0.0000	0.29	0.592
Error (b)	35	0.0054	0.0002		

Table 57. Analysis of variance table for Mg concentrations in soybean grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	62	0.0218			
Rep	3	0.0006	0.0002	0.32	0.813
Among main units					
Irrigation (I)	1	0.0005	0.0005	0.79	0.396
Crop System (S)	1	0.0010	0.0010	1.66	0.230
S x I	1	0.0000	0.0000	0.03	0.870
Error (a)	9	0.0054	0.0006		
Within main units					
Phosphorus (P)	1	0.0000	0.0000	0.05	0.819
Potassium (K)	1	0.0003	0.0003	1.20	0.281
P X K	1	0.0003	0.0003	1.37	0.250
I X P	1	0.0002	0.0002	0.67	0.420
I X K	1	0.0021	0.0021	8.81	0.005
I X P X K	1	0.0001	0.0001	0.28	0.603
S X P	1	0.0001	0.0001	0.25	0.623
S X K	1	0.0015	0.0015	6.08	0.019
S X P X K	1	0.0000	0.0000	0.04	0.835
S X I X P	1	0.0003	0.0003	1.33	0.256
S X I X K	1	0.0012	0.0012	5.09	0.030
S X I X P X K	1	0.0001	0.0001	0.24	0.625
Error (b)	35	0.0084	0.0002		

Table 58. Analysis of variance table for Mn concentrations in soybean grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL	OSL‡
Total	62	143.107				
Rep	3	37.378	12.459	8.16	0.006	
Among main units						
Irrigation (I)	1	11.264	11.264	7.38	0.024	0.015
Crop System (S)	1	1.187	1.187	0.78	0.401	0.416
S x I	1	0.005	0.005	0.00	0.956	0.959
Error (a)	9	13.734	1.526			
Within main units						
Phosphorus (P)	1	0.012	0.012	0.01	0.936	0.922
Potassium (K)	1	0.009	0.009	0.01	0.943	0.937
P x K	1	0.478	0.478	0.26	0.612	0.594
I x P	1	1.766	1.766	0.97	0.332	0.330
I x K	1	2.065	2.065	1.13	0.294	0.290
I x P x K	1	0.258	0.258	0.14	0.709	0.696
S x P	1	0.102	0.102	0.06	0.814	0.826
S x K	1	6.308	6.308	3.46	0.071	0.067
S x P x K	1	1.237	1.237	0.68	0.416	0.400
S x I x P	1	2.938	2.938	1.61	0.213	0.199
S x I x K	1	0.417	0.417	0.23	0.635	0.621
S x I x P x K	1	0.804	0.804	0.44	0.511	0.498
Error (b)	35	63.782	1.822			
Error (pooled)	44	77.516	1.762			

‡OSL using error (pooled) as denominator in calculating F ratio.

Table 59. Analysis of variance table for Fe concentrations in soybean grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	62	50819.14			
Rep	3	5848.91	1447.64	2.69	0.110
Among main units					
Irrigation (I)	1	492.68	492.68	0.68	0.431
Crop System (S)	1	439.75	439.75	0.61	0.456
S x I	1	1800.41	1800.41	2.48	0.150
Error (a)	9	6528.21	1447.64		
Within main units					
Phosphorus (P)	1	39.08	39.08	0.07	0.796
Potassium (K)	1	270.43	270.43	0.47	0.498
P x K	1	3470.51	3470.51	6.02	0.019
I x P	1	570.39	570.39	0.99	0.327
I x K	1	5573.04	5573.04	9.67	0.003
I x P x K	1	53.50	53.50	0.09	0.762
S x P	1	185.50	185.50	0.32	0.574
S x K	1	3168.63	3168.63	5.50	0.025
S x P x K	1	430.11	430.11	0.75	0.394
S x I x P	1	17.86	17.86	0.03	0.861
S x I x K	1	508.94	508.94	0.88	0.354
S x I x P x K	1	512.37	512.37	0.89	0.352
Error (b)	35	20164.30	576.12		

Table 60. Analysis of variance table for Al concentrations in soybean grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	61	986.648			
Rep	3	137.944	45.981	1.90	0.200
Among main units					
Irrigation (I)	1	63.682	63.682	2.63	0.139
Crop System (S)	1	22.291	22.291	0.92	0.362
S x I	1	0.052	0.052	0.00	0.964
Error (a)	9	217.598	24.178		
Within main units					
Phosphorus (P)	1	35.094	35.094	3.13	0.086
Potassium (K)	1	0.056	0.056	0.00	0.944
P x K	1	52.092	52.092	4.64	0.038
I x P	1	14.072	14.072	1.25	0.271
I x K	1	14.787	14.787	1.32	0.259
I x P x K	1	0.093	0.093	0.01	0.928
S x P	1	9.738	9.738	0.87	0.358
S x K	1	3.301	3.301	0.29	0.591
S x P x K	1	5.633	5.633	0.50	0.483
S x I x P	1	0.010	0.010	0.00	0.977
S x I x K	1	1.556	1.556	0.14	0.712
S x I x P x K	1	1.684	1.684	0.15	0.701
Error (b)	34	381.511	11.221		

Table 61. Analysis of variance table for B concentrations in soybean grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL	OSL‡
Total	62	269.411				
Rep	3	5.403	1.601	0.58	0.643	
Among main units						
Irrigation (I)	1	23.701	23.701	7.64	0.022	0.012
Crop System (S)	1	19.002	19.002	6.12	0.035	0.024
S x I	1	14.351	14.351	4.62	0.060	0.048
Error (a)	9	27.933	3.104			
Within main units						
Phosphorus (P)	1	0.207	0.207	0.06	0.810	0.750
Potassium (K)	1	15.504	15.504	4.38	0.044	0.046
P x K	1	0.628	0.628	0.18	0.676	0.609
I x P	1	5.143	5.143	1.45	0.236	0.261
I x K	1	3.861	3.861	1.09	0.304	0.262
I x P x K	1	0.252	0.252	0.07	0.791	0.860
S x P	1	0.270	0.270	0.08	0.784	0.718
S x K	1	0.454	0.454	0.13	0.723	0.775
S x P x K	1	0.100	0.100	0.03	0.867	0.939
S x I x P	1	3.500	3.500	0.99	0.327	0.365
S x I x K	1	26.161	26.161	7.39	0.010	0.011
S x I x P x K	1	3.205	3.205	0.90	0.348	0.392
Error (b)	35	123.958	3.542			
Error (pooled)	44	151.892	3.452			

‡OSL using error (pooled) as denominator in calculating F ratio.

Table 62. Analysis of variance table for Cu concentrations in soybean grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	63	71.4331			
Rep	3	1.0474	0.4331	0.35	0.486
Among main units					
Irrigation (I)	1	0.0848	0.0848	0.09	0.776
Crop System (S)	1	28.3436	28.3436	28.81	0.001
S x I	1	0.6850	0.6850	0.70	0.426
Error (a)	9	8.8532	0.4837		
Within main units					
Phosphorus (P)	1	6.2894	6.2894	13.06	0.001
Potassium (K)	1	0.2133	0.2133	0.44	0.510
P x K	1	0.0786	0.0786	0.16	0.689
I x P	1	0.0627	0.0727	0.13	0.720
I x K	1	0.8989	0.8989	1.87	0.180
I x P x K	1	2.2511	2.2511	4.67	0.037
S x P	1	0.3861	0.3861	0.80	0.377
S x K	1	0.2700	0.2700	0.56	0.459
S x P x K	1	0.2768	0.2768	0.57	0.453
S x I x P	1	1.1473	1.1473	2.38	0.132
S x I x K	1	3.1849	3.1849	6.61	0.014
S x I x P x K	1	0.0172	0.0172	0.04	0.851
Error (b)	36	17.3427	0.4817		

Table 63. Analysis of variance table for Zn concentrations in soybean grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL	OSL‡
Total	63	729.771				
Rep	3	106.986	35.662	8.33	0.006	
Among main units						
Irrigation (I)	1	4.213	4.213	0.98	0.347	0.414
Crop System (S)	1	85.933	85.933	20.07	0.002	0.0005
S x I	1	91.441	91.441	21.36	0.001	0.0004
Error (a)	9	38.534	4.282			
Within main units						
Phosphorus (P)	1	33.408	33.408	5.01	0.032	0.025
Potassium (K)	1	14.803	14.803	2.22	0.145	0.129
P x K	1	45.461	45.461	6.82	0.013	0.010
I x P	1	1.328	1.328	0.20	0.658	0.646
I x K	1	20.931	20.931	3.14	0.085	0.073
I x P x K	1	0.106	0.106	0.02	0.900	0.897
S x P	1	12.852	12.852	1.93	0.174	0.157
S x K	1	3.213	3.213	0.48	0.492	0.475
S x P x K	1	2.198	2.198	0.33	0.569	0.554
S x I x P	1	14.688	14.688	2.20	0.146	0.131
S x I x K	1	2.641	2.641	0.40	0.533	0.517
S x I x P x K	1	10.956	10.956	1.64	0.208	0.190
Error (b)	36	240.079	6.669			
Error (pooled)	45	278.613	6.191			

‡OSL using error (pooled) as denominator in calculating F ratio.

Table 64. Analysis of variance table for total N removed in soybean grain harvest (grain N concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL	OSL‡
Total	63	26146.6				
Rep	3	1019.2	339.7	2.67	0.1110	
Among main units						
Irrigation (I)	1	4157.5	4157.5	32.64	0.0003	0.0003
Crop System (S)	1	3552.3	3552.3	27.89	0.0005	0.0007
S x I	1	884.7	884.7	6.95	0.027	0.077
Error (a)	9	1146.2	127.4			
Within main units						
Phosphorus (P)	1	741.7	741.7	2.42	0.129	0.105
Potassium (K)	1	2475.4	2475.4	8.07	0.007	0.004
P x K	1	42.9	42.9	0.14	0.711	0.693
I x P	1	88.9	88.9	0.29	0.594	0.570
I x K	1	15.0	15.0	0.05	0.826	0.815
I x P x K	1	176.3	176.3	0.57	0.453	0.424
S x P	1	43.8	43.8	0.14	0.708	0.690
S x K	1	8.5	8.5	0.03	0.869	0.860
S x P x K	1	88.9	88.9	0.29	0.594	0.570
S x I x P	1	11.1	11.1	0.04	0.850	0.840
S x I x K	1	624.5	624.5	2.04	0.162	0.136
S x I x P x K	1	26.6	26.6	0.09	0.770	0.756
Error (b)	36	11043.0	306.8			
Error (pooled)	45	12189.2	270.9			

‡OSL using error (pooled) as denominator in calculating F ratio.

Table 65. Analysis of variance table for total P removed in soybean grain harvest (grain P concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL	OSL‡
Total	62	307.664				
Rep	3	7.205	2.402	0.79	0.528	
Among main units						
Irrigation (I)	1	46.966	46.966	15.50	0.003	0.0006
Crop System (S)	1	33.002	33.002	10.89	0.009	0.003
S x I	1	5.927	5.927	1.96	0.196	0.195
Error (a)	9	27.275	3.031			
Within main units						
Phosphorus (P)	1	12.231	12.231	3.48	0.071	0.059
Potassium (K)	1	20.288	20.288	5.77	0.022	0.017
P x K	1	0.311	0.311	0.09	0.768	0.808
I x P	1	0.956	0.956	0.27	0.605	0.638
I x K	1	12.494	12.494	3.55	0.068	0.071
I x P x K	1	0.402	0.402	0.11	0.737	0.688
S x P	1	0.228	0.228	0.06	0.801	0.758
S x K	1	1.261	1.261	0.36	0.553	0.589
S x P x K	1	0.815	0.815	0.23	0.633	0.670
S x I x P	1	2.214	2.214	0.63	0.433	0.459
S x I x K	1	11.367	11.367	3.23	0.081	0.066
S x I x P x K	1	0.053	0.053	0.02	0.903	0.950
Error (b)	35	123.122	3.518			
Error (pooled)	44	150.397	3.418			

‡OSL using error (pooled) as denominator in calculating F ratio.

Table 66. Analysis of variance table for total K removed in soybean grain harvest (grain K concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL	OSL‡
Total	62	2549.19				
Rep	3	59.45	19.82	2.01	0.183	
Among main units						
Irrigation (I)	1	461.97	461.97	46.87	0.0001	0.0001
Crop System (S)	1	412.62	412.62	41.86	0.0001	0.0002
S x I	1	119.42	119.42	12.12	0.007	0.032
Error (a)	9	88.71	9.86			
Within main units						
Phosphorus (P)	1	56.21	56.21	2.01	0.165	0.124
Potassium (K)	1	206.79	206.79	7.40	0.010	0.005
P x K	1	16.04	16.04	0.57	0.4538	0.448
I x P	1	0.97	0.97	0.03	0.854	0.882
I x K	1	31.39	31.39	1.12	0.297	0.286
I x P x K	1	5.03	5.03	0.18	0.674	0.613
S x P	1	11.55	11.55	0.41	0.525	0.466
S x K	1	0.40	0.40	0.01	0.905	0.940
S x P x K	1	21.19	21.19	0.76	0.390	0.382
S x I x P	1	6.88	6.88	0.25	0.623	0.633
S x I x K	1	43.22	43.22	1.55	0.222	0.171
S x I x P x K	1	3.61	3.61	0.13	0.721	0.663
Error (b)	35	978.29	27.95			
Error (pooled)	44	1067.00	24.25			

‡OSL using error (pooled) as denominator in calculating F ratio.

Table 67. Analysis of variance table for total Ca removed in soybean grain harvest (grain Ca concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL	OSL[‡]
Total	62	44.5713				
Rep	3	1.9865	0.6622	2.08	0.174	
Among main units						
Irrigation (I)	1	2.6133	2.6133	8.20	0.019	0.055
Crop System (S)	1	1.2810	1.2810	4.02	0.076	0.175
S x I	1	0.7400	0.7400	2.32	0.162	0.300
Error (a)	9	2.8674	0.3186			
Within main units						
Phosphorus (P)	1	1.5195	1.5195	1.99	0.167	0.135
Potassium (K)	1	3.9116	3.9116	5.12	0.030	0.019
P x K	1	0.0518	0.0518	0.07	0.796	0.801
I x P	1	0.0562	0.0562	0.07	0.788	0.795
I x K	1	0.0024	0.0024	0.00	0.955	0.980
I x P x K	1	0.0008	0.0008	0.00	0.975	0.947
S x P	1	0.1201	0.1201	0.16	0.694	0.659
S x K	1	0.1821	0.1821	0.24	0.629	0.585
S x P x K	1	1.2989	1.2989	1.70	0.201	0.181
S x I x P	1	0.2947	0.2947	0.39	0.539	0.531
S x I x K	1	0.5435	0.5435	0.71	0.405	0.356
S x I x P x K	1	0.0093	0.0093	0.01	0.913	0.882
Error (b)	35	26.7599	0.7646			
Error (pooled)	44	29.6273	0.6733			

[‡]OSL using error (pooled) as denominator in calculating F ratio.

Table 68. Analysis of variance table for total Mg removed in soybean grain harvest (grain Mg concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL	OSL‡
Total	62	40.0141				
Rep	3	1.1121	0.3707	0.81	0.522	
Among main units						
Irrigation (I)	1	3.1294	3.1294	6.80	0.028	0.014
Crop System (S)	1	2.6067	2.6067	5.67	0.041	0.025
S x I	1	1.0270	1.0270	2.23	0.169	0.151
Error (a)	9	4.1390	0.4599			
Within main units						
Phosphorus (P)	1	0.9470	0.9470	1.95	0.171	0.150
Potassium (K)	1	4.5363	4.5363	9.35	0.004	0.003
P x K	1	0.0040	0.0040	0.01	0.929	0.873
I x P	1	0.2301	0.2301	0.47	0.496	0.536
I x K	1	1.4850	1.4850	3.06	0.089	0.101
I x P x K	1	0.0669	0.0669	0.14	0.713	0.654
S x P	1	0.0180	0.0180	0.04	0.849	0.799
S x K	1	0.3001	0.3001	0.62	0.437	0.479
S x P x K	1	0.6716	0.6716	1.38	0.247	0.274
S x I x P	1	0.6088	0.6088	1.25	0.270	0.299
S x I x K	1	1.8881	1.8881	3.89	0.057	0.045
S x I x P x K	1	0.0339	0.0339	0.07	0.793	0.853
Error (b)	35	16.9874	0.4854			
Error (pooled)	44	21.1264	0.4801			

‡OSL using error (pooled) as denominator in calculating F ratio.

Table 69. Analysis of variance table for total Mn removed in soybean grain harvest (grain Mn concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL	OSL‡
Total	62	4124.17				
Rep	3	243.12	81.04	3.01	0.087	
Among main units						
Irrigation (I)	1	927.48	927.48	34.45	0.0002	0.0001
Crop System (S)	1	440.70	440.70	16.37	0.003	0.002
S x I	1	133.16	133.16	4.95	0.053	0.073
Error (a)	9	242.28	26.92			
Within main units						
Phosphorus (P)	1	81.25	81.25	1.90	0.176	0.152
Potassium (K)	1	348.29	348.29	8.16	0.007	0.004
P x K	1	6.07	6.07	0.14	0.708	0.715
I x P	1	25.81	25.81	0.60	0.442	0.439
I x K	1	24.68	24.68	0.58	0.452	0.454
I x P x K	1	1.98	1.98	0.05	0.831	0.800
S x P	1	10.90	10.90	0.26	0.616	0.585
S x K	1	8.93	8.93	0.21	0.650	0.658
S x P x K	1	35.05	35.05	0.82	0.371	0.365
S x I x P	1	0.18	0.18	0.00	0.948	0.970
S x I x K	1	75.56	75.56	1.77	0.192	0.163
S x I x P x K	1	1.09	1.09	0.03	0.874	0.846
Error (b)	35	1493.75	42.68			
Error (pooled)	44	1736.03	39.46			

‡OSL using error (pooled) as denominator in calculating F ratio.

Table 70. Analysis of variance table for total Fe removed in soybean grain harvest (grain Fe concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL	OSL‡
Total	62	339670				
Rep	3	37588	12529	4.20	0.041	
Among main units						
Irrigation (I)	1	45042	45042	15.10	0.004	0.001
Crop System (S)	1	3967	3967	1.33	0.279	0.312
S x I	1	1921	1921	0.64	0.443	0.481
Error (a)	9	26850	2983			
Within main units						
Phosphorus (P)	1	5015	5015	1.25	0.271	0.300
Potassium (K)	1	9729	9729	2.43	0.128	0.090
P x K	1	9215	9215	2.30	0.138	0.101
I x P	1	4736	4736	1.18	0.284	0.323
I x K	1	18667	18667	4.66	0.038	0.024
I x P x K	1	7	7	0.00	0.965	0.865
S x P	1	5077	5077	1.27	0.268	0.302
S x K	1	14551	14551	3.63	0.065	0.044
S x P x K	1	6557	6557	1.64	0.209	0.240
S x I x P	1	9	9	0.00	0.964	0.938
S x I x K	1	89	89	0.02	0.882	0.781
S x I x P x K	1	1631	1631	0.41	0.528	0.438
Error (b)	35	140166	4005			
Error (pooled)	44	167016	3796			

‡OSL using error (pooled) as denominater in calculating F ratio.

Table 71. Analysis of variance table for total Al removed in soybean grain harvest (grain Al concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	61	5423.254			
Rep	3	680.907	226.969	1.93	0.196
Among main units					
Irrigation (I)	1	700.576	700.576	5.94	0.038
Crop System (S)	1	266.915	266.915	2.26	0.167
S x I	1	14.242	14.242	0.12	0.736
Error (a)	9	1060.620	117.847		
Within main units					
Phosphorus (P)	1	61.169	61.169	1.03	0.318
Potassium (K)	1	74.190	74.190	1.25	0.272
I x P	1	48.522	48.522	0.81	0.373
I x K	1	65.457	65.457	1.10	0.302
I x P x K	1	4.915	4.915	0.08	0.776
S x P	1	94.352	94.352	1.58	0.217
S x K	1	11.675	11.675	0.20	0.661
S x P x K	1	39.842	39.842	0.67	0.419
S x I x P	1	7.903	7.903	0.13	0.718
S x I x K	1	0.461	0.461	0.01	0.930
S x I x P x K	1	5.410	5.410	0.09	0.765
Error (b)	34	2024.522	59.545		

Table 72. Analysis of variance table for total B removed in soybean grain harvest (grain B concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL	OSL‡
Total	62	10428.2				
Rep	3	342.6	114.2	1.33	0.325	
Among main units						
Irrigation (I)	1	827.2	827.2	9.63	0.013	0.010
Crop System (S)	1	1387.9	1387.9	16.15	0.003	0.001
S x I	1	8.8	8.8	0.10	0.756	0.782
Error (a)	9	773.2	85.9			
Within main units						
Phosphorus (P)	1	211.8	211.8	1.74	0.195	0.147
Potassium (K)	1	1585.2	1585.2	13.05	0.0009	0.0007
P x K	1	3.0	3.0	0.02	0.875	0.972
I x P	1	50.3	50.3	0.41	0.524	0.594
I x K	1	4.0	4.0	0.03	0.856	0.760
I x P x K	1	2.5	2.5	0.02	0.888	0.777
S x P	1	38.0	38.0	0.31	0.580	0.487
S x K	1	74.2	74.2	0.61	0.440	0.491
S x P x K	1	112.9	112.9	0.93	0.342	0.395
S x I x P	1	70.3	70.3	0.58	0.452	0.520
S x I x K	1	794.8	794.8	6.54	0.015	0.016
S x I x P x K	1	8.0	8.0	0.07	0.799	0.902
Error (b)	35	4251.6	121.5			
Error (pooled)	44	5024.8	114.2			

‡OSL using error (pooled) as denominator in calculating F ratio.

Table 73. Analysis of variance table for total Cu removed in soybean grain harvest (grain Cu concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL	OSL‡
Total	63	952.585				
Rep	3	16.977	5.659	0.62	0.620	
Among main units						
Irrigation (I)	1	139.844	139.844	15.30	0.004	0.001
Crop System (S)	1	1.243	1.243	0.14	0.721	0.747
S x I	1	24.335	24.335	2.66	0.137	0.158
Error (a)	9	82.247	9.139			
Within main units						
Phosphorus (P)	1	0.037	0.037	0.00	0.957	0.956
Potassium (K)	1	105.074	105.074	8.40	0.006	0.005
P x K	1	0.123	0.123	0.01	0.922	0.919
I x P	1	0.268	0.268	0.02	0.884	0.881
I x K	1	2.532	2.532	0.20	0.655	0.646
I x P x K	1	19.449	19.449	1.56	0.220	0.206
S x P	1	21.835	21.835	1.75	0.195	0.181
S x K	1	15.024	15.024	1.20	0.280	0.266
S x P x K	1	0.998	0.998	0.08	0.779	0.773
S x I x P	1	5.353	5.353	0.43	0.517	0.505
S x I x K	1	65.096	65.096	5.21	0.029	0.024
S x I x P x K	1	2.073	2.073	0.17	0.686	0.678
Error (b)	36	450.076	12.502			
Error (pooled)	45	532.323	11.829			

‡OSL using error (pooled) as denominator in calculating F ratio.

Table 74. Analysis of variance table for total Zn removed in soybean grain harvest (grain Zn concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL	OSL‡
Total	63	11996.9				
Rep	3	392.1	130.7	2.67	0.111	
Among main units						
Irrigation (I)	1	1478.2	1478.2	30.16	0.0004	0.002
Crop System (S)	1	221.4	221.4	4.52	0.063	0.219
S x I	1	37.8	37.8	0.77	0.402	0.609
Error (a)	9	441.1	49.0			
Within main units						
Phosphorus (P)	1	49.3	49.3	0.30	0.589	0.559
Potassium (K)	1	2058.9	2058.9	12.42	0.001	0.0004
P x K	1	110.2	110.2	0.66	0.420	0.384
I x P	1	0.9	0.9	0.01	0.941	0.936
I x K	1	89.4	89.4	0.54	0.467	0.432
I x P x K	1	52.1	52.1	0.31	0.579	0.549
S x P	1	333.1	333.1	2.01	0.165	0.133
S x K	1	140.0	140.0	0.84	0.364	0.327
S x P x K	1	40.2	40.2	0.24	0.625	0.598
S x I x P	1	40.5	40.5	0.24	0.624	0.596
S x I x K	1	436.4	436.4	2.63	0.114	0.087
S x I x P x K	1	105.4	105.4	0.64	0.431	0.394
Error (b)	36	5969.7	165.8			
Error (pooled)	45	6410.8	142.5			

‡OSL using error (pooled) as denominator in calculating F ratio.

Table 75. Analysis of variance table for monocrop grain sorghum grain yield, 1982.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	28	10526699			
Rep	3	4323842	1441281		
Irrigation (I)	1	77548	77548	0.10	0.770
Error (a)	3	2261674	753891		
Phosphorus (P)	1	73951	73951	0.45	0.513
Potassium (K)	1	84300	84300	0.51	0.486
P x K	1	892822	892822	5.41	0.034
I x P	1	101179	101179	0.61	0.446
I x K	1	66628	66628	0.40	0.535
I x P x K	1	33456	33456	0.20	0.659
Error (b)	15	2473822	164921		

Table 76. Analysis of variance table for N concentrations in grain sorghum grain.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL	OSL[‡]
Total	31	0.3272				
Rep	3	0.0609	0.0203			
Irrigation (I)	1	0.0153	0.0153	5.44	0.102	0.179
Error (a)	3	0.0084	0.0028			
Phosphorus (P)	1	0.0028	0.0028	0.32	0.579	0.558
Potassium (K)	1	0.0153	0.0153	1.74	0.203	0.179
P x K	1	0.0153	0.0153	1.74	0.203	0.179
I x P	1	0.0253	0.0253	2.88	0.107	0.089
I x K	1	0.0003	0.0003	0.04	0.853	0.845
I x P x K	1	0.0253	0.0253	2.88	0.107	0.089
Error (b)	18	0.1581	0.0088			
Error (pooled)	21	0.1666	0.0079			

[‡]OSL using error (pooled) as denominator in calculating F ratio.

Table 77. Analysis of variance table for total N removed in grain sorghum grain harvest (grain N concentration x grain yield).

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	28	3688.0			
Rep	3	624.8	208.2		
Irrigation (I)	1	221.8	221.8	0.98	0.396
Error (a)	3	680.2	226.7		
Phosphorus (P)	1	4.4	4.4	0.05	0.825
Potassium (K)	1	18.9	18.9	0.22	0.646
P x K	1	588.2	588.2	6.83	0.020
I x P	1	160.7	160.7	1.87	0.192
I x K	1	43.6	43.6	0.51	0.488
I x P x K	1	7.9	7.9	0.09	0.766
Error (b)	15	1291.5	86.1		

VITA

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Doctor of Philosophy

Thesis: EFFECTS OF IRRIGATION, PHOSPHORUS AND POTASSIUM FERTILIZATION, AND MONO AND DOUBLE CROPPING SYSTEMS ON YIELDS AND GRAIN ELEMENTAL COMPOSITION OF WHEAT, SOYBEANS AND GRAIN SORGHUM.

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