EFFECTS OF SUBSURFACE DRIP IRRIGATION ON CHEMICAL SOIL PROPERTIES AND COTTON YIELD

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EFFECTS OF SUBSURFACE DRIP IRRIGATION ON CHEMICAL SOIL PROPERTIES AND COTTON YIELD

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EFFECTS OF SUBSURFACE DRIP IRRIGATION ON CHEMICAL SOIL PROPERTIES AND COTTON YIELD

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THESIS ABSTRACT

EFFECTS OF SUBSURFACE DRIP IRRIGATION ON CHEMICAL SOIL PROPERTIES AND COTTON YIELD

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Subsurface drip irrigation (SDI) has proven to be an economical method of irrigation for agronomic row crops. It is suitable for small irregular shaped fields and has the highest water use efficiency of any other irrigation system available. The objective of this research is to determine the effects on soil chemical properties and cotton yield from fertilizing through a sub-surface drip irrigation system compared to the conventional method of broadcast surface fertilizing cotton. Research was conducted at two locations: Tennessee Valley Research and Extension Center (TVREC) on a Decatur silt loam (fine thermic, Rhodic Paleudults) and Wiregrass Research and Extension Center (WREC) on

Dothan sandy loam (fine, loamy siliceous, thermic Plinthic Kandiudults). Fertilization treatments were: (1) conventional, surface broadcast fertilizer over the top with no irrigation, (2) conventional broadcast fertilizer over the top with sub-surface drip irrigation, and (3) fertilizer through the sub-surface drip irrigation system. Data was taken from soil samples using a Giddings soil probe after five years. Phosphorus, K, Mg, Ca, and pH samples were taken at four depths and at four distances from the drip tape emitter. The sub-surface fertilize increased the cotton yields one year when there was not enough rainfall to push the surface fertilize to the plant roots to supply the plant needs. When normal rainfall occurred there were no significant yield differences between the fertilized treatments. The data showed significant soil differences from fertilizing with the subsurface drip irrigation system but these differences were not enough to show an effect on crop production after five years; difference could be more dramatic after a longer period of time.

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LITERATURE REVIEW

Types of Irrigation Systems

Subsurface drip irrigation (SDI) is increasing in popularity all around the globe and all across the United States. SDI has proven to be compatible type irrigation for row crops such as corn, cotton, and peanuts compared to the traditional overhead sprinkler, furrow, and even surface drip irrigation systems.

There are several types of sprinkler irrigation including movable solid set, center pivot, lateral tow, and hard hose. Solid set sprinkler irrigation runs for several hours, the water turned off, and the pipe moved by hand a joint at a time (Bowers, 1977). Moving the pipes is labor intensive, and is a major disadvantage for this system.

The hard hose gun is on a cart connected to the hard hose and is pulled across a field. Water flowing through a turbine turns a reel rolling the hose back up and pulling the gun across the field irrigating the crop as the hose is rolled. A hard hose irrigation system reduces labor of moving pipe but still requires the labor of moving the system to the next section to irrigate. Labor required to make sure the system continues to run properly is an added expense.

The center pivot system consists of a sprinkler line with one end anchored to a fixed pivot point. The system moves continuously in a circle around the pivot point

(Bowers, 1977). The lateral tow irrigation system consists of the same components as the center pivot system. The difference is the lateral tow moves laterally across the field instead of a circle around a fixed point.

Furrow irrigation systems are developed by smoothing the land surface, delivering water to the high corner of the land to be irrigated and running the water down the slope (Parsons, 1977). Furrow irrigation has been around longer than any other type irrigation. It is an effective system but requires that the initial landscape be fairly level and a water infiltration rate that is not too excessive.

Subsurface Drip Irrigation

In SDI, water is supplied to the plants at its root zone through a network of pipes (Padmakumari, 1985). Regardless of the type of subsurface drip system, the same basic components are used and can be segregated into three categories: (1) filter station, (2) valving and PVC pipelines, and (3) drip tape. The filter station is composed of a water pressure source (e.g., deep well turbine, booster pumps, centrifugal pump reservoir setups, etc.), screen and/or media filters, injection pumps, and irrigation controllers (Tollefson, 1983). The injection pumps are optional but are extremely useful for precision injection of fertilizers, insecticides, fungicides, and soil-water amendments into the water delivery system (Tollefson, 1983). The computer controller, a relatively new concept, enables irrigators to water and fertilize around-the-clock (Tollefson, 1983). The computer controller can be programmed to irrigate for a week at a time and keep records of every irrigation schedule. The valving and PVC pipelines are buried 0.91 meters deep in the soil to accommodate farm machinery. The pipelines carry the water through the electrically controlled valving to the drip tape, which is made from a polyethylene hose ranging in size from 8-15 mil (8 -15 μm) thick buried about 0.2 to 0.3 m below the soil surface (Tollefson, 1983). The water is then distributed through emitters that are spaced along the tape. There have been several tests on lateral spacing of drip tape under every row or between every other row. In regions where rainfall around planting time is fairly reliable and germination and stand establishment is acceptable, one tape every other row is as effective as one tape per row (Powell and Wright, 1993; Camp et al.1989; Camp et al., 1997; Lamm et al., 1997), and one tape every other row has a economical advantage over one tape per row.

There are several benefits of SDI in relation to the traditional types of irrigation. SDI does not require the labor of moving pipes and starting the system because the tape is buried beneath the soil surface and the system is started with an electronic controller. SDI requires less water pressure than the overhead sprinkler irrigation, which allows for less horsepower to pump the water and lower energy costs. SDI has pressure compensating emitters that allow irrigation in sloping fields where furrow irrigation will not work. Subsurface drip irrigation is buried below the soil surface which prevents damage by rodents, which is common with surface drip irrigation.

Research reports for over 30 crops indicated that in most cases SDI resulted in greater or equal yield than those for other irrigation methods and required less water in many cases (Camp, 1998). SDI is proving to be an economical method of water application to agronomic row crops such as corn, peanuts, and cotton (Khalilian et al., 2000). Some of the major advantages that have been identified are: reduced tillage, reduced weed control inputs, enhanced fertility management, reduced water and energy use, and increased yield (Tollefson, 1983). Maximum yield increases can be obtained when needed nutrients (N, P, and K and others) are injected precisely through the drip irrigation system (Phene et al., 1992). A subsurface drip irrigation system offers many advantages compared to other irrigation systems: (1) there is less annual labor and an increased life expectancy; (2) a dry soil surface reduces the occurrences of soilborne diseases and helps to control weed infestations; (3) the dry soil in furrow enhances trafficability and reduces soil compaction; and; (4) there is more efficient use of water and nutrients; and (5) there is a significant improvement in yield and quality components (Phene et al., 1987).

Proper irrigation has proven to be beneficial to cotton producers. Subsurface drip irrigation can be used economically with cotton to achieve an increase in yield and water efficiency (Phene et al., 1992). The yield of cotton, which is very sensitive to irrigation, can be increased three to four times by irrigation (Ertek et al., 2003). On the other hand, irrigation which is not done at the proper time may lower the yield (Tekinel and Kanber, 1989). Excessive irrigation can cause an increase in vegetative growth and a decrease in yield. Infrequent irrigation can cause an increase in shedding and thus, a drop in yield (Ertek et al., 2003).

Beginning in the early 1980's, cotton producers in West Texas began to install subsurface drip irrigation (SDI) systems to stretch declining groundwater resources (Enciso et al., 2005). Henggeler (1995a) reported that adoption of SDI improved yield and water use efficiency for several producers, and noted a 27% increase in yield over surface (furrow) irrigation, and yield increases greater than 2.5 times over non-irrigated yields. Henggeler (1995b) stated that SDI cotton acreage in West Texas increased from

3,300 acres in 1995 to 8,000 acres in 1996 and projected to be 13,000 acres in 1997. Freirich (2004) reported that Texas had 220,000 acres of cotton irrigated with SDI in 2004. After years of drought, the need to conserve water is utmost in the minds of all those living in western irrigated areas (DeTar et al., 1992). In West Texas there are several factors behind the rising rate of drip irrigation: pre-irrigate off-season, irrigate odd-shaped pieces of arable land, improve water use efficiency, and irrigate contoured, terraced, and sloping land (Pier, 1997).

In Israel, where cotton is also an important irrigated crop and water is limited, irrigation has gradually moved from sprinkler to drip irrigation and approximately 85 percent of the irrigated area is now being irrigated by drip irrigation (Phene et al., 1992). In Spain, Mateos et al. (1992) compared furrow and subsurface drip irrigation methods in cotton and determined that the SDI method was better. It was shown in their study that the water use efficiency rate of drip irrigation was 30% higher than that of furrow irrigation.

Need for Irrigation in Alabama

There is a potential for SDI in Alabama's contoured, terraced, sloping, land with small irregular shapes. Alabama has an abundance of water but water available for irrigation is limited (Hairston, 1990). Alabama's total farm acres have declined from 5.1 million ha (12.7 million acres) in 1980 to 3.5 million ha (8.6 million farm acres) in 2006. Farm acres will continue to decline in Alabama if more irrigation infrastructure is not established helping keep the farmer in business. The coastal plain region represents 1.8 million ha (4.5 million farm acres) and 50% of the total row crop acres in Alabama. The soils in the Coastal Plains are coarse-textured and low in fertility, have a compacted E horizon and have a low water storage capacity and limited rooting depth (Camp, 1999). The climate in Alabama is humid and foliar diseases can be a problem (Weeks, 2000). Subsurface irrigation avoids the risks of disease that is encountered from rainfall or sprinkler irrigation (Wright et al., 1986). The SDI may also enhance fertility management by the ability to inject fertilize to the crop through drip tape and directly into the root zone.

Only 40,500 ha of 3.5 million ha in production were irrigated in Alabama in 2007 (Helms and AAS, 2007). This low irrigation percentage is due to irregularly shaped, sloping fields and a groundwater water supply that is too deep to be economically feasible (Helms, 2007 and Pier, 1997).

In the southeastern Coastal Plain, crop yields are reduced by drought stress about every other year because of poor rainfall distribution, short term droughts, and low soil water storage (Sheridan et al., 1979). From 1996 to 2007 the Headland, Alabama, area endured an average of 13.7 weeks per growing season from 1 April to 31 October without receiving at least 2.54 mm (0.10 in.) of rain (AWIS, Alabama Weather Information System). There are only 30 weeks during the growing season. This area is in some type of drought 45% of the time. At peak flowering (the time of peak water consumption by a cotton crop), cotton in the southeastern United States can use up to 6.6 mm of water per day (Thomas, 1987). Thomas et al. (2002) reported that a Dothan sandy loam had a water holding capacity of 32 - 44 mm in the top 30 cm of soil. The root depth of a cotton plant ranges from 18 -55 cm. Therefore, if a soil contains the maximum available water it will supply the cotton plant for 6.9 days without additional rain or irrigation. Bauer et al., (1997) stated that the needed water can readily be replaced by daily drip applications. Cotton yield is dependent upon the production and retention of bolls, both of which can be decreased by water stress (Guinn and Mauney, 1984).

Most row crop production in the Southeast is in the Coastal Plains. The sandy soils typical of this region are inherently low in fertility and water holding capacity along with an organic matter content of less than 1.0% (Khalilian et al., 2000). These conditions cause poor soil tilth and reduce rainfall infiltration. Infiltration is the maximum rate at which a soil, in a given condition at a given time, can absorb rain (Brady, 2002). Low infiltration rates can cause inefficiencies with surface irrigation.

There are management practices which can improve infiltration rates. Runoff on a clean tilled Miles fine sandy loam (fine-loamy, mixed, Thermic Udic Paleustalf) with 0.3% organic matter was 7.34 cm compared to 1.12 cm with 7.5 Mg/ha straw (Gerald, 1987). Katsvairo et al. (2007) stated that water infiltration rates were higher in both cotton and peanut after bahiagrass compared with conventional peanut/cotton rotation in 2003. Katsvairo's research was conducted on a Dothan sandy loam (fine, loamy siliceous, thermic Plinthic Kandiudults). The peanut after bahiagrass infiltration rate was 691 $\mu m\ s^{-1}$compared to 51$\mu m\ s^{-1}$ for the cotton after peanut rotation. Sullivan (1984) stated that many fields across Georgia, Florida, and Alabama consisted of sandy surface layers over loamy and clayey subsoils and were low in fertility. When subsoil was mixed with the remaining topsoil she saw excessive crusting, clodiness, and reduced rainfall infiltration.

Fertigation

Drip irrigation allows continuous irrigation and fertilizer injection into the root zone. Accurately applying N through the growing season reduces the potential for groundwater contamination from nitrate and may also enhance crop yield (Bucks and Davis, 1986). Bar-Yosef (1999) reported a number of potential agronomic advantages for fertigation with subsurface drip irrigation (SDI) over surface drip irrigation. These advantages included nutrient application to the center of the root system, and the utilization of nutrient rich secondary municipal effluents. Nakayama and Bucks (1986) also pointed out that injection of fertilizer through the drip irrigation system can increase fertilizer efficiency by placing the material where the roots are concentrated. Point source application methods have been shown to produce different distribution patterns of soil N under sprinkler and surface irrigation and rainfall (Onken et al., 1979). Different patterns could be expected when N is applied with SDI systems, but the water carrier and application point should exert additional and different effects (Mitchell, 1981; Mitchell and Sparks, 1982; Onken et al., 1979; Bar-Yosef, 1999). The sandy soil in the Coastal Plain region would benefit from fertilizing through the SDI system because of a leaching potential. Without fertigation, all of the N fertilizers are applied within 6 weeks of planting and several inches of rainfall in a short period of time can leach NO_3 –N out of the root zone, and create a need for additional N.

Tube Placement and Soil Compaction

The soils of the southeastern Coastal Plain typically have a coarse-textured Ap horizon. Some may have a compacted layer beneath the plow layer that restricts root growth and development to a shallow soil layer that is often less than 0.3 m (Camp et al., 1999). These restrictive layers are called plow pans, or traffic pans, or hardpans. Restricted root growth prevents the roots from reaching water at lower depths. Plants effected by soil compaction can be stunted and wilt in dry weather. The roots remain above the compacted layer, and taproots of cotton may turn at a right angle above the layer if penetration is prevented (Watkins, 1981).

Khalilian (1999) conducted studies to determine optimum tube placement in a Coastal Plain soil by looking at the effects of subsurface drip irrigation on soil compaction. He set up his experiment with tape depths of 8, 12, and 16 inches with tape spacing of every row and every other row. A subsoiler was used in the spring to compare the effects of the deep tillage with no-tillage. The biggest difference in soil compaction was found in the E-horizon (Khalilian et al., 1999). The compaction was observed by the use of cone index readings taken 48 hours after irrigation. Cone index values above 1.5 megapascals (150 psi) generally reduce crop yield and values above 3.0 megapascals (300 psi) stop root growth (Taylor and Gardner, 1963; Carter and Tavernetti, 1968). Khalilian et al (1999) found that sub-soiled plots with irrigation laterals buried 16 inches deep had the least cone index values at depths of 6-18 inches. They found that the shallow lateral tape placement at 8 inches creates high soil surface moisture which causes higher weed infestations than other treatments. Depth of the irrigation tubes had an effect on cotton yield, with the cotton yield increasing with depth of tape. There were no differences in yield between every row versus alternate row installation at any of the three placement depths. With drip irrigation, subsoiling did not increase yield.

Tillage

Annual deep tillage is generally recommended for soils with hard pans to increase rooting depth and to increase plant available water, especially when irrigation is not used (Camp et al., 1999). Double cropping wheat and soybean as a rotation with cotton are economically competitive alternatives to monocropping cotton in the southeastern Coastal Plain (Camp et al., 1999). If irrigation is not used in a double cropping system, the first crop (wheat) can deplete stored soil water, which causes seedbed water deficits for the second crop (soybean), especially if a drought period occurs when the wheat is maturing in the spring (Frederick and Camberato, 1994, 1995). Research on rainfed production of these crops on Coastal Plain soils indicates some form of deep tillage is needed for roots to explore subsoil moisture (Camp et al., 1999). Deep tillage consists of tilling at depths of more than 12 inches and is designed to shatter compacted soils at that depth.

Deep tillage is problematic with SDI because of possible damage to drip lines, especially when they are installed at depths of 0.30 m or less (Camp et al., 1999). There is a possibility that conservation tillage especially with SDI can eliminate the need for deep tillage. With conservation tillage crops are planted into the previous crop residue. The residue helps control weeds and slows surface runoff rates which increase water infiltration rates. Although there were no differences in the yields of three crops, Camp et al. (1999) found that a shallow compacted zone can limit root growth and reduced irrigation efficiency on crops grown in Coastal Plain soils. Strategies to reduce soil strength at relatively shallow soil depths are needed for conservation tillage culture in these soils before the full benefits of subsurface drip irrigation can be realized (Camp et al., 1999). Knowing the difficulty of using deep tillage where compaction is a problem in subsurface drip irrigation, Camp et al. (2000) looked at three tillage methods and two different drip lateral spacings of 97 and 193 cm (38 and 76 inches) to see if soil strength could be reduced. Tillage methods included two shallow 15 cm (6in.) tillage methods, an in-row subsoiler (Beasley) and a stubble mulch plow, and the standard no-tillage, which was no surface or subsurface tillage. Unfortunately the shallow tillage was not effective in distributing the irrigation water to the shallow root zone or increasing cotton yield and there were no differences in cotton lint yield among the three tillage methods or between the two subsurface drip lateral spacings.

Water Quality

Groundwater quality is a major concern in the United States and across the world. The U.S. Environmental Protection Agency (EPA) estimated that nearly 52% of the community wells and 57% of the rural domestic wells contain nitrate-N (Langemeier, 1991). Only 2% of these wells contain nitrate levels above the maximum contaminant level of 10-mg/kg; however, any nitrate-N found in wells raises concern with the public. Batie and Deibel, (1991) reported that high N concentrations in groundwater were found in agricultural areas all across the United States. Hagin and Lowengart, (1996) stated that an increase in nitrate concentrations from about 40-105 mg L^{-1} in water wells was observed in an intensively cropped valley in Israel. The EPA and other government agencies are encouraging the development and use of Best Management Practices (BMPs) to protect water quality while still providing producers a way to remain economically viable (Lamm et al., 2004). Another strategy developed by the government is The President's Water Quality Initiative (WQI) (Phene and Ruskin, 1995). The purpose of WQI is to relate agricultural activities to groundwater quality and to develop farm management strategies to protect groundwater.

The staff of the Water Management Research Laboratory (USDA-ARS-Fresno) has developed a method that would achieve the President's goal in the (WQI). Phene and Ruskin, (1995) stated that the method known as deep, high-frequency, subsurface drip irrigation (SDI) would minimize leaching if the following conditions were met: 1) irrigation events are short and frequent and designed to replace crop water uptake as closely as possible (no leaching fraction); 2) N is applied with the water through the SDI system at a rate equivalent to the uptake rate of the crop less the amount mineralized from the soil; 3) the crop is deep rooted; and 4) the shallow water table is at least 203cm (80 inches) from the soil surface. Three physical characteristics, unique to SDI, contribute to its advantages and to minimizing nitrate-N leaching: 1) Reduced evaporation component of evapotranspiration; 2) larger wetted soil volume and surface area than drip irrigation; and 3) deeper rooting than surface drip irrigation (Phene and Ruskin, 1995). The wetted soil volume with a SDI system has lower water content than the drip irrigation system, thus the potential for leaching is decreased. The SDI system allows for a closer emitter spacing than the drip irrigation. The closer emitter spacing results in a shorter wetted radius and a more uniform distribution of fertilizer. The SDI method shows some unique and economical potential for safely irrigating field crops with treated wastewater (Phene and Ruskin, 1995). In addition to the controlled movement of nitrate nitrogen (NO_3-N) to the groundwater, the mere fact that treated wastewater does not come to the soil surface adds another safety dimension to the handling of a potentially hazardous material (Phene and Ruskin, 1995).

Nitrogen Management

Numerous approaches can be taken to improve N management in crop production. Lamm et al., (2004) improved N management by looking at: 1) N source; 2) temporary immobilization; 3) split and/or multiple applications; 4) precision placement; and 5) combined management of irrigation and rainfall.

Best Management Practices in reducing pollution were with split/multiple N applications. The important pollution-reducing management elements related to split/multiple applications in the development of this Best Management Practice (BMP) are: 1) small amount of starter fertilizer (mixture of UAN 32-0-0 and ammonium polyphosphate 10-34-0 in this study) reduces the pool of N available for leaching during periods when precipitation exceeds crop ET; 2) injected UAN (32-0-0 in this study) contained about 50% of its nitrogen in the nitrate-N form which can be absorbed immediately by the plant roots; and 3) weekly just-in-time injections, reduce the pool of N available for leaching (Lamm et al., 2004). Precision placement is an effective means of increasing N use efficiency. Concentrations of N necessary for optimum plant growth, precisely placed in a limited soil volume, can reduce the total pool of N available for leaching (Lamm et al., 2004).

Lamm et al. (2004) used a mixture of urea ammonium nitrate (32-0-0) and ammonium polyphosphate (10-34-0) as a starter fertilizer and stated that the ammonium polyphosphate is contained the non-leachable ammonium-N preferred by the crop in early life. Injecting the mixture of 25% nitrate-N, 25% ammonium-N, and 50% urea-N allowed them to have a readily absorbed nitrate-N and the less mobile ammonium-N which can be absorbed directly by the plant or microbially transformed to nitrate-N.

They also used a nitrification inhibitor to keep the N in the ammonium-N form to reduce the leaching potential. (Lamm et al., (2004) observed no significant differences in corn yields between weekly injections of N with a subsurface drip irrigation system as compared with the surface-applied preplant N banded in the furrow. However, they postulated that delaying the N injections until the first irrigation in mid to late June (40 days after emergence) decreases the chance of nitrate leaching during a period when rainfall exceeds crop water use.

Nitrogen applied through drip irrigation is an effective method of application. Phene et al. (1979) determined that the injection of fertilizer through the drip irrigation system increased fertilizer use efficiency of potatoes by more than 200% over that from conventional application methods. Miller et al., (1976) reported that N injected through a drip irrigation system was used more efficiently than when banded on tomatoes. Mohtar et al., (1989) concluded that N application for cherries with a trickle irrigation system was a viable alternative to ground application at even one-half the ground applied amount. The important pollution-reducing management element related to positional placement in the development of this BMP is that the injected UAN can be immediately absorbed by the roots which will be very active at the 40-45 cm dripline depth due to rapid plant growth and favorable soil water conditions (Lamm et al., 2004).

Nutrients needed by Crops

The elements N, P, and K constitute about 3 to 5 % of the dry weight of most plants and are most frequently deficient nutrients in Alabama soils (Adams et al., 1994). Nitrogen supply is the dominant fertility factor in determining rate and amount of growth of most crops. Unfortunately, soil test are not reliable for determining the amount of N in the soil in humid regions such as Alabama. Adams et al. (1994) stated several reasons for not being able to predict N fertilizer needs. N is stored in the soil's organic matter and the rate of N release for crop use is affected by temperature, moisture, length of growing season, and other factors that make it impossible to predict the amount of N that will be supplied by the soil for a growing crop. Second, Alabama soils are low in organic matter and do not vary much in their capacity to supply N (Adams et al. 1994). Therefore, N recommendations are based on the crop to be grown and historical responses to applied N. The general recommendation for cotton in Alabama is 67-101 kg N/ha (60-90 lb/ac). The recommendation varies due to the different soil types across Alabama. North Alabama has a silt loam soil type with a higher C.E.C. that requires only about 67 kg N/ha while South Alabama has a sandy loam soil type with a lower C.E.C. requiring 101 kg N/ha.

Phosphorus (P) may be absorbed by the plant as an inorganic monovalent or divalent phosphate anion (Bidwell, 1979). If the pH is below 7 the monovalent form ($H_2PO_4^-$) is dominant and if the pH is above 7 the divalent (HPO_4^{2-}) is dominant. Crops require much smaller quantities of P than of N or K and usually plants contain about 0.2 to 0.3% P on a dry weight basis (Adams et al., 1994).

Adams et al., (1994) stated that P does not leach through soils but forms compounds with other elements in the soil and is released slowly but P is lost with eroded soils. Surface P levels may also be diluted when the soils are turned deeper than usual. In 1994, 50% of all the soil samples received by the Soil Testing Laboratory at Auburn University have been "High" in P and crops grown on those soils would not be expected to respond to P applications (Adams et al., 1994). In 2007 of all the soil samples received by the Soil Testing Laboratory at Auburn University, 51% tested High in P. So the number of soil samples high in P has not changed in thirteen years. There have been several experiments in Alabama that have shown that the lack of a P application will not reduce the yield of most crops when the P level is High or Very High (Mehlich-1 extractable soil test P >25 mg kg^{-1}).

Most sandy soils in Alabama are low in K, while the clays are likely to be high. The sandy soils are lower in K because of a lower C.E.C. and the higher percolation rate than the clay soils. Another reason is the potassium ions may be held as an exchangeable ion on surrounding colloids or clay solids. Adams et al., (1994) stated that as yields have been increased by higher N and P fertilization, the need for K on some soils has increased. Numerous experiments throughout the state have shown a response to the addition of K fertilizer. Adams et al., (1994) stated that growers could cease K fertilizer applications on cotton when Mehlich-1 extractable K > 60 mg kg^{-1} on soils with a C.E.C. between 4.6 and 9.0 cmole kg^{-1}.

The lack of K results in the "cotton rust" symptom - a yellowish white mottling that turns light, yellowish green, with yellow spots developing between veins of the oldest leaves (Watkins, 1981). Leaves eventually dry and shed prematurely, beginning with the lower leaves, where symptoms first occur (Watkins, 1981).

Secondary plant nutrients are calcium (Ca), magnesium (Mg), and sulfur (S). A calcium deficiency is not likely to occur where soil pH is maintained in the proper range. Calcium is supplied in both calcitic and dolomitic lime. According to soil test fertilizer recommendations for Alabama growing cotton on a soil with a CEC < 4.6 cmol/kg soil would require lime if the pH is below 5.8. The importance of calcium in the formation of calcium pectates in cell wall development is reflected in loss of stands in early season during cool, unfavorable weather (Watkins, 1981). Therefore a calcium deficiency could increase susceptibility to seedling diseases and poor stalk strength.

Magnesium (Mg) is a constituent of the chlorophyll molecule and therefore is very important to photosynthesis (Bidwell, 1979). The uptake of Mg^{2+} is dependent on the presence of other cations. The higher the concentration of other cations, the less Mg^{2+} is absorbed by the plant (Marschner, 1986). Adams et al., (1994) stated the most practical way to prevent Mg deficiency is by using dolomitic lime when soil tests indicate that Mg is Low (Mehlich 1 Mg ≤ 25 mg kg^{-1}).

In Alabama, drip irrigation has primarily been used as an economic way to irrigate vegetables. Mainly due to high per acre cost and values a producer cannot afford not to irrigate vegetables. Like any irrigation system, drip is not without problems of its own. The system enables the farmer to better manage his crop, thus increase yields, but it requires more intensive management and technical expertise (Tollefson, 1983). As the popularity continues to increase with subsurface drip irrigation, the more fertigation will be used to apply nutrients to row crops. Research is needed to determine the effects on the different chemical soil properties and cotton yield resulting from fertilizing through a subsurface drip irrigation system over several years.

MATERIALS AND METHODS

The objective of this research was to compare the effects of fertilizing through a sub-surface drip irrigation system with a conventional method of fertilizing by surface broadcast on soil chemical properties and cotton yield. We used data taken from soil samples where fertilizer was injected for at least five years 31cm (15 inches) deep into the soil profile. The soil samples were taken at different depths and analyzed for pH, Phosphorus, Potassium, Magnesium, and Calcium.

Fertilization treatments were: (1) conventional, surface broadcast fertilizer over the top with no irrigation, (2) conventional broadcast fertilizer over the top with sub-surface irrigation, and (3) fertigation through the sub-surface drip irrigation system. The experiment was located at the Tennessee Valley Research and Extension Center (TVREC) in Belle Mina on a Decatur silt loam (fine thermic, Rhodic Paleudults) and the Wiregrass Research and Extension Center (WREC) in Headland on a Dothan sandy loam (fine, loamy siliceous, thermic Plinthic Kandiudults). The two drip irrigation sites were established in 1998 at TVREC and 1999 at WREC. These drip sites were established at these locations five years prior to sampling in the spring of 2004. Five years should allow enough time to measure any differences from fertilizer treatments. Conservation tillage was used at both locations. Cotton was planted at both tests into wheat stubble. Both sites were a randomized block design with four replications. Plot size at TVREC was four rows, 102 cm (40 inches) apart and 61 m (200 feet) long. At WREC plot size was four rows, 91 cm (36 inches) apart and 58 m (190 feet) long. The middle two rows at each location were used as harvest rows. The total length of plot for each of the four reps was harvested and bagged. Once the plot was weighed and lint percent was determined (38%) the yield was calculated. This process was repeated each year at each location for yield.

Rainfall data was collected from both the WREC and the TVREC location from the AWIS website using Alabama Mesonet data (AWIS, 2009). The rainfall was recorded from April through the end of September. Data was recorded in inches and converted to centimeters for both locations.

The fertilizer recommendations for the two different growing regions for cotton production were determined from soil samples 15-20 cm (6-8 inches) deep taken before the crop was planted. Samples were analyzed at the soil testing lab in Auburn, Alabama. The extractable nutrients for both WREC and TVREC are shown in Tables 1 and 2, respectively. No statistically differences were observed between blocks or years from the samples in Tables 1 and 2.

Timing and type of fertilizers applied in kg/ha at WREC and TVREC are shown in Table 3 and 4. A starter fertilizer was used on all plots except in 1998 and 1999 at TVREC. Sidedress fertilizer was applied to the non-irrigated and the drip non-fertigated plots. The injected fertilizer was applied to the drip fertigated plots every 2-3 days until August at the WREC and was applied in eight equal applications at the TVREC. Different liquid fertilizers were used at the WREC from the TVREC drip fertilized plots (Table 5 and 6).

Soil samples were taken before the planting season in 2004 using a Giddings® soil probe with a diameter of 5 cm (2 in) down to a depth of 61 cm (24 in). The first step was to locate the drip tape that was buried 38 cm (15 inches) deep in the soil profile. Then we located an emitter along the tape line. Emitters were 61 cm (24 inches) apart. This allowed us to be in undisturbed soil, where we would take four core samples. The core sample sites were 13, 23, and 46 cm (5, 9, and 18 inches) perpendicular to the emitter at the WREC site and 13, 25, and 51 cm (5, 10, and 20 inches) perpendicular to the emitter at the TVREC site. Then another core sample was taken 13 cm from the tape but 31 cm (12 inches) from the emitter along the tape line. Figure 1 shows the sampling diagram.

The spacing was different for the two sites because the rows are 91 cm (36 inches) apart at the WREC and 102 cm (40 inches) apart at the TVREC site. Since the tape was buried between every other row the 46 and 51 cm (18 and 20 inch) core sites would be in the center of a row at each of the locations. The core sample 31 cm (12 inches) up the line gives a sample half way between two emitters. Samples were taken in 15 cm (6 inch) increments at four different depths from 0-15, 15-31, 31-46, and 46-61 cm (0-6, 6-12, 12-18, and 18-24 inches) for each of the core sample sites. The sampling procedure totaled 576 soil samples per location.

Soil samples taken from the Giddings Soil probe was analyzed at the soil testing lab. Soil pH was measured with a 1:1 soil water ratio followed by an Adams Evans Buffer for lime requirement (Adams and Evans, 1962). Phosphorus, Potassium, Magnesium, and Calcium were obtained with the Mehlich-I (Double Acid Extraction) test (Mehlich, 1953). The extractions were then analyzed on the Inductively-coupled Argon Plasma Spectrometer (ICAP).

RESULTS AND DISCUSSION

Fertilizing through the sub-surface drip increased cotton yields at both locations in certain years. Figure 2 shows the cotton yield for the WREC location. Only during a dry year did we see a significant yield difference in the cotton with the sub-surface fertilize compared to the surface fertilize drip plots. Figure 4 shows the rainfall for the WREC location. The rainfall data shows below average rainfall during the 2000 crop year at the WREC. There was not enough rainfall in 2000 to move the fertilizer down to the roots enabling the plant to obtain the nutrients needed for maximum growth and yield. Figure 3 shows the cotton yield for the TVREC location. There was only one year at the TVREC that we saw a significant yield difference from the sub-surface fertilized plots and the surface fertilized drip plots. During the 1999 and 2000 seasons at TVREC (Fig. 5) the rainfall was below average. Only during the 1999 season was the cotton yield significantly different (Fig. 3). This is because we didn’t get enough rainfall to move the nutrients to the roots. During the 2000 crop year at TVREC (Fig. 5) there was below average rainfall but no significant differences in yield (Fig. 3). This was due to the fact that TVREC received enough rainfall in during the early months of the growing season.

Analysis of Variance indicated significant differences in some soil properties due to treatments (Tables 7 and 8). Table 8 shows that there is a treatment effect with all elements except P when you look at the depth*depth*trt at the WREC. The depth*depth*trt is presented graphically in Fig. 6-14 with depth as the regressor. The lines are the fitted regressions and the symbols are the means on which that line is based.

There are no significant differences due to irrigation/fertilization on Mehlich-1 extractable soil P at TVREC (Fig. 6). This stands to reason because no P was injected through the sub-surface drip irrigation. Figure 7 from the WREC does not show any differences either between treatments. The extractable soil P value is the highest at the soil surface where the P fertilizer was applied. The level of P decreases due to plant uptake as you move down the soil profile until reaching the subsoil level.

Irrigation/fertilization did not effect Mehlich –1 extractable soil K at TVREC (Fig. 8). This is surprising since we did inject K through the sub-surface drip irrigation. However there did not appear to be a problem with the delivery of the K through the injection because extractable K was similar in all the treatments. The lines are also inside the high range for soil test K which is 120-160 mg K/kg for the soil type at this location. This suggests that adequate K was available to the plant no matter if it was applied the traditional way with a dry broadcast material over the top or injected with a water soluble material through the sub-surface drip. Irrigation treatments at WREC did result in differences in extractable K (Fig. 9). At the WREC, extractable K increases above and below 38 cm (15 inches). Injecting K through the sub-surface drip with the water carried the material to the soil surface as well as deeper into the profile.

Apparently, soil Mg leached faster with the two irrigated treatments at WREC resulting in lower extractable Mg compared to the non-irrigated treatment below 38 cm (Fig 10).

Extractable Ca at TVREC is higher at the soil surface with the injected fertilizer treatment (Fig. 11). This may be because N is being applied through the injection system and we are reducing the potential for N leaching as nitrate with Ca^{2+}. All treatments show decreasing extractable Ca as you move through the soil profile. Extractable Ca at WREC is similar to TVREC except that the total extractable Ca is much less in the low CEC soils of this region (Fig. 12). The injected treatment resulted in higher extractable Ca near the surface at WREC (Fig. 12) as at TVREC. However the surface and injected treatments both increase in Ca has you move deeper in the soil profile. Extractable Ca increases with depth at WREC with the two irrigated treatments because the water is coming from a limestone aquifer which is rich Ca.

Soil pH at TVREC (Fig. 13) follows the same pattern as extractable Ca at TVREC. Injecting N through the sub-surface drip enables the pH to stay higher at the soil surface than with the other treatments where the N drives the pH down creating a more acidic soil. All treatments have the same effect allowing the soil pH to decrease in value with increasing soil depth. At the WREC (Fig. 14) soil pH is higher at the soil surface under injection irrigation compared to surface irrigation just as it was at TVREC (Fig. 9). The difference with pH at the WREC from TVREC is that pH increases with depth with both surface and injected treatments. Soil pH and extractable Ca behave similarly at WREC. Calcium sources such as ground agricultural limestone ($CaCo_3^-$) raises soil pH. The soil pH is lowered from the use of ammonia-based fertilizers. The ammonia fertilizers nitrify into nitrate (NO_3^-) which releases more H^+ to lower the soil pH. When the N fertilizers where injected through the subsurface drip irrigation the soil maintained a higher soil pH and a high soil Ca level at both locations (Fig. 11-14).

Table 1. Soil pH and Mehlich 1 extractable nutrients (mg/kg) at the WREC.

Year	Block	pH	P	K	Mg	Ca
			mg/kg			
1999	1	6.3	24	53	65	335
1999	2	5.9	29	62	45	280
1999	3	6.6	25	80	77	330
2000	1	5.9	26	93	41	275
2000	2	6.3	28	87	48	250
2000	3	6.2	21	112	61	325
2000	4	5.8	25	124	37	190
2001	1	6.2	32	73	49	245
2001	2	6.3	30	87	42	290
2001	3	6.2	28	98	47	280
2001	4	6.0	31	83	41	250
2002	1	6.0	34	68	40	235
2002	2	5.8	36	102	37	230
2002	3	6.2	38	96	54	345
2002	4	5.9	31	94	45	250
2003	1	6.0	45	98	43	270
2003	2	5.7	44	105	31	250
2003	3	6.0	45	132	42	335
2003	4	6.0	45	121	39	265

*There were no statistical differences between blocks or years for Table 1.

Table 2. Soil pH and Mehlich 1 extractable nutrients (mg/kg) at the TVREC.

Year	Block	pH	P	K	Mg	Ca
			mg/kg			
1999	1	6.2	19	200	64	1025
1999	2	6.2	21	157	71	1065
1999	3	5.8	13	166	58	945
1999	4	6.3	17	163	79	1125
2000	1	5.9	18	169	57	905
2000	2	6.0	20	216	68	990
2000	3	6.9	19	200	69	1410
2000	4	6.4	19	182	79	1155
2001	1	5.9	18	169	57	905
2001	2	6.0	20	216	68	990
2001	3	6.3	20	200	69	1410
2001	4	6.4	19	182	79	1155
2002	1	7.0	19	227	79	1350
2002	2	7.1	19	241	87	1430
2002	3	7.0	21	242	167	1240
2002	4	6.7	17	221	90	1125
2003	1	7.0	19	227	83	1350
2003	2	7.1	19	241	87	1430
2003	3	7.0	21	242	167	1215
2003	4	6.7	17	221	90	1125

*There were no statistical differences between blocks or years for Table 2.

Table 3. Timing and Type of Fertilizers Applied in kg/ha at WREC.

Year	Time of Application	Fertilizer treatment	Amendment				
			$CaCO_3$	N	P_2O_5	K_2O	S
			Mg/ha	-----------kg/ha-----------			
1999	At planting	Starter	0	22	67	22	0
1999	1st week July	Sidedress	0	78	0	78	11
1999	1st week July	Injected	0	78	0	78	0
2000●	Pre-Plant	Starter	2.24	22	67	0	0
2000	End June	Sidedress	0	78	0	78	22
2000	End June	Injected	0	73	36	73	0
2001	At planting	Starter	0	22	45	0	22
2001	End June	Sidedress	0	78	0	78	0
2001	End June	Injected	0	78	0	78	3
2002*	Late June	Sidedress	0	94	20	78	11
2002	Late June	Injected	0	98	20	81	0
2003**	Late June	Sidedress	0	90	0	90	17
2003	Late June	Injected	0	90	0	90	0

●2.24 metric tons/ha of Lime was applied preplant.
*4.48 metric tons/ha of Broiler Litter was applied preplant.
**5.04 metric tons/ha of Broiler Litter was applied preplant

Table 4. Timing and Type of Fertilizers Applied in kg/ha at TVREC.

Year	Plots	Fertilizer Treatment	Amendment		
			N	P_2O_5	K_2O
			-----------kg/ha-----------		
1998-1999	Dryland/Irr	Sidedress	78	0	0
1998-1999	Irrigated	Injected	67	0	67
2000-2002	Dryland/Irr	Pre-Plant	34	0	0
2000-2002	Dryland	Sidedress	45	0	0
2000-2002	Irrigated	Injected	101	0	67
2003	Dryland/Irr	Pre-Plant	67	0	0
2003	Dryland	Sidedress	45	0	0
2003	Irrigated	Injected	101	0	67

Table 5. Liquid fertilizer sources used on the WREC drip fertilized plots.

Year	Fertilizer grade	Ammonomical Nitrogen (%)	Ammonium Nitrate (%)	Urea (%)	Soluble Nitrogen(%)
1999	10-10-10	0	0	7.5	2.5
2000	20-10-20	8.0	16.0	0	0
2001	24-0-24-1	8.0	16.0	0	0
2002	24-5-20	8.5	9.5	10.0	0
2003	23-0-23	8.5	14.5	0	0

Table 6. Liquid Fertilizers used on the TVREC Drip Fertilized Plots.

Year	Fertilizer grade	Source of nutrients
1998-1999	10-0-10-7	32%AmmoniumThiosulfate
2000-2003	6.2-0-4.14	Urea and Potassium Nitrate

*All liquid fertilizers in table 6 from TVREC were injected in eight equal applications.

Table 7. Results from ANOVA at TVREC. Highlighted areas are significant at P<0.05.

			TVS		
Effect	P	K	Ca	Mg	pH
	------------------------------------	------------------------------------Pr > F	-----------------------		
Trt	0.0069	0.1174	0.1724	0.2865	0.0539
Spacing	0.0224	0.0000	0.7674	0.5024	0.5972
Spacing*Trt	0.7557	0.1736	0.9101	0.9281	0.9977
Depth	0.0000	0.0000	0.3616	0.0003	0.0001
Depth*Trt	0.0008	0.0047	0.0131	0.1557	0.0017
Depth*Spacing	0.4861	0.0000	0.8588	0.7144	0.8940
Depth*Spacing*Trt	0.8613	0.7650	0.9002	0.8240	0.9952
Depth*Depth	0.0000	0.0000	0.0000	0.0001	0.0708
Depth*Depth*Trt	0.0110	0.0254	0.0183	0.1875	0.0056
Depth*Depth*Spacing	0.8452	0.0000	0.9122	0.8515	0.9090
Depth*Depth*Spacing*Trt	0.9230	0.8471	0.9785	0.8708	0.9997

Table 8. Results from ANOVA at WREC. Highlighted areas are significant at P<0.05.

			WGS		
Effect	P	K	Ca	Mg	pH
	--------------------------------------Pr > F---------------------				
Trt	0.0722	0.0080	0.0026	0.0008	0.0010
Spacing	0.1905	0.8950	0.0994	0.9908	0.2618
Spacing*Trt	0.3849	0.7625	0.4306	0.8611	0.9966
Depth	0.0000	0.0000	0.0000	0.0000	0.5472
Depth*Trt	0.2184	0.0000	0.0103	0.0033	0.0078
Depth*Spacing	0.5845	0.6030	0.0211	0.4384	0.0449
Depth*Spacing*Trt	0.5994	0.5852	0.4524	0.8810	0.9712
Depth*Depth	0.0000	0.0000	0.0000	0.0000	0.9628
Depth*Depth*Trt	0.3311	0.0000	0.0401	0.0065	0.0003
Depth*Depth*Spacing	0.8098	0.5784	0.1607	0.1730	0.1802
Depth*Depth*Spacing*Trt	0.6792	0.4932	0.8648	0.8539	0.9934

Figure 1. Sampling Site Diagram.

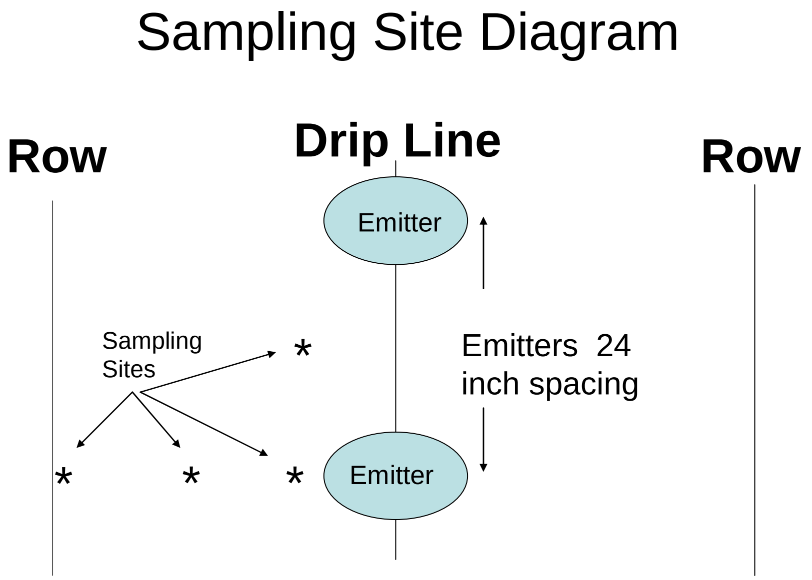


Figure 2. WREC lint cotton yield in kg/ha. Values followed by the same letter are not significantly different within each year using P<0.05.

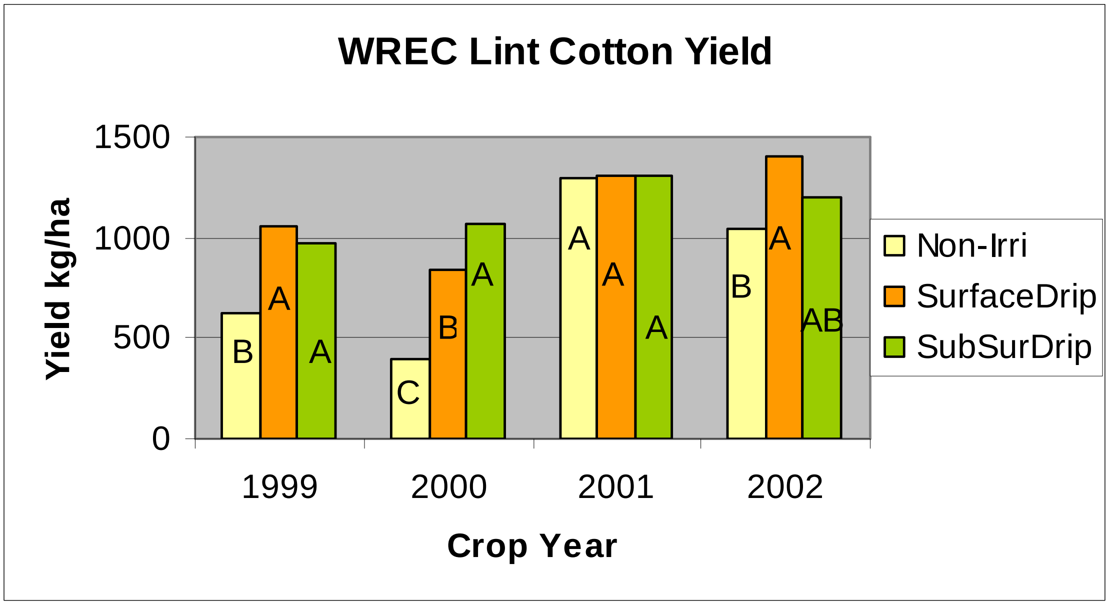


Figure 3. TVREC lint cotton yield in kg/ha. Values followed by the same letter are not significantly different within each year using $P<0.05$.

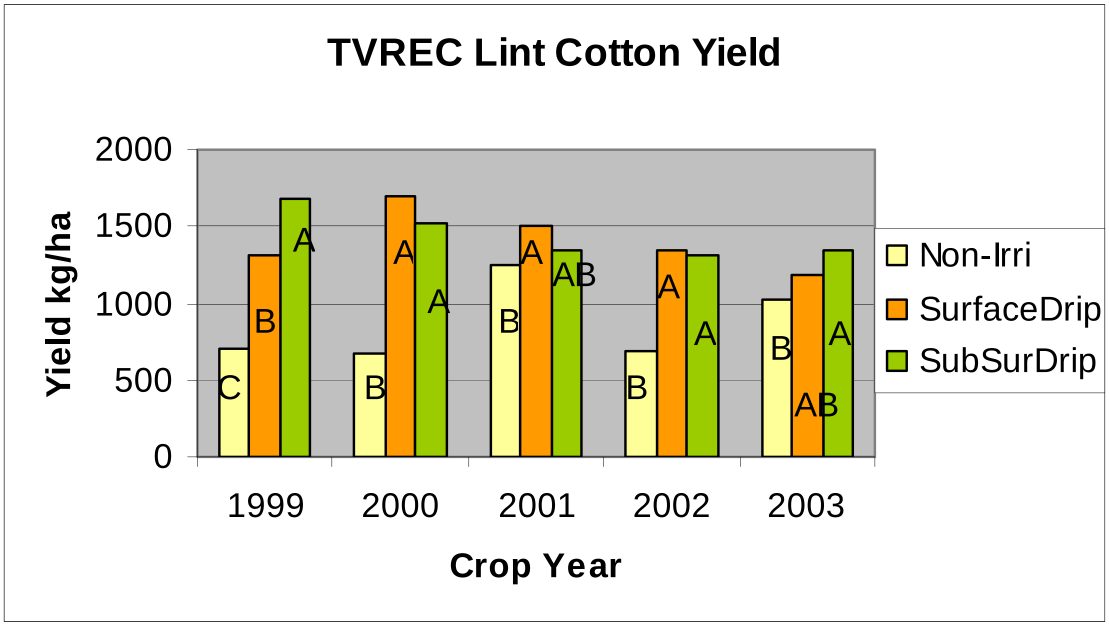
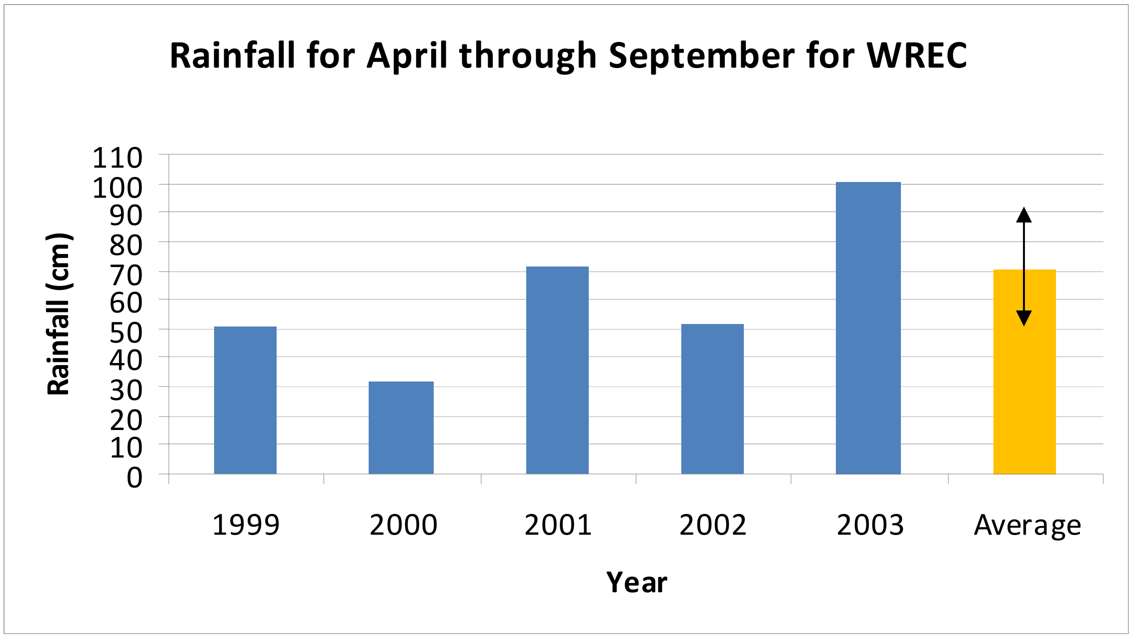
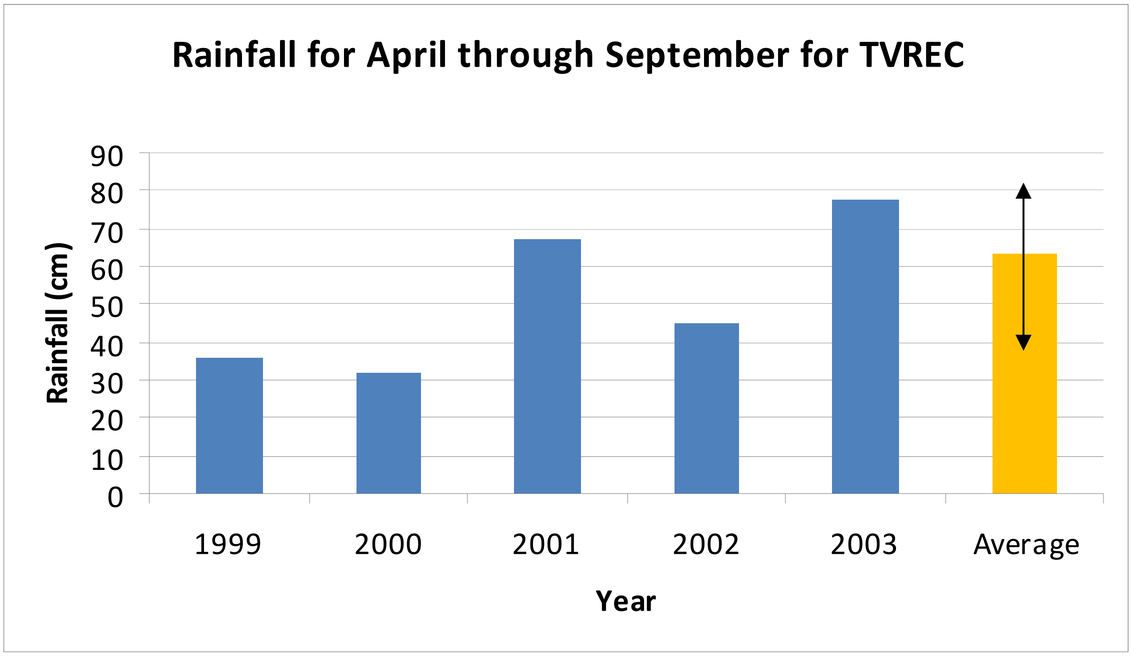


Figure 4. Rainfall for WREC in (cm).



*Arrow indicates standard deviation.

Figure 5. Rainfall for TVREC in (cm).



*Arrow indicates standard deviation.

Figure 6. The effect of irrigation on Mehlich-1 extractable soil P with depth at TVREC.

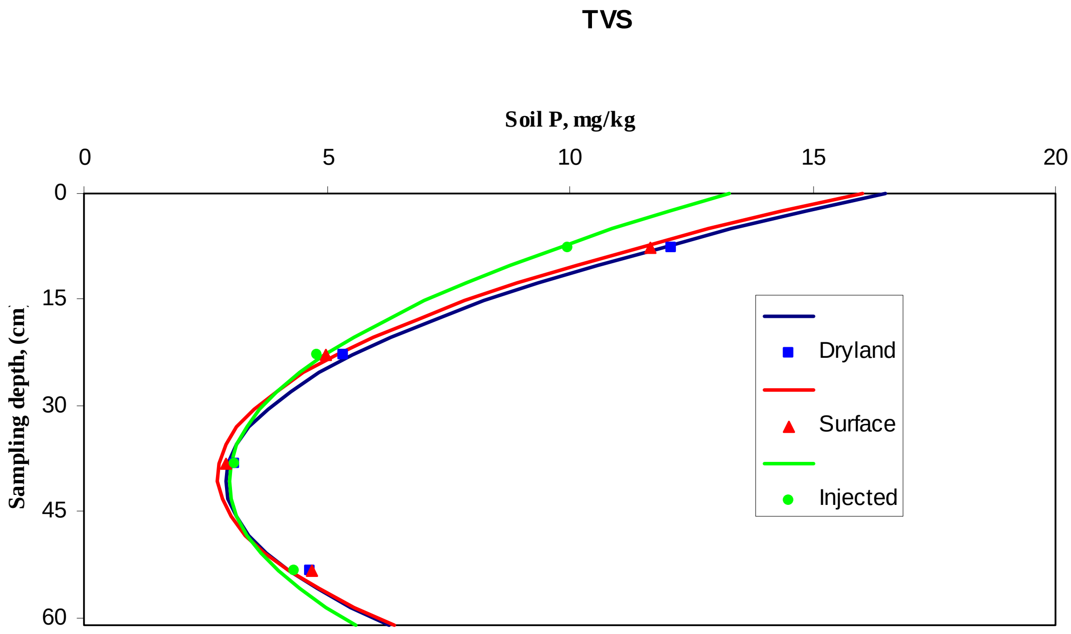


Figure 7. The effect of irrigation on Mehlich-1 extractable soil P with depth at WREC.

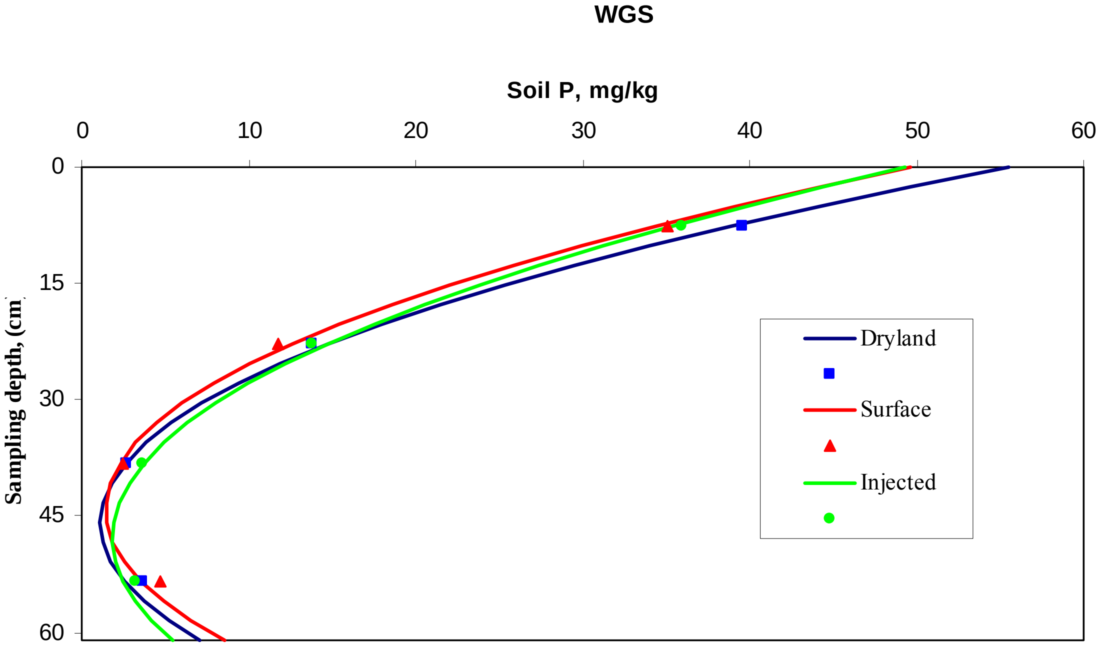


Figure 8. The effect of irrigation on Mehlich-1 extractable soil K with depth at TVREC.

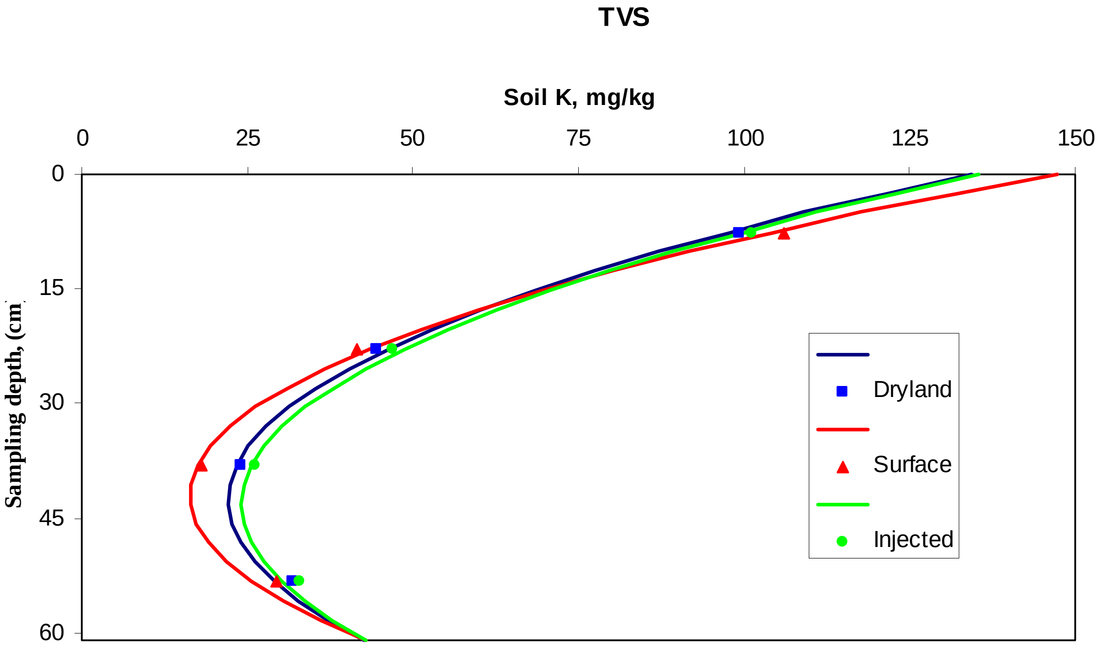


Figure 9. The effect of irrigation on Mehlich-1 extractable soil K with depth at WREC.

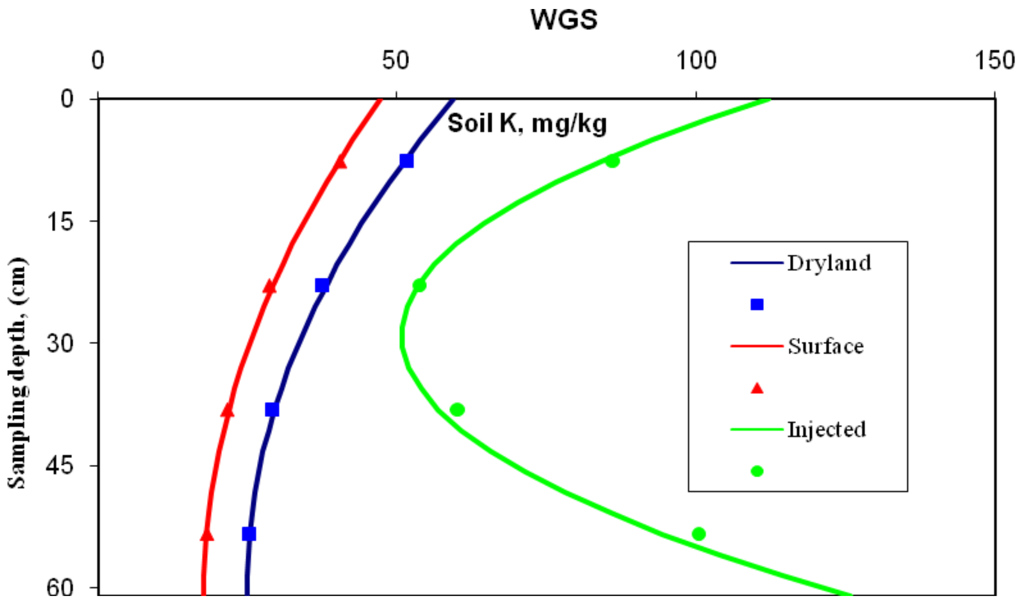


Figure 10. The effect of irrigation on Mehlich-1 extractable soil Mg with depth at WREC.

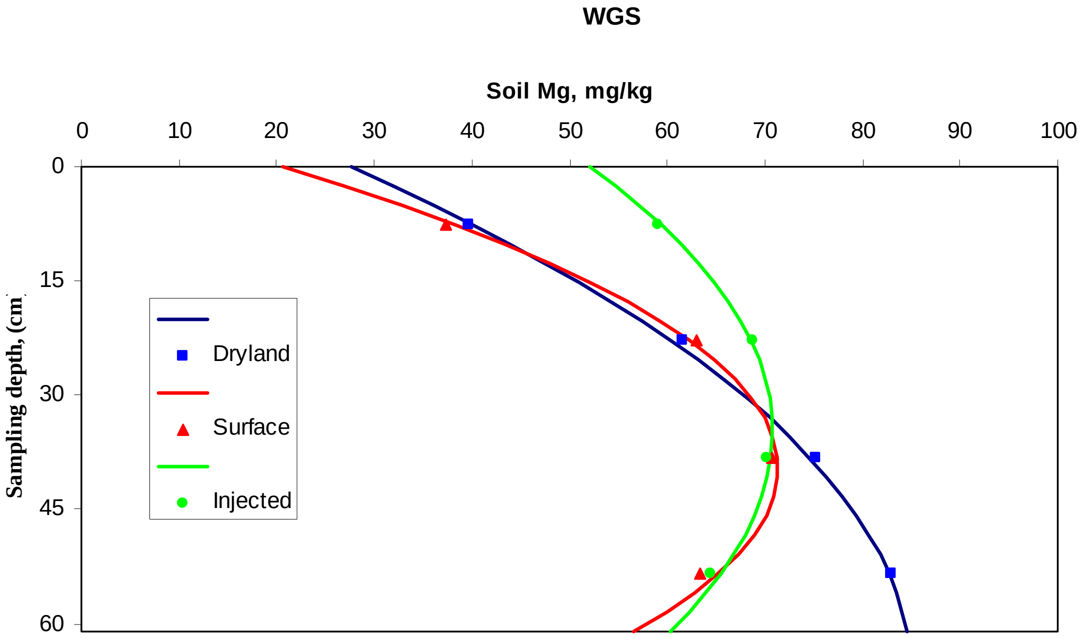


Figure 11. The effect of irrigation on Mehlich-1 extractable soil Ca with depth at TVREC.

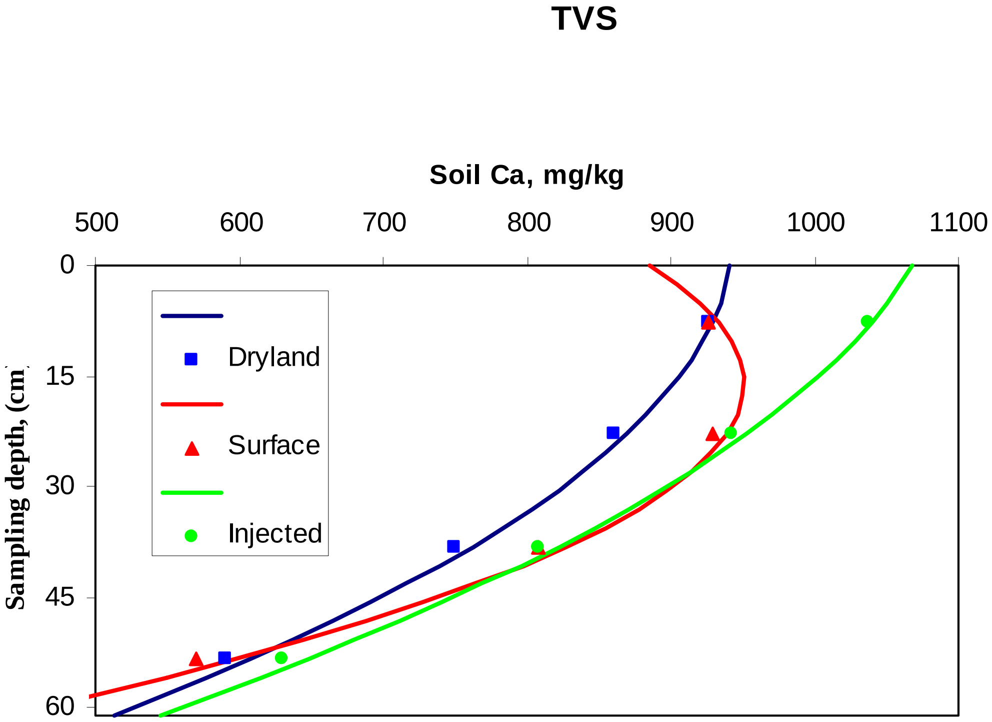


Figure 12. The effect of irrigation on Mehlich-1 extractable soil Ca with depth at WREC.

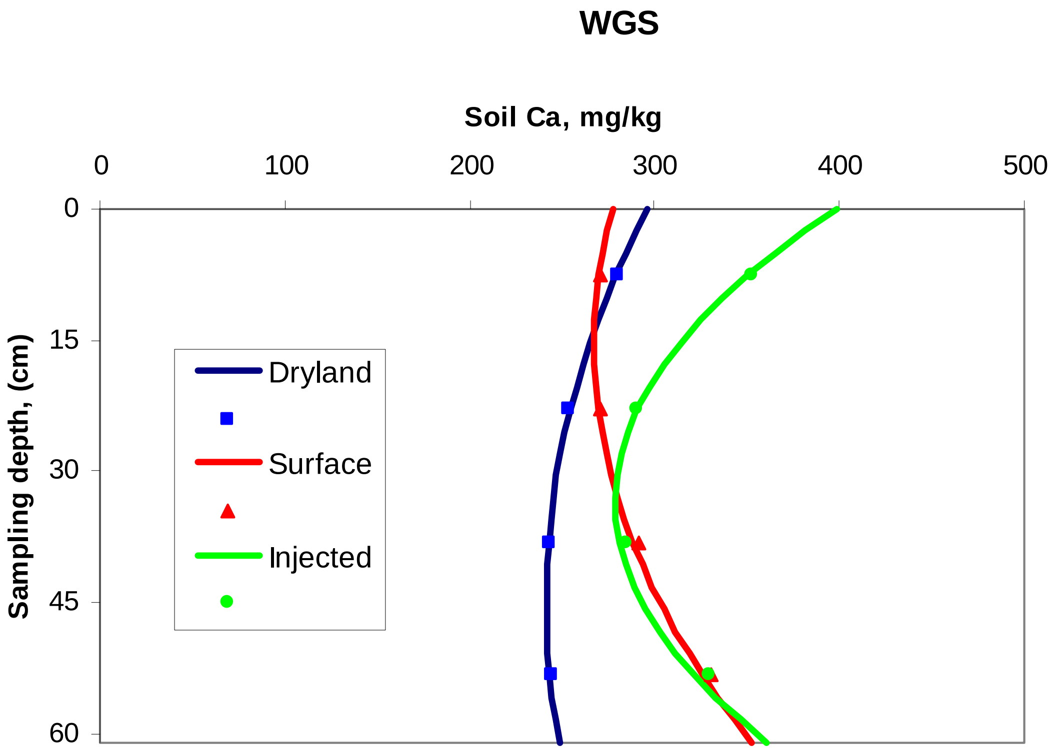


Figure 13. The effect of irrigation on Mehlich-1 extractable soil pH with depth at TVREC.

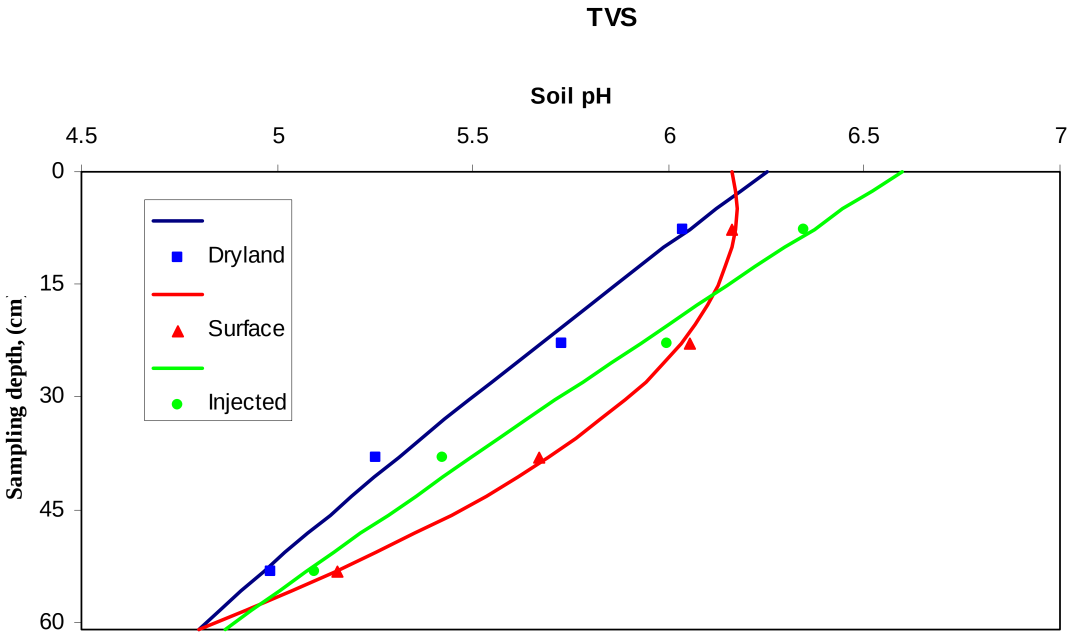
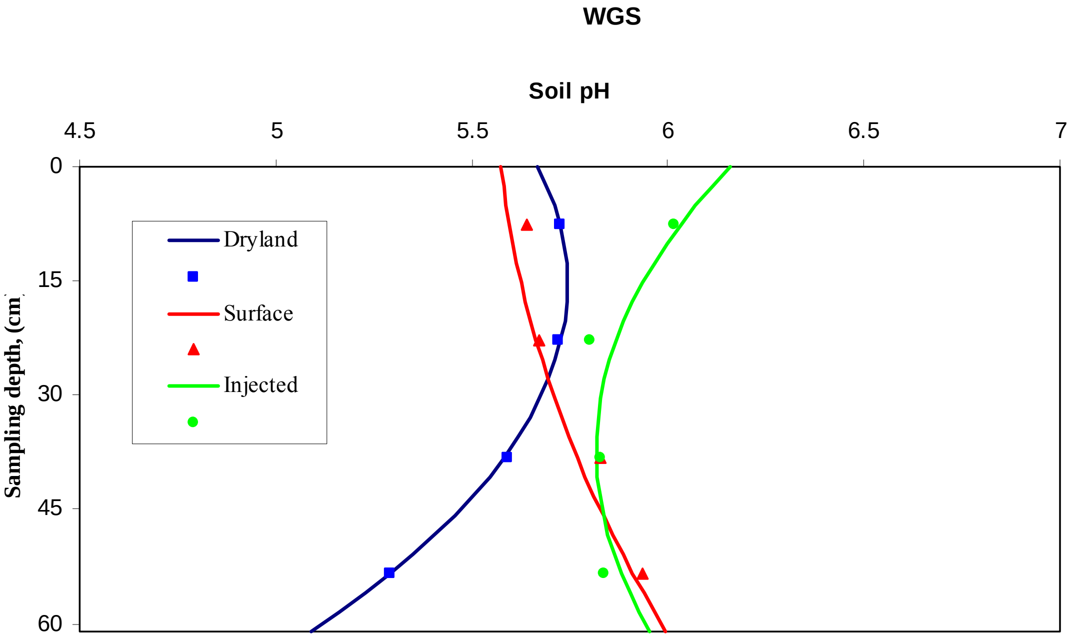


Figure 14. The effect of irrigation on Mehlich-1 extractable soil pH with depth at WREC.



SUMMARY AND CONCLUSIONS

This study was to measure any significant differences from fertilizing through a sub-surface drip irrigation (SDI) on the soil chemical properties and cotton yield at two different locations in Alabama. We measured differences in cotton yield and some soil properties due to irrigatioin at both the TVREC and WREC.

There was an increased cotton yield at both the TVREC and the WREC from fertilizing with the SDI. There was one out of five years at each location when there was below average rainfall and fertilizing through the SDI system had a significantly higher yield than the traditional surface applied method of fertilizing. This was due to insufficient rainfall early enough in the growing season that surface-applied fertilizer did not move to the roots in time to benefit the cotton in supplying adequate nutrients for maximum yields. The research demonstrates that you can effectively inject fertilizer through the drip to cotton as effectively as broadcast fertilizer over the top as is traditional. Not only did we observe a positive effect from SDI in dry years at both locations but the irrigation system resulted in differences in extractable soil K, Mg, and Ca and soil pH after 5 years. There was little effect on soil P due to irrigation method. Extractable soil K was higher at the soil surface and deep in the soil profile at the WREC. Extractable Ca and soil pH were higher at the soil surface for both locations. This result was from injecting N through the subsurface drip versus applying N broadcast on the surface of the soil. We did not anticipate the benefits of pumping water from the limestone aquifer at WREC and the differences in soil test results with depth. This was in addition to the benefit of injecting the N and K to the cotton weekly through the SDI system keeping those essential nutrients more readily available for plant uptake by not subjecting N and K to leaching. The injection of fertilizer through the SDI system did have an effect on soil chemical properties. However, the differences were not dramatic after five years, but could have a greater effect over a longer period of time showing an effect on crop production.

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