UNIVERSITY OF CAPE COAST

THE EFFECTS OF DEFICIT IRRIGATION, DEFICIT IRRIGATION-CHICKEN MANURE AND DEFICIT IRRIGATION-NPK 15:15:15 INTERACTIONS ON THE GROWTH AND YIELD OF OKRA (*Abelmoschus esculentus*) IN POT AND FIELD EXPERIMENTS

BY

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THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING, SCHOOL OF AGRICULTURE, COLLEGE OF AGRICULTURE AND NATURAL SCIENCES, UNIVERSITY OF CAPE COAST, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY IN IRRIGATION TECHNOLOGY

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DECLARATION

Candidate's Declaration

I hereby declare that all contents and details of this research work is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: …… Date: ……

Candidate's Name: Washington Koko Toe Willie

Supervisors' Declaration

We hereby declare that the preparation and presentation of this research work was supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

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ABSTRACT

The research was conducted at University of Cape Coast Research Farm, Cape Coast, Ghana, from February 2014 to February 2015. The objective of the research was to investigate the effects of deficit irrigation, deficit irrigation-chicken manure combination and deficit irrigation-NPK 15:15:15 combination on the growth and yield of Okra in pot and field experiments. The Randomized Complete Block Design was used for the pot experiment with nine (9) treatments replicated three (3) times. The 9 treatments were 100% (T1) crop water requirement (CWR), 90% CWR (T2), 80%CWR (T3), 100%CWR + 5t/ha chicken manure (T4), 100%CWR + 10t/ha chicken manure (T5), 90%CWR + 5t/ha chicken manure (T6), 90%CWR + 10t/ha chicken manure (T7), 80%CWR + 5t/ha chicken manure (T8), and 80%CWR + 10t/ha chicken manure (T9). It was observed in the pot experiment that T7 had a comparable yield with 100% CWR + chicken manure and 80% deficit irrigation + chicken manure performed poorly. In the field experiment, T1-T9 was maintained but six (6) NPK treatments were added to bring the total to 15. The 6 NPK treatments added were 100%CWR + 200kg/ha NPK (T10), 100%CWR + 250kg/ha NPK (T11), 90%CWR + 200kg/ha NPK (T12), 90%CWR + 250kg/ha (T13), 80%CWR + 200kg/ha NPK (T14) and 80%CWR + 250kg/ha NPK (T15). Deficit and full irrigation-chicken manure performed better than deficit and full irrigation-NPK at 100%CWR and 90%CWR. Twenty percent deficit irrigation plus high doses of chicken manure and NPK performed poorly. Ten percent deficit irrigation with 10t/ha chicken manure and 250kg/ha NPK are best for okra production.

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DEDICATION

This research work is dedicated to the Late Knight P.Andy Pabai (K.S.J. Int'l) and the Late Mr. Andrew Toe. You are gone but not forgotten.

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CHAPTER ONE

INTRODUCTION

Background to the Study

Irrigated agriculture is a key contributor to food security, producing nearly 40 percent of food and agricultural commodities on 17 percent of agricultural land (FAO, 2012). Irrigated areas have almost doubled in recent decades and contributed much to the growth in agricultural productivity over the last 50 years. Irrigated agriculture uses more than 70 percent of the water withdrawn from the earth's rivers in developed countries and over 80 percent in developing countries**.**

Scarce water resources and growing competition for water reduce availability for irrigation. At the same time there is the need to meet the growing demand for food and this requires increased crop production from less water. Achieving greater efficiency of water use though a challenge includes the employment of techniques and practices that deliver a more accurate supply of water to crops. In this context, deficit irrigation can play an important role in increasing water use efficiency (WUE).

Agricultural productivity and water use are linked and water has always been the main factor limiting crop production. In the context of improving water productivity and efficiency for agricultural purposes, there is a growing interest in deficit irrigation, an irrigation practice whereby crop water requirement or

evapotranspiration is reduced below maximum levels and mild stress is allowed with minimal effects on yield.

In regions where the cost of water is high or water is limited it can be more beneficial for a farmer to maximize crop water efficiency instead of maximizing the harvest per unit land. The extra water can be used for other works or to irrigate extra units of farmland.

Vegetables are increasingly becoming important as produce for domestic and export markets. They have a great potential to improve the nutrition, and therefore the health of consumers as most are good sources of vitamins, minerals and proteins needed for the proper functioning and development of the human body (Wills *et al.,* 1998).

Okra, *Abelmoschus esculentus* L. (Moench), is an economically important vegetable crop grown in tropical and sub-tropical parts of the world. This crop is suitable for cultivation as a garden crop as well as on large commercial farms.
In Ghana, okra is among the non-traditional export crops of importance, contributing 0.02% of Gross Domestic Product (GEPC, 2002). Annual production of okra in Ghana is estimated between 1,548 to 4,507 metric tonnes (SRID-MOFA, 2007). Okra is cultivated for its fibrous fruits or pods which contain round, white seeds. The fruits are harvested when immature and eaten as a vegetable.

Problem Statement

In Ghana, analysis of 40-year climatic data (1960-2000) from the Ghana Meteorological Agency reveals a progressive and visible rise in temperature with a simultaneous decline in rainfall across all agro-ecological zones (EPA, 2007). Climate change scenarios developed based on the forty-year data, predicted a continuous rise in temperature with an average increase of about 0.6ºC, 2.0ºC and 3.9ºC by the year 2020, 2050 and 2080 respectively. Rainfall is also predicted to decline on average by 2.8%, 10.9% and 18.6% by 2020, 2050 and 2080 respectively in all agro-ecological zones in Ghana (EPA, 2007). These predicted changes can have impact on the pattern of agricultural production in Ghana, especially in the regions where the agro-ecological systems are in transition. Smallholder farmers in Ghana who produce the bulk of the food and cash crops are the most vulnerable to the various manifestations of climate change.

The scope for further irrigation development to meet food requirements in the coming years is, however, severely constrained by decreasing water resources and growing competition for clean water. While on a global scale water resources are still ample, serious water shortages are developing in the arid and semi-arid regions as existing water resources reach full exploitation. The situation is exacerbated by the declining quality of water and soil resources. The dependency on water has become a critical constraint on further progress and threatens to slow down development, endangering food supplies and aggravating rural poverty. The great challenge for the coming decades will therefore be the task of increasing

food production with less water, particularly in countries with limited water and land resources.

With the ever-increasing competition for finite water resources worldwide and the progressively rising demand for agricultural commodities, the call to improve the efficiency and productivity of water use for crop production, to ensure future food security and address the uncertainties associated with climate change, has never been more urgent than now (FAO, 2012).

Moreover, drought periods or dry seasons represent a threat to the sustainability of irrigation, not only because water supply is restricted, but also because of the uncertainty in determining when it will be available.

Depending on the amount and distribution of rainfall and probability of occurrence, the regions of the world vary greatly in the supply of water. In many countries of the world, the average annual rainfall is not uniformly distributed. Lower amount of rainfall is characterised by higher variability necessitating the efficient use of irrigation water to carry on agricultural productivity. High variability in rainfall leads to greater incidence of famines and droughts. Drought leads to failure of crops.

Therefore, apportioned water for agriculture has to be utilized in an efficient and rationalized manner. Two issues that need attention are:

I. Finding a means of lowering the current level of water use by some efficient water use techniques, and

II. Promoting economic return to the farmers in an effort to enhance economic incentives.

Hence, supplemental irrigation or deficit irrigation is one major solution to reduce the severity of the droughts effect and secure limited amount of water for continuous agricultural crop production.

Objectives of the Research

General Objective

The general objective of the research was to determine the effects of deficit irrigation, deficit irrigation-organic (chicken manure) fertilizer combination and deficit irrigation-inorganic (NPK 15:15:15) fertilizer combination on the growth and yield of Okra.

Specific Objectives

The specific objectives of the research were:

I. To determine the effects of deficit irrigation on the growth and yield of Okra.

II. To determine the effects of deficit irrigation-chicken manure on the growth and yield of Okra.

III. To determine the effects of deficit irrigation-NPK 15:15:15 on Okra growth and yield

IV. To compare the interaction effects of deficit irrigation and chicken manure in a pot experiment and to assess the interaction effects of deficit irrigation-chicken manure and deficit irrigation-NPK 15:15:15 in a field experiment on Okra growth and yield.

Justification of the Study

As agriculture accounts for 70% of freshwater withdrawals worldwide and, furthermore, as most irrigation systems are very inefficient (only 30 to 50% of the water distributed is taken up by the plant), deficit irrigation is not only of high significance in water-scarce areas or in dry seasonal periods; it also has the potential to optimize and reduce water use in irrigated systems (Sadras et.al, 2007).

Deficit irrigation techniques are very interesting when it comes to an efficient allocation of scarce water resources. These techniques maximize water use, generally with good or unchanged harvest quality (Spreer et. al., 2007). It is particularly relevant for crops in which flowering and fruit development take place in the dry season. Due to the application of relatively small amounts of water the harvest can be stabilized over time and it improves economic planning for farmers, which is increasingly interesting under climate change conditions where water resources are becoming scarce and rains unpredictable. Furthermore, since water use is reduced, the irrigated area can be increased and additional crops can be irrigated amplifying the diversity of the household production, which decreases the farmers' risk aversion.

The application of less water reduces the leaching effects of nutrients from the root-zone and agrochemicals, and the groundwater quality is preserved (Pandey et. al., 2000). Furthermore, it reduces the risk of the development of certain fungal diseases linked with high humidity that are common in full irrigation systems.

When water supplies are limiting, the farmer's goal should be to maximizing net income per unit water used rather than per unit land. In recent times, emphasis has been placed on the concept of water productivity (WP), defined either as the yield or net income per unit of water used in evapotranspiration (ET) (Kijne et al., 2003). WP increases under deficit irrigation, relative to its value under full irrigation, as shown experimentally for many crops (Zwart and Bastiaansen, 2004; Fan et al., 2005).

In response to the increasing world population and economic growth, water withdrawals for human consumption increases, thereby increasing the competition for water between municipal, industrial, agricultural, environmental and recreational needs. If present trends continue with water withdrawal under present practices and policies, it is estimated that by 2025 water stress will increase in more than 60 percent of the world (Cosgrove and Rijsberman, 2000). In this respect, providing food for the growing population is a major challenge as agriculture is already by far the largest water consumer in most regions in the world.

The overuse and misuse of water in irrigated agriculture has not only resulted in large-scale waterlogging, salinity and overexploitation of groundwater resources, but also depriving the downstream users of sufficient water and polluting fresh water resources with contaminated irrigation return flow and deep percolation losses. Water pollution might threaten public health.

With increasing scarcity and growing competition for water, there is need for more research to be done to have more widespread adoption of deficit

irrigation especially in arid and semi - arid regions. However, as different crops respond differently to water stress, it is important that the technique undergoes continuous refinement and improvement, as deficit irrigation requires more sophisticated water controls, accurate water management and soil water monitoring. With these techniques, it is then possible to identify irrigation scheduling strategies that maximize water use with minimal impacts on yields.

Under such circumstances, and looking into the future food demand, it is vital that agriculture improves the efficiencies for the use of the limited water and ensure substantial productivity gains.

CHAPTER TWO

LITERATURE REVIEW

Influence of Water Shortages on Crop Growth and Yields

Under ideal irrigation, crops do not suffer from water shortages as irrigation water is applied before the crops suffer from any drought stress. However, one may not be able to apply the irrigation water at the time the crop requires the water; especially during a dry year when the river may not have enough water to irrigate all the fields on time, or if the farmers are badly organized and lose too much water at the upstream end of the scheme, and consequently causing water shortage downstream. In such cases of water shortages, it is good to know:

(a) The crops which suffer most from water shortages, i.e. crops that will have severe yield reductions when the water is in short supply; and

(b) The growth stages during which the various crops suffer most from water shortages.

(c) The economic value of the crops may also influence the decision on how best to divide scarce water.

Irrigation Water Needs

The irrigation water need of a crop is the difference between the crop water need and the part of the rainfall that can be used by the crop (the effective rainfall), (Awulachew et. al., 2009).

The irrigation schedule indicates how much irrigation water has to be given to the crop, and how often or when this water is given. How much and how often water has to be given depends on the irrigation water need of the crop (Hansen et. al., 1980; Garg, 1989; Taffa, 2002; Panda, 2005).

An irrigation water need of 8 mm/day, does not mean that this 8 mm of water has to be supplied by irrigation every day. In theory, water could be given daily. But, this would be time and labour consuming. It is therefore preferable to have a longer irrigation interval. It is, for example, possible to supply 24 mm every 3 days or 40 mm every 5 days. The irrigation water will then be stored in the root zone and gradually be used by the plants say, 8 mm every day. The irrigation interval has to be chosen in such a way that the crop will not suffer from water shortage.

The soil type influences the maximum amount of water, which can be stored in the soil per meter depth. Sandy soils can store only a little water or have low available water content and therefore need to be irrigated frequently with a small amount of water. Clay soils, on the other hand have high available water content, and therefore larger amounts of irrigation water can be applied to it but less frequently.

Crop Water Needs

Without water crops cannot grow. Crop water needs are the sum of crop transpiration and evaporation from the crop leaves and plant and soil surface. The water need of a crop, thus, consists of transpiration plus evaporation. This crop water need is also called 'evapotranspiration' (Blaney and Criddle 1950; Doorenbos and Pruitt 1975). The water need of a crop is usually expressed in mm/day, mm/month or mm/season.

The highest crop water needs are thus found in areas, which are hot, dry, windy and sunny. The lowest values are found when it is cool, humid and cloudy with little or no wind. From the above, it is clear that one crop grown in different climatic zones will have different water needs.

Consumptive Water Use

Among the various consumptive uses, the water use in agriculture has been characterized as one with the highest expression because of the large amount of water normally used for irrigation. The water consumption determination in crops is one parameter key for planning and design with techniques and methodologies which aim at improving and/or ensuring adequate production levels with maximum water utilization and minimal wastage (Oliveira et al., 2010; Souza et al., 2011).

The crop evapotranspiration is an excellent tool to assist the irrigation project development, sizing and planning, reservoir management, among many other applications (Borges and Mendiondo, 2005).

Methods employed in the evapotranspiration determination can be direct or indirect. The indirect methods are based on parameterized equations that employ meteorological data, often not available at the place or in the interest region. One of these methods, is the Class A Pan Method. Due to its simplicity in operation and low cost, it has been frequently used for obtaining crop water consumption.

In this method, the evaporation is obtained in a given time interval and based on Kp, a coefficient which depends on place of installation, influences and changes in meteorological parameters (temperature, humidity and wind) are applied as corrections. However, there are several methods for obtaining Kp that may have different values for the same local conditions (Snyder, 1992; Pereira et al., 1995; Raghuwanshi & Wallender, 1998; Cuenca, 1989). In general, regional surveys are critical for specific definitions of methodologies for Kp estimated values, for applications in rational water management in irrigated crops (Mendonça et al., 2006; Esteves et al., 2010; Lopes et al., 2012).

Crop Evapotranspiration (ET_c)

The crop evapotranspiration differs distinctly from the reference evapotranspiration (ET_o) as the ground cover, canopy properties and aerodynamic resistance of the crop are different from grass. The effects of characteristics that distinguish field crops from grass are integrated into the crop coefficient (K_c). In the crop coefficient approach, crop evapotranspiration is calculated by multiplying ET_o by K_c.

Measurement Procedures

Direct Measurement

The evapotranspiration rate from a cropped surface can be directly measured by the mass transfer or the energy balance method. It can also be derived from studies of the soil water balance determined from cropped fields.

Crop evapotranspiration can also be derived from meteorological and crop data by means of the Penman-Monteith equation. By adjusting the albedo and the aerodynamic and canopy surface resistances to the growing characteristics of the specific crop, the evapotranspiration rate can be directly estimated. The albedo and resistances are, however, difficult to estimate accurately as they may vary continually during the growing season as climatic conditions change, as the crop develops, and with wetness of the soil surface. The canopy resistance will further be influenced by the soil water availability, and it increases strongly if the crop is subjected to water stress.

As there is still a considerable lack of consolidated information on the aerodynamic and canopy resistances for the various cropped surfaces, the FAO Penman-Monteith method is used only for estimating ET_o, the evapotranspiration from a well-watered hypothetical grass surface having fixed crop height, albedo and surface resistance.

Crop Coefficient Approach

The crop coefficient Kc integrates the effect of characteristics that distinguish a typical field crop from the grass reference, which has a constant appearance and a complete ground cover. Consequently, different crops will have

different K_c coefficients. The changing characteristics of the crop over the growing season also affect the K_c. Finally, as evaporation is an integrated part of crop evapotranspiration, conditions affecting soil evaporation will also have an effect on K_c. In the crop coefficient approach the crop evapotranspiration, ET_c, is calculated by multiplying the reference crop evapotranspiration, ET_o, by a crop coefficient, K_c:

$$ETc = ETo \times Kc \quad \text{..... equ. 1}$$

Where:

ETc is the crop evapotranspiration (mm/day)

Kc is the Crop Coefficient (dimensionless)

ET_o reference crop evapotranspiration [mm/day].

Most of the effects of the various weather conditions are incorporated into the ET_o estimate. Therefore, as ET_o represents an index of climatic demand, K_c varies predominately with the specific crop characteristics and only to a limited extent with climate. This enables the transfer of standard values for K_c between locations and between climates. This has been a primary reason for the global acceptance and usefulness of the crop coefficient approach and the K_c factors developed in past studies. The reference evapotranspiration, ET_o, is defined and calculated using the FAO Penman-Monteith equation. The crop coefficient, K_c, is basically the ratio of the crop ET_c to the reference ET_o, and it represents an integration of the effects of four primary characteristics that distinguish the crop from reference grass.

The soil surface wetness and the fraction of ground covered by vegetation influence the surface resistance, r_s. Following soil wetting, the vapour transfer rate from the soil is high, especially for crops having incomplete ground cover.

Growth stages of the Crop

As the crop develops, the ground cover, crop height and the leaf area change. Due to differences in evapotranspiration during the various growth stages, the K_c for a given crop varies over the growing period. The growing period can be divided into four distinct growth stages: initial, crop development, mid-season and late season.

Initial Stage

The initial stage runs from planting date to approximately 10% ground cover. The length of the initial period is highly dependent on the crop, the crop variety, the planting date and the climate. For perennial crops, the planting date is replaced by the 'greenup' date, i.e., the time when the initiation of new leaves occurs.

During the initial period, the leaf area is small, and evapotranspiration is predominately in the form of soil evaporation. Therefore, the K_c during the initial period ($K_{c\ ini}$) is large when the soil is wet from irrigation and rainfall and is low when the soil surface is dry.

Crop Development Stage

The crop development stage runs from 10% ground cover to effective full cover. Effective full cover for many crops occurs at the initiation of flowering. For row crops where rows commonly interlock leaves such as beans, sugar beets, potatoes and corn, effective cover can be defined as the time when some leaves of plants in adjacent rows begin to intermingle so that soil shading becomes nearly complete, or when plants reach nearly full size if no intermingling occurs. For some crops, especially those taller than 0.5 m, the average fraction of the ground surface covered by vegetation (f_c) at the start of effective full cover is about 70-80%.

As the crop develops and shades more and more of the ground, evaporation becomes more restricted and transpiration gradually becomes the major process. During the crop development stage, the K_c value corresponds to amounts of ground cover and plant development. Typically, if the soil surface is dry, K_c = 0.5 corresponds to about 25-40% of the ground surface covered by vegetation due to the effects of shading and due to micro scale transport of sensible heat from the soil into the vegetation. A K_c = 0.7 often corresponds to about 40-60% ground cover. These values vary, depending on the crop, frequency of wetting and whether the crop uses more water than the reference crop at full ground cover (e.g., depending on its canopy architecture and crop height relative to clipped grass).

Mid-Season Stage

The mid-season stage runs from effective full cover to the start of maturity. The start of maturity is often indicated by the beginning of the ageing, yellowing or senescence of leaves, leaf drop, or the browning of fruit to the degree that the crop evapotranspiration is reduced relative to the reference ET_o. The mid-season stage is the longest stage for perennials and for many annuals, but it may be relatively short for vegetable crops that are harvested fresh for their green vegetation.

At the mid-season stage the K_c reaches its maximum value. The value for K_c ($K_{c\ mid}$) is relatively constant for most growing and cultural conditions. Deviation of the $K_{c\ mid}$ from the reference value '1' is primarily due to differences in crop height and resistance between the grass reference surface and the agricultural crop and weather conditions.

Late Season Stage

The late season stage runs from the start of maturity to harvest or full senescence. The calculation for K_c and ET_c is presumed to end when the crop is harvested, dries out naturally, reaches full senescence, or experiences leaf drop.

For some perennial vegetation in frost free climates, crops may grow year round so that the date of termination may be taken as the same as the date of planting.

Water Quality for Irrigation

Quality should infer how well a water supply fulfills the irrigation needs of the intended user and must be evaluated on the basis of its suitability for the intended use.

Water used for irrigation always contains some quantities of dissolved salts from the parent rocks of the soil and dissolving of lime, gypsum and other salt sources as water passes over or percolates through the soil.

The suitability of water for irrigation is determined by the amount and kind of salts present. With poor water quality, various soil and cropping problems can be expected to develop and special management practices are then required to maintain full crop productivity.

The problems that result from using poor quality water vary both as to kind and degree but the most common ones are:

- **Salinity**: A salinity problem related to- water quality occurs if the total quantity of salts in the irrigation water gives a specific Ec value that salts accumulate in the crop root zone to the extent that yields are affected. If excessive quantities of soluble salts accumulate in the root zone, the crop has extra difficulty in extracting enough water from the salty soil solution
- **Permeability**: A permeability problem related to water quality occurs when the rate of water infiltration into and through the soil is reduced by the effect of specific salts or lack of salts in the water to such an extent that the crop is not adequately supplied with water and yield is reduced.

- **Toxicity**: A toxicity problem occurs when certain constituents in the water are taken up by the crop and accumulate in amounts that result in a reduced yield. This is usually related to one or more specific ions in the water namely boron, chloride and sodium.

Irrigation water quality refers to its suitability for use. Good quality water has the potential to allow maximum yield under good soil and water management practices.

Soil- Plant -Water- Relationships

Soil-Plant-Water relationships describe those properties of soils and plants that affect the movement, retention, and use of water essential to plant growth.

In planning an irrigation system, an engineer is concerned primarily with the water-holding capacity of a soil, particularly in a plant's root zone; the water-intake rate of the soil; the root system of the crop to be grown; and the amount of water that the crop uses. But he must also have a working knowledge of all soil-plant-water relationships in order to plan efficient irrigation for particular crops grown on a particular soil and to adjust the design to various conditions. This general knowledge also enables him to assist an irrigator in managing the system efficiently.

Since a constant supply of water in the soil is necessary for plant survival and growth, the irrigation engineer is concerned with how water moves in a given soil, how much water a soil can hold and how much of it is available to plants, and how the water supply can be replenished. The first two are related to size and

distribution of the soil pores and to size of the soil particles and their attraction for moisture. The amount of water a soil holds also depends on the amount of organic matter in the soil. Generally, the finer the soil particles and the larger the amount of organic matter, the more water a soil holds.

Soil is a storehouse of plant nutrients, a habitat for bacteria, an anchorage for plants, and a reservoir that holds the water needed for plant growth. The amount of water a soil can hold available for plant use is determined by its physical properties. This amount determines the length of time a plant can survive without water being added. It determines both the frequency of irrigation and the capacity of the irrigation system needed to ensure continuous crop growth.

In many irrigated soils, the soil solution contains an appreciable amount of salts. The osmotic pressure developed by the soil solution retards the uptake of water by plants since the total moisture stress is the sum of the soil-moisture tension and the osmotic pressure of the soil solution. Plants growing in a soil in which the soil-moisture tension is 1 atmosphere apparently can extract enough moisture for good growth. But if the osmotic pressure of the soil solution is 10 atmospheres, the total stress is 11 atmospheres and plants cannot extract enough water for good growth.

In designing an irrigation system and in making recommendations for improved techniques of applying water, the engineer needs to know how much of the water in a soil is available to plants. The soil is like a tank and holds just so much available water. Its capacity is limited by the total amount of water it can hold between field capacity and the permanent wilting point. In addition to soil-

moisture tension and the osmotic pressure of the soil solution, availability of water also depends on the temperature of the soil. Low soil temperatures decrease availability. Field capacity is usually considered as the amount of water a well-drained soil holds after free water has drained off or the maximum amount it can hold against gravity. The large pores in the soil are filled with air, the microspores are filled with water, and any further drainage is slow. In this condition, the soil is said to be at field capacity.

A sandy loam is soil containing a high percentage of sand but having enough silt and clay to make it somewhat coherent. The individual sand grains can be readily seen and felt. Squeezed when dry, a sandy loam forms a cast that falls apart readily. If squeezed when moist, a cast can be formed that bears careful handling without breaking.

To design a successful irrigation system, the irrigation engineer must know the rooting characteristics of plants and how plants use moisture. Since a continuous supply of available moisture is necessary for good plant growth, the irrigation system for any given crop must ·be designed to supply the right amount of water during that crop's peak-use period.

To determine the amount of soil moisture available to that crop, it is necessary to know from what depth of soil the plants get their moisture, or their moisture-extraction pattern, and how fast they use moisture. The size of the soil reservoir that holds water available to a plant is determined mostly by that plant's rooting characteristics. The distribution of its roots determines its moisture-extraction pattern. Most plants have an enormous absorbing root surface. Near

the growing tip of each root or rootlet, there are many root hairs in close contact with soil particles and with the air spaces from which roots get their oxygen. Through osmotic and other forces, root hairs extract moisture from the film of water that surrounds each soil particle. Two phenomena seem to explain how a plant gets the enormous amount of water it takes in and transpires: (1) Capillary movement of water to plant roots and (2) growth of roots into moist soil.

As roots take up moisture, tension around the soil particles increases and water moves toward these points of plant absorption. How effective capillary movement is depends on how much water can be delivered to the soil around the roots and how fast it gets there. But since there is little root extension when the soil-moisture content is low, it is likely that near the wilting point any water that reaches plant roots must move-to them.

During favorable growing periods, roots often elongate so rapidly that satisfactory moisture contacts can be maintained even when the soil moisture content declines and without much help from capillary movement. Where a good root system has developed during favorable growing periods, a plant can draw its moisture supply from deeper soil layers. Thus if the roots in the upper part of the soil have depleted the moisture there to below the wilting point, plant needs can still be met provided roots have already grown into deeper layers that contain an adequate moisture supply.

Irrigation as Influenced by Soil Physical Properties

The mineral particles of the soil differ widely in size and can be classified, depending on their size, as gravel, sand, silt and clay.

Table 1: Soil Classification (Awulachew et. al., 2009)

Name of Particles	Size limits in mm	Distinguishable with naked eye
Gravel	Larger than 1	Obviously
Sand	1 to 0.5	Easily
Silt	0.5 to 0.002	Barely
Clay	less than 0.002	Impossible

The amount of sand, silt and clay present in the soil determines the soil texture.

In coarse textured soils: sand is predominant (sandy soils).

In medium textured soils: silt is predominant (loamy soils).

In fine textured soils: clay is predominant (clayey soils).

In a field, soil texture can be determined by rubbing the soil between the fingers. Farmers often talk of light soil and heavy soil. A coarse-textured soil is light because it is easy to work, while a fine-textured soil is heavy because it is hard to work. The texture of a soil is permanent, the farmer is unable to modify or change it.

Table 2: Expression used by Farmers to Classify Soils, (Awulachew et. al., 2009)

Expression used by farmer	Expression used in Literature	
Light	Sandy	Coarse
Medium	Loamy	Medium
Heavy	Clayey	Fine

Soil structure refers to the grouping of soil particles (sand, silt, clay, organic matter and fertilizers) into porous compounds (Hansen et al., 1980; Garg, 1989; Schwab et. al., 1993; Murthy, 2007). These are called aggregates. Soil

structure also refers to the arrangement of these aggregates separated by pores and cracks. The basic types of aggregate arrangements are granular, blocky, prismatic, and massive structures.

When present in the topsoil, a massive structure blocks the entrance of water and makes seed germination difficult due to poor aeration. On the other hand, if the topsoil is granular, the water enters easily and the seed germination is better. In a prismatic structure, movement of the water in the soil is predominantly vertical and therefore the supply of water to the plant roots is usually poor. Unlike texture, soil structure is not permanent. By means of cultivation practices (ploughing, ridging etc.), farmers try to obtain a granular topsoil structure for their fields.

When irrigation water is supplied to a field, it seeps into the soil. This process is called infiltration. The velocity at which water can seep into the soil is called the infiltration rate. It is commonly measured as a depth of the water layer (in mm) that the soil can absorb in an hour. An infiltration rate of 15 mm/hour means that a water layer of 15 mm on the surface of the soil will take one hour to infiltrate.

The infiltration rate of a soil depends on factors that are constant, such as the soil texture. It also depends on factors that vary, such as the soil moisture content and the soil structure (FAO, 1985; Panda, 2005; Murthy, 2007).

- **Soil texture**

Coarse textured soils have mainly large particles in between which there are large pores. On the other hand, fine textured soils have mainly small particles in

between which there are small pores. In coarse soils, the rain or irrigation water enters and moves more easily into larger pores; it takes less time for the water to infiltrate into the soil. Therefore the infiltration rate tends to be higher for coarse textured soils than for fine textured soils.

- **The soil moisture content**

The water infiltrates faster (higher infiltration rate) when the soil is dry, than when it is wet. As a consequence, when irrigation water is applied to a field, the water at first infiltrates easily, but as the soil becomes wet, the infiltration rate decreases, (Awulachew et. al., 2009).

- **The soil structure**

According to Awulachew et. al. (2009), water infiltrates quickly (high infiltration rate) into granular soils but very slowly (low infiltration rate) into massive and compact soils.

Because farmers can influence the soil structure (by means of cultivation practices), they can also change the infiltration rate of their soil.

Water Uptake by Crop Roots

Water uptake is carried out by root hairs located at the zone of differentiation. Many root hairs increase the surface area available for water absorption. Fugal hyphae attached to roots also absorb water and pass it on to roots. The process of water intake at the roots is called osmosis. Osmosis is the movement of a substance through a membrane. Water moves because the overall water potential (amount of water) in the soil is higher than the water potential in

the roots and plant parts. Water continues to diffuse from the inside of the root hairs, through the ground tissue and into the xylem of the root. The water can then travel up through the xylem of the root and stem, into the petiole, and into the leaves of the plant.

There are two (2) processes that enable the water to move up a plant. They are root pressure and transpiration.

1. **Root Pressure**: Water moves into the roots. As new water moves into the roots it causes the water to move up the plant. Root pressure is capable, under ideal atmospheric conditions, of pushing water one or two feet above the ground. Since root pressure is not strong enough to move water up very high another process is needed to enable the water to continue up the plant. This is transpiration.

2. **Transpiration**: Transpiration is the loss of water through the leaves and other parts of the plant. Most transpiration occurs through openings, called stomata, on the underside of the leaves. Water moves, because of root pressure, up into the stem. Because water is being lost out of the stomata of the leaves the water in the stems is being pulled up. This is so because water molecule clings to each other by cohesion. As water molecules cling to each other as they move up the stem and into the leaves they pull the molecules up as they transpire out of the stomata. This is called The Cohesion-Tension Model of water transport in xylem. As water molecules are stuck together by cohesion the entire column of water in the xylem adheres to the sides of the xylem. It is said that the water is under tension as the

column moves up the xylem. At the same time, the xylem tube narrows because of the tension.

Minerals/Fertilizers Uptake by Roots

A plant cannot live on water and sugar alone. Plants also depend on nutrients that they cannot make themselves, so they have to get them from the soil. The main nutrients a plant needs are nitrogen, phosphorus and potassium. These are called macronutrients because plants need large quantities of them to be healthy. A few other macronutrients are calcium, magnesium and sulfur.

Some nutrients are essential to plant life, but plants do not need very much of them. These are called micronutrients, because plants only need small quantities of them. Micronutrients include boron, copper, iron, chloride, manganese, molybdenum and zinc.

Nutrients have to be transported through the vascular tissue too. Roots take in nutrients from the soil and then inorganic molecules move up the plant through the xylem. Phloem takes care of the organic molecules. Nutrients are delivered to where they are needed in the plant, such as new leaves or branches.

In addition to soil transport, nutrient uptake is controlled by the spatial distribution of roots, as influenced by its architecture, morphology and presence of active sites of nutrient uptake, including root hairs. For nutrients that are immobile (e.g. phosphorus) or slowly mobile (ammonium), a root system must develop so that it has access to the nutrients, by increasing their exploration volume. Alternatively, the roots may increase its exploitation power for the specific nutrient by local adaptation of the rooting system, allowing for increased

uptake efficiency of the nutrient. In the case of non-adsorbing nutrients, nutrient uptake is controlled by mass flow, as is the case of nitrate-nitrogen, which is hardly adsorbed by the soil.

Effects of Organic and Inorganic fertilizers on Soil Status and Crop Production

Tropical soils are beset with problems of acidity, low nutrient contents, nutrient imbalance and soil erosion. The use of fertilizers (organic and inorganic) has been found to solve these problems (Babatola and Olaniyi, 1997; Ekpe, 2008). The stability of production depends on replenishing nutrients removed from the soil by crops, maintaining desirable physical condition of the soil, preventing an increase in soil acidity and toxic elements and minimizing or preventing erosion (Sanwal et al., 2007). This emphasizes the importance of fertility restoration in achieving and maintaining high crop productivity and it can be achieved through the use of external fertilizer input.

The application of organic manure to soil not only enhances its nutrient status but also reduces the incidence of pest (Adilakshi *et al*., 2007). Improvement of soil fertility through the application of fertilizers has become an essential factor that enables the world to feed billions of people of its population (Brady and Weil, 1999). Soil fertility is usually maintained by the application of organic and inorganic fertilizers (Okigbo, 1985), and there is also an improvement in the physical and biological properties of the soils (Okwuagwu *et al*., 2003). The use of inorganic fertilizers also improves crop yields, soil pH, total nutrient content and nutrient availability (Akande *et al*., 2010); most especially in the tropics

where soils are adversely affected by low soil soil fertility and erosion causing deterioration of the nutrient status and changes in population of soil organisms (ECA, 2001). However, the use of inorganic fertilizers is constrained by scarcity, nutrient imbalance and it is no longer within the reach of resource-poor farmers due to its high cost. When excessively used, it also has a depressing effect on yield. This causes a reduction in number of fruits, delays and reduces fruit setting (John *et al*., 2004).

The use of organic manures as a means of maintaining and increasing soil fertility has been advocated (Alasiri and Ogunkeye, 1999). Some of these materials have also been found to control pathogens (Muhammed *et al*., 2001). Animal manures, when efficiently and effectively used, ensure sustainable crop productivity by immobilizing nutrients that are susceptible to leaching. Nutrients contained in manures are released more slowly and are stored for a longer time in the soil thus ensuring longer residual effects; improve root development and higher crop yields (Sharma and Mittra, 1991; Abou-Magel *et al*., 2006).

Poultry manure's relative resistance to microbial degradation is essential for establishing and maintaining optimum soil physical condition and is important for plant growth (Dauda *et al*., 2008). It is also very cheap and effective as a good source of nitrogen for sustainable crop production (Dauda *et al*., 2008). Surekha and Rao (2001) and Prakash *et al*. (2002) had earlier explored the use of organic manures for managing the pests of okra.

Akanbi et al. (2010) noted that inorganic fertilizers can improve crop yields and soil pH, total nutrient content, and nutrient availability, but their use is

limited due to scarcity, high cost, nutrient imbalance and soil acidity. Therefore, there is a need to look for alternative ways of improving this crop plant.

The Okra Plant

General Description

Okra, *Abelmoschus esculentus* L. (Moench), is an economically important vegetable crop grown in tropical and sub-tropical parts of the world. This crop is suitable for cultivation as a garden crop as well as on large commercial farms. It is grown commercially in India, Turkey, Iran, Western Africa, Yugoslavia, Bangladesh, Afghanistan, Pakistan, Burma, Japan, Malayasia, Brazil, Ghana, Ethiopia, Cyprus and the Southern United States. India ranks first in the world with 3.5 million tonnes (70% of the total world production) of okra produced from over 0.35 million ha land (FAOSTAT, 2008).

Okra is known by many local names in different parts of the world. It is called lady's finger in England, gumbo in the United States of America, guino-gombo in Spanish, guibeiro in Portuguese and bhindi in India. It is quite popular in India because of easy cultivation, dependable yield and adaptability to varying moisture conditions.

Geographical Origin and Distribution

Abelmoschus esculentus is found all around the world from Mediterranean to equatorial areas. The spread of the other species is the result of their introduction to America and Africa. There are two hypotheses concerning the geographical origin of *A. esculentus*. Some authors argue that one putative

ancestor (*A. tuberculatus*) is native to Uttar Pradesh in northern India, suggesting that the species originated from this geographic area. For *A. caillei*, only found in West Africa, it is difficult to suggest an origin outside. Its origin by hybridization with *A. manihot* is difficult to accept even if its presence, mentioned in the Flora of West Africa (Hutchinson and Dalziel, 1958) was not recently confirmed in this area and herbarium samples are lacking.

Climatic and Soil Requirements

Okra is a tropical plant and is easily grown both in the wet and dry seasons. It is a short day plant (Njoku, 1958; Oyolu, 1977; Nwoke, 1980) and strongly responds to photo period.

Okra is not fussy about soils. It however, grows best in Sandy loam into which well-rotted compost has been incorporated. The soil should be well drained. Okra requires a long, warm and humid growing period. It can be successfully grown in hot humid areas. It is sensitive to frost and extremely low temperatures.

Okra requires a moderate rainfall of 80 – 100 cm well distributed to produce its young edible fruits over a relatively long period. An average temperature of 20°c to 30°c is considered optimum for growth, flowering and fruiting. Soil type does not appear to influence growth or development to any marked extent as a wide range of soil types has been found suitable. At 24°C the first flower bud may appear in the third leaf axil while at 28°C it may appear in sixth leaf axil. This higher position is not necessarily accompanied with a delay in time because at higher temperatures the plants grow faster and the higher position is reached earlier. For faster plant growth still higher temperature helps though it

delays the fruiting. But at higher temperatures beyond 40°–42°C, flowers may desiccate and drop, causing yield losses.

For seed germination optimum soil moisture and a temperature between 25°C and 35°C is needed with fastest germination observed at 35°C. Beyond this range the germination will be delayed and weak seeds may not even germinate.

Adjustment of climatic factors helps in taking at least one (summer) crop in hills, 2 or even 3 (summer, kharif and late kharif) crops in the east, west and north Indian plains and almost year-round cultivation under moderate climate in south India. It is grown on sandy to clay soils but due to its well-developed tap root system, relatively light, well-drained, rich soils are ideal. As such, loose, friable, well manured loam soils are desirable. A pH of 6.0–6.8 is ideally-suited. However, okra Pusa Sawani has some tolerance to salts and thus also to larger pH range. All soils need to be pulverized, moistened and enriched with organic matter before sowing.

Planting

Okra is propagated by seed. Germination is often delayed or fails owing to the very hard testa of the seed. Percent germination is doubled and germination rate greatly accelerated if the seeds are soaked in water for 24 hours prior to sowing.

Germination can also be hastened by soaking the seeds for 30 minutes in acetone and alcohol.

Fertilization

The plant responds to high organic content in the soil. It is therefore beneficial to incorporate well-decomposed organic matter at the rate of 20-25t/ha (Norman, 1992) into the soil at least a fortnight before planting. Commercial fertilizers are applied prior to planting in the form of 15-15-15 compound fertilizers at 250-300kg/ha and sulphate of ammonia or calcium ammonium nitrate at 68-125kg/ha.

When fruiting commences the plants benefit from occasional side-dressing of nitrogen. The plants are usually side-dressed with 15-20kg nitrogen per hectare at 6, 10, 14 and 18 weeks after sowing.

Also, pre-planting application of up to 50kg P_2O_5/ha in the form of superphosphate is given. The plants are then side-dressed with 50kg N/ha in the form of calcium ammonium nitrate applied in 2 split application at 2 weeks after germination and at fruit set.

Growth and Development

Okra is mainly propagated by seeds and has duration of 90-100 days. It is generally an annual plant. Its stem is robust, erect, and variable in branching and varying from 0.5 to 4.0 m in height. Leaves are alternate and usually palmately five lobed, whereas the flower is axillary and solitary.

Harvesting

Harvesting starts 8 to 12 weeks after seed sowing and the plants remain in harvest for 3-12 weeks depending upon the cultivar. The pods should be picked

when young and tender. Older pods are tough, woody and inedible. Harvesting is done three times weekly, for frequent harvesting, not only, ensures that the pods do not get old, but also, increases fruit set. In picking, the tender pods are broken from the stalks.

Okra pods are harvested at the age of 4-6 days (after fruit set) in order to have high quality pods for the table.

Iremiren et al. (1991) studied effect of age of harvesting after pod set on okra. They found that differences in the age at which okra pods were harvested (4, 7, 10 or 13days after pod set) had no effect on vegetative growth or pod yield, but pods harvested more than seven days after pod set were of poorer quality. The reduction in pod quality arose mainly from an increase in crude fibre and a reduction in moisture, crude protein and ash content of older pods

Yield

Yields of okra are dependent on the cultivar, harvesting frequency and the period the okra is in harvest. At Kumasi yields of up to 50 fruits per plant (6.3t/ha) have been recorded for the Asuntem white cultivar. At Samara, Majambu et al. (1982) obtained yields of 5.3t/ha for NHAE 47-4 and 4.1t/ha for white velvet.

Norman (1988) showed that harvesting of leaves of okra (used as spinach) significantly decreased fruit production, both in number and weight, and pod size.

Uses of Okra

The okra plant is grown primarily for its soft immature fruit. The pods contain a glutinous substance that thickens soups and stews. The pods are mainly

used in soups and stews, although they are also boiled or fried and eaten as a vegetable. They are also dried, stored and powdered for use in soups in the dry season when okra fruits are scarce.

Okra provides an important source of vitamins, calcium, potassium and other mineral matter which are often lacking in the diet of developing countries.

Table 3 The Composition of the Edible Portion of Okra (Gopalan *et al.*, 2007).

Moisture	**89.6 g**	**Minerals**	**0.7 g**
Protein	1.9 g	Carbohydrates	6.4 g
Fat	0.2 g	Calcium	66 mg
Fibre	1.2 g	Iron	0.35 mg
Calories	35	Potassium	103 mg
Phosphorus	56 mg	Thiamine	0.07 mg
Sodium	6.9 mg	Nictonic acid	0.6 mg
Sulphur	30 mg	Vitamin C	13 mg
Riboflavin	0.1 mg	Magnesium	53 mg
Oxalic acid	8 mg	Copper	0.19 mg

CHAPTER THREE

THE EFFECTS OF DEFICIT IRRIGATION AND CHICKEN MANURE INTERACTIONS ON THE GROWTH AND YIELD OF OKRA IN A POT EXPERIMENT

Introduction

Globally, food production from irrigated land is greater than 40% of the total and uses only about 17% of the land area devoted to food production (Fereres and Connor, 2004). Nevertheless, irrigated agriculture is still practiced in many areas in the world with complete disregard to basic principles of water conservation and irrigation. Therefore, irrigation water management in an era of water scarcity has to be carried out most efficiently, aiming at saving water and maximizing its productivity.

Materials and Method

Research Location

The research was conducted at the School of Agriculture Teaching and Research Farm, University of Cape Coast, Cape Coast, Ghana from February 2014 to June 2014. It is found on Latitude $05\text{-}06^0$ N and Longitude $01\text{-}15^0$ S at altitude of 1.1m at sea level.

The soil at the research site is sandy loam and is slightly acidic. The site lies within the Coastal Savannah vegetation zone of Ghana. The annual

temperature ranges between 23.2-33.2 ^{O}C with an annual mean of 27.6 ^{O}C and a relative humidity of 81.3-84.4% (Owusu-Sekyere and Andoh, 2011).

There were two rainy seasons observed at the research site: the major season which started from May to July and the minor which commenced from September and to the middle of November. The mean annual rainfall for the site is between 900mm and 1000mm (Asamoah, 1973; Owusu-Sekyere and Annan, 2010).

Experimental Design and Field Layout

The experiment was laid out in a Randomized Complete Block Design (RCBD) with nine (9) treatments and each treatment was replicated three times. The treatments were 100% Crop Water Requirement (T1), 90% Crop Water Requirement (T2) and 80% Crop water Requirement (T3), while Crop Water Requirement (CWR) and chicken manure were combined in 100% CWR + 5t/ha chicken manure, (T4), 100% CWR + 10t/ha chicken manure (T5), 90% CWR + 5t/ha chicken manure (T6), 90% CWR + 10t/ha chicken manure (T7), 80% CWR + 5t/ha chicken manure (T8) and 80% CWR + 10t/ha chicken manure (T9).

The experimental site was divided into plots on which the pots were arranged. There were a total of twenty-seven (27) plots with each plot containing five (5) pots. The plot size was 1m × 1m. A total of one hundred and thirty-five (135) pots were used for the research. The pots were filled with eight (8) kilograms soil each.

Planting of the Crop

A local variety of okra was used for the experiment. The seeds were placed in water for a day before planting to increase sprouting. The seeds were sown directly on the 20th of February 2014, three seeds per bucket following 60 cm × 60 cm spacing between each bucket and plants. The Chicken Manure was applied a week before planting. After a week of sowing, the three plants per bucket were thinned to one.

Cultural Practices

Handing weeding was done in the pots as the need arose.

Insect pests were controlled by using the Pawa Insecticide at three weeks interval.

Research Population

Each plot contained 5 buckets with each bucket containing a plant. There were a total of 27 plots. The total plant population was one hundred and thirty-five (135) plants.

Irrigation Regime Employed

A two-day irrigation interval was employed. Each experimental bucket was weighed using a scale during each irrigation day to determine the loss of water and amount to replace. The amount of water loss in volume was calculated and was applied for each water treatment (100% CWR, 90% CWR and 80% CWR).

A Rain shelter was constructed to house the 135 experimental buckets to avoid any external moisture.

Soil and Chicken Manure Analysis

Before the start of the research, composite surface soil samples were randomly collected from the experimental site and were carefully mixed together. The samples were divided into four and two opposite quadrants were taken out. This was repeated and each time the process was done, another opposite quadrant was taken off until a considerable amount was obtained. The sample was then air dried for a week after which it was grounded and then analyzed for percent Organic Matter, the amount of Nitrogen, Phosphorous and Potassium as well as soil pH and textural class.

Chicken Manure samples were also taken and air dried and analyzed for percent nitrogen, phosphorus, potassium and pH. Table 4 shows the results of the analysis.

Table 4: Chemical Compositions of the Soil and Chicken Manure Samples

Samples	Organic matter (%)	Nitrogen (%)	Phosphorus (µgP/g)	Potassium (cmol/kg)	pH
Soil	0.44	0.04	21.89	0.41	5.97
Chicken Manure	----------	2.92	6296.41	28.57	7.33

Plant Data Collection

Five plants per plot were selected for the measurement of the following parameters: **1**- Plant Height (in cm) -- a meter rule was used, **2**- Leaf Area (in cm^2) -- length from the petiole line was multiplied by the breadth of the leaf, **3**- Stem Circumference (in cm), **4**- Number of Pods per treatment -- pods were

counted per treatment during each harvest till the final harvest, **5**- Pod weight (in grams was measured using an electronic balance and converted ton per hectare) per treatment was determined, **6**- Pod length (in cm), **7**- pod circumference (in cm) and **8**- Root length (in cm) were measured using a 30 centimeters ruler.

Statistical Analysis

Treatment effects on Okra growth and yield components were analyzed using Analysis of Variance (ANOVA) procedure of GenStat Version 16. Mean comparisons were performed using Duncan Multiple Range Test (DMRT) at p = 0.05 to statistically find any significant difference between treatment means.

Results and Discussion

The effects of different levels of Crop Water Requirements (CWR) and their combination with chicken manure on the growth parameters of okra; plant height, leaf area, stem circumference and root length and yield parameters such as number of pods per treatment, pod weight, pod length, and pod circumference are presented in Table 5 and Table 6 respectively. The results showed variations among all the treatments and were found to be statistically significant at 5% level.

Okra Growth Parameters

Plant Height

The 100% CWR, 90% CWR and 80% CWR or in combination with Chicken Manure (CM) had some effects on okra plant height (Table 5). Plots treated with 100% CWR + 10t/ha CM (T5) had the tallest plant (134.5cm) but was not statistically different from T4 (100% CWR + 5t/ha CM; 116.1cm) and T7

(90%CWR + 10t/ha CM; 126.9cm). The plant height were in descending order T5>T7>T4>T6>T1>T8>T2>T9>T3. With the application of CWR alone at 100% (T1), 90% (T2) and 80% (80%), T1 produced the tallest plants compared to T2 and T3. There was significant difference between T1, T2 and T3 but no significant (PR 0.05) difference existed between T2 and T3.

Leaf Area

T5 produced the largest leaf area (278.6cm^2) (Table 5). The second largest leaf area (220.8cm^2) was obtained by T7. No significant difference existed between T4 (205.8cm^2) and T7. Furthermore, no significant difference existed between T8 (107.6cm^2) and T9 (91.9cm^2). T1, T2, and T3 had statistically similar results with T8 and T9. T3 had the least leaf area (Table 5).

Stem Circumference

Statistically, similar stem circumferences were obtained from T4 (7.9cm), T5 (8.9cm), T6 (6.4cm) and T7 (7.4cm) with T5 producing the biggest stem circumference followed by T4, T7 and T6 in that order. The T1, T6 and T7 showed no significant difference even though T6 and T7 had organic fertilizers. There were no significant difference among the sole CWR treatments but T1 gave the biggest stem circumference followed by T2 and T3 with T3 producing the least stem circumference of all the treatments (Table 5)

Root Length

According to Table 5, deficit irrigation and chicken manure combinations had effects on root length. T9 had the longest root length (28.3cm) while T4 had the least root length (16.5cm). T9, T8 (27.4cm), T3 (25.7cm), T7 (25.1cm) and T6

(21.7cm) had no significant differences. Furthermore, T1 (18.9cm), T2 (18.9cm), T3, T5 (18.9cm), T6, and T7 had no significant effects. T1, T2, T4, T5 and T6 had similar results statistically with T6 producing the longest root length and T4 producing the least. It was observed that deficit irrigation had a great influence on root length: the lower the water application and the higher the chicken manure concentration, the longer the root length.

It was observed that the addition of chicken manure to crop water requirement treatments (T1-100%, T2-90% and T3-80%) resulted in increase in growth parameters as compared to the crop water requirement treatments alone. This means that chicken manure was in a readily accessible form for easy absorption by the plant roots. Hence, there was an increase in the morphological growth of Okra plant. The results obtained agreed with the finding of Onwu et al. (2014) and Ajari et al. (2003), in Okra production in which they reported that organic manure, especially poultry manure, could increase plant height and crop branches. Data analyzed showed that increase in the level of chicken manure from 5t/ha to 10t/ha with 100% CWR and 90% CWR had significant effects on the growth parameters of Okra. This result is in line with the findings of Onwu et al. (2014), Aliyu (2000), and Onwu et. al. (2008), that there is increase in growth with increased organic manure.

Table 5: Growth parameters of Okra as affected by Full, Deficit Irrigation and Deficit Irrigation-Chicken Manure Interactions

Treatment Coding	Mean Plant Height (cm)	Mean Leaf Area (cm^2)	Mean Stem Circumference (cm)	Mean Root Length (cm)
T1	100.2 cd	127.6 cd	4.3 bcde	18.9 bc
T2	74.0 ef	116.3 cd	3.7 cde	18.9 bc
T3	53.0 f	88.5 d	2.4 e	25.7 ab
T4	116.1 a	205.8 b	7.9 a	16.5 c
T5	134.5 abc	278.6 b	8.9 a	18.9 bc
T6	110.6 bc	155.7 a	6.4 abcd	21.7 abc
T7	126.9 ab	220.8 c	7.4 abc	25.1 ab
T8	84.0 de	107.6 cd	3.4 de	27.4 a
T9	63.0 ef	91.9 d	3.8 cde	28.3 a

Means followed by common letters in a column are not significantly different at 5% Probability level using DMRT**.**

Okra Yield Parameters

Table 6 shows yield parameters of okra which included number of pod per treatment, pod weight in ton per hectare, pod length and pod circumference. The effects of CWR alone (100%, 90% and 80%) and CWR-chicken manure combination had significant effects on number of pods, pod weight (t/ha), pod length and pod circumference.

Number of Pods per Treatment

The number of pod per treatment was affected by both irrigation water levels and levels of chicken manure. The highest number of pods (61) was seen in T4 followed by T5 (53), T7 (49), and T6 (31) in that order of decreasing number of pods. The differences among T1 (21 pods), T2 (16 pods) and T3 (9 pods), were not statistically significant, T1 produced the highest number of pods followed by T2. T3 gave the least number of pods among all the treatments.

Statistically, no significant difference existed between T4 and T5. Similar results were seen between T5 and T7 (49 pods) where no significant difference existed. T1 and T6 (31 pods) had no significant difference even though T6 had the higher number of pods. Additionally, T1, T2, T8 and T9 had no significant differences and T2, T8 and T9 had no significant differences. T2 in each case gave the highest number of pods (Table 6).

Table 6: Yield Parameters of Okra as affected by Deficit Irrigation and Deficit Irrigation-Chicken Manure Interactions in a Pot Experiment

Treatment Coding	Mean Number of Pod/Trmt	Mean Pod Weight (grams)	Mean Pod Weight (ton/ha)	Mean Pod Length (cm)	Mean Pod Circumference (cm)
T1	21 cd	196.8 cd	2.0 cd	6.4 c	6.6 de
T2	16 de	176.4 cde	1.8 cde	4.1 de	5.3 ef
T3	9 d	67.5 f	0.7 f	3.5 e	4.0 f
T4	61 a	402.6 b	4.0 b	8.8 b	9.1 b
T5	53 ab	517.6 a	5.2 a	11.6 a	11.2 a
T6	31 c	247.5 c	2.5 c	9.4 b	7.3 cd
T7	49 b	417.3 b	4.2 b	10.1 ab	8.6 bc
T8	12 de	119.8 def	1.2 def	6.1 cd	6.0 de
T9	15 de	100.8 ef	1.0 ef	5.5 cde	6.5 de

Means followed by same letters in a column are not significantly different at 5% Probability level using DMRT.

Pod Weight (t/ha)

The data in Table 6 indicate that of all the treatments, T5 gave the highest Okra weight (5.2 t/ha) and was significantly different from all the other treatments. T7 was second in terms of pod weight (4.2 t/ha) followed by T4 (4.0 t/ha). T3 produced the least pod weight (0.7 t/ha). Comparing T4 and T7, there was no significant difference. Yields from T1, T2 and T6 were statistically similar. Also, T1, T2, and T8 were not significantly different. Moreover, T2, T8

and T9 had statistically similar results. Comparing T3, T8 and T9, though T3 produced the least, no significant differences existed among them.

Pod Length

From Table 6, T5 had the longest pod length (11.6cm) followed by T7 (10.1cm) and then T6 (9.4cm). Statistically, no significant difference existed between T5 and T7. In addition to treatments comparison, T4 (8.8cm), T6 and T7 showed no significant difference likewise T1 (6.4cm), T8 (6.1cm) and T9 (5.5cm). T2 (4.1cm), T8 and T9 had no significant difference even though the longest pod length was produced by T8. On the other hand, T2, T3 and T9 had no significant difference but T9 produced the longest pod.

Pod Circumference

From Table 6, the biggest pod circumference (11.2cm) was recorded by T5 and was significantly different from the rest of the treatments while the T3 produced the least pod circumference (4.0cm). T4 (9.1cm) and T7 (8.6cm) showed no statistical difference. No significant difference existed between T6 (7.3cm) and T7. Similar results were observed among T1 (6.6cm), T6 (7.3cm), T8 (6.0cm) and T9 (6.5cm) where no significant differences were seen. Besides, T1, T2, T8 and T9 had no significant differences.

According to Owusu-Sekyere and Annan (2010) and Calvache and Reichardt (1999), water deficit during vegetative growth leads to decline in yield. This was evident from the results in Table 3.3 where T1, T2 and T3 gave 21, 16 and 9 pods respectively. The effects of water stress also led to reduction in pod length and pod circumference.

From Table 6 it is seen that yield parameters were greater in Deficit Irrigation-Chicken Manure combination (T4, T5, T6, T7, T8 and T9) than T1, T2 and T3. Also, it can be observed that as the level of chicken manure increased from 5t/ha to 10t/ha, there were increases in pod weight, pod length and pod circumference at the same level of irrigation water applied. This shows that chicken manure has beneficial effects on okra yield. The result is in conformity with (Abd El-Kader et.al, (2010) and Rajpaul et al., (2004) who reported the beneficial effect of chicken manure on growth and yield of different vegetables.

Conclusion

The cultivation of okra under water stress condition is a promising solution to overcome water scarcity, high cost of water and maximizing water use efficiency especially when deficit irrigation is in combination with chicken manure. It was observed that 100%CWR + 10t/ha chicken manure (T5) dominated in growth and yield parameters followed by T4 (100% CWR + 5t/ha CM). T7 (90% CWR + 10t/ha CM) produced similar results with T4. It was also observed that as the full CWR is reduced by 20% with a high level (10t/ha) of chicken manure, growth and yield parameters tend to decrease. A 20% reduction in CWR with less chicken manure is a promising practice for okra production without causing significant yield reduction. It can therefore be concluded that a 10% reduction in CWR plus 10t/ha chicken manure can produce statistically the same results compared to full CWR, 100%CWR + 5t/ha. Below 90%CWR + 5t/ha or 10t/ha of chicken manure, growth and yield parameters will decrease especially at a higher level of chicken manure.

CHAPTER FOUR

EFFECTS OF DEFICIT IRRIGATION, DEFICIT IRRIGATION-CHICKEN MANURE AND DEFICIT IRRIGATION-NPK 15:15:15 INTERACTIONS ON THE GROWTH AND YIELD OF OKRA IN A FIELD EXPERIMENT

Introduction

Drought is considered one of the most important factors that limit plant production in arid and semi-arid zones (Ehdaie, 1995; Hussein et. al., 2011), where such areas are subjected to a wide range of climate variation as well as climate changes. Under such conditions, lower yield and lower water use efficiency take place especially under the instability of water amounts from year to year (Owies *et al.,* 2000).

Irrigation approach has been to supply irrigated areas with adequate water so that the full crop water requirements are met throughout the season. This approach is increasingly challenged by segments of society in regions especially where water is scarce, because of large amounts of water required by irrigation and its negative effects that such diversions have on nature. Thus, a strategic change in irrigation management is taking place; one that limits the supply available for irrigation to what is left after all other sectors of higher priority satisfy their needs.

The application of water below the crop water requirements is termed deficit irrigation. Even though deficit irrigation is simply a technique aimed at the optimization of economic output when water is limited, the reduction in the supply for irrigation to an area imposes many adjustments in the agricultural system.

Improvement of soil fertility through the application of fertilizers has become an essential factor that enables the world to feed billions of its population (Brady and Weil, 1999). Soil fertility is usually maintained by the application of organic and inorganic fertilizers (Okigbo, 1985), and there is also an improvement in the physical and biological properties of the soils (Okwuagwu *et al*., 2003).

Research Methodology

Research Setting

This research was carried out on the School of Agriculture Research Farm, University of Cape Coast, Cape Coast, Ghana, West Africa.

Research Design and Field Layout

The field experiment was setup under a Rain Shelter from August, 2014 to February 2015. Fifteen (15) treatments with three (3) replications were laid out in a Randomized Complete Block Design (RCBD). The 15 treatments were 100% Crop Water Requirement (CWR), (T1); 90% CWR (T2); 80% CWR (T3); 100%CWR + 5 t/ha chicken manure (T4); 100% CWR + 10 t/ha chicken manure (T5); 90%CWR + 5t/ha chicken manure (T6); 90%CWR + 10t/ha chicken manure (T7); 80%CWR + 5t/ha chicken manure (T8); 80%CWR + 10t/ha chicken manure

(T9); 100%CWR + 200kg/ha NPK 15:15:15 (T10); 100%CWR + 250kg/ha NPK (T11); 90%CWR + 200kg/ha NPK (T12); 90%CWR + 250kg/ha NPK (T13); 80%CWR + 200kg/ha NPK (T14) and 80%CWR + 250kg/ha NPK (T15).

Each plot measured 1.50m × 1.50m making a plot size of 2.25m^2. A total of 45 plots were under the rain shelter.

Planting of Okra Seeds

The seeds were sown on 23rd August 2014, three seeds per hole following 50 cm × 50 cm spacing between rows and plants. After a week, the 3 three plant per hole were thinned to one (1). The chicken manure was applied 2 weeks before sowing the seeds and the NPK 15:15:15 was applied a week after sowing. After planting, regular weeding and spraying of insecticide were done.

Research Population

Of the 45 plots, each had 16 plants. A total of 720 plants constituted the research population. A sample of 8 plants on each plot was selected for growth, yield and yield related data analysis. The total research sample size was 360 plants.

Statistical Analysis

Data collected were subjected to analysis of variance (ANOVA) using GenStat 10.3. Mean comparisons were performed using Duncan Multiple Range Test (DMRT) at 5% probability level.

Calculation of Crop Water Requirement and Irrigation Water Application

An irrigation interval of two days was adopted for the research. And the water application for each watering day was generated from the computed reference crop evapotranspiration and adopted Kc of okra at the four growth stages by using the formula:

$$ETc = ETo \times Kc$$

Where: ETc is the crop evapotranspiration (mm/day)

Kc is the crop coefficient (dimensionless)

ET_o is reference crop evapotranspiration [mm/day].

The crop coefficient (Kc) for okra was adopted from the work done by Owusu-Sekyere and Annan, (2010), for the four growth stages (Initial = 0.20, 10 days; Developmental = 0.40, 31 days; Mid-season = 1.0, 25 days; and Late Season = 0.90, 20 days).

ETo was calculated using the formula: $ETo = Epan \times Kpan$ ..... equ. 2

Where: Epan is the depth of water lost from the evaporation pan during each irrigation water application day and Kpan is the pan coefficient which was 0.8.

A US Class A Evaporation Pan was used to obtain the evapotranspiration rate.

Table 7: Crop Water Requirements for the Four Growth Stages

% CWR Applied	Water requirements (mm/day)			
	Initial (mm/10)	Developmental (mm/31days)	Mid (mm/25days)	Late (mm/20days)
100	16.04	131.52	236.80	164.16
90	14.44	118.37	213.12	147.74
80	12.83	105.22	189.44	131.33

At the end of each growth stage, crop evapotranspiration was calculated (Table 7).

Okra Growth and Yield Parameters

Plant Height, Leaf Area and Stem Circumference after every growth stage were measured using a thread and a metre rule. Number of pod per treatment, pod weight, pod length, and pod circumference were measured and these constituted the yield parameters.

Results and Discussion

The Effects of Deficit Irrigation, Deficit Irrigation-chicken manure Combination and Deficit irrigation-NPK 15:15:15 Combinations on the Growth Parameters (Plant Height, Leaf Area and Stem Circumference).

Data collected during the four growth stages (Initial, Developmental, Mid-Season and Late Season) on plant height are presented in Table 8. The results show that there were significant ($P<0.05$) differences among some of the treatments applied.

Plant Height for the Four Growth Stages

For the initial stage, T11 (100%CWR + 250kg/ha NPK) recorded the tallest plants (53.6cm) followed by T13 (90%CWR + 250kg/ha NPK), (46.9cm) and T10 > T6, > T12 > T5 > T9 > T4 > T7 > T8 > T2 > T1 > T14 > T15 > T3 in that order (Table 8). No significant difference existed between T11, T13 and T10. Also, T13, T10, T6, T12, T5, T9, T4, T7, and T8 had no significant difference. T6, T12, T5, T9, T4, T7, T8 and T2 means had no significant difference. T1 (100%CWR), 34.00cm, and T2 (90%CWR), 36.55cm had no significant difference. The least plant height in the Initial Stage was produced by T3 (80%CWR) but was not different from T14 and T15 statistically. Deficit irrigation-NPK 15:15:15 treated plots at 100%CWR and 90%CWR had taller plant height than Deficit irrigation-chicken manure treated plots at 100%CWR and 90%CWR in the initial growth stage. On the other hand, T8 (80% CWR + 5t/ha CM) and T9 (80% CWR + 10t/ha CM) better than T14 (80%CWR + 200kg/ha NPK) and T15 (80%CWR + 250kg/ha) (Table 8).

At the developmental stage, the mean tallest plants (105.6cm) was obtained in plots treated with 100%CWR + 250kg/ha NPK (T11) while T8 (80%CWR + 5t/ha CM) gave the least plant height (45.6cm). Statistically, no significant difference was seen among T11, T13, T6, T10 and T5. Though T10 (100%CWR + 200kg/ha NPK), T5 (100%CWR + 10t/ha CM) and T4 (100%CWR + 5t/ha CM) had their full CWR, there were no significant difference in the plots treated with a 10% CWR reduction (T6, 90%CWR + 5t/ha CM). The application of CWR alone, T1 (100%CWR), T2 (90%CWR) and T3 (80%CWR)

had no significant effects. No significant difference was seen among T2, T3, T9, T15, T14 and T8.

Table 8: Mean Plant Height for the Four Growth Stages (cm)

Treatment Coding	Initial Stage	Developmental Stage	Mid Stage	Late Stage
T1	34.0 de	73.9 ef	123.7 b	167.3 b
T2	36.6 cde	61.0 fg	115.1 b	159.0 b
T3	20.0 f	60.0 fg	107.2 b	151.7 bc
T4	41.1 bcd	88.7 bcde	192.3 a	208.0 a
T5	43.7 bc	90.3 abcd	194.5 a	225.0 a
T6	44.3 bc	95.4 abc	176.2 a	202.0 a
T7	38.6 bcd	80.1 cde	188.3 a	216.7 a
T8	38.6 bcd	45.6 g	120.8 b	154.7 bc
T9	41.9 bcd	60.0 fg	109.4 b	129.7 cd
T10	46.6 ab	94.6 abcd	182.7 a	204.3 a
T11	53.7 a	105.6 a	195.9 a	215.3 a
T12	43.8 bc	79.1 de	169. 8 a	197.0 a
T13	46.9 ab	103.0 ab	180.5 a	214.0 a
T14	28.2 ef	46.1 g	102.1 b	140.0 bcd
T15	21.1 f	50.2 g	91.9 b	114.0 d

Means within the same column with similar letters are not significantly different at 5% probability level.

Recorded data on mean plant height during the mid-season stage had significant effects at $p<0.05$ (Table 8). It was observed that the tallest plant (195.9cm) was recorded in the plots treated with 100%CWR + 250kg/ha NPK (T11) and the least plant height was seen in the plots treated with 80%CWR + 250kg/ha NPK (T15). From the results in Table 8, no significant differences existed among T11, T5, T4, T7, T10, T13, T6, and T12 though with decreasing plant height in that order. T1, T8, T2, T9, T3, T14 and T15 had no significant difference. Plots treated with chicken manure at 100%CWR and 90%ETc combinations had taller plants than those treated with NPK at 100%CWR and 90%ETc in the mid-season stage.

At the late season stage, the tallest plant was recorded in T5 (100%CWR + 10t/ha CM), 225cm, followed by T7 (90%CWR + 10t/ha CM). The third and fourth tallest plants were produced by T11 (100%CWR + 250kg/ha NPK), 215.3cm and T13 (90%CWR + 250kg/ha NPK), 214.0cm respectively. There were no significant differences among T5, T7, T11, T13, T4, T10, T6 and T12. Similarly, no significant effects were seen among T1, T2, T8, T3, and T14 (Table 8). Moreover, T8, T3, T14 and T9 had no statistical difference. T14, T9 and T15 produced statistically the same results even though T15 produced the least plant height among all the treatments. It was also observed that as the level of fertilizers increases be it chicken manure or NPK, plant height also increases at 100% CWR and 90%CWR compared to 80%CWR.

Leaf Area for the Four Growth Stages

Leaf area for the four growth stages was analyzed and presented in Table 9. Deficit irrigation, Deficit irrigation-chicken and deficit irrigation-NPK combinations affected leaf area. It was observed from the initial stage that the leaf area from plants subjected to T11 (100%CWR + 250kg/ha NPK), 168.4cm^2, T10 (100%CWR + 200kg/ha), 165.9cm^2 and T5 (100%CWR + 10t/ha CM), 162.0cm^2 had no significant difference There was no significant difference between T5 and T12 (90%CWR + 200kg/ha NPK, 148.7cm^2). T4 (100%CWR + 5t/ha CM) was significantly different from the rest of the treatments but produced the fifth largest leaf area. Besides, T13, T7, T9, T1, T6, and T2 had statistically the same results. Comparably, identical statistical results were seen among T15, T8 and T14. T8, T14 and T3 had no significant difference among them (Table 9).

Table 9: Mean Leaf Area for the Four Growth Stages (cm^2)

Treatment Coding	Initial Stage	Developmental Stage	Mid Stage	Late Stage
T1	79.5 d	161.6 de	186.3 de	259.1 e
T2	78.4 d	160.3 de	183.3 de	256.0 ef
T3	30.0 f	99.7 f	104.4 f	217.3 efg
T4	119.8 c	251.6 b	315.4 b	428.4 b
T5	162.0 ab	207.0 c	377.0 a	478.5 a
T6	78.5 d	277.8 ab	312.8 b	437.5 ab
T7	89.2 d	288.4 a	339.9 ab	467.0 ab
T8	43.5 ef	141.9 e	180.2 de	211.4 efg
T9	84.4 d	185.4 cd	204.2 cd	208.3 fg
T10	165.9 a	209.8 c	329.3 ab	360.1 cd
T11	168.4 a	288.7 a	345.7 ab	373.1 c
T12	148.7 b	204.8 c	332.4 ab	321.9 d
T13	93.9 d	284.6 b	250.7 c	353.1 cd
T14	43.3 ef	81.7 fg	161.0 de	200.9 gh
T15	49.8 e	59.9 g	140.7 ef	156.1 h

Means within the same column with similar letters are not significantly different at 5% probability level.

T11 produced the largest leaf area (288.7cm^2) compared to the rest of the treatments while T15 (80%CWR + 250kg/ha NPK) produced the least leaf area (59.9cm^2) in the developmental stage. Statistically, similar results were seen among T11, T7, T13, and T6 on one hand, while T6 and T4 were the same on the hand. T10 (100%CWR + 200kg/ha NPK), 209.8cm^2, T5 (100%CWR + 10t/ha CM), 207.0cm^2, T12 (90%CWR + 200kg/ha NPK), 204.8cm^2, and T9 (80%CWR + 10t/ha CM), 185.4cm^2 had no significant differences among them. Also, identical statistical results were recorded among T9, T1 and T2. Though T1 had the largest leaf area compared to T2 and T8, no statistical differences were seen among them. T3 (80%CWR), 99.7cm^2 and T14 (80%CWR + 200kg/ha NPK), 81.8cm^2, had no significant difference between them. The increment of NPK

fertilizer from 200kg/ha to 250kg/ha had no significant effect when combined with 80%CWR (T14 and T15) in the developmental stage.

Treatments imposed had significant effect on leaf area during the mid-season stage and were significant at 5% probability (Table 9). The data collected during the mid-season stage showed that 80%CWR had the least leaf area, 104.4cm^2, while T5 (100%CWR + 10t/ha CM), 377.0cm^2 had the largest leaf area among all the treatments. There were no significant difference among T5, T11, T7, T12 and T10 on one hand, and no statistical difference among T11, T7, T12, T10, T4 and T6 on the other hand (Table 9). Mean leaf area showed that no significant difference existed among T1, T2, T8, T14 and T15. T15 (80%CWR + 250kg/ha NPK) and T3 (80%CWR) had no significant difference.

Plots treated with chicken manure plus 100%CWR and 90%CWR combinations gave larger leaf area in the late growth stage than those treated with NPK plus 100%CWR and 90%CWR combinations. T5 (100%CWR + 10t/ha CM) recorded the largest leaf area while T15 (80%CWR + 250kg/ha NPK) recorded the least. No significant difference existed among T5, T7 and T6. Also, T7, T6 and T4 had no significant difference though there was 10% water reduction in T6 and T7. T11 (100%CWR + 250kg/ha NPK), 373.1cm^2, T10 (100%CWR + 200kg/ha NPK), 360.1cm^2 and T13 (90%CWR + 250kg/ha NPK), 353.1cm^2 had no significant effects. In addition, plants treated with 100%CWR + 200kg/ha NPK (T10), 90%CWR + 250kg/ha NPK (T13) and 90%CWR + 200kg/ha NPK (T12) had no significant effects. T1, T2, T3 and T8 had statistically similar results. T2, T3, T8 and T9 had no significant effects despite the fact that T8 and

T9 had some levels of chicken manure as compared to T2 and T3. No significant effects were recorded among T3, T8, T9, and T14. 80%CWR + 200kg/ha (T14) and 80%CWR + 250kg/ha NPK (T15) had no significant difference despite the increase of NPK from 200kg/ha to 250kg/ha.

Stem Circumference for the Four Growth Stages

There were significant differences ($p<0.05$) in stem circumference at various growth stages (Table 10). In the initial stage, T11 (100%CWR + 250kg/ha NPK) produced the biggest stem circumference (3.0cm) but was not significantly different from T13, T5, T10, T6, T4, T1, T14, and T7 while T5 (100%CWR + 10t/ha CM) gave the biggest stem circumference (6.2cm) in the developmental stage, the Mid-season stage (8.4cm) and the late season stage (13.0cm). T3 produced the least stem circumference in the initial stage while T15 gave the least in the developmental stage (3.4cm), mid-season stage (5.3cm) and the late season stage (6.5cm). The second, third and fourth biggest stem circumference were produced by plants treated with T13 (90%CWR + 250kg/ha NPK), 2.9cm, T5 (100%CWR + 10t/ha CM), 2.7cm, and T10 (100%CWR + 200kg/ha NPK), 2.6cm but were not statistically different from T6, T4, T1, T14, T7, T2 and T9 in the initial growth stage while the second, third and fourth biggest stem circumference were produced by T7, T11 and T6 but were not significantly different from T5, T13 and T12 in the developmental growth stage.

Table 10: Mean Stem Circumference for the Four Growth Stages (cm)

Treatment Coding	Initial Stage	Developmental Stage	Mid Stage	Late Stage
T1	2.2 abcd	4.1 def	6.9 bc	9.5 e
T2	2.1 bcd	4.2 def	6.7 bcd	9.5 e
T3	1.1 e	4.1 def	5.8 cde	7.4 fgh
T4	2.3 abcd	5.0 bcd	7.5 ab	11.2 bc
T5	2.7 abc	6.2 a	8.4 a	13.0 a
T6	2.6 abc	5.8 ab	7.7 ab	11.0 bcd
T7	2.2 abcd	5.9 ab	7.8 ab	11.9 b
T8	1.9 cde	4.0 ef	6.4 bcde	8.3 f
T9	2.1 bcd	3.9 ef	6.6 bcde	7.8 fg
T10	2.6 abc	4.7 cde	7.3 ab	11.0 bcd
T11	3.0 a	5.8 ab	7.0 abc	11.6 b
T12	1.9 cde	5.2 abc	6.7 bcd	10.0 de
T13	2.9 ab	5.3 abc	7.5 ab	10.2 cde
T14	2.2 abcd	3.5 f	5.5 de	6.9 gh
T15	1.6 de	3.4 f	5.3 e	6.5 h

Means within the same column with similar letters are not significantly different at 5% probability level.

Similarly, the second, third and fourth biggest stem circumference were recorded by T7, T6 and T4 plants but were not significantly different from T5, T13, T10 and T11 in the Mid-season stage, while T7, T11, and T4 recorded the second, third and fourth biggest stem circumference in the late season stage but were statistically similar to T6 and T10. In the initial growth stage, T5, T10, T6, T4, T1, T14, T7, T2, T9, T8 and T12 were statistically the same and also, there were no significant differences among T4, T1, T14, T7, T2, T9, T8, T12 and T15. T8, T12, T15 and T3 had no significant difference in the initial stage. At the end of the developmental stage, data collected on stem circumference showed that no significant difference existed among T13, T12, T4 and T10 on one hand, and T4, T10, T2, T1, and T3 on the other hand. Furthermore, T10, T2, T1, T3, T8 and T9 had no statistical difference and T2, T1, T3, T8, T9, T14 and T15 obtained similar

statistical results in the developmental stage. No significant difference existed among T11, T1, T12, T2, T9, T8, and T3 while T12, T2, T9, T8, T3, and T14 had no statistical difference among them in the mid-season stage. Plants treated under T9, T8, T3, T14 and T15 showed no significant difference in the mid-season stage. The late season stage stem circumference showed no significant difference among T4, T6, T10 and T13 on one side, and T6, T10, T13 and T12 on the other side. Treated plants with T13, T12, T1 and T2 showed no statistical difference and T8, T9 and T3 had similar results statistically. T9, T3 and T14 had stem circumference of 7.8cm, 7.4cm and 6.8cm respectively, but no significant difference existed among them while T3, T14 and T15 produced similar results in the late stage.

The combinations of deficit irrigation-chicken manure and deficit irrigation-NPK had great effects on growth parameters of okra. It was observed in the first two growth stages, i.e. initial and developmental, that deficit irrigation-NPK combination dominated in plant height, leaf area and stem circumference as compared to deficit irrigation-chicken manure. This was a clear indication that NPK was readily available to the plants for utilization. It was also seen that at 100%CWR and 90%CWR, as the NPK level increased from 200kg/ha to 250kg/ha, the growth parameters also increased except for 80%CWR where NPK performed poorly. The improvement of growth parameters with increase in NPK rate could be due to increased uptake of NPK, their roles in chlorophyll synthesis and hence the process of photosynthesis and carbon dioxide assimilation (Jasso-

chaverria et. al. 2005, Rono et. al, 2013) leading to enhanced growth. This was evident in the work.

In the mid and late season stages, deficit irrigation-chicken manure combinations dominated in the growth parameters. This shows the long term effects of organic fertilizer as they decompose slowly. The beneficial effects of chicken manure on growth and yield of different vegetables were also reported by earlier investigators (Abou-Hadid and Sawan, 2003; Rajpaul et al., 2004, El-Nemer et al., 2005; Faten and Ismaeil 2005; Yasmeen et al., 2009). Also, plant height, leaf area and stem circumference were improved as chicken manure rate was increased from 5t/ha to 10t/ha when they were in combinations with 100%CWR and 90%CWR. Again, 20% CWR reduction with 5t/ha and 10t/ha chicken manure combination had no comparable results with full CWR and 10% CWR reduction. Moreover, there was no statistically significant difference in 100%CWR, 90%CWR and 80%CWR treatments alone even though there was growth reduction.

Effects of Deficit Irrigation, Deficit Irrigation-chicken manure and Deficit Irrigation-NPK Interactions on the Yield, Yield related Components and Root Length.

The effects of the treatments on the yield, yield related parameters and root length are presented in Table 11. Results obtained showed significant differences at 5% probability level.

The highest number of pod per treatment was recorded in plot treated with 100%CWR + 10t/ha CM (T5), 76, and was statistically different from the rest of the treatments. The second (73), third (71) and fourth (70) highest number of pods were produced by 90%CWR + 10t/ha CM (T7), 100%CWR + 250kg/ha CM (T11), and 90%CWR + 250kg/ha NPK (T13) respectively. T4 (100%CWR + 5t/ha CM), 66, and T6 (90%CWR + 5t/ha CM), 65, had no statistical difference. T12 (90%CWR + 200kg/ha NPK), 61, and T10 (100%CWR + 200kg/ha NPK), 42 were statistically different from each other and different from the rest of the treatments. Though there was reduction in number of pods in 100%CWR, 90%CWR and 80%CWR treatments alone, no significant difference was seen among them. Similarly no statistically significant difference existed among T8 (80%CWR + 5t/ha CM), 23, T9 (80%CWR + 10t/ha CM), 23, and T14 (80%CWR + 200kg/ha NPK), 21 on one hand, and T9, T14 and T15 (80%CWR + 250kg/ha NPK), 19 on the other hand.

At the end of the research, pod weight in grams per treatment was converted and expressed in ton per hectare (t/ha). The first four highest pod weight in ton per hectare were recorded by plots treated with 100%CWR + 10t/ha CM, (T5), 8.9t/ha; 100%CWR + 250kg/ha NPK, (T11), 8.8t/ha; 90%CWR + 10t/ha (T7) 8.6t/ha and 100%CWR + 5t/ha (T4), 8.4t/ha, but were not statistically significant from T6 (90%CWR + 5t/ha CM),8.2t/ha, T13 (90%CWR + 250kg/ha NPK),8.2t/ha, T10 (100%CWR + 200kg/ha NPK), 8.0t/ha, and T12 (90%CWR + 200kg/ha NPK), 7.9t/ha. Yield decreased as full CWR was reduced by 10% and 20% in T2 and T3 but no significant difference existed among T1 (100%CWR),

6.0t/ha, T2 (90%CWR), 5.7t/ha and T3 (80%CWR), 5.7t/ha. No significant differences were seen among T8 (80%CWR + 5t/ha CM), 4.1t/ha, T14 (80%CWR + 200kg/ha NPK), 3.9t/ha and T9 (80%CWR + 10t/ha CM), 3.7t/ha. Moreover, T14, T9 and T15 (80%CWR + 250kg/ha NPK), 2.3t/ha expressed no significant differences.

Table 11: Yield Parameters and Root Length of Okra

Treatment Coding	Mean number of Pod/Trmt	Mean Pod weight (grams)	Mean Pod weight (t/ha)	Mean Pod Length (cm)	Mean Pod Circum (cm)	Mean Root Length (cm)
T1	31 f	453.0 b	6.0 b	8.2 de	8.2 ef	23.9 gh
T2	30 f	447.8 b	6.0 b	8.1 de	7.5 ef	24.0 gh
T3	28 f	429.1 b	5.8 b	8.0 de	7.4 ef	30.3 def
T4	66 c	628.9 a	8.4 a	10.4 c	11.4 bc	21.1 h
T5	76 a	669.3 a	8.9 a	13.6 a	12.3 ab	24.4 gh
T6	65 c	614.3 a	8.2 a	10.9 bc	9.8 d	26.8 efg
T7	73 b	644.0 a	8.6 a	12.8 a	12.8 a	30.1 def
T8	23 g	310.2 c	4.1 c	6.8 f	8.4 e	30.9 cde
T9	23 gh	280.4 cd	3.7 cd	7.2 ef	7.1 f	33.4 cd
T10	42 e	599.0 a	8.0 a	9.9 c	10.2 d	25.2 fgh
T11	71 b	661.6 a	8.8 a	11.7 b	11.3 bc	26.6 efgh
T12	61 d	589.0 a	7.9 a	8.4 d	10.6 cd	31.9 cde
T13	70 b	613.7 a	8.2 a	10.4 c	9.6 d	36.2 bc
T14	21 gh	292.8cd	3.9 cd	6.4 fg	6.3 gh	40.8 b
T15	19 h	170.6 d	2.3 d	5.8 g	6.0 h	47.4 a

Means within same column with similar letters are not significantly different at 5% probability level.

Pod length and pod circumference were measured during every harvest till the last harvest. From the results obtained, T5 gave the longest pod length and the second longest pod length was produced by T7 but no significant difference existed between the two while the biggest pod circumference was given by T7 and the second biggest pod circumference by T5 again with no significant

difference between the two. There was no significant difference between T11 and T6 there was no significant difference among T6, T13, T4 and T10 in term of pod length. Though T12 had 90%CWR + 200kg/ha NPK, it had no significant difference with T1, T2 and T3 in pod length. T1, T2, T3 and T9 showed statistically the same pod length. T9, T8 and T14 recorded no significant difference in pod length. T14 and T15 had statistically the same pod length.

The biggest pod circumference was produced by T7 (12.8cm) but was not statistically different from T5 (12.3cm). The least pod circumference was given by T15 (6.0cm). No significant difference existed among T5, T4 and T11. Similar results were seen among T4, T11, and T12 on one hand and T12, T10, T6 and T13 on the other hand. Plots treated with 100% CWR, 90% CWR and 80% CWR alone were not significantly different from each other and from T8. Moreover, T1, T2, T3 and T9 had no significant difference. T9 and T14 had the same results while T14 and T15 had statistically the same results.

Plots treated with crop water requirement treatments alone had decreasing yield and yield related components as water was decreased from 100%CWR to 90%CWR and 80%CWR. This result is in line with the work done by Owusu-Sekyere and Annan (2010) and Calvache and Reichardt (1999) where water stress during vegetative growth led to decline in yield.

There were higher increases in yield in plots treated with chicken manure in combination with 100%CWR and 90%CWR than NPK-deficit irrigation plots. This could be due to available nutrients such as N and organic matter that are essential for the growth of the crop. This is in agreement with work done by

Ojeniyi and Adejobi (2002) and Ojeniyi (2000). Also, there were increase in yield and yield related components as both chicken manure and NPK 15:15:15 increase from 5t/ha to 10t/ha chicken manure and 200kg/ha to 250kg/ha NPK in combination with 100%CWR and 80%CWR. 80%CWR in combination with chicken manure and NPK performed poorly especially with high fertilizer doses.

The root is the first organ of the crop to be exposed to water deficit. The change in moisture status in the soil also affects the spatial distribution of the roots and the efficiency of available nutrient and water absorption. The roots and shoots of the crop would function normally and benefit from each other when the conditions of the water and nutrient are favorable. Otherwise, their functions would be weak (Price et. al., 2002; Woodall and Ward, 2002; Benjamin and Nielson, 2006). High or moderate water stress may induce the spread of roots in deeper layers of soil, so that plants would obtain a larger spatial distribution from which to uptake more nutrients and water (Zhang and Wang, 1997; Yan et. al., 2008).

Data was collected to determine root length variations among the fifteen (15) treatments. Data collected show significant differences among some of the treatments (Table 11). The longest root length was produced by T15 (47.38cm) and was statistically different from the rest of the treatments and the least root length was given by T4. Root lengths collected from T14 and T13 showed no significant difference. Also, T13, T9, T12 and T8 had no significant difference in root length. Comparable results were seen among T9, T12, T8, T3 and T7 where no significant difference existed. T12, T8, T3, T7, T6 and T11 had no significant

difference among them. In addition to treatment comparison, T3, T7, T6, T11, and T10 had no significant differences. Statistically, similar results existed among T6, T11, T10, T5, T2, and T1 while similar statistical results also existed among T11, T10, T5, T2, T1 and T4.

Soil Analysis

Table 12 indicates some soil parameters before and after the experiment. The initial results indicate that the initial soil was acidic with low organic matter. Also, the initial soil was low in nitrogen, phosphorus, potassium and available moisture content. The addition of crop water to the soil through irrigation and the application of chicken manure and NPK affected the soil properties. From Table 4.6, initial soil pH (4.82) increased in all the treated plots except the 80%CWR + NPK which decreased. This result is in line with work done by Fubara-Manuel (2005) and Dikinya and Mufwanzala (2010) who found similar increase in pH in soil treated with chicken manure. Ano and Agwu (2006) also observed increase in pH after the addition of organic manure to the soil. However, Ouda and Mahadeen (2008) found that soil pH was not significantly affected by different doses of organic and inorganic fertilizers. There was enhancement in soil organic matter in plots given chicken manure and NPK than crop water requirement treatments alone. Moreover, there were decreases in N, P and K in plots with crop water requirement treatments alone which could be due to the uptake of those available minerals by the crop but the N, P and K increased in plots treated with 100%CWR, 90%CWR and 80%CWR plus chicken manure.

Table 12: Some Chemical properties Before (Initial) and After the Experiment

	Soil pH	Organic Matter (%)	Nit-rogen (%)	Phos-phorus (µgP/g)	Potassium (cmol/kg)	Moisture Content (% by volume)
Initial	**4.82**	**0.61**	**0.06**	**20.98**	**0.46**	**13.71**
100%CWR	5.34	0.44	0.04	9.11	0.28	21.34
90%CWR	5.55	0.41	0.05	8.42	0.21	19.32
80%CWR	5.49	0.35	0.03	7.30	0.30	9.11
100%CWR + CM	5.95	2.62	0.08	47.92	7.00	23.21
90%CWR + CM	6.07	2.44	0.06	45.72	6.00	26.45
80%CWR+ CM	5.58	0.77	0.03	35.06	4.00	19.25
100%CWR + NPK	5.75	0.68	0.07	11.32	6.00	21.22
90%CWR + NPK	5.03	0.62	0.08	10.60	6.00	13.44
80%CWR+ NPK	4.03	0.47	0.07	12.84	7.00	11.36

Comparing chicken manure and NPK treated plots at the three levels of crop water requirements, chicken manure improved the soil properties more than NPK. Similar observations were made by Fubara-Manuel (2005) and Adesodun et al. (2005).

The soil moisture content increased from the initial (13.71%) in some plots as a result of water applied (Table 12). There were increases at 100%CWR and 90%CWR treatments alone but a drop in 80%CWR. Moisture content was higher in chicken manure plots than NPK plots. Aluko and Oyedele (2005) attributed the improvement of soil moisture with poultry manure to the mulching effect of the manure, which in term improved moisture retention and the soil structure.

Conclusion

It was observed that combination of full CWR and deficit irrigation and fertilizer sources increased growth and yield of okra at 100%CWR and 90%CWR compared to the water treatments alone. Growth and yield also increased as chicken manure dose was increased from 5t/ha to 10t/ha and NPK 15:15:15 dose from 200kg/ha to 250 kg/ha when they were combined with 100%CWR and 90%CWR. Comparing chicken manure and NPK fertilizer performances on okra growth and yield, chicken manure had better results than NPK. Moreover, at either 80% CWR combination with chicken manure or NPK, 80% CWR + chicken manure performed better than 80%CWR + NPK.

On the other hand, there were no significant differences among the crop water requirement treatments alone (100%CWR, 90%CWR and 80%CWR) though there were growth and yield reduction as water decreased. In a water scarce environment, With respect to deficit irrigation without any fertilizers added, 80%CWR can be used to produce okra without significant yield reduction.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

Summary

Production of vegetables is continuing to increase and the prospects for increase in all year round production will possibly come mostly from irrigation and amendment of the soil fertility status as rainfall is unpredictable and the soil is of low fertility. Research in irrigation water management for efficient use of water by crops will have a pivotal role in contributing to such improvements.

Major findings of the study are summarized as follows:

From the Pot Experiment:

- Plots treated with T2 and T3 had no statistical difference with full CWR (T1). Also, as the CWR decreased from T1 to T2 and T3, growth and yield parameters also decreased.
- Yield parameters were greater in deficit irrigation-chicken manure combination (T4, T5, T6, T7, T8 and T9) than T1, T2, T3. On the other hand, as the level of chicken manure was increased from 5t/ha to 10t/ha, growth and yield parameters also increased.
- T5 dominated in both growth and yield followed by T4 for full crop water requirements.
- T7 produced similar results with T4.

- It was observed also that 20% deficit irrigation with high dose of chicken manure led to reduction in growth and yield parameters.

From the Field Experiment

- No significant difference existed among T1, T2 and T3. It was also recorded from the field experiment that as the level of CWR decreased from T1 to T2 & T3, growth and yield parameters also decreased.
- Deficit irrigation-chicken manure combination and deficit irrigation-NKP had great effects on okra growth parameters. It was recorded from the first two growth stages (initial & developmental) that deficit irrigation-NPK dominated in plant height, leaf area and stem circumference than deficit irrigation-chicken manure. At the late mid and late stages, deficit irrigation-chicken manure dominated in growth parameters (plant height, leaf area & stem circumference).
- Growth and yield parameters were increased as the levels of chicken manure and NPK were increased especially at 90%CWR.
- It was observed that plots treated with 10% deficit irrigation-chicken manure combination had higher yield than those treated with 10% deficit irrigation-NPK combination.
- On the overall results, comparing deficit irrigation-chicken manure combination and deficit irrigation-NPK combination, deficit irrigation-chicken combination did better in terms of growth and yield than deficit irrigation-NPK.

- Variations existed among root length of various treatments. As the level of CWR decreased from 100% to 90% and 80%, the length of the root started to increase. Longest root lengths were seen in plots treated with T3, T9 and T15.
- Some chemical properties of the soil were improved at the end of the research as a result of the addition of water, chicken manure and NPK to the soil.

Conclusion

From the research results, it can be concluded that:

(a). 80% crop water requirement without any fertilizer combination is the best application for okra in a water scarce environment.

(b). The okra yield in plots treated with crop water treatments alone was low but due to the addition of organic and inorganic fertilizers to 100%CWR and 90%CWR, there were significant increases in yield.

(c). Chicken manure was superior to NPK 15:15:15 in terms of yield and improvement of the soil properties after the experiment (Table 11 & 12)

(d). The combination of chicken manure and 80%CWR and NPK and 80%CWR performed poorly. This could be due to high doses of both fertilizers.

Recommendations

Based on the results obtained, the researcher would like to make the following recommendations:

- That 20% deficit irrigation is suitable for okra production in an area where water is scarce and the cost of water is high.
- That similar research is done in multi locations of the various Agro-ecological zones of Ghana.
- A 10% deficit irrigation plus 5-10t/ha chicken manure and 200-250 kg/ha NPK 15:15:15 are recommended for a comparable yield with 100% full crop water requirements.
- That lesser doses of fertilizer trials be carried out along with 20% deficit irrigation since 80%CWR plus high doses of either fertilizers performed poorly in this experiment.
- That similar research should consider soil analysis after every growth stage of the crop.
- Economic analysis of yield and water use efficiency of the crop should be discussed in further experiments.

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APPENDIX A

EXPERIMENT ONE

TOPIC: Effects of Deficit Irrigation and Deficit Irrigation-chicken manure Interactions on the Growth and Yield of Okra in a Pot Experiment

GenStat Release 10.3DE

T1= 100%CWR, **T2**= 90%CWR, **T3**= 80%CWR, **T4**= 100%CWR + 5t/ha chicken manure, **T5**= 100%CWR+10t/ha chicken manure, **T6**= 90%CWR+5t/ha chicken manure, **T7**= 90%CWR+10t/ha chicken manure, **T8**= 80%CWR+5t/ha chicken manure, **T9**= 80%CWR+ 10t/ha chicken manure

Identifier	Values	Missing	Levels
Block	27	0	3

Identifier	Values	Missing	Levels
Treatment	27	0	9

Analysis of Variance

Variate: Plant Height_cm

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	417.2	208.6	1.46	
Treatment	8	19938.0	2492.2	17.47	<.001
Residual	16	2282.8	142.7		
Total	26	22638.1			

Tables of Means

Variate: Plant Height_cm

Grand mean 95.8

Treatment	**T1**	**T5**	**T4**	**T2**	**T6**	**T7**
	100.2	134.5	116.1	74.0	110.6	126.9

Treatment	**T8**	**T9**	**T3**
	84.0	63.0	53.0

Standard Errors of Differences of Means

Table	Treatment
REP.	3
D.F.	16
S.E.D.	9.753

Least Significant Differences of Means (5% level)

Table	Treatment
REP.	3
D.F.	16
L.S.D.	20.675

Variance = 142.6762 with 16 degrees of freedom

Duncan's Multiple Range Test

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.120
3	0.9025	2.223
4	0.8574	2.287
5	0.8145	2.332
6	0.7738	2.364
7	0.7351	2.387
8	0.6983	2.406
9	0.6634	2.419

Identifier	Mean	
T5	134.5	a
T7	126.9	a b
T4	116.1	a b c
T6	110.6	b c
T1	100.2	c d
T8	84.0	d e
T2	74.0	e f
T9	63.0	e f
T3	53.0	f

Analysis of Variance

Variate: Leaf Area_cm^2

Source Of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	3719.2	1859.6	2.62	
Treatment	8	105274.7	13159.3	18.51	<.001
Residual	16	11375.7	711.0		
Total	26	120369.6			

Tables of means

Variate: Leaf Area_cm^2

Grand Mean 154.8

Treatment	**T1**	**T7**	**T4**	**T2**	**T5**	**T6**
	127.6	220.8	205.8	116.3	278.6	155.7

Treatment	**T8**	**T9**	**T3**
	107.6	91.9	88.5

Standard errors of differences of means

Table	**Treatment**
REP.	3
D.F.	16
S.E.D.	21.771

Least significant differences of Means (5% level)

Table	**Treatment**
REP.	3
D.F.	16
L.S.D.	46.153

All pairwise comparisons are tested.

Variance = 710.9810 with 16 degrees of freedom

Duncan's Multiple Range Test
Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.120
3	0.9025	2.223
4	0.8574	2.287
5	0.8145	2.332
6	0.7738	2.364
7	0.7351	2.387
8	0.6983	2.406
9	0.6634	2.419

Identifier	**Mean**	
T5	278.6	a
T7	220.8	b
T4	205.8	b
T6	155.7	c
T1	127.6	c d
T2	116.3	c d
T8	107.6	c d
T9	91.9	d
T3	88.5	d

Analysis of variance

Variate: Stem Circumference_cm

Source of Variation	**D.F.**	**S.S.**	**M.S.**	**V.R.**	**F PR.**
Block	2	0.763	0.382	0.10	
Treatment	8	131.171	16.396	4.28	0.007
Residual	16	61.357	3.835		
Total	26	193.291			

Tables of Means
Variate: Stem Circumference_cm
Grand Mean 5.4

Treatment	**T1**	**T4**	**T5**	**T2**	**T6**	**T7**
	4.3	7.9	8.9	3.7	6.4	7.4

Treatment	**T8**	**T9**	**T3**
	3.4	3.8	2.4

Standard Errors of Differences of Means

Table	Treatment
REP.	3
D.F.	16
S.E.D.	1.599

Least Significant Differences of Means (5% level)

Table	Treatment
REP.	3
D.F.	16
L.S.D.	3.390

All pairwise comparisons are tested.
Variance = 3.8348 with 16 degrees of freedom

Duncan's Multiple Range Test
Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.120
3	0.9025	2.223
4	0.8574	2.287
5	0.8145	2.332
6	0.7738	2.364
7	0.7351	2.387
8	0.6983	2.406
9	0.6634	2.419

Identifier	Mean	
T5	8.9	a
T4	7.9	a b
T7	7.4	a b c
T6	6.4	a b c d
T1	4.3	b c d e
T9	3.8	c d e
T2	3.7	c d e
T8	3.4	d e
T3	2.4	e

Analysis of Variance

Variate: Number of Pod_Tmt

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	209.85	104.93	2.93	
Treatment	8	9252.74	1156.59	32.34	<.001
Residual	16	572.15	35.76		
Total	26	10034.74			

Tables of Means

Variate: Number of pod per tmt

Grand Mean 30

Treatment	**T1**	**T4**	**T5**	**T2**	**T6**	**T7**
	21	61	53	16	31	49

Treatment	**T8**	**T9**	**T3**
	12	15	9

Standard Errors of Differences of Means

Table	**Treatment**
REP.	3
D.F.	16
S.E.D.	4.883

Least Significant Differences of Means (5% level)

Table	**Treatment**
REP.	3
D.F.	16
L.S.D.	10.351

All pairwise comparisons are tested.
Variance = 35.7593 with 16 degrees of freedom

Duncan's Multiple Range Test
Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.120
3	0.9025	2.223
4	0.8574	2.287
5	0.8145	2.332
6	0.7738	2.364
7	0.7351	2.387
8	0.6983	2.406
9	0.6634	2.419

Identifier	Mean				
T4	61	a			
T5	53	a	b		
T7	49		b		
T6	31			c	
T1	21			c	d
T2	16				d e
T9	15				d e
T8	12				d e
T3	9				e

Analysis of Variance

Variate: Pod Weight per tmt_grm

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	10913.0	5456.11	2.41	
Treatment	8	610987.1	76373.13	33.74	<.001
Residual	16	36217.2	2264.01		
Total	26	658117.1			

Tables of Means
Variate: Pod Weight per tmt_grm

Grand Mean: 249.6

Treatment	T1	T4	T5	T2	T6	T7
	196.83	402.56	517.61	176.40	247.48	417.30

Treatment	T8	T9	T3
	119.77	100.81	67.47

Standard Errors of Differences of Means

Table	Treatment
REP.	3
D.F.	16
S.E.D.	38.846

Least Significant Differences of Means (5% level)

Table	Treatment
REP.	3
D.F.	16
L.S.D.	82.350

All pairwise comparisons are tested.
Variance = 2263.5333 with 16 degrees of freedom

Duncan's Multiple Range Test
Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.120
3	0.9025	2.223
4	0.8574	2.287
5	0.8145	2.332
6	0.7738	2.364
7	0.7351	2.387
8	0.6983	2.406
9	0.6634	2.419

Identifier	Mean	
T5	517.6	a
T7	417.3	b
T4	402.6	b
T6	247.5	c
T1	196.8	c d
T2	176.4	c d e
T8	119.8	d e f
T9	100.8	e f
T3	67.5	f

Analysis of Variance
Variate: Yield_ ton per ha

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	1.1005	0.5502	2.43	
Treatment	8	61.0679	7.6335	33.68	<.001
Residual	16	3.6259	0.2266		
Total	26	65.7943			

Tables of Means

Variate: Yield_ ton per ha

Grand Mean: 2.5

Treatment	T1	T4	T5	T2	T6	T7
	2.0	4.0	5.2	2.0	2.5	4.2

Treatment	T8	T9	T3
	1.2	1.0	0.7

Standard Errors of Differences of Means

Table	Treatment
REP.	3
D.F.	16
S.E.D.	0.3887

Least Significant Differences of Means (5% level)

Table	Treatment
REP.	3
D.F.	16
L.S.D.	0.8240

All pairwise comparisons are tested.
Variance = 0.2266 with 16 degrees of freedom

Duncan's Multiple Range Test
Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.120
3	0.9025	2.223

4	0.8574	2.287
5	0.8145	2.332
6	0.7738	2.364
7	0.7351	2.387
8	0.6983	2.406
9	0.6634	2.419

Identifier	Mean	
T5	5.2	a
T7	4.2	b
T4	4.0	b
T6	2.5	c
T1	2.0	c d
T2	1.8	c d e
T8	1.2	d e f
T9	1.0	e f
T3	0.7	f

Analysis of variance
Variate: Pod Length_cm

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	14.933	7.467	5.45	
Treatment	8	187.522	23.440	17.10	<.001
Residual	16	21.928	1.371		
Total	26	224.384			

Tables of Means

Variate: Pod Length_cm

Grand Mean: 7.3

Treatment	T1	T4	T5	T2	T6	T7
	6.4	8.8	11.6	4.1	9.4	10.1
Treatment	T8	T9	T3			
	6.1	5.5	3.5			

Standard Errors of Differences of Means

Table	**Treatment**
REP.	3
D.F.	16
S.E.D.	0.956

Least Significant Differences of Means (5% level)

Table	Treatment
REP.	3
D.F.	16
L.S.D.	2.026

All pairwise comparisons are tested.
Variance = 1.3705 with 16 degrees of freedom

Duncan's Multiple Range Test
Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.120
3	0.9025	2.223
4	0.8574	2.287
5	0.8145	2.332
6	0.7738	2.364
7	0.7351	2.387
8	0.6983	2.406
9	0.6634	2.419

Identifier	Mean	
T5	11.6	a
T7	10.1	a b
T6	9.4	b
T4	8.8	b
T1	6.4	c
T8	6.1	c d
T9	5.5	c d e
T2	4.1	d e
T3	3.5	e

Analysis of Variance

Variate: Pod Circumference_cm

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	4.8728	2.4364	2.71	
Treatment	8	114.8517	14.3565	15.97	<.001
Residual	16	14.3818	0.8989		
Total	26	134.1063			

Tables of Means

Variate: Pod Circumference_cm

Grand Mean: 7.2

Treatment	**T1**	**T4**	**T5**	**T2**	**T6**	**T7**
	6.6	9.1	11.2	5.3	7.3	8.6

Treatment	**T8**	**T9**	**T3**
	6.0	6.5	4.0

Standard Errors of Differences of Means

Table	**Treatment**
REP.	3
D.F.	16
S.E.D.	0.774

Least Significant Differences of Means (5% level)

Table	**Treatment**
REP.	3
D.F.	16
L.S.D.	1.641

All pairwise comparisons are tested.
Variance = 0.8989 with 16 degrees of freedom

Duncan's Multiple Range Test
Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.120
3	0.9025	2.223
4	0.8574	2.287
5	0.8145	2.332
6	0.7738	2.364
7	0.7351	2.387
8	0.6983	2.406
9	0.6634	2.419

Identifier	**Mean**
T5	11.2a
T4	9.1 b
T7	8.6 b c
T6	7.3 c d

T1	6.6	d e
T9	6.5	d e
T8	6.0	d e
T2	5.3	e f
T3	4.0	f

Analysis of Variance

Variate: Root Length_cm

Source Of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	59.62	29.81	2.19	
Treatment	8	448.06	56.01	4.12	0.008
Residual	16	217.66	13.60		
Total	26	725.34			

Tables of Means

Variate: Root Length_cm

Grand Mean: 22.4

Treatment	**T1**	**T4**	**T5**	**T2**	**T6**	**T7**
	18.9	16.5	18.9	18.9	21.7	25.1
Treatment	**T8**	**T9**	**T3**			
	27.4	28.3	25.7			

Standard Errors of Differences of Means

Table	**Treatment**
REP.	3
D.F.	16
S.E.D.	3.011

Least Significant Differences of Means (5% level)

Table	**Treatment**
REP.	3
D.F.	16
L.S.D.	6.384

All pairwise comparisons are tested.
Variance = 13.6035 with 16 degrees of freedom

Duncan's Multiple Range Test
Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.120
3	0.9025	2.223
4	0.8574	2.287
5	0.8145	2.332
6	0.7738	2.364
7	0.7351	2.387
8	0.6983	2.406
9	0.6634	2.419

Identifier	**Mean**	
T9	28.3	a
T8	27.4	a
T3	25.7	a b
T7	25.1	a b
T6	21.7	a b c
T5	18.9	b c
T2	18.9	b c
T1	18.9	b c
T4	16.5	c

APPENDIX B

EXPERIMENT TWO

Effects of Deficit Irrigation, Deficit Irrigation-chicken manure and Deficit Irrigation-NPK 15:15:15 Interactions on the Growth and Yield of Okra in a Field Experiment

GenStat Edition 4

Treatments: T1= 100%CWR**, T2=** 90%CWR**, T3=** 80%CWR, **T4=** 100%CWR+5t/ha chicken manure**, T5=** 100%CWR+10t/ha chicken manure**, T6=** 90%CWR+5t/ha chicken manure**, T7=** 90%CWR+10t/ha chicken manure**, T8=** 80%CWR+5t/ha chicken manure**, T9=** 80%CWR+10t/ha chicken manure**, T10=** 100%CWR+200kg/ha NPK**, T11=** 100%CWR+250kg/ha NPK**, T12=** 90%CWR+200kg/ha NPK**, T13=** 90%CWR+250kg/ha NPK, **T14=** 80%CWR+200kg/ha NPK, **T15=** 80%CWR+250kg/ha NPK.

Identifier	Values	Missing	Levels
Treatment	45	0	15

Identifier	Values	Missing	Levels
Block	45	0	3

Initial Stage Plant Height
Analysis of Variance
Variate: Initial Stage Plant Height (centimeters)

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	57.51	28.75	1.15	
Treatment	14	3739.07	267.08	10.68	<.001
Residual	28	699.89	25.00		
Total	44	4496.47			

Tables of Means

Variate: Initial Stage Plant Height (centimeters)

Grand Mean: 38.59

Treatment	**T1**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**
	34.0	46.6	53.7	43.8	46.9	28.2	21.1

Treatment	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
	36.6	20.0	41.1	43.7	44.3	38.6	38.6

Treatment	T9
	41.9

Standard Errors of Differences of Means

Table	Treatment
REP.	3
D.F.	28
S.E.D.	4.082

Least Significant Differences of Means (5% level)

Table	Treatment
REP.	3
D.F.	28
L.S.D.	8.362

All pairwise comparisons are tested.
Variance = 24.9961 with 28 degrees of freedom

Duncan's Multiple Range Test (DMRT)
Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267
6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411
13	0.5404	2.420
14	0.5133	2.427
15	0.4877	2.434

Identifier	Mean	
T11	53.7	**a**
T13	46.9	**a b**
T10	46.6	**a b**
T6	44.3	**b c**
T12	43.8	**b c**
T5	43.7	**b c**
T9	41.9	**b c d**

T4	41.1	**b c d**
T7	38.6	**b c d**
T8	38.6	**b c d**
T2	36.6	**c d e**
T1	34.0	**d e**
T14	28.2	**e f**
T15	21.1	**f**
T3	20.0	**f**

Developmental Stage Plant Height
Analysis of Variance

Variate: Developmental Stage Plant Height (cm)

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	482.58	241.29	3.31	
Treatment	14	17820.92	1272.92	17.45	<.001
Residual	28	2042.04	72.93		
Total	44	20345.54			

Tables of Means

Variate: Developmental Stage Plant Height (cm)

Grand Mean: 75.6

Treatment	**T1**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**
	73.9	94.6	105.6	79.1	103.0	46.1	50.2
Treatment	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
	61.0	60.0	88.7	90.3	95.4	80.1	45.6
Treatment	**T9**						
	60.0						

Standard Errors of Differences of Means

Table	**Treatment**
REP.	3
D.F.	28
S.E.D.	6.973

Least Significant Differences Of Means (5% level)

Table	**Treatment**
REP.	3
D.F.	28
L.S.D.	14.283

All pairwise comparisons are tested.
Variance = 72.9300 with 28 degrees of freedom

Duncan's Multiple Range Test (DMRT)

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267
6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411
13	0.5404	2.420
14	0.5133	2.427
15	0.4877	2.434

Identifier	**Mean**							
T11	105.6	**a**						
T13	103.0	**a**	**b**					
T6	95.4	**a**	**b**	**c**				
T10	94.6	**a**	**b**	**c**	**d**			
T5	90.3	**a**	**b**	**c**	**d**			
T4	88.7		**b**	**c**	**d**	**e**		
T7	80.1			**c**	**d**	**e**		
T12	79.1				**d**	**e**		
T1	73.9					**e**	**f**	
T2	61.0						**f**	**g**
T3	60.0						**f**	**g**
T9	60.0						**f**	**g**
T15	50.2							**g**
T14	46.1							**g**
T8	45.6							**g**

Mid-Season Stage Plant Height
Analysis of Variance

Variate: Mid-Season Stage Plant Height (cm)

Source of Variation	D.F.	S.S.	M.S.	V.R.	F Pr.
Block	2	2238.4	1119.2	3.29	
Treatment	14	66991.6	4785.1	14.07	<.001
Residual	28	9524.3	340.2		
Total	44	78754.3			

Tables of Means

Variate: Mid-Season Stage Plant Height (cm)

Grand Mean: 150.0

Treatment	**T1**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**
	123.7	182.7	195.9	169.8	180.5	102.1	91.9

Treatment	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
	115.1	107.2	192.3	194.5	176.2	188.3	120.8

Treatment	**T9**
	109.4

Standard Errors of Differences of Means

Table	**Treatment**
REP.	3
D.F.	28
S.E.D.	15.059

Least Significant Differences of Means (5% level)

Table	**Treatment**
REP.	3
D.F.	28
L.S.D.	30.847

All pairwise comparisons are tested.

Variance = 340.1553 with 28 degrees of freedom

Duncan's Multiple Range Test (DMRT)
Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267
6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411
13	0.5404	2.420
14	0.5133	2.427
15	0.4877	2.434

Identifier	**Mean**	
T11	195.9	**a**
T5	194.5	**a**
T4	192.3	**a**
T7	188.3	**a**
T10	182.7	**a**
T13	180.5	**a**
T6	176.2	**a**
T12	169.8	**a**
T1	123.7	**b**
T8	120.8	**b**
T2	115.1	**b**
T9	109.4	**b**
T3	107.2	**b**
T14	102.1	**b**
T15	91.9	**b**

Late Season Plant Height
Analysis of Variance

VARIATE: Late Season Plant Height (cm)

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	3725.9	1863.0	7.86	
Treatment	14	55375.0	3955.4	16.69	<.001
Residual	28	6636.8	237.0		
Total	44	65737.6			

Tables of Means
Variate: Late Season Stage Plant Height (cm)

Grand Mean: 179.9

Treatment	**T1**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**
	167.3	204.3	215.3	197.0	214.0	140.0	114.0

Treatment	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
	159.0	151.7	208.0	225.0	202.0	216.7	154.7

Treatment	**T9**
	129.7

Standard Errors of Differences of Means

Table	**Treatment**
REP.	3
D.F.	28
S.E.D.	12.571

Least Significant Differences of Means (5% level)

Table	**Treatment**
REP.	3
D.F.	28
L.S.D.	25.750

All pairwise comparisons are tested.
Variance = 237.0270 with 28 degrees of freedom

Duncan's Multiple Range Test (DMRT)
Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267

6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411
13	0.5404	2.420
14	0.5133	2.427
15	0.4877	2.434

Identifier	Mean	
T5	225.0	**a**
T7	216.7	**a**
T11	215.3	**a**
T13	214.0	**a**
T4	208.0	**a**
T10	204.3	**a**
T6	202.0	**a**
T12	197.0	**a**
T1	167.3	**b**
T2	159.0	**b**
T8	154.7	**b c**
T3	151.7	**b c**
T14	140.0	**b c d**
T9	129.7	**c d**
T15	114.0	**d**

Initial Stage Leaf Area
Analysis of Variance

Variate: Initial Stage Leaf Area (cm^2)

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	1274.27	637.14	7.14	
Treatment	14	92733.33	6623.81	74.20	<.001
Residual	28	2499.41	89.26		
Total	44	96507.01			

Tables of Means

Variate: Initial Stage Leaf Area (cm^2)

Grand Mean: 95.7

Treatment	T1	T10	T11	T12	T13	T14	T15
	79.5	165.9	168.4	148.7	93.9	43.3	49.8

Treatment	T2	T3	T4	T5	T6	T7	T8
	78.4	30.0	119.8	162.0	78.5	89.2	43.5

Treatment	T9
	84.4

Standard Errors of Differences of Means

Table	Treatment
REP.	3
D.F.	28
S.E.D.	7.714

Least Significant Differences of Means (5% level)

Table	Treatment
REP.	3
D.F.	28
L.S.D.	15.802

All pairwise comparisons are tested.
Variance = 89.2647 with 28 degrees of freedom

Duncan's Multiple Range Test (DMRT)

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267
6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411
13	0.5404	2.420
14	0.5133	2.427
15	0.4877	2.434

Identifier	Mean	
T11	168.4	**a**
T10	165.9	**a**
T5	162.0	**a b**
T12	148.7	**b**
T4	119.8	**c**
T13	93.9	**d**
T7	89.2	**d**
T9	84.4	**d**
T1	79.5	**d**
T6	78.5	**d**
T2	78.4	**d**
T15	49.8	**e**
T8	43.5	**e f**
T14	43.3	**e f**
T3	30.0	**f**

Developmental Stage Leaf Area
Analysis of Variance

VARIATE: DEVELOPMENTAL STAGE LEAF AREA (cm^2)

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	5573.8	2786.9	10.30	
Treatment	14	244194.9	17442.5	64.45	<.001
Residual	28	7578.1	270.6		
Total		44	257346.8		

Tables of Means

Variate: Developmental Stage Leaf Area (cm^2)
Grand Mean: 193.6

Treatment	**T1**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**
	161.6	209.8	288.7	204.8	284.6	81.8	59.9
Treatment	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
	160.3	99.7	251.6	207.0	277.8	288.4	141.9
Treatment	**T9**						
	185.4						

Standard Errors of Differences of Means

Table	**Treatment**
REP.	3
D.F.	28
S.E.D.	13.432

Least Significant Differences of Means (5% level)

Table	**Treatment**
REP.	3
D.F.	28
L.S.D.	27.515

All pairwise comparisons are tested.
Variance = 270.6465 with 28 degrees of freedom

Duncan's Multiple Range Test (DMRT)
Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267
6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411
13	0.5404	2.420
14	0.5133	2.427
15	0.4877	2.434

Identifier	**Mean**	
T11	288.7	**a**
T7	288.4	**a**
T13	284.6	**a**
T6	277.8	**a b**
T4	251.6	**b**
T10	209.8	**c**
T5	207.0	**c**
T12	204.8	**c**
T9	185.4	**c d**
T1	161.6	**d e**
T2	160.3	**d e**
T8	141.9	**e**
T3	99.7	**f**
T14	81.8	**f g**
T15	59.9	**g**

Mid-Season Stage Leaf Area
Analysis of Variance

Variate: Mid-Season Stage Leaf Area (cm^2)

Source of Variation	D.F.	S.S.	M.S.	V.R.	F Pr.
Block	2	4183.3	2091.6	2.51	
Treatment	14	333619.0	23829.9	28.54	<.001
Residual	28	23379.1	835.0		
Total	44	361181.4			

Tables of Means

VARIATE: MID-SEASON STAGE LEAF AREA (cm2)

Grand Mean: 250.9

Treatment	**T1**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**
	186.3	329.3	345.7	332.4	250.7	161.0	140.8

Treatment	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
	183.3	104.4	315.4	377.0	312.8	339.9	180.2

Treatment	**T9**
	204.2

Standard Errors of Differences of Means

Table	**Treatment**
REP.	3
D.F.	28
S.E.D.	23.593

Least Significant Differences of Means (5% level)

Table	**Treatment**
REP.	3
D.F.	28
L.S.D.	48.329

All pairwise comparisons are tested.

Variance = 834.9677 with 28 degrees of freedom

Duncan's Multiple Range Test (DMRT)

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267
6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411
13	0.5404	2.420
14	0.5133	2.427
15	0.4877	2.434

Identifier	Mean					
T5	377.0	**a**				
T11	345.7	**a**	**b**			
T7	339.9	**a**	**b**			
T12	332.4	**a**	**b**			
T10	329.3	**a**	**b**			
T4	315.4		**b**			
T6	312.8		**b**			
T13	250.7			**c**		
T9	204.2			**c**	**d**	
T1	186.3				**d**	**e**
T2	183.3				**d**	**e**
T8	180.2				**d**	**e**
T14	161.0				**d**	**e**
T15	140.7					**e** **f**
T3	104.4					**f**

Late Season Leaf Area
Analysis of Variance
Variate: Late Season Stage Leaf Area (cm^2)

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	9437.8	4718.9	6.44	
Treatment	14	483444.8	34531.8	47.15	<.001
Residual	28	20505.2	732.3		
Total	44	513387.8			

Tables of Means

Variate: Late Season Stage Leaf Area (cm^2)
Grand Mean: 315.2

Treatment	**T1**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**
	259.1	360.1	373.1	321.9	353.1	200.9	156.1

Treatment	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
	256.0	217.3	428.4	478.5	437.5	467.0	211.4

Treatment	**T9**
	208.3

Standard Errors of Differences of Means

Table	**Treatment**
REP.	3
D.F.	28
S.E.D.	22.096

Least Significant Differences of Means (5% level)

Table	**Treatment**
REP.	3
D.F.	28
L.S.D.	45.261

All pairwise comparisons are tested.
Variance = 732.3280 with 28 degrees of freedom

Duncan's Multiple Range Test (DMRT)
Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267
6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411
13	0.5404	2.420
14	0.5133	2.427
15	0.4877	

Identifier	Mean								
T5	478.5	**a**							
T7	467.0	**a**	**b**						
T6	437.5	**a**	**b**						
T4	428.4		**b**						
T11	373.1			**c**					
T10	360.1			**c**	**d**				
T13	353.1			**c**	**d**				
T12	321.9				**d**				
T1	259.1					**e**			
T2	256.0					**e**	**f**		
T3	217.3					**e**	**f**	**g**	
T8	211.4					**e**	**f**	**g**	
T9	208.3						**f**	**g**	
T14	200.9							**g**	**h**
T15	156.1								**h**

Initial Stage Stem Circumference
Analysis of Variance

Variate: Initial Stage Stem Circumference (cm)

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	2.5942	1.2971	6.96	
Treatment	14	9.9659	0.7118	3.82	0.001
Residual	28	5.2193	0.1864		
Total	44	17.7794			

Tables of Means

Variate: Initial Stage Stem Circumference (cm)

Grand Mean: 2.2

Treatment	**T1**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**
	2.3	2.6	3.0	1.9	2.9	2.2	1.6

Treatment	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
	2.1	1.2	2.3	2.7	2.6	2.2	1.9

Treatment	**T9**
	2.2

Standard Errors of Differences of Means

Table	Treatment
REP.	3
D.F.	28
S.E.D.	0.353

Least Significant Differences of Means (5% level)

Table	Treatment
REP.	3
D.F.	28
L.S.D.	0.722

All pairwise comparisons are tested.
Variance = 0.1864 with 28 degrees of freedom

Duncan's Multiple Range Test (DMRT)

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267
6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411
13	0.5404	2.420
14	0.5133	2.427
15	0.4877	2.434

Identifier	Mean
T11	3.0 a
T13	2.9 a b
T5	2.7 a b c
T10	2.6 a b c
T6	2.6 a b c
T4	2.3 a b c d
T1	2.2 a b c d
T14	2.2 a b c d
T7	2.2 a b c d

T2	2.1	b c d
T9	2.1	b c d
T8	1.9	c d e
T12	1.9	c d e
T15	1.6	d e
T3	1.1	e

Developmental Stage Stem Circumference
Analysis of Variance

Variate: Developmental Stage Stem Circumference (cm)

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	18.3100	9.1550	29.36	
Treatment	14	36.4755	2.6054	8.36	<.001
Residual	28	8.7314	0.3118		
Total	44	63.5169			

Tables of Means

Variate: Developmental Stage Stem Circumference (cm)

Grand Mean: 4.7

Treatment	**T1**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**
	4.1	4.7	5.8	5.2	5.3	3.5	3.4
Treatment	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
	4.2	4.1	5.0	6.2	5.8	5.9	4.0
Treatment	**T9**						
	3.9						

Standard Errors of Differences of Means

Table	**Treatment**
REP.	3
D.F.	28
S.E.D.	0.456

Least Significant Differences of Means (5% level)

Table	Treatment
REP.	3
D.F.	28
L.S.D.	0.934

All pairwise comparisons are tested.
Variance = 0.3118 with 28 degrees of freedom

Duncan's Multiple Range Test (DMRT)
Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267
6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411
13	0.5404	2.420
14	0.5133	2.427
15	0.4877	2.434

Identifier	Mean	
T5	6.2	a
T7	5.9	a b
T11	5.8	a b
T6	5.8	a b
T13	5.3	a b c
T12	5.2	a b c
T4	5.0	b c d
T10	4.7	c d e
T2	4.2	d e f
T1	4.1	d e f
T3	4.1	d e f
T8	4.0	e f
T9	3.9	e f
T14	3.5	f
T15	3.4	f

Mid-Season Stage Stem Circumference
Analysis of Variance
Variate: Mid-Season Stage Stem Circumference (cm)

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	16.3454	8.1727	15.04	
Treatment	14	32.9284	2.3520	4.33	<.001
Residual	28	15.2131	0.5433		
Total	44	64.4870			

Tables of Means

Variate: Mid-Season Stage Stem Circumference (cm)

Grand Mean: 6.9

Treatment	**T1**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**
	6.9	7.3	7.0	6.7	7.5	5.5	5.3
Treatment	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
	6.7	5.8	7.5	8.4	7.7	7.8	6.4
Treatment	**T9**						
	6.6						

Standard Errors of Differences of Means

Table	**Treatment**
Rep.	3
D.F.	28
S.E.D.	0.602

Least Significant Differences of Means (5% level)

Table	**Treatment**
REP.	3
D.F.	28
L.S.D.	1.233

All pairwise comparisons are tested.

Variance = 0.5433 with 28 degrees of freedom

Tables of Means

Variate: Mid-Season Stage Stem Circumference (cm)

Experimentwise error rate = 0.0500

Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267
6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411
13	0.5404	2.420
14	0.5133	2.427
15	0.4877	2.434

Identifier	**Mean**	
T5	8.4	a
T7	7.8	a b
T6	7.7	a b
T4	7.5	a b
T13	7.5	a b
T10	7.3	a b
T11	7.0	a b c
T1	6.9	b c
T12	6.7	b c d
T2	6.7	b c d
T9	6.6	b c d e
T8	6.4	b c d e
T3	5.8	c d e
T14	5.5	d e
T15	5.3	e

Late Season Stem Circumference
Analysis of Variance

Variate: Late Season Stage Stem Circumference (cm)

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	32.2903	16.1452	48.56	
Treatment	14	162.2321	11.5880	34.85	<.001
Residual	28	9.3099	0.3325		
Total	44	203.8323			

Tables of Means

Variate: Late Season Stage Stem Circumference (cm)

Grand Mean: 9.7

Treatment	**T1**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**
	9.5	11.0	11.6	10.0	10.2	6.9	6.5

Treatment	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
	9.5	7.4	11.3	13.0	11.0	12.0	8.3

Treatment	**T9**
	7.8

Standard Errors of Differences of Means

Table	**Treatment**
REP.	3
D.F.	28
S.E.D.	0.471

Least Significant Differences of Means (5% level)

Table	**Treatment**
REP.	3
D.F.	28
L.S.D.	0.964

All pairwise comparisons are tested.
Variance = 0.3325 with 28 degrees of freedom

Duncan's Multiple Range Test (DMRT)
Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267
6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411
13	0.5404	2.420
14	0.5133	2.427
15	0.4877	2.434

Identifier	**Mean**	
T5	13.0	a
T7	11.9	b
T11	11.6	b
T4	11.2	b c
T6	11.0	b c d
T10	11.0	b c d
T13	10.2	c d e
T12	10.0	d e
T1	9.5	e
T2	9.5	e
T8	8.3	f
T9	7.8	f g
T3	7.4	f g h
T14	6.9	g h
T15	6.5	h

Number of Pod per Treatment
Analysis of Variance
Variate: Number of Pod Per Treatment

Source of Variation	**D.F.**	**S.S.**	**M.S.**	**V.R.**	**F PR.**
Block	2	48.400	24.200	6.00	
Treatment	14	21079.467	1505.676	373.31	<.001
Residual	28	112.933	4.033		
Total	44	21240.800			

Tables of Means

Variate: Number of Pod per Treatment

Grand Mean: 47

Treatment	**T1**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**
	31	42	71	61	70	21	19

Treatment	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
	30	28	66	76	65	73	23

Treatment	**T9**
	23

Standard Errors of Differences of Means

Table	**Treatment**
REP.	3
D.F.	28
S.E.D.	1.640

Least Significant Differences of Means (5% level)

Table	**Treatment**
REP.	3
D.F.	28
L.S.D.	3.359

All pairwise comparisons are tested.
Variance = 4.0333 with 28 degrees of freedom

Duncan's Multiple Range Test (DMRT)
Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267
6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411

13	0.5404	2.420
14	0.5133	2.427
15	0.4877	2.434

Identifier	Mean	
T5	76	a
T7	73	b
T11	71	b
T13	70	b
T4	66	c
T6	65	c
T12	61	d
T10	42	e
T1	31	f
T2	30	f
T3	28	f
T8	23	g
T9	23	g h
T14	21	g h
T15	19	h

Pod Weight
Analysis of Variance
Variate: Pod Weight (grams)

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	69272.1	34636.0	7.15	
Treatment	14	1142505.02	81608.1	16.85	<.001
Residual	28	135594.1	4843.01		
Total	44	1347372.1			

Tables of Means

Variate: Pod Weight (grams)

Grand Mean: 493.6

Treatment	**T1**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**
	453.0	599.0	661.6	589.0	613.7	292.8	170.6

Treatment	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
	447.8	429.1	628.9	669.3	614.3	644.0	310.2

Treatment	**T9**
	280.4

Standard Errors of Differences of Means

Table	Treatment
REP.	3
D.F.	28
S.E.D.	56.819

Least Significant Differences of Means (5% level)

Table	Treatment
REP.	3
D.F.	28
L.S.D.	116.389

All pairwise comparisons are tested.
Variance = 4842.6380 with 28 degrees of freedom

Duncan's Multiple Range Test (DMRT)

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267
6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411
13	0.5404	2.420
14	0.5133	2.427
15	0.4877	2.434

Identifier	Mean	
T5	669.3	a
T11	661.6	a
T7	644.0	a
T4	628.9	a
T6	614.3	a
T13	613.7	a
T10	599.0	a
T12	589.0	a

T1	453.0	b
T2	447.8	b
T3	429.1	b
T8	310.2	c
T14	292.8	c d
T9	280.4	c d
T15	170.6	d

Pod Weight (ton/ha)
Analysis of Variance

Variate: Pod Weight (ton/ha)

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	12.3204	6.1602	7.15	
Treatment	14	203.1441	14.5103	16.85	<.001
Residual	28	24.1144	0.8612		
Total	44	239.5789			

Tables of Means

VARIATE: Pod Weight (ton/ha)

Grand Mean: 6.6

Treatment	**T1**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**
	6.0	8.0	8.8	7.9	8.2	3.9	2.3

Treatment	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
	6.0	5.7	8.4	8.9	8.2	8.6	4.1

Treatment	**T9**
	3.7

Standard Errors of Differences of Means

Table	**Treatment**
REP.	3
D.F.	28
S.E.D.	0.758

Least Significant Differences of Means (5% level)

Table	Treatment
REP.	3
D.F.	28
L.S.D.	1.552

All pairwise comparisons are tested.
Variance = 0.8612 with 28 degrees of freedom

Duncan's Multiple Range Test (DMRT)

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267
6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411
13	0.5404	2.420
14	0.5133	2.427
15	0.4877	2.434

Identifier	Mean			
T5	8.9	a		
T11	8.8	a		
T7	8.6	a		
T4	8.4	a		
T6	8.2	a		
T13	8.2	a		
T10	8.0	a		
T12	7.9	a		
T1	6.0		b	
T2	6.0		b	
T3	5.7		b	
T8	4.1			c
T14	3.9			c d
T9	3.7			c d
T15	2.3			d

Pod_Length
Analysis of Variance
Variate: Pod Length (cm)

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	7.7664	3.8832	12.86	
Treatment	14	235.5343	16.8239	55.70	<.001
Residual	28	8.4571	0.3020		
Total	44	251.7578			

Tables of Means

Variate: Pod Length (cm)

Grand Mean: 9.2

Treatment	**T1**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**
	8.2	9.9	11.7	8.4	10.4	6.4	5.8
Treatment	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
	8.1	8.0	10.4	13.6	10.9	12.8	6.8
Treatment	**T9**						
	7.2						

Standard Errors of Differences of Means

Table	**Treatment**
REP.	3
D.F.	28
S.E.D.	0.4487

Least Significant Differences of Means (5% level)

Table	**Treatment**
REP.	3
D.F.	28
L.S.D.	0.9192

All pairwise comparisons are tested.
Variance = 0.3020 with 28 degrees of freedom

Duncan's Multiple Range Test (DMRT)
Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267
6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411
13	0.5404	2.420
14	0.5133	2.427
15	0.4877	2.434

Identifier	**Mean**						
T5	13.6	a					
T7	12.8	a					
T11	11.7		b				
T6	10.9		b	c			
T13	10.4			c			
T4	10.4			c			
T10	9.9			c			
T12	8.4				d		
T1	8.2				d	e	
T2	8.1				d	e	
T3	8.0				d	e	
T9	7.2					e	f
T8	6.8						f
T14	6.4						f g
T15	5.8						g

Pod Circumference
Analysis of Variance

Variate: Pod Circumference (cm)

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	18.9486	9.4743	26.75	
Treatment	14	198.1098	14.1507	39.95	<.001
Residual	28	9.9186	0.3542		
Total	44	226.9770			

Tables of Means

Variate: Pod Circumference (cm)

Grand Mean: 9.3

Treatment	**T1**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**
	8.2	10.2	11.3	10.6	9.6	6.3	6.0
Treatment	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
	7.5	7.4	11.4	12.3	9.8	12.8	8.4
Treatment	**T9**						
	7.1						

Standard Errors of Differences of Means

Table	**Treatment**
REP.	3
D.F.	28
S.E.D.	0.486

Least Significant Differences of Means (5% level)

Table	**Treatment**
REP.	3
D.F.	28
L.S.D.	0.995

All pairwise comparisons are tested.
Variance = 0.3542 with 28 degrees of freedom

Duncan's Multiple Range Test (DMRT)

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267
6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411
13	0.5404	2.420
14	0.5133	2.427
15	0.4877	2.434

Identifier	**Mean**							
T7	12.8	a						
T5	12.3	a	b					
T4	11.4		b	c				
T11	11.3		b	c				
T12	10.6			c	d			
T10	10.2				d			
T6	9.8				d			
T13	9.6				d			
T8	8.4					e		
T1	8.2					e	f	
T2	7.5					e	f	
T3	7.4					e	f	
T9	7.1						f	g
T14	6.3							g h
T15	6.0							h

Root Length
Analysis of Variance

Variate: Root Length (cm)

Source of Variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block	2	214.121	107.061	11.94	
Treatment	14	2107.891	150.564	16.79	<.001
Residual	28	251.088	8.967		
Total	44	2573.100			

Tables of Means

Variate: Root Length (cm)

Grand Mean: 30.2

Treatment	**T1**	**T10**	**T11**	**T12**	**T13**	**T14**	**T15**
	23.9	25.2	26.6	31.9	36.2	40.8	47.4
Treatment	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
	24.0	30.3	21.1	24.4	26.8	30.1	30.9
Treatment	**T9**						
	33.4						

Standard Errors of Differences of Means

Table	**Treatment**
REP.	3
D.F.	28
S.E.D.	2.445

Least Significant Differences of Means (5% level)

Table	**Treatment**
REP.	3
D.F.	28
L.S.D.	5.008

All pairwise comparisons are tested.
Variance = 8.9674 with 28 degrees of freedom

Duncan's Multiple Range Test (DMRT)

Experimentwise error rate = 0.0500
Comparisonwise error rates

2	0.9500	2.048
3	0.9025	2.152
4	0.8574	2.219
5	0.8145	2.267
6	0.7738	2.303
7	0.7351	2.331
8	0.6983	2.354
9	0.6634	2.372
10	0.6302	2.387
11	0.5987	2.400
12	0.5688	2.411
13	0.5404	2.420
14	0.5133	2.427
15	0.4877	2.434

Identifier	**Mean**	
T15	47.4	a
T14	40.8	b
T13	36.2	b c
T9	33.4	c d
T12	31.9	c d e
T8	30.9	c d e
T3	30.3	d e f
T7	30.1	d e f
T6	26.8	e f g
T11	26.6	e f g h
T10	25.2	f g h
T5	24.4	g h
T2	24.0	g h
T1	23.9	g h
T4	21.1	h