CORN PERFORMANCE IN RELATION TO RESIDUAL MOISTURE AND WATER TABLE FLUCTUATIONS AT LANDZUN INLAND VALLEY, BIDA, NIGERIA.

BY

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A THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING, SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY, FEDERAL UNIVERSITY OF TECHNOLOGY MINNA, NIGER STATE, NIGERIA. IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTERS OF ENGINEERING DEGREE (M. ENG.) IN AGRICULTURAL ENGINEERING (SOIL AND WATER OPTION).

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DECLARATION

I, Mohammed Musa (M. ENG/SEET/2001/851), declare that this thesis titled "Corn Performance in Relation To Residual Moisture and Water Table Fluctuations at Landzun Inland Valley, Bida, Nigeria", presented for the award of Masters of Engineering in Agricultural Engineering (Soil and Water option) has not been presented for any other degree elsewhere.

....
Mohammed Musa DATE

15/06/2005

CERTIFICATION

This thesis titled "Corn Performance in Relation to Residual Moisture and Water Table Fluctuations at Landzun Inland Valley, Bida, Nigeria". By Mohammed Musa (M.ENG/SEET/2001/851) meets the regulations governing the award of the degree of masters in Engineering (M.ENG.) of the Federal University of Technology, Minna, and is approved for its contribution to scientific knowledge and literary presentation.

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ABSTRACT

Crops growth and yield are affected by fluctuations in the water table and soil moisture. A better understanding of their response is required in order to optimize irrigation, drainage and crop yield. Performance of maize crop in an inland valley under different water table depth range (40 to ≤ 110cm and > 110 to ≤ 250cm) during dry season was investigated. Sources of water to meet the water requirement of the crop were the residual soil moisture at valley bottom and surface watering for crops used as control at valley top. Corn yield was highest (2831.3kg/ha) under water table depth range of 110 to ≤160 cm at water use efficiency of 6.17kg /ha/mm; for the crops under surface watering. The 40 to ≤ 110cm water table depth range depressed yield, with the least yield (1762.5 kg/ha) obtained in plots within water table depth range of 40 to ≤ 60cm. However, a higher Benefit / Cost ratio (1.93) was obtained at the 40 to ≤ 110cm water table depth range; which implies the better performance in cost recovery. Comparative analysis between the corn yield estimated by an agrometeorological (AGROMET) model and that recorded at the inland valley were performed using the Least Significant Difference (LSD) Test. The model gave a satisfactory estimate of corn yield in one plot and over-estimated yield in most of the plots investigated. Further investigation is required in order to determine the cause for these differences. The results indicate that residual soil moisture cropping can be a viable alternative to maize cultivation under rainfed and irrigation practices.

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CHAPTER ONE

1.0. INTRODUCTION

The traditional shifting cultivation in which bush fallow is relied on for the restoration of soil fertility has gradually become inappropriate due to the rapid increase in human population resulting in increased pressure on the land. Consequently, the fallow period has shortened thus severely limiting fertility restoration, which has resulted in low crop yields. In addition to low crop yields, there is also rapid deforestation and its attendant consequences. A major challenge, therefore, is adopting the agricultural production systems, which maintain soil fertility, enhance biological diversity and conserve the environment. It is becoming apparent that intensification of production is inevitable. For Nigeria, this poses a great challenge in the face of very limited inputs and appropriate machinery.

Jalloh (2003) found that one possible option for ensuring increased food crop production to feed the growing population in Africa is to intensify crop production in those ecosystems like the Inland Valley Swamp Ecology (IVE) that lend themselves to sustainable intensification while decreasing the intensity of production in the more fragile ecologies particularly the uplands. Inland valleys are located upstream from the flood plains of river basins. Flooding during the rainy seasons ensures adequate water for growing crops while residual moisture together with easy access through shallow wells to the water table during the dry season ensures year round cultivation. There is increasing cultivation of traditional upland crops (e.g. maize), which do not tolerate flooding in the inland valleys during the dry season when the water table recedes below soil surface (Tulu, 2002).

From time immemorial, man has learnt to modify his behaviour depending on the presence or absence of water and has been forced to accept schedules and timetables determined by climatic and geographical factors, which are beyond his control. At the same time, however, man has always tried to tame the water within his reach. Throughout the world, water management is a basic human activity through the control of runoff, flooding and spate flow, the storing of small or large quantities of water, crop irrigation and swamp drainage. Mohammed (2003) reported that managing water is part of national economies of most countries because of its many purposes; the improvement of agriculture and livestock, the reduction of ecological and human (drought and flooding, for instance), and all the activities of enterprises charged with water development projects.

Water is a key life- supporting resource, its scarcity both in terms of quantity and quality can have far-reaching implications. The paramount influence of water in agriculture in general and crop production in particular is fairly well established. Water in fact appears to be the most important natural limiting factor in world food production. It is evident therefore that water as an environment variable has received and will continue to receive major attention in the global need to increase food production. Water availability depends on water balance, a difference between intake and outflow for much of agriculture, these imply rainfall and evapotranspiration. Although humid regions by definition receive rainfall in excess of evapotranspiration, short – term variations in its distribution result in periods of negative water balance and moisture stress on crops during the growing season. These periods vary in length and frequency according to sub region or zone (Critchley et al., 1994). Therefore a good knowledge of the water use by crops in this area is required for better planning of the cropping cycles to reduce the risk of crop failure and to increase production.

Food production per capita in Nigeria has decreased drastically in the past decade, where as the country population has increased significantly in the same period.

In the face of growing population pressures and land degradation, valley-bottom cultivation has come to play an increasing crucial role in local food security. For smallholder valley-bottom farmers, improved water abstraction and conveyance systems are the key to their agricultural production, especially in drought prone areas where the limiting factor is water and not land. Research information by Veit et al. (1995) showed that Africa has 23 per cent of the world's land, but only less than 25 per cent of the arable land is cultivated. The valley- bottom cultivation is an essentially dry season activity, contrasted with upland dry and wet season's cultivation with which it is closely linked. However, it does not receive the attention it merits owing to the dominant perception among outsiders that it is a side-line informal agricultural activity. Fisher et al. (1999) discovered that management systems that use sub irrigation or controlled water tables throughout the growing season could increase and stabilize crop yields.

The performance of a crop is the integrated result of a number of physiological processes, and thus requires different soil water regimes for optimum production. Several investigators have measured the use of shallow ground water by agricultural crops, under both irrigated and dry land conditions. Ground water use, as a percentage of total water use by a crop can be affected by water table depth, soil type, climate, and the quantity of the ground water. Variations in crops, soils, depth and fluctuations of water tables, climate, and irrigation make it difficult to extend and generalize the results. Egharevba and Mudiare (1999) reported that successful use of shallow water depends on several factors, including water table depth, the water retaining and transmitting properties of the soil, evaporation demand and the distribution of plant root system.

One of the greatest challenges we will undoubtedly face in the coming century is developing innovative strategies for water resources development and management. Water resources has become one of the most important issues in the world as it influences human development through the occurrence of extreme events such as flooding on one hand and the sustenance of agricultural production on the other. The slowdown in irrigation growth and mounting environmental damage from irrigation and the prospect of climate change all combine severely to constrain future use of limited water resources for agricultural production. Together these trends point to the need for a much more creative, innovative, and diverse approach to watering crops. Katerere (1999) observed that future water resources management will require re-orientation from managing water as an isolated response to food production, to one that treat it as part of a wider vision of economic development.

1.1 Research Objectives.

The objectives of this study are as follows:

(i). To describe the Landzun inland valley soil profile and monitor the ground water table fluctuations.

(ii). To investigate corn yield response to water table depths and residual soil moisture.

(iii). Determination of the relationship between crop evapotranspiration rate and corn yields under fluctuating water table conditions.

(iv). To compare the economic returns of corn produce under irrigation and residue soil moisture conditions.

1.2 Justification

Water is essential for crop production and best use of available water must be made for efficient crop production and high yields. This requires a proper understanding of the effect of residual moisture, water table depths and / or irrigation on crop growth and yield under different growing conditions. Investigation carried out on aspects of water relations in corn growth and attempts made to understand its response to water table depth through growth, presents a methodology and results that would assist the farmer with:

(i). Assessment of corn yield under different water supply regimes;

(ii). Corn cultivation on residual soil moisture in relation to water table depth;

(iii). Irrigation periods and frequency from seasonal fluctuations of water table, hydraulic conductivity, water holding capacity and soil moisture management for optimum corn production.

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. Soil – Water Relationships

Soil – water relationship relate to the proper ties of soil that affect the movement, retention and use of water (Black, 1997). Soil provides the room for water to be used by plants through the roots present in the same medium. Water as such and as a carrier of large amount of nutrients, is required in a large measure for the successful growth of crops. Water is absorbed by the plant roots, lost by the plant roots, and lost by the leaves during transpiration. Most of the water absorbed is lost through transpiration. It is balanced between water intake and loss, which is important. If there is not much water available for absorption to compensate for transpiration loss, a water deficit develops in the plants.

The availability of water can be considered in terms of the total quantity of water available in the root zone of the crop. When there is rain or when the field is irrigated, the soil is said to be under saturation capacity or maximum water holding capacity. The tension of water at saturation capacity is almost zero and it is equal to free water, soon after rainfall, the drainage of excess water from the soils starts under the constant pull of gravity. After the draining out of the surplus water from the root-zone, the remaining soil water can vary between field capacity and a condition in which it reduced to a microscopic layer around individual soil particles, termed the permanent witting point (Michael, 1995). Both these extreme conditions are unfavorable for plant growth, the former because water – logging and the exclusion of oxygen from the root environment occurs, and the later because water is held too tightly by the soil and the resistance to the movement of water becomes very high. In both these conditions, water is not available to the plants, but between these two points there is a range of conditions in which water becomes available, although the degree of availability varies considerably with crop species.

There is need to manage water better and waste less. Gloomy scenarious about water conflicts have drowned out a lot of positive initiatives, hopeful experiments and sound policy steps. In situations of absolute water, scarcity people have developed their own coping strategies. When water is scarce, the first thing that comes to mind is saving, storing and conserving water and alternative cultivation methods. Spore (2001) reported a rainwater harvesting in Kenya, fog collection in Cape Verde, increasing infiltration by constructing small, lunar – shaped ridges in West Africa, capturing seasonal discharges in small dams in Zimbabwe, receding flood for farming on the banks of the Niger and using waste water for irrigation.

2.2. Plant-Water Relationships.

Corn (*Zea mays L.*) is essentially a worm and humid season crop, though in areas with a mild climate it can be grown throughout the year. Its water requirement varies with the type of soil and the season in which it is grown, but in general, it is about 620mm (Onwueme and Sinha, 1999). In previous experiments, Brouwer and Heibloem (1986) discovered that corn water requirement per growing season ranges between 500 – 800mm. World Bank (1995) reported that in the rainy season, irrigation might be required to meet crop water requirements demand whenever soil moisture falls below the desired level. The early vegetative stage (20-40 days after sowing) and tasselling and silking stages (40-60 days after sowing) have been found to be critical stages in the demand for water. Maize is very sensititive to excess water and waterlogging. The submergence of the soil for 3-5 days during the seedling or flowering periods reduces the yield considerably (Kim et al., 1984).

Dry season farming, is an ancient and widespread practice in northern Nigeria, which is traditionally carried out on the floodplains or 'fadama'. The so-called 'fadama farming' involved small-scale production of vegetables and other crops (tomato, maize, etc). Corn has gained increased importance in recent years as one of the major crop traditionally grown in the low lying 'fadama' areas where water supply to the crop is provided primarily from residual soil moisture, occasionally supplemented with 'shadoof' irrigation. Water management in the smallholdings of the 'fadama' areas relies on residual moisture and irrigation scheduling with decisions largely based on individual farmer's experience. However, Nwadukwe and Abdulmumin (1990) observed that this development has not been matched by research in respects of crops water use under the soil condition of the flood plains. Efficient production of crops has to be based on sound irrigation scheduling practice. This requires a good understanding of the crop response to water under the prevalent soil and climate conditions.

The water requirements and time of maximum demand vary with different crops. Although growing crops are continuously using water, Schwab et al. (1993) reported that the rate of evapotranspiration depends on the kind of crop, the degree of maturity, and the atmospheric conditions, such as radiation, temperature, wind and humidity. Where sufficient water is available, the soil water content should be maintained for optimum growth. The rate of growth at different soil water content varies with different soils and crops. Doorenbos and Kassam (1981) discovered that during the early stages of growth the water needs are generally low but increase rapidly during the maximum growth period to the fruiting stage. During the later stages of maturity water use decreases and irrigation is usually discontinued when the crop are ripening.

To make a maximum use of available water supplies, the irrigator must have knowledge of the total seasonal water requirements of crops and how water varies during the growing season. The seasonal requirement is necessary to select crops and areas that match the available water supply. Knowledge of the variation during the season aids in scheduling irrigation. It should be noted that expected effective rainfall is considered in determining the field irrigation requirement. The duration and length of periods of inadequate precipitation during the growing season in the humid and sub-humid regions largely determine the economic feasibility of irrigation (James, 1988).

Severe water stress at any developmental stages of crops will usually result in some growth reduction. However, certain stages of growth are sensitive to even slight water stresses (Michael, 1995). According to Whittty and Chambliss (2002), knowledge of these particular sensitive growth stages and evapotranspiration rates during these growth periods can be helpful when deciding whether to irrigate or delay irrigation for a few days in anticipation of rainfall. To obtain maximum yields from agronomic crops, plant should remain relatively free from water stress. Although different crops may vary in their response to water deficits, the amount of water used by a crop is closely associated with final vegetative and grain yield.

2.3. Soil Moisture Availability

Water is one of the main requirements for healthy plant growth. Most arid and semi-arid regions, however, suffer from insufficient and unreliable rainfall. In these areas a high rate of evaporation in the growing season is also common (Otterloo, 1997). Water flow within the soil/plant system may be viewed as a single directional flow in which roots absorb moisture from the soil, this water is passes from the roots to the stem and leaves through a series of resistance and then finally evaporates from leaf stomata. The availability of soil moisture to plant is a function of water inputs, moisture retention and rooting depth. Russell (1983) reported that roots are readily able to absorb soil moisture at field capacity, 0.1 – 0.5bar, depending on mineralogy and soil structure, and become less able to do so until 15bar is reached, referred to as the wilting point. The universality of this relationship is challengeable (Sanchez, 1990). At farm level, however, it may be said that unless irrigation is possible, water inputs from rainfall are beyond the control of farmers.

Moisture retention is both an intrinsic property of soils and subject to management. The pores of sandy soils are emptied of gravitational water at 0.1bar, while silicate layered clayey soils retain this moisture until 0.5bar (Sanchez, 1990). Other soils, including most of those in the tropics, fall some where in between. Farmers manage moisture retention in many ways, the most obvious and important one being the reduction of water run-off along the soil surface by terracing, contour ridges and other more elaborate water capture strategies (Woomer and Muchena, 1993). Added benefits to run-off reduction are control of nutrient losses and less soil erodibility. A key to reduced run-off and its subsequent benefits is protection of the soil surface with mulch. Nill and Nill (1993) demonstrated that 60% surface cover of Guinea grass leaves reduced run-off by 60% and controlled soil erosion in southern Cameroon.

The depth of rooting is often an overlooked component of moisture availability and one that need not be universally associated with shallow soils. The ability of plant roots to extract moisture reserves from deeper soil layers may be inhibited by the inability of plant roots to penetrate to that depth by physical and chemical barriers (Sanchez, 1986). Little can be done to improve rooting depth in Leptosols or extremely rocking soils. Hard pan develop in clayey soil immediately beneath the shallow tillage layer due to compaction from mechanical tillage. Yamoah et al. (1990) discovered that acidic sub – soils may limit a rooting system's ability to recover moisture reserves. This is a common limitation in Oxisols and ultisols where moisture in the well – structured surface horizon is depleted but abundant moisture in the acidic subsoil remains un-exploited and moisture stress ensues.

Boyer et al (1990) observed that most of the variability of crop response is related to soil properties that affect water availability. Effective soil rooting depth is one such property. Frye et al (1985) reported higher correlation between corn grain yields and soil depths during years of low rainfall than years with greater rainfall where plant-rooting depth was limited by a hardpan. Since area with deeper soils that facilitate extensive root growth tend to be more productive, it would be useful to have a tool to estimate or quantify the potential productivity due to water availability related to soil depth.

Crop simulation models have become a useful tool to characterized and quantify yield and available water. Paz et al (1998) using a system model showed that yield variability correlated with variability of simulated water stress. Rooting depth and soil water holding capacity were important variables. Soil depth was a important parameter in productivity index model used by Khakural et al (1996) to estimate the spatial variability of crop yields. Berka et al (2003) showed that the agrometeological model (AGROMET) integrated in a Geographical information system (GIS) proved a powerful tool to analyse the effect of both temporal and spatial variability of weather data on saybean yield. According to Timlin et al (2000), many of the models currently applied in precision of agriculture have complex input requirements and may be more detailed than necessary for certain applications. They also require some certain calibration.

Often scarcity of water is the most severe constraint for crop production in arid and semi-arid regions. Surface water is usually not available in amounts sufficient to maintain natural rainfed agriculture. The agricultural production in these regions is widely affected by the sporadic character of rainfalls. Production could be largely increased by a better utilization of water resources. Simple techniques, which do not require heavy investigations or entail high maintenance costs, could bring considerable improvement. A number of studies (Phillips-Howard et al, 1990; Konyha et al., 1992; Ogban and Ibia, 1997; He et al., 2002) have shown that one of such techniques involves crops cultivation on residual moisture. Tauer and Humborg (1992) noted that a rational utilization of water, collected from small watersheds, enables adequate water savings for crop production. Essien (2002) has found that water savings irrigation technology is successful in Enyong Creek catchments. This involves utilization of recessional soil moisture within the moisture recession period to reduce irrigation requirement in the after rains (dry season) farming.

Furthermore Essien (2001) reported that wet season farming in the Eyong Creek swamps is rainfed rice cultivation. This is only in areas developed by the government or riparian farmers in few swamp rice fields. However, after this period, the fields are less utilized in the dry season for farming largely because of the dependence on flooded irrigation. Thus the riparian community remain unoccupied and the field lie waste. To encourage continuos crop productivity alternate dry and wet irrigation is needed to carry on with production (Essien, 2002). The passive drainage in the area allows standing water at the end of the rain to drain by evapotranspiration, percolation and seepage from the field. As the water drains, the topsoil undergoes recessional soil moisture change. But with observed water table being shallow (Hydrotech, 1994) and base-flow being perennial in the main rivers, the recession moisture is gradual (Essien, 1999). Thus, much water could be available in the soil during the long recession period for various crops depending on their water requirements, rooting depths or moisture extraction pattern.

2.4. Valley Bottom Cultivation.

The potentials for development of small-scale valley bottom irrigation systems in Nigeria are tremendous. Over one million hectares of 'fadama' land is estimated to be available for irrigation development (Musa, 2001). These irrigation systems are constructed to divert water from the valley bottom streams and the lowland flood plains with high water table for agricultural production. The technologies favoured for agricultural production in the valley bottom include water lifting from streams or rivers supplemented with washbore or shallow tube wells using small or large pumps or residual moisture. The farmers mostly manage the systems.

These potentials needs to be planned and developed from the point of view of initiating appropriate technology, that are efficient and economical to the farmers while taking advantages of the existing farming methods and institutional arrangement at the farm level. The most important consideration is to ensure a process by which the system could evolve through assisting farmers develop their systems rather than impose foreign culture and systems on them. Unfortunately, many of the early projects missed this important consideration. They were thus developed as an infrastructure rather than a system requiring a number of elements for it to function and deliver the stream of benefits. The input of the beneficiary farmers and the aspects of operation, maintenance and management of the system received inadequate attention. Farmers were seldom consulted and involved in the management.

The cultivation of valley bottomlands in Njombe district is one of the oldest indigenous land- use practices in southern Tanzania. It increasingly has come to play a key role in meeting local household food security. Studies by Lema (1996) revealed that over 90 per cent of households in the district depend on products from valley bottom cultivation and the signs are that there is growing dependence on them. Nevertheless, the positive contributions of this technique are threatened by a number of factors. One of these is degradation of the bottomlands. Dupritz and De Leener (1992) found that cultivation on receding flood is been practiced in Mali when the floodwaters withdraw after a period of flooding. This type of cultivation tries to benefit from the groundwater reserves built up by flooding and is therefore always practiced at the end of the rainy season (Chleq and Dupriez, 1988). Farmers in this area grow crops along the valley bottom. The first plots are on the highest ground and are the first to produced crops, the plants taking up the water stored in the ground. Short life cycles plants are cultivated since the stored water is not replenished.

Phillips-Howard (1996) reports the rapid evolution of small basin agriculture on the Jos Plateau in Northern Nigeria, in response to recent social and economic changes. The technique has created new and profitable opportunities for agricultural production. It enables crops to be produced during the dry season as well during periods of drought in the wet season. Although irrigation has been an important agricultural strategy for many years, the technology and its application have changed dramatically. It is argued here that while the potential to expand small basin agriculture on the plateau is great, the predominant obstacle remain the substantial investment in labour and capital, which are required to exploit it.

2.5 Crop Yield and Water Table Depth.

The relationship between water table depth and crop yield is particularly well documented. Smedema and Rycroft (1988) investigated this relationship for sandy loam and clay soils in experimental fields in which the water table during the growing season was narrowly controlled within a certain depth range below the soil surface. It was discovered that under the variable water table regime that is much more typical of the conditions in a field, crop responses vary with the pattern of the regime. Relationship may also be expected to exist between water table depth and farm operation parameters such as tillage costs, and the number of workable days. Available data generally indicate a continuous improvement with increasing water table depths up to 50 – 100cm for light soils and up to 150 – 200cm for heavy soils (Wesseling, 1984).

In Nigeria, local geology and traditional inefficient surface irrigation practices as well as inadequate drainage facilities, combined to create high water tables under much of the irrigated areas (Egharevba and Mudiare, 2000). Maurya and Sanchan (1985) reported a groundwater survey conducted between 1966 and 1967 in the Kano River Project area, which showed that the water table was below a depth to 1.5m from ground surface during the rainy season, prior to irrigation development. However, a similar study conducted from 1979 to 1984 in the area showed that the water table is between 30 and 40cm below the ground surface at the peak of the rains. This trend severely affected the performance of maize crop during the period. Nwa (1982) has shown that high water table conditions had become a problem in the Kadawa sector of the project within seven years of continuous irrigation. The water table rose to within 80cm below the ground surface in the rainy season and within 40cm of the soil surface during the irrigation period. As a result, crop failures have been reported in the area (Mbajiorgu and Muhammad, 1997).

A lysimeter experiment conducted by Kang et al (2004) to study the impacts of groundwater tables on the capillary contribution, evapotranspiration and crop coefficient of maize and winter wheat growing in a semi – arid region in less loam soils, showed that the rate of capillary contribution from groundwater to crop root zone was influenced mainly by the depth of the water tables. Novek (1993) discovered that shallow groundwater table with depth less than or equal to 1.5m below the soil surface (maize) strongly influence the water regime of soil and plants during dry and average seasons. During the wet year the contribution of shallow groundwater table on the soil water regime were found negligible. Izuno et al (1988) observed that water table depth is one of the most important physical features of a cropped field, and that its measurement is vital for optimum management. Agricultural demand on water and the negative effects of shallow water table on field crops could decrease appreciably through better control of drainage water and permissible water table fluctuations.

In water table management, a target water table level is selected and water is either added to or removed from the field or farm according to whether the existing water table is lower or higher than the target, respectively. The water table depth and the amount it is allowed to deviate from the target level are dependent on soil properties, crop characteristics, pumping capacities, and the level of protection from flood or drought conditions desired by the farmer (Smajstrla et al., 1984). Izuno et al (1988) showed that water table monitoring, and its effective incorporation into a farm water management program, requires that four distinct activities be carried out. First, observation wells must be constructed and installed at strategic locations in the area to be monitored. Second, water levels in the wells must be accurately read and recorded on a regular basis. Third, the resulting data must be analyzed and put into a readily useful form for the front line water managers.

CHAPTER THREE

3.0. MATERIALS AND METHODS

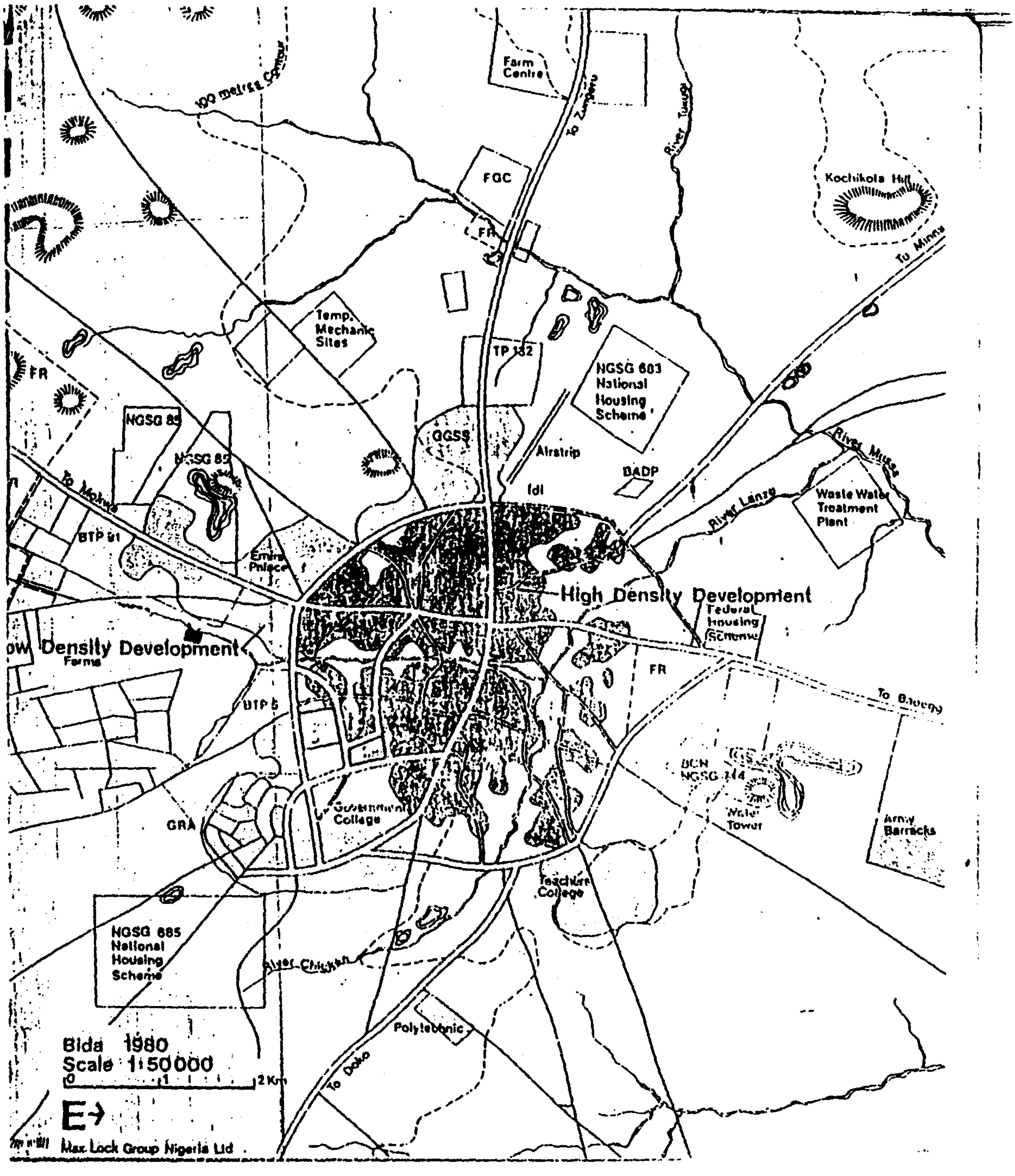
3.1. Study Area.

The experiment was conducted at the Landzun inland valley, Bida, about 87km South of Minna, Niger State, Nigeria. Bida is geographically in the middle belt of Nigeria under Guinea Savannah Zone and lies approximately on latitude 9.05^0 North and longitude 6.07^0 East (Fig.3.1). The area found within the basement complex and Nupe sandstone is low lying with altitude 142 and 150m above sea level (Suleiman, 1998). Rainfall distribution is mononodal, with average amounts varying between 1000 to 1200mm and most of the rain falls in August or September.

Peasant farming dominated this area; scattered holdings with size ranging from 0.5 ha to 1.5 ha are common. The farming is mainly for subsistence, in which case most of the farm produce is consumed locally. Rice is grown on large scale in both wet and dry seasons. Other crops are sugar cane, maize, sweet potato and vegetables (amaranths, tomatoes, pepper and okro).

3.2. Topographic Survey

The field is an area spreading across a valley formation, which is about 155m in breath (plate I). A topographic survey of an integral part of the valley was conducted using a levelling instrument, staff, compass, clinometer and measuring tape following the recommendation of Guijt (1995) and Loedman (2000). The topographic map of the valley showing the experimental plots is shown in Fig.3.2. The slope varies from 2.8 per cent to 3.3 per cent (average 3.03 per cent) at the valley top and 2.3 per cent to 2.65 per cent (average 2.52 per cent), with an average traverse slope of 0.45 per cent.



■ Research Location

Fig. 3.1. Map of Bida showing research location.
Source: Ministry of Lands, Survey and Town Planning Bida. Niger State.

Plate 1: View of the valley formation showing cornfields, 56DAP

ampling

Samples of soil were collected from two experimental plots at the valley top and valley bottom using a 50mm diameter soil sampling auger with 1m long extension rods, to depths of 0 – 30cm for top soil and 30 – 120cm in steps of 30 – 60cm, 60 – 90cm and 90 – 120cm for subsoil analysis. On each plot, soil samples were collected at three points following the procedure described by Singh (1989).

3.4. Particle Size Analysis.

Individual cores were taken at each depth, mixed thoroughly and all foreign matter removed. Riffling was done on samples obtained from each layer using a riffle box so as to obtain a representative samples for the tests.

Samples collected were air-dried and grinded using mortar and rubber pestle. The particle size distribution was analysed using the hydrometer method described by Foth (1990).

51g of the soil sample were soaked for 24hours in 50ml sodium hexametaphosphate solution in order to facilitate dispersion. The mixture was stirred with a glass rod, poured into a 1000ml-measuring cylinder and distilled water added which brought the content to 1000ml mark. The soil suspension was thoroughly resuspended with the help of the stirrer and the time immediately noted. Two hydrometer readings were taken of the soil suspension using a soil hydrometer. A reading taken at 40secs determined the grains of silt and clay remaining in suspension, since sand has settled to the bottom. Another reading taken after three hours gave the grams of clay. The silt content was calculated by the difference. The percent sand, silt and clay were computed and the soil texture determined from a soil textured triangle.

...lk Density

A 5.5cm diameter core sampler was used in the determination of the soil bulk density within the profiles. The computation were carried out using the expression:

$$\text{Bulk density} = \frac{\text{weight of oven dry soil (g)}}{\text{Volume of oven dry soil (cm}^3\text{)}} \quad (1)$$

3.6. Soil Porosity

Soil sample was taken with the 5.5cm diameter metallic core sampler. The core was placed in a bowl of water until saturated and then weighed in a moisture can. The sample was then oven dried to a constant weight at 105^{0}C for 24 hours and then reweighed. The porosity was calculated using equation (2):

$$\text{Total porosity} = \frac{\text{weight of saturated soil} - \text{weight of oven dried soil}}{\text{Volume of core sampler}} \times \frac{100}{1} \quad (2)$$

3.7. Soil Moisture Content

Soil water changes in the profile were monitored in the 0 – 120cm depth in steps of 30cm by gravimetric method, following the procedure of Stolte et al. (1992) and Miles (1998). Soil sample were collected by a 50mm soil auger from soil depths within the experimental site. Sub – samples were placed in moisture can with tight fitting lid. The moist samples were weighed immediately, dried to constant weight in an oven at 105^{0}C for 24hours and reweighed after cooling in a desiccator. Soil moisture content by weight (Mw %) was estimated as follows.

$$\text{Mw (\%)} = \frac{\text{loss in weight on drying}}{\text{Weight of oven dry soil}} \times \frac{100}{1} \quad (3)$$

Capacity

The field capacity was determined by the method of Michael (1995), which involves ponding a plot of land $2m^2$ with water and mulching it to prevent evaporation. Soil samples were taken from the soil after one day at various depths 0 – 30cm to determine moisture content gravimetrically. The values were converted to depth (d) units using the expression given in equation (4) (Hansen et al., 1980):

$$d = \frac{P_w \times As \times D}{100} \qquad (4)$$

where, d is the depth of moisture in cm, P_w is the available soil moisture in percent, As is the apparent specific gravity of the soil, and D is the soil depth in cm.

3.9. Infiltration Rate.

The infiltration rate was measured using the double ring infiltrometer with diameters of 300mm and 600mm for the inner and outer cylinders respectively. The method followed the works of Jury et al. (1991) and Michael (1995).

The two cylinders were installed with minimum soil disturbance inside the inner cylinder. Water was added to the outer cylinder first and then to the inner cylinder. The depth of water in the inner cylinder was read at 1, 2, 5, 10, 15, 20, 25, 30 minutes and thereafter at 15minutes interval. The measurement was continued for three and half hours. During the test, water in the cylinder was topped to maintain water depth at 5cm for the inner cylinder and 8cm for the outer cylinder. From the measurements taken, a table of cumulative infiltration and infiltration rate against elapsed time was complied.

3.10. Hydraulic Conductivity

The hydraulic conductivity of plots at the valley top and bottom were determined, using the inverse auger hole and auger hole methods respectively: following the procedure described by Smedema and Rycroft (1988).

On a plot at the valley top, an auger hole was made to 90cm depth using a 50mm diameter soil auger. The soil in the vicinity of the auger hole was first saturated with water. There after, the hole was filled up to 50cm level with water and its subsequent rate of fall recorded using an improvised measuring stick as water flows from the hole into the surrounding soil. The hydraulic conductivity was calculated from the expression;

$$K = 1.15r \frac{[\log(ho + r/2) - \log(ht + r/2)]}{t} \qquad (5)$$

where, k is the hydraulic conductivity in $cmsec^{-1}$, r is the radius of the cavity in cm, ho is the initial water level at time t_o in cm and ht is the final water level at time t_n in cm.

At the valley bottom, an auger hole was made to a depth of 125cm with a 50mmdiameter soil auger. A 5cm diameter PVC pipe, randomly perforated to a depth of 100cm was inserted in the hole as a filter casing and to prevent caving-in of the hole. The water level was then allowed to rise in the hole and later lowered after 15 minutes by pumping with a centrifugal (8.5m suction head) pump. A detailed record of the rising water level in the hole was maintained over a period of 240secs, at 30secs interval.

3.11. Evapotranspiration

The potential evapotranspiration was obtained from Blaney – Morin – Nigeria formula developed by Duru (1984).

$$Et_p = \frac{r_f (0.45T + 8)(520 - R^{1.31})}{100} \qquad (6)$$

where, Et_p (Eto) is potential evapotranspiration in mm day $^{-1}$, r_f is radiation factor, T is air temperature in °C and R is relative humidity in percent. The Et_p at various months of the year were calculated using the 2003 climatic data for Bida, Nigeria (Table 3.1). The r_f for each month was obtained from Doorenbos and Pruitt (1984).

Table 3.1 Climatic data for Landzun inland valley, Bida (2003).

Month	Rainfall (mm)	Temperature (°c)	Relative humidity(%)	Radiation Ratios
January	0.0	26.0	51	0.0768
February	0.0	29.0	58	0.0748
March	0.0	31.0	50	0.0881
April	20.2	31.5	69	0.0875
May	210.1	30.0	73	0.0896
June	169.4	27.5	84	0.0854
July	238.4	27.0	86	0.0885
August	151.7	26.5	89	0.0894
September	162.8	26.9	87	0.0856
October	72.9	28.0	82	0.0842
November	36.0	27.5	75	0.0757
December	0.0	24.5	57	0.0744

Source: NCRI Metrological Station, Badeggi, Niger State.

3.12. Net Irrigation Requirement

The net irrigation requirement (NIR) is the depth of irrigation water, exclusive of rainfall, carry over soil moisture or groundwater contribution or other gains in soil moisture, that is required consumptively for crop production (Michael, 1995). The NIR was computed as follows;

NIR = Field capacity – moisture content (at the time of irrigation) (7)

3.13. Irrigation Frequency

Irrigation frequency refers to the number of days between irrigation during periods without rainfall. Frequency of irrigation was estimated from equation (8), (Michael, 1995).

...cy of irrigation = $\frac{NIR}{\text{Peak moisture use rate}}$ (8)

3.14. Crop Coefficient

The effect of crop coefficient characteristics on crop water requirements is given by the crop coefficient (kc), which presents the relationship between potential evapotranspiration and crop evapotranspiration (Etc).

Corn (Jo – 195) was planted in November 2003. Its development stages are initial (15 days), crop development (30 days), mid - season (35days) and late season (20 days). Adopting the standard procedure outlined by Doorenbos and Pruitt (1984), the average kc values for the initial, mid season and late season stages were obtained. The kc for growth stage 1 was estimated with the following equation (James, 1988);

$$Kc = a\ ETo^{b} \qquad (9)$$

.where, kc is the crop coefficient for growth stage 1, ETo is average crop Et during growth stage 1, a and b, are coefficient and exponent respectively, which depend on frequency of irrigation. The kc value was obtained from the plotted graph for each selected period at mid point of 10 days period. The kc values were used to plot the crop coefficient curve (Fig. 3.3).

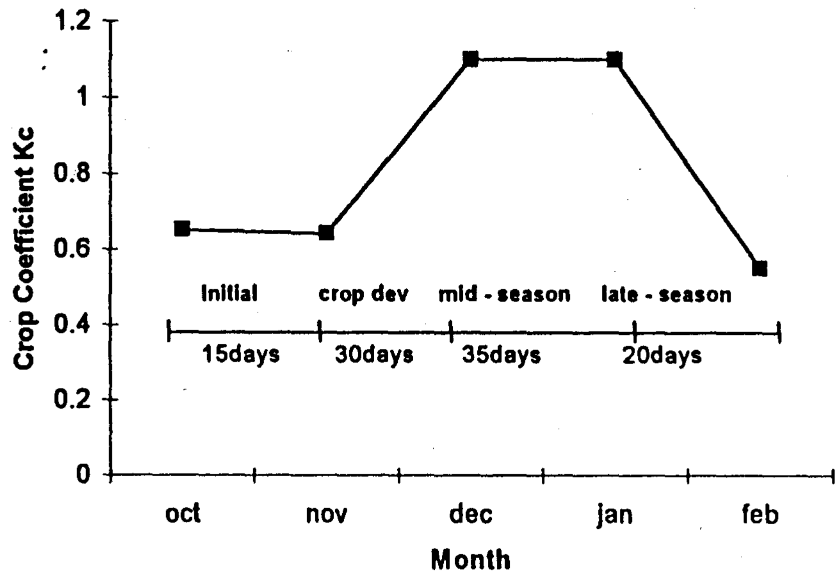


Fig. 3.3: Crop coefficient curve for corn.

3.15. Crop Evapotranspiration

The crop evapotranspiration (Etc) was evaluated using equation (10):

$$Etc = kc \times Eto \qquad (10)$$

where, Eto is the average potential Et in mm day^{-1} and kc is the average crop coefficient.

3.16. Crop Water Requirements.

The crop water requirement is the total amount of water that must be supplied over a growing season to a crop that is not limited by water, fertilizer, salinity, or disease (Schwab et al., 1993). The water requirement for corn was estimated from the simplified water balance equation;

$$IR = \frac{kc \times Eto}{Ea} = \frac{Etc}{Ea} \qquad (11)$$

where, IR is the crop water requirement in mm and Ea is water application efficiency in %.

Evaluation of Water Quality

Water samples were collected in November 2003, from three different locations along Landzun river (upstream (U), center stream (C) and downstream (D)) in three 2.25 liters plastic bottles after rinsing the bottles with the water being sampled. Each point was separated 1km apart. The bottles were securely corked, transferred promptly to the laboratory and store in a refrigerator, at a temperature of 5°C until after all the planned experiments.

The water samples were analysed at the Soil and Water, Science Technology Laboratories, Federal Polytechnic, Bida. The cation concentrations were determined using the Shimadzu Spectrophotometer (Model UV – 120 – 01). Appropriate standards covering the expected ranges of concentrations, were prepared from standard stock solutions and the concentrations of the chosen elements were measured, using appropriate wavelengths. The concentrations of anions were determined by titration. The pH, electrical conductivity (EC) and total dissolved solid (TDS) were measured using pH meter (kent Eil 7045) and conductometer (Model E587) respectively.

3.18. Uniformity of Water Application.

On a 10m long bed, 10cm diameter and 8cm high open cans were placed at 30cm intervals along the bed. A 20 litres capacity watering can having 4mm diameter holes, $8.33 \times 10^{-5}\ m^3\ sec^{-1}$ application rate; held at 0.5m above the ground was used to apply water along the bed. Field observations of depth of water caught in these cans were used to compute the uniformity coefficient using the method suggested by Michael (1995) as given in equation (12):

$$Cu = 100\ (1.0 - \Sigma\ x/mn) \qquad (12)$$

e, m is the average value of all observations (average application rate) in mm, n is the total number of observation points and x is numerical deviation from application rate.

3.19. Source and Method of Irrigation.

Irrigation water was transported manually in two 20litres watering cans from river Landzun to the plot on the valley top 124m away. The distance there and back is 248m with an average time between two applications of 6.8minutes, including an hourly rest period.

3.20. Time Required for Irrigation

The time required for irrigation was evaluated from equation (13).

$$\text{Time} = \frac{GIR}{\text{Average infiltration rate}} \qquad (13)$$

where, time is in hours, GIR is the gross irrigation requirement in mm and average infiltration rate is in $cmhr^{-1}$.

3.21. Water Use Efficiency

The water utilization by crop is generally described in terms of water use efficiency (WUE). The WUE was estimated following the works of Michael (1995).

$$WUE = \frac{Y}{WR} \qquad (14)$$

where, WUE is the water use efficiency in kg ha^{-1} mm^{-1}, Y is crop yield in $kgha^{-1}$ and WR is the total amount of water used in the field in mm.

Field Water Balance.

Field water balance is a computation of gains and losses of water to and from an agro – ecosystem for a specified soil depth and over a time interval, which could be a few days, a week, a month, duration of a crop or a year. In its simplest form, the water balance states that in a given volume of soil, the difference in the amount of water added, (Win) and the amount of water withdrawn, (Wout) during a certain period is equal to the change in water content, (ΔS) during the same period.:

$$Win - Wout = \Delta S \quad (15)$$

In this study, a water balance equation of the form (equation 16) was used (Aneke, 1988).

$$I = Q \pm \Delta S + Et + L \quad (16)$$

where, I is irrigation in mm, Q is run off in mm, □S is change in soil moisture storage in mm, Et is evapotranspiration in mm and L is deep percolation losses in mm. The L was evaluated following the works of Michael (1995) and Aneke (1988); which assumed losses to be a function of irrigation (equation 17);

$$L = x\,I \quad (17)$$

where, x is a factor of irrigation given as 20 percent of the total amount of water applied. L was calculated on monthly basis for the corresponding irrigation for the study period.

3.23. Experimental Design

The experiment was conducted in the dry season between November 2003 and February 2004. A split-plot in randomized complete block design was used to make a total of 12 flat beds, four beds per sub-plot on the valley top (VT); and 36 flat beds, 12 beds per sub-plot on the valley bottom (VB). The data collected include crop gence, plant height, leaf area, grain yield and water table depth. The data were subjected to analysis of variance for test of significance as described by Gomez and Gomez (1984). The treatment means were compared using least significant difference (LSD) at $p = 0.05$ and 0.01.

3.24. Experimental Procedure.

A plot each was obtained at the VT and VB. The plots were prepared manually with traditional hoes, marked and divided into sub-plots on which flat beds were made. At the VT, the plot was divided into three sub-plots along the slope. Each sub-plot in the layout consisted of four beds of corn (10m x 0.85m and raised to 0.4m heights). The beds and the sub-plots were separated by 0.3m and 1.0m alleys respectively. Similarly plot on the VB was divided into three sub-plots across the slope; each contained 12 flat beds (3.0m x 0.85m and raised to 0.5m heights). The beds were demarcated by 0.4m space, whereas, the sub-plots were separated by 0.5m alleys. These arrangements gave a gross area of $150m^2$ per plot and net areas of $103m^2$ and $95.4m^2$ at VT and VB respectively.

3.25. Cultural Operations.

Corn seeds (JO – 195) which are an early – maturing variety (100days) were planted (after dressing with APRON STAR) at 30cm x 90cm spacing, 3cm depth and three seeds per hole. These were later thinned, down to two seeds per hole, 14 days after planting (DAP); leaving about 37,835 plants per hectare at the VT and 36, 805 plants per hectare at the VB. Compound fertilizer (NPK 15: 15: 15) was applied at a rate of 250kg per hectare in two equal split dosages, at 7DAP and 28DAP using band method at 5cm depth and 10cm from the base of the plant stand. The experimental area was relatively weed – free throughout the experiment. This was done three times at three weekly intervals from three weeks after planting (WAP).

3.26. Measurement of Crop Performance.

Crop germination and emergence was measured by counting at 7DAP and 14DAP. This was done by counting the number of crops that emerged on each plot, divided by the total number of crops planted per plot. Measurement of plant height and leaf area was carried out at two weeks intervals. The height of plant was measured from the soil surface to the tip of plant. Ten plants per plot were sampled for height measurement and the average represented the plant height for each plot. The shape of each leaf was carefully traced on a cardboard paper and the area was determined with ALLBRIT zero – setting compensating planimeter. The average value represents the leaf area for each plot.

3.27. Harvesting

Corn was harvested at 108 DAP by handpicking. The husks were removed and shelled using a hand maize Sheller. Grains moisture content at harvest and after air – drying were measured using OGA digital grain moisture meter (model TD –5).

3.28 Evapotranspiration and Corn yield Relationship

The relationship between evapotranspiration (ET) and crop yield is an object of scientific research. A generalized agrometeorological model (AGROMET) was used to relate crop yield to ET at the inland valley. Yield estimate by the model (AGROMET) was based on the following equation (Doorenbos and Kassam, 1981):

$$Y_e = Y_m \left[1 - ky \left(1 - \frac{ETa}{ET_m}\right)\right] \qquad (18)$$

e, Ye is estimated yield in kg/ha, Y_m is the maximum harvested yield in kg/ha, ETa is the actual evapotranspiration in mm/day., ET_m is the maximum ET in mm/day and ky is the yield response factor.

The AGROMET model requires weather, soil and crop data. Weather data include temperature, maximum and actual evapotranspiratrion through out the crop growing season. Soil data required are soil water holding capacities and water table depths. Plant data that the model requires include leaf area, crop growth stages and period, and crop genetic characteristics.

The model application is based on the assumptions that the climatic requirements of the crop are met and that water, nutrients, salinity, pests and diseases do not affect crop growth and potential yield. Under actual farming conditions, yield losses will occur due to adverse climatic conditions over short periods. Limited water and nutrient supply and problematic farm operations including preparation, weeding and harvesting (Doorenbos and Kassan, 1981). These constraints are complex and it is difficult to quantify their effect on yield

Maximum yield (Ym) is established by the genetic characteristics of the crop and by the degree of the crop adaptation to the environment (Doorenbos and Kassan, 1981; Berka et al., 2003). In this work, Y_m was adjusted to the maximum yield average achieved for a healthy crop without water and nutrient deficiencies. Y_m (kg/ha) was estimated by the following restrictions and equations:

If $Y_m > 20$kg/ha/hr, then:

$$Y_m = cL.\ cN.\ cH.\ G\,[\,F\,(0.8 + 0.01y_m)\,y_o + (1- F)(0.5 + 0.025y_m)y_c] \qquad (19)$$

If $Y_m < 20$kg/ha/hr, then:

$$Y_m = cL.\ cN.\ cH.\ G\,[\,F\,(0.5 + 0.025y_m)\,y_o + (1- F)(0.05y_m)y_c] \qquad (20)$$

re cL is the leaf area correction factor, cH is the harvest factor, cN is the net dry matter production factor, G is the total growing period (days), F is the fraction of the day which is cloudy, y_m is the production rate of dry matter for the maize crop (kg/ha/hr); y_o is the production rate of dry matter of a standard crop in completely cloudy days (kg/ha/day), y_c is the production rate of a standard crop in clear days (kg/ha/day).

The maximum evapotranspiration (ET_m) was obtained from Table 4.3. the determination of actual evapotranspiration (ET_a) depends on three factors: the maximum evapotranspiration, the remaining available soil water and the available soil water index (ASI); (Doorenbos and Kassam, 1981). ET_a was determined based on a look-up table given by Doorenbos and Kassam (1981) that considers the three factors mentioned. Finally all necessary variables to estimate crop yield (Y_e) based on equation 18 were obtained. The statistical comparison between the corn yield at the inland valley and that of the AGROMET was performed using Least Significant Difference(LSD) Test (Gomez and Gomez, 1984). Appendix F presents detail computation of the parameters discussed in 3.28.

3.29 Installation of Piezometers.

A 50mm diameter hand driven soil auger with extension rods, each measuring 1m long was used to drill the well to 3m and 1.5m depths at the VT and VB respectively. The piezometric pipes (4.5cm diameter and 150cm length) were perforated radially at 2cm apart across the length of the pipe up to 75cm. This was done to ensure sufficient and effective inflow of groundwater into the pipe to assume its original form and level. The piezometric pipes were centralized and installed along the valley breadth at 5m intervals with their perforated end below the ground surface. The clearance een the well and the pipe was laid with a sleeve of gravel and coarse sand to prevent the perforation from clogging. The top was sealed up using grasses and clay soil. A total of nine piezometers were installed, three on the VT and six on the VB (Fig. 3.4).

3.30 Water tables Measurement

Calibrated dipstick method was used to determine the water level in the peizometer tube (Plate II). The difference between the value obtained from the dipstick measurement and the depth of installed pipe from the ground surface gave the water table depth below the ground surface. Readings were taken at weekly interval for nine months beginning from the month of October 2003 to June 2004.

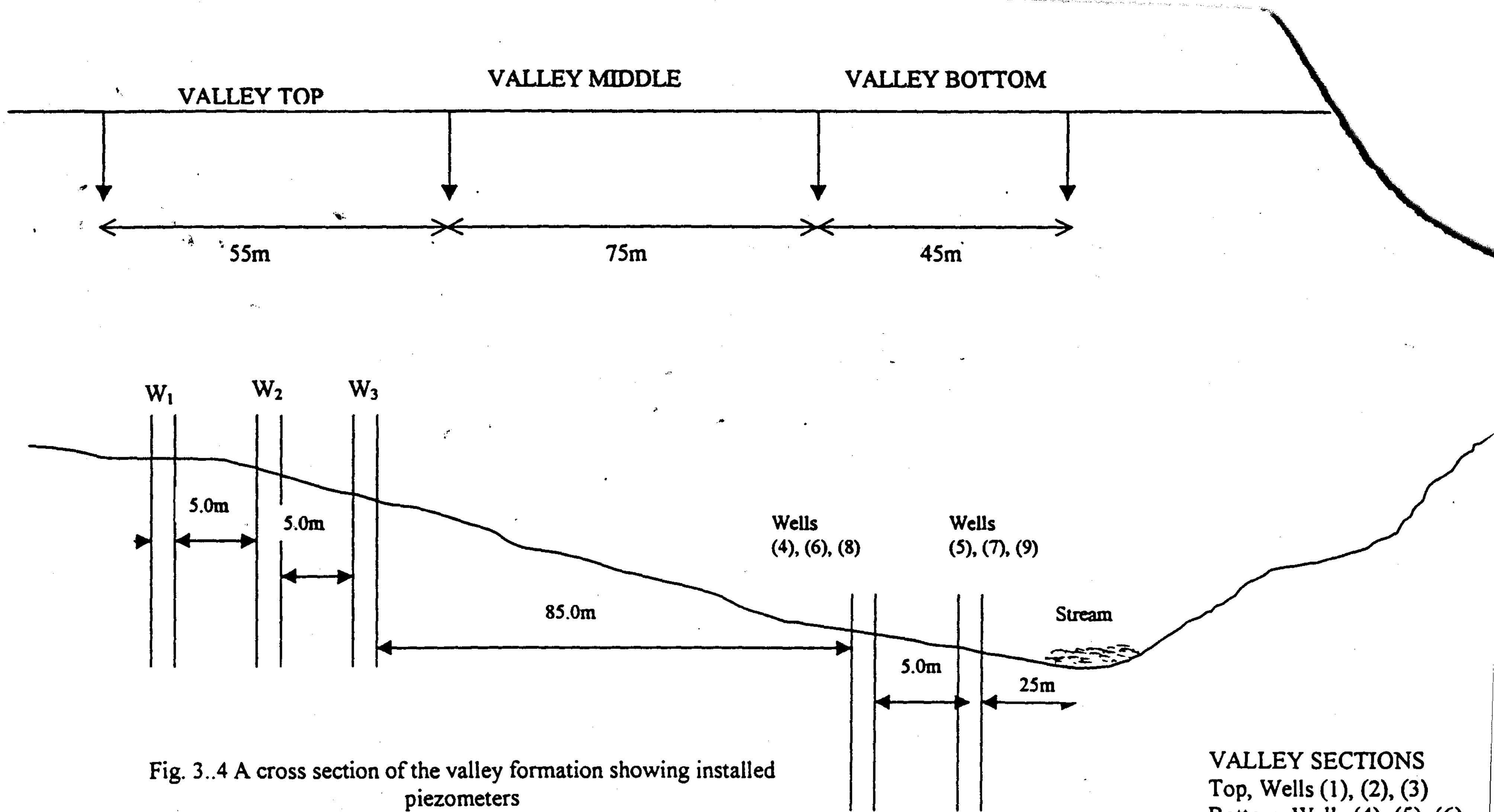


Fig. 3..4 A cross section of the valley formation showing installed piezometers

Plate II. Installed Piezometer: Measurement of water table. 56 DAP

Farm Input Costs

Farm input cost are expenses incurred in the operation. The farm input costs were obtained from the prevailing charges during the study period.

The fixed costs, comprising of mainly cost of watering cans and tools were determined based on depreciation costs. A depreciation rate of 25 per cent was adopted (Sturrock, 1992; Abubakar and Chikwendu, 1995). Fixed costs were incurred by the two treatments (VT and VB), and were considered constant during the analysis. In costing the labour requirement for irrigation, six working hours was taken as 1 man-day, at a prevailing rate of ₦800.00 per man-day. Labour used in operations such as land preparation, seed planting, fertilizer application, weeding, picking, loading and transportation of corn were also costed using the same rate of ₦800.00/ man-day. The costs of materials such as fertilizer, seeds and insecticide were estimated based on cost of the quantity used. The total production cost was then subtracted from the gross income from corn sale to obtain profit for each treatment.

The Benefit-Cost (B/C) indices were used for the data analysis. In computing the net returns from sales of corn for each treatment, payment of taxes and insurance costs were neglected because the farmers do not pay for these charges presently. Gross income from corn sale was based on the prevailing price of ₦31.00 per kg. The Benefit -Cost ratio was computed as:

$$\text{Benefit- Cost ratio} = B/C \qquad (23)$$

where, C is production cost incurred in each treatment to produce corn in ₦ and B is gross income in each treatment from corn sale in ₦. The higher the B/C ratio for a treatment, the better the treatment's performance in cost recovery.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

In discussing the result, the following limitations are firstly enumerated:

1. The condition of the soil varies due to history and cultural practices on the soil.
2. Unavailability of a precision sensor for water level indicator to measure the water table depth below the ground surface.
3. In the infiltrometer test, the time of refilling the inner and outer cylinders after every reading varies about 2 to 3 seconds.
4. For field water balance computation, there was no lysimeter to measure deep percolation losses. Values were estimated based on the method discussed in section 3.22
5. Ideally, Eto of the reference crop should have been experimentally measured with a lysimeter to correlate the values obtained through the Blaney-Morin-Nigeria Method.

4.1 Climate

Average monthly growing season temperatures, relative humidity and rainfall for 2003 during the cropping period are given in Table 3.1. The highest average monthly temperature, relative humidity and rainfall amount are 31.5^{0}C, 89 per cent and 238.4mm respectively.

4.2 Soil Physical Analysis

Soil texture varied from sandy soils at the valley top (VT) to loamy sand of the valley bottom (VB) in the topsoil as well as the sub-soil but with increasing clay down the soil profile to constitute an argillic horizon (Table 4.1). Texturally therefore, the basement complex soils at 60 to 120cm depth, of the plots sampled have adequate clay content particularly in the subsoil for enhanced soil moisture retention and productivity. However, the high percentage sand composition in the top soil (0 – 30cm depth) resulted in poor soil moisture retention capacity (Table 4.1). The result agrees with the findings by Odunze (1990).

Table 4.1 presents the results of the soil bulk densities for inland valley toposequence. The bulk density ranges from 1.480gcm^{-3} to 1.530gcm^{-3} in the topsoils and 1.540 gcm^{-3} to 1.683gcm^{-3} in the sub-soils for both VT and VB.

The mean values of the porosity obtained for plots are given in Table 4.1. The values ranged from 29.80 to 34.56 per cent (average 31.83 per cent) at the VT and 30.53 to 35.62 per cent (average 32.6 per cent) in the VB. It can be observed from the table that as soil depth increased, porosity decreased. This can be attributed to the natural increase in density with depth due to weight.

Table 4.1: Mechanical composition, bulk density, porosity, field capacity, hydraulic conductivity and infiltration rate at Landzun inland valley.

Sample depth (cm)	Zone (cm)	Mechanical composition (%)			Textural class*	Bulk density (gcm^{-3})	Porosity (%)	Field capacity (mm/m)	Hydraulic conductivity (cm/hr)	Infiltration rate (cm/hr)
VALLEY TOP										
15.0	0-30	3.3	2.4	94.3	S	1.530	34.56	34.0**	7.6×10^{-1}**	10.2**
45.0	30-60	6.7	1.2	92.1	S	1.552	32.70			
75.0	60-90	7.5	0.9	91.6	S	1.621	30.25			
105.0	90-120	8.2	1.4	90.4	S	1.650	29.80			
VALLEY BOTTOM										
15.0	0-30	8.0	5.3	86.7	S	1.480	33.35	43.8	6.9×10^{-1}	8.4
45.0	30-6-	10.0	6.7	83.3	LS	1.540	35.62			
75.0	60-90	12.0	8.0	80.0	LS	1.625	30.90			
105.0	90-120	11.7	4.0	84.3	LS	1.683	30.53			

S = Sand, LS = Sandy loam

** = Each data represents mean of three tests.

Residual soil moisture at VB, which was determined on function of weeks after planting, is shown in Fig 4.1. The figure showed that in general, soil moisture decreased with increased WAP. This can be attributed to the effect of surface evaporation, which accelerates the rate of moisture loss to the atmosphere at the soil surface. Furthermore, it can be seen that soil moisture depletion was highest in the surface 0-30cm depth, and occurred in the first two weeks after planting (WAP), while the lowest was obtained in the 12th WAP. Soil moisture decrease persisted over the crop growth period. Whether this decrease causes an internal water deficit to develop in the crop could not be verified. However, yield were generally depressed which could be attributed to the shallow water table since the water requirements of the crop were fully met.

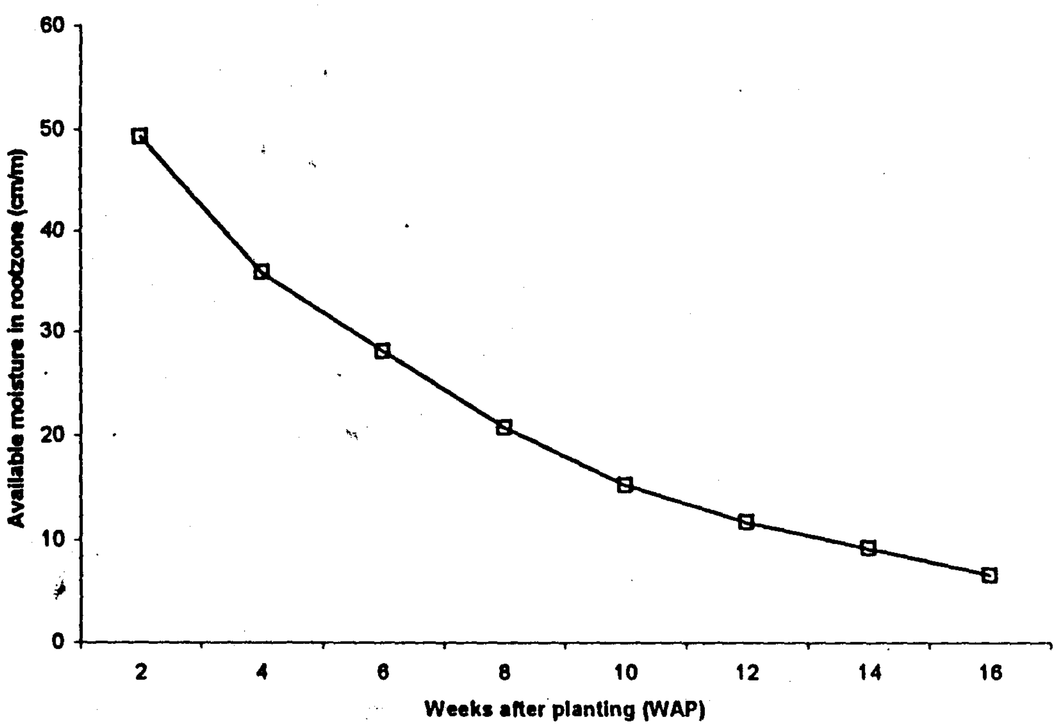


Fig. 4.1 Biweekly residue moisture depletion at valley bottom

The average infiltration rates for VT and VB amounted to 10.2cmhr^{-1} and 8.4cmhr^{-1} respectively (Table 4.1). Figs.4.2 and 4.3 present the plots of accumulated infiltration and average infiltration rate against elapsed time for VT and VB respectively. The average infiltration rate increases with time, while the accumulated infiltration decreases with time.

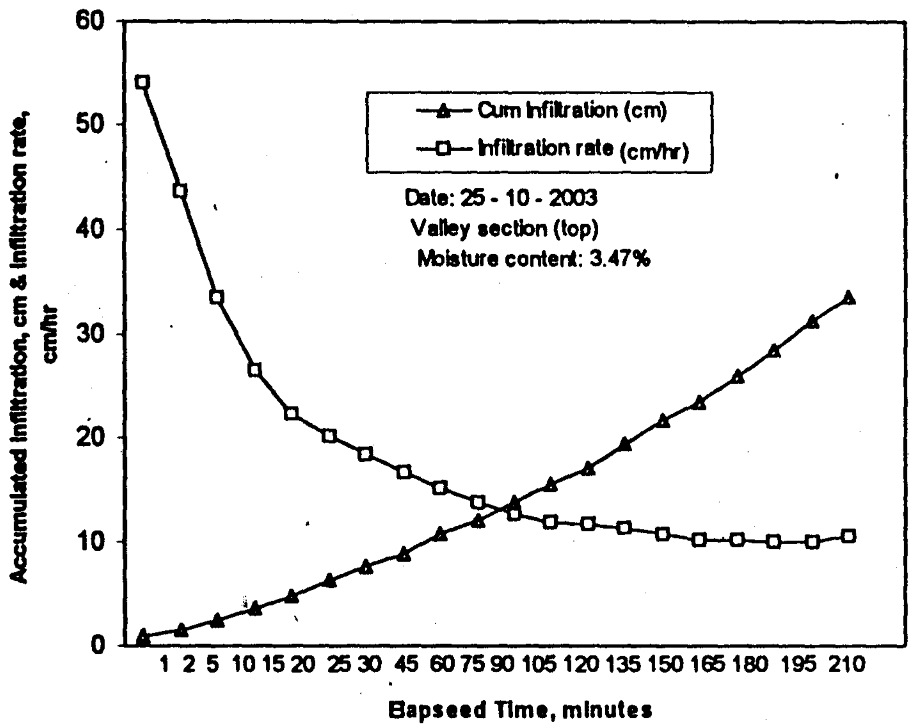


Fig. 4.2 Accumulated infiltration and average infiltration rate against elapsed time.

The mean hydraulic conductivity (k) for the VT and VB were 7.6 x 10^{-1} cmhr^{-1} and 6.9 x 10^{-1} cmhr^{-1} respectively (Table 4.1). The general trend of high k could be attributed to the texture of the soil, which agrees with the observation made by Michael (1995) and Otterloo (1997). These values are adequate and could have aided cropping in this area. Detail computations of the hydraulic conductivity values are given in Appendix D.

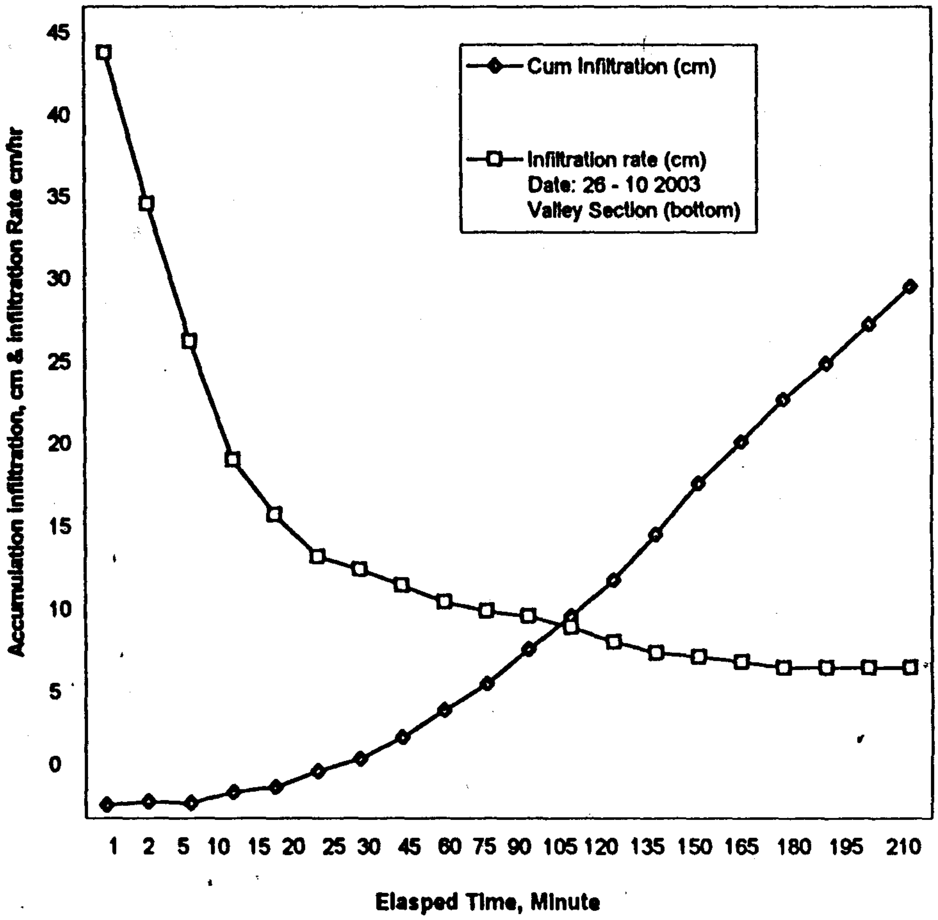


Fig. 4.3 Accumulation Infiltration and average Infiltration rate against elapsed time

4.3 Chemical Analysis of Water Samples.

Table 4.2 presents the results of analysis carried out on the samples. The pH ranges between 6.8 and 7.3 in the inland valley. The values fall within the minimum and maximum values of quality water recommended by WHO (1992). In addition the inland valley pH values were within 5.0-9.0 optimum pH range of working condition for irrigation waters (FAO, 1999).

The values of the three samples for calcium concentration were within the permissible limit of 75-200 mg/l recommended by WHO. The three samples are not

Table 4.2: Results of physico- chemical analysis of water samples.

Chemical/physical Characteristics	Sampling site U	C	D	FAO (1999)	WHO (1992)
PH at 25^{0}C	6.8	7.3	7.1	5.0-9.0	6.3-9.2
Calcium	74.3	83.4	75.8	-	75-200
Magnesium	37.3	40.5	48.2	-	30-150
Sodium	22.1	24.2	31.7	-	200
Potassium	10.3	14.5	17.6	-	20-100
Chloride	32.4	38.3	46.5	250	20-600
Sulphate	25.2	23.9	30.2	500	200-400
Nitrate	10.7	12.3	9.5	15	45
Bicarbonate	76.0	73.9	82.4	-	-
Boron	NIL.	NIL	NIL	0.75	1.0
TDS	145.0	153.4	162.3	-	1000
EC (μS/cm)	207.6	215.5	200.7	2000	-
SAR	0.52	0.54	0.70	< 6	-

All values in mg/l except where stated.

U = Upstream C = Centre stream, D = Down stream, Nil = 0.00 value

FAO = Food and Agricultural Organisation

WHO = World Health Organization recommended values hard because the test for magnesium is within the permissible limit of 30-150 mg/l by WHO. Potassium concentration in all samples is below the WHO standards of 20-100 permissible limits. The sodium concentration is low. The risk of sodium alkalinization as measured by the sodium adsorption ratio SAR is extremely low and far less than the permissible limit given by FAO (1999). Low sodium water can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. The SAR values of the sample points vary from 0.52 to 0.70 with a mean of 0.59 (Table 4.2). The water sample falls within class one rating scale of sodium adsorption ratio range of 0-10mg/l (Hamill and Bell, 1986; Ayers and Westcot, 1994). It implies that samples can be used for irrigation on almost all soils but with a little danger of developing harmful exchangeable sodium.

A toxicity problem occurs when certain constituents in the water are taken up by the crop and their accumulation result in reduced yield (Michael, 1995). This is usually related to one or more specific ions in water, namely, sodium, chloride and Boron. Chloride concentration varies from 32.4 to 46.5 mg/l (Table 4.2). The recommended FAO permissible limit for irrigation is 250 mg/l. Boron was not detected in all the samples tested. Also Nitrates and Bicarbonate concentrations were below the permissible limit (FAO, 1999).

The electrical conductivity (EC) values vary from 200.7 to 215.5 µs/cm, with a mean value of 207.9 µs/cm, which is well below the 2000 µs/cm level for maximum limit for irrigation (FAO, 1999). The concentration of the total dissolved solid (TDS) ranges from 145.0 to 162.3 mg/l, with an average of 153.6 mg/l. The values are low, and thus, the turbidity level, which would have inhibited effective plant growth, and development is low, hence the water quality is classified average. The groundwater quality in the project location had been reported to be good (Mohammed and Osunde, 2001) with no negative effect on the crop performance.

4.4 Evapotranspiration and Crop Water Required

Table 3.1 shows the meteorological parameter values used to compute the Etp for maize for each month. The most important parameters that influence the Etp rate are temperature, radiation factor and crop coefficient. There is a variation in the monthly computed values, with the highest value recorded in January at a ground water table depth range of 50 to 235cm (Table 4.3). The most important factor that is responsible for this variation is the high value of kc , which occurred as a result of high Etc within that period. The Etc of corn throughout the growing season shows a relatively lower value at the beginning of growing stages and increase during the period of rapid growth to a maximum and declining at maturity (Table 4.3). This discovery is in agreement with the findings of Adeogun and Idike (1999).

Table 4.3 Reference evapotranspiration (Eto) and computed parameters for corn during the growing season (November 2003 – February 2004)

Month	Ten–day *periods	Eto (mm/day)	Kc	Etc (mm/day`)	Etc/ (10days)	IR** (mm)
November	1st	4.8	0.64	3.1	31	41.3
	2nd	4.8	0.70	3.4	34	45.3
	3rd	5.2	0.86	4.5	45	60.0
December	4th	5.2	1.02	5.3	53	70.7
	5th	5.2	1.10	5.7	57	76.0
	6th	5.2	1.10	5.7	57	76.0
January	7th	5.3	1.10	5.8	58	77.3
	8th	5.3	1.10	5.8	58	77.3
	9th	5.3	0.82	4.3	43	77.3
February	10th	5.0	0.55	2.3	23	30.7
	Average	5.1	0.90	4.59	Σ459	612 .0

*Length of growing season = 100 days.
** IR = crop water requirement.

4.5 Water-table Depth Effects on Corn Growth and Yield

Table 4.4 shows that crop emergence, height and leaf area are higher at treatment A (Water table depth range of >110 to ≤ 250cm, VT) when compared with treatment B (water table depth range of ≤ 40 to ≤ 110cm, VB) at 14, 28, 42, 56 DAP and maturity. It could be observed that during the early stages of germination, seed emergence was lowest on plots with water table depth range ≤ 40 to ≤ 110cm. This may be as a result of excessive soil water in the root zone resulting from shallow water table. The creation of acidic conditions which tend to be toxic could also be responsible. Statistical analysis showed that water table depths significantly influenced percentage seed emergence at

7DAP and 14 DAP. However, there was no significant difference on plant height and leaf area among treatments (p=0.05) measured at two weeks interval (Table 4.4). The crop under treatment A benefit from adequate surface watering. Plots at 110 to 160cm water table depth produced more leaves and luxuriant growth when compared with plots at 140 to 250cm water table depth. The reason could be a result of non-supply of some of the crop water requirements by the water table in these plots.

The yield for the >160 to ≤ 250cm depth range was lowest when compared to the yield of the water table depth range of >110 to ≤ 160cm. The highest yield (2831.3 $kgha^{-1}$) was obtained at the depth range of 110 to ≤ 160 cm, while that at 140 to 220 cm and 160 to ≤ 250 cm gave 11.0 per cent and 28.8 per cent less yields respectively. Corn yield at treatment B were depressed (average 1817.37 kg/ha), with the least yield recorded at the water table depth range of 40 to 110 cm. The reason for the low yield, could be attributed to the very shallow water table at treatment B that significantly affected crop emergence (Table 4.4). The highest yield (1856.1 $kgha^{-1}$) under treatment B was obtained at water table depth range of 60 to ≤ 110 cm (Table 4.4). Although this is lower than the average hybrid maize yield of 3.8t ha^{-1} recorded by Sasakawa Global (2003), during the wet season in the middle belt region of Nigeria; but is higher than the 1.5t ha^{-1} reported in Africa, CGIR (2004); and 1.2t/ ha for fadama maize yield reported by Graham (2003) in Sokoto State during the 1996/97 cropping season. However, research carried out by Egharevba and Mudiare (2000) at NCRI, Badeggi (inland valley), showed that plot within the range of 0.6 to 1.0m water table dep th resulted in higher yield (2.22 t/ ha) during the dry season under sub-irrigation.

Table 4.4: Mean values of yield indices and grain yield under different water table depth range.

Water table depths range(cm)	Emergence (%) 7*	14	Plant height (cm) 14	28	42	56	M	Leaf area (cm^2) 14	28	42	56	M	Grain Yield (kgha^{-1})	Grain moisture content (%)
VALLEY TOP														
> 110 ≤ 160	92.8	95.7	6.5	44.3	82.5	159.5	194.6	24	220	450	600	840	2831.3	10.7
≤ 140 ≤ 220	91.5	94.8	6.2	41.5	72.0	143.8	184.3	23	198	403	570	755	2521.5	10.5
> 160 ≤ 250	90.1	92.0	5.9	40.3	70.2	138.5	175.6	20	173	320	546	735	2014.7	9.8
VALLEY BOTTOM														
40 ≤ 60	78.4	81.3	5.5	33.4	60.8	135.5	164.2	26	180	380	530	570	1762.5	11.1
> 60 ≤ 110	84.6	87.5	6.9	37.8	69.1	148.5	183.8	18	210	370	518	640	1856.1	11.3
> 60 ≤ 110	80.5	83.4	6.0	34.9	62.5	140.2	168.7	22	205	365	507	595	1833.5	10.9
SE ±	7.49	7.35	0.39	5.08	9.38	9.92	10.53	2.24	21.12	36.43	38.88	41.06		
LSD(0.05)	9.44**	9.57	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		

* Days after planting ; M = Maturing; ** : Significant at 0.05 level; NS = no significant among treatments at 0.05 level

Furthermore, from the analysis of variance, the difference in the yields from plots under surface watering were found to be significant at 1% level of significance (Table 4.5). However, there was no significant difference among the plots under residual moisture (Table 4.6). Also, a comparison between treatment difference showed significant differences (p=0.05) in grain yields between treatment A and B (Table 4.7). Crop in treatment B was able to satisfy its water use requirement from residual soil moisture and groundwater; since there was no rainfall or surface water application.

The plot with water table depth range of 60 to 110 cm (Table 4.5) seems more favourable to the plant and may be considered as optimum ground water depth for the maize crop under residual moisture condition (treatment B). The implication of this is that the water table was effective at 60 to 110 cm range when the bed height of 0.5m is considered. This result is consistent with the findings of Egharevba and Mudiare (2000) as well as Kang et al. (2004).

Table 4.5. Analysis of variance of the effect of water table depths on corn grain yield under surface watering.

Source of variation	Degree of freedom	Sum of squares	Mean squares	Computed F-Ratio
Replication	2	6527.17	3263.58	0.41^{ns}
Treatment	2	1019657.84	509828.92	63.30^{**}
Error	4	32215.63	8053.91	
Total	8	1058400.64		

CV = 3.65%; ns: not significant ; **: significant at 1% level

Table 4.6: Analysis of variance of the effect of water table depths on corn grain yield under residual soil moisture.

Source of variation	Degree of freedom	Sum of squares	Mean squares	Computed F-Ratio
Replication	2	3495.29	1747.65	0.77[ns]
Treatment	2	14312.72	7156.36	3.14[ns]
Error	4	9105.67	2276.42	
Total	8	26913.68		

CV = 2.63%; ns: not significant at 5% level

Table 4.7: Comparison between mean yields of corn under surface watering and residual moisture at different water table depth range using LSD Test.

Treatment[a] number	Mean yields[b] (kg/ha)	Difference (kg/ha)	LSD values 5%	1%
1	2831.3			
2	2521.5			
3	2014.7			
4	1762.5	1068.8**	129.6	184.3
5	1856.1			
6	1833.5			

a = water table depths range (Table 4.4)

b = mean of three replication **: significant at 1% level

The plots of the weekly water table measurements for all wells are shown in Fig 4.4. Two distinct sections can be identified, VT and VB. Wells (1), (2) and (3) fluctuates within the depth of 100 to 270cm, while fluctuations in wells (4), (5), (6), (7), (8) and (9) was within 40 to 110cm during the cropping period (November, 2003 to February, 2004). These values showed that water table fluctuations at VT are below the reach of shallow rooted crops, while it is within their reach at the VB. However, at the onset of rains, towards the end of April, a steady rise in the water table was observed, until they hit their peak in the month of June (Fig.4.4).

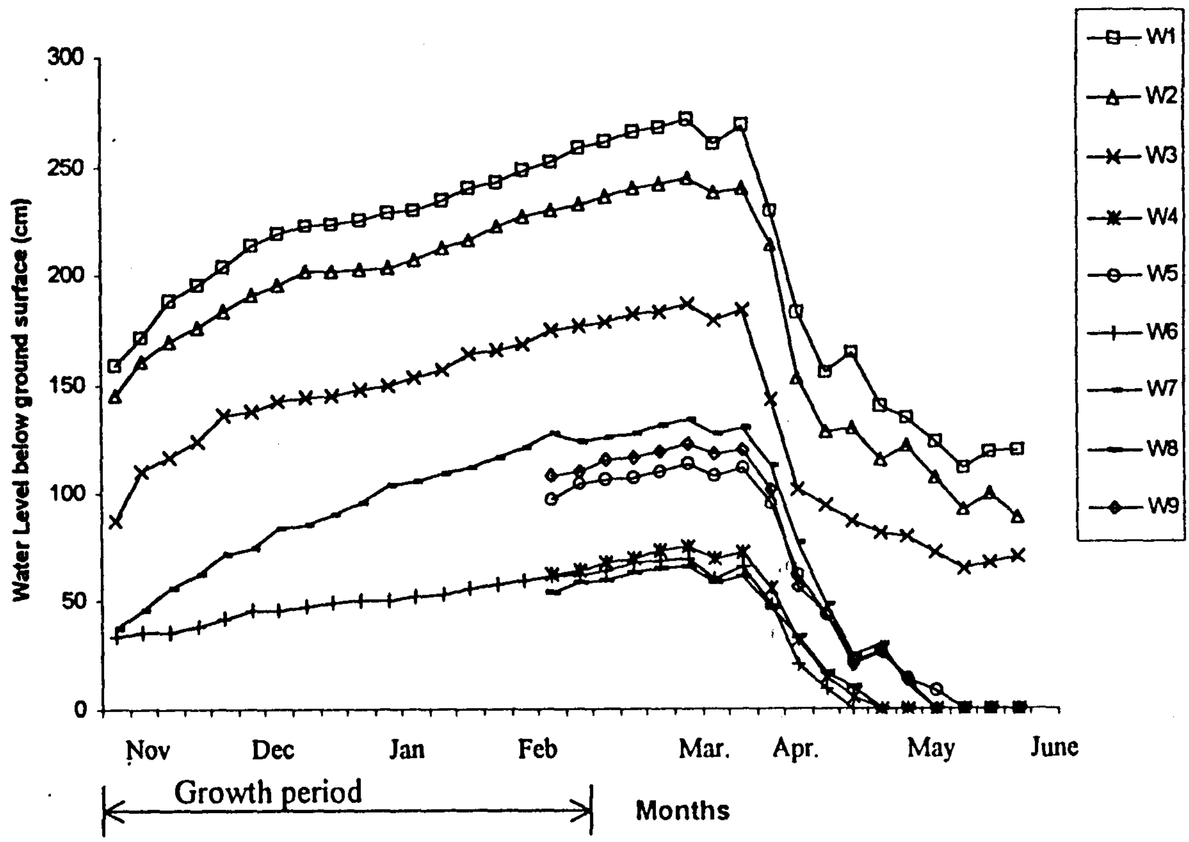


Fig. 4.4. Plots of weekly water table measurements

4.6 Corn water use and Water use Efficiency

The cumulative water used during the corn-growing season is outlined in Table 4.8. All plots in treatment A received the same amount of water (459mm per plot). The relationship between corn water use and time is shown in Fig.4.5. The graph shows that water use increased from 3.1mm day^{-1} at the early vegetative stage to a maximum of 5.8mm day^{-1} at 8 WAP. Thereafter, the water use dropped to 2.3mm day^{-1} at maturity. This agrees with the work of Igbadun and Mudiare (1998).

Table. 4.8. Total water applied, corn yield, crop water use and WUE

Water table depths range (cm)	Total water applied (mm)	Yield (kg ha^{-1})	Crop water use (mm)	WUE* ($kgha^{-1}mm^{-1}$)
≤ 110 ≤ 160	612	2831.3	459	6.17
≤ 140 ≤ 220	612	2521.5	459	5.50
≤ 160 ≤ 250	612	2014.7	459	4.38

*WUE = Water use efficiency.

The water use efficiency, which is the ratio of the yield to water used, was highest (6.17 kg/ha/mm) for 110 to ≤ 160cm water table depth range. The 160 to ≤ 250 cm water table depth range (Table 4.8) had the lowest water used efficiency (4.38 kg/ha/mm). Detail computation is given in Appendix G.

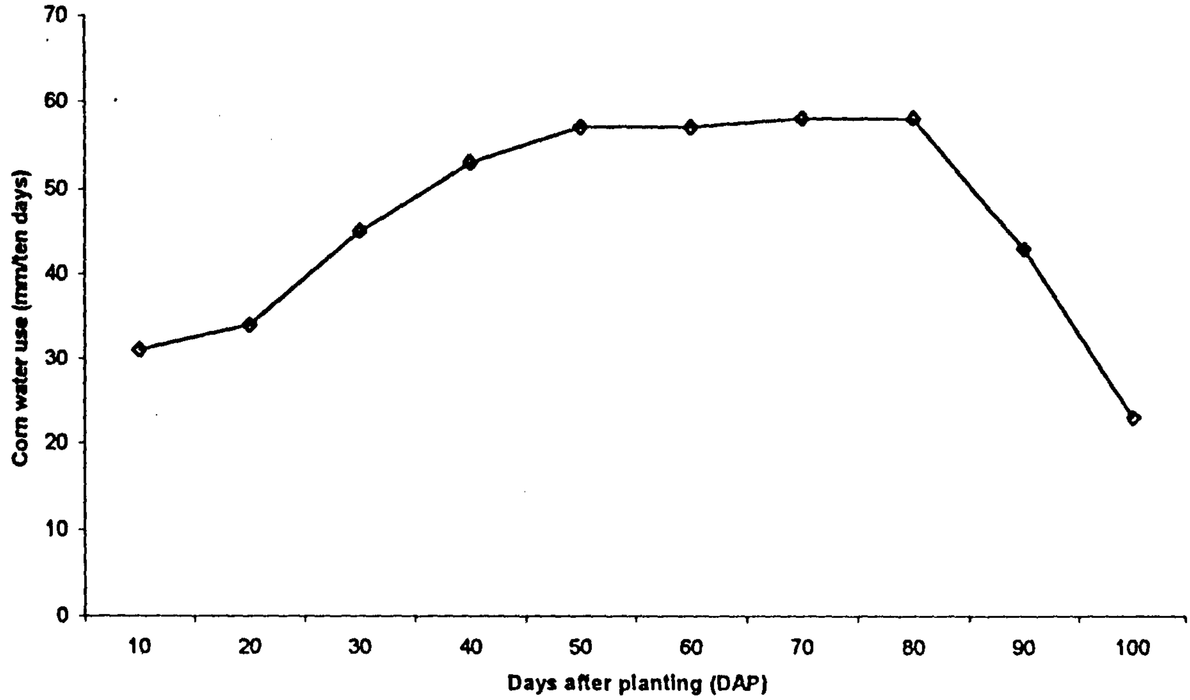


Fig. 4.5. Corn water use for various days after planting at VT

4.7 Water Balance

Knowledge of the water balance is necessary to evaluate the possible methods to minimize loss and to maximize gain and utilization of water, which is so often the limiting factor in crop production. Table 4.9 presents the absolute values of the parameters in the water balance equation for the study period. Run off was assumed to be negligible, since there was no rainfall during this period. Efficient management of water was made possible with the field water balance values. The highest evapotranspiration and irrigation were observed at 56DAP, with the least values recorded at maturity. Water loss to deep percolation gave the highest amount at 35 to 56 DAP. This was expected since the plot received the highest amount of watering during this period and the least at maturity. Detail computation of parameters in Table 4.9 and observed pattern of water requirements of corn (Jo-195) during growth are given in Appendix G.

Table 4.9. Field water balance. November 2003 – February 2004

Month	I (mm)	Q (mm)	ΔS (mm)	Et (mm)	L (mm)
November	165.2	0.0	2.56	129.6	33.04
December	189.72	0.0	-9.42	161.2	37.94
January	189.72	0.0	-12.52	164.3	37.94
February	67.32	0.0	-1.14	55.0	13.46

NB: I = Irrigation; Q = run off; ΔS = Change in soil moisture storage
Et = Evapotranspiration ; L = Deep percolation losses.

4.8 AGROMET Model, Corn Yield Estimation and Actual Yields.

Table 4.10 presents the mean yields and estimated yield of corn at the Landzun inland valley (LIV) for the research period. For the VT (plot 3) the AGROMET model under-estimated corn yield by 7.7% in relation to LIV (Table 4.10), which corresponds to a significant difference of 218.7 kg/ha (p=0.01). The reasons for this under-estimation may be partly related to parameters that still need be adjusted and refined in the model such as nutrient supply, salinity, land preparation, weeding and harvesting. In the VT (plot 2), no significant difference was found between the AGROMET estimate and LIV corn yields (Table 4.10), indicating that the climatic effect on corn yield was well modeled by the AGROMET. At the VT (plot 1) and all plots at VB, the model over-estimated corn yields by 29.7%, 42.5%, 40.7% and 48.2% respectively, as compared to the LIV yields, which correspond to significance differences of 597.9kg/ha, 779.0g/ha, 756.0kg/ha and 850.1kg/ha respectively (p=0.01); (Table 4.10). These differences can be attributed to the shallow water table and creation of acidic conditions at the VB which, significantly affected corn yields.

Table 4.10. Comparison between mean yields and the estimated yield from AGROMET model using LSD Test.

Valley Section		Mean Yield (kg/ha)	Standard Deviation	Difference (kg/ha)	Relative Difference (%)
VT-1	LIV	2014.7	78.8		
	AGROMET	2612.6		579.9**	29.7
VT-2	LIV	2521.5	72.5		
	AGROMET	2612.6		91.1ns	3.6
VT-3	LIV	2831.3	88.9		
	AGROMET	2612.6		218.7**	7.7
VB-1	LIV	1833.5	38.4		
	AGROMET	2612.6		779.0**	42.5
VB-2	LIV	1856.1	48.6		
	AGROMET	2612.6		756.0**	40.7
VB-3	LIV	1762.5	49.6		
	AGROMET	2612.6		850.0**	48.2

VT = Valley top plots; VB = Valley bottom plots

LIV = Landzun inland valley ** : Significant at 1% level; ns: not significant

4.9 Production Cost

The fixed costs incurred by each treatment differed in this study. The cost for watering and farm tools was estimated for the period of the study to be ₦2400.00 and ₦900.00 for treatments A and B respectively.

The variable costs of the treatments (A and B) ranged from ₦28, 239.23 per ha to ₦38,136.84 per ha (Table 4.11). The data further showed that seed/planting, irrigation service fees and fertilizer/application constitutes 25.3 per cent, 20.5 per cent and 25.2 per cent respectively of the total variable costs of treatment A; whereas seed/planting and fertilizer constitutes 34.7 per cent and 32.4 per cent respectively of the total variable costs of treatment B. The other expense that is land clearing/preparation, weeding, corn picking, loading and transportation constitutes the

Table 4.11: Production cost for treatments (₦ per ha).

S/N	Cost Items	Cost per Treatment		Total
		A(VT)	B(VB)	
1.	VARIABLE COST			
a.	Labour Cost:			
i.	Land clearing/preparation	4,800.00	4,445.83	9,245.83
ii.	Seed planting	1,600.00	1,481.94	3,081.94
iii.	Weeding (manual)	2,400.00	2,222.91	4,622.91
iv.	Fertilizer application	1,200.00	1112.46	2,312.46
v.	Irrigation service	8,320.00	-	8,320.00
vi.	Picking, loading and transportation of corn	2,000.00	1,852.43	3,852.43
vii.	Miscellaneous expenses			
b.	Material Cost:			
i.	Corn seeds	8,666.84	8,637.74	17,304.58
ii.	Fertilizer	9,000.00	8,335.92	17,335.92
iii.	APRON STAR	150.00	150.00	300.00
	Total variable cost	38,136.84	28,239.23	66,376.07
2.	FIXED COST			
i.	Watering cans (less depreciation)	1,500.00	-	1,500.0
ii.	Farm tools (less depreciation)	900.00	900.00	1,800.00
	Total Fixed Cost	2,400.00	900.00	3,300.00
	Total average	40,536.34	29,139.23	34,838.04

remaining 29 per cent and 32.9 per cent of the farm input costs for treatments A and B respectively (Table 4.12). Egharevba and Otitolaiye (2004) reported that the objective of a small-scale farmer in farm labour management is to increase output per unit of labour used or to produce the same level of output at a reduced level of labour input (i.e. at reduced cost).

Generally, treatment A had the higher variable cost. The variation in production cost can be attributed mainly to difference in labour costs.

Table 4.12 Farm input cost as percentage of total cost of production

Farm input	Percentage	Cost of production
	A*	B
Land clearing/preparation	11.8	15.3
Seed/planting	25.3	34.7
Weeding (manual)	5.9	7.6
Fertilizer/application	25.2	32.4
Irrigation services	20.5	-
Picking, loading and transportation	5.0	6.4
APRON STAR	0.4	0.5
Depreciation of watering can	3.7	-
Depreciation of farm tools	2.2	3.1
Total	100.0%	100.0%

* A = VT; B = VB

4.10 Overall Performance

Table 4.13 presents a summary of the overall economic analysis for the two treatments. It can be seen that profit realized seem to be higher in treatment A. This trend is consistent with those of corn yield between the treatments. Benefit- Cost ratios obtained were 1.87 and 1.93 for treatments A and B respectively. Treatment B had the higher B/C ratio, which implies the better performance in cost recovery.

Table 4.13: Costs and returns for treatments, per ha

Treatment	Corn yield (kg)	Total production cost (₦)	Gross Income (₦)	Profit Realized (₦)	Benefit / Cost indices
A	2455.83*	40536.84	76126.16	35589.32	1.87
B	1817.37	29139.23	56335.09	27195.86	1.93

* Mean per plot.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions could be drawn from the results obtained in this study:

1 In the valley top, the water table depths fluctuate between 90 to 270 cm in the dry season and 70 to 120 cm ranges in June, during the rainy season. At the valley bottom, the fluctuation was between 30 to 75cm depths in the dry season and comes up on to the ground surface during the rainy season.

2 The germination, growth and yield of corn were found to be significantly depressed by shallow water table depths (40 to ≤ 60 cm) due to reduced aeration associated with root and soil volume for mineral nutrient up-take.

3 The yield increased with increasing water table depth. The best soil moisture regime for corn grown in the valley bottom was discovered to be at 60 to ≤ 110cm water table depth range. This resulted in the maximum grain yield of 1856.1 kg/ha.

4 Corn growth and yield parameters decreased with increased residual soil moisture. Crop emergence was significantly affected at 7DAP and 14DAP.

5 The water use efficiency was highest (6.17 kg/ha/mm) at 110 to ≤ 160cm water depth range. This gave a maximum corn yield of 2831.3 kg/ha under surface watering. There was also a significant difference at 1% probability level in the yield for all the water table depths range.

6 The agrometeorological model (AGROMET) overestimated corn yields on most plots at the inland valley. The model generated corn yield estimate comparable to the inland valley yield for one out of the six plots analysed.

7 Higher corn production cost was obtained in the water table depth range of 110 to ≤ 250cm (VT) when compared with water table depth range of 40 to 110cm (VB). Results of income and profits realized showed some trend with corn yield, with 110 to ≤ 250cm depths (VT) giving the best result. However, the performance of the cost recovery was better for the 40 to 110cm water table depths range.

5.2 Recommendations

1. This study shows that shallow water table depths and excessive residual moisture not only affected crop emergence but growth yield parameters. In order to maximize yield for the maize crop in this area, the water table depth range of 60 to 110cm should be maintained. Furthermore, farmers in the inland valley should be encouraged to establish adequate drainage on farm plots before sowing of maize.
2. Agricultural demands on water supplies and the negative effects of shallow water table on crop production could decrease appreciably through better control of target water levels and permissible fluctuations. The water table data obtained could be useful to frontline water managers. Also the data generated from the inland valley can be incorporated into scheduling and managing irrigation and drainage events. Adherence to this would enable a grower (farmer) to optimize his water usage with water table management, irrigation and drainage systems.
3. In order to avoid high production cost and poor water management practices that could result in low water utilization, low crop yield and even possible crop failure, proper inland valley cultivation should be encouraged. It is

evident that excessive water in the root zone had contributed to low yield and loss in come. Early maize cropping on residual moisture by farmers should be reviewed in favour of delay in maize cultivation in the inland valley.

4. Additional research work is required to provide the needed information on the cause for the difference between corn yield estimated by the AGROMET model and actual yields at the inland valley. Furthermore, the model can be interfaced with a Geographic Information System (GIS) to monitor corn crop during growing season to estimate crop yields.

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APPENDIX A

Table A-1. Biweekly measurement of soil moisture at Landzun inland valley.

WAP*	Sample depth (cm)	Zone	Moisture content (%)	Dry bulk density (ρ_b) (g/cm^3)	Volumetric mc(θ) $w x \rho_b$ (cm^{3}cm^{-3})	Depth of Am ΔZ (cmm^{-})	Available moisture (Am) in root zone ΣAM (cmm^{-1})
2	15	0-30	18.65	1.480	0.276	8.28	
	45	30-60	21.50	1.500	0.323	9.69	
	75	60-90	27.75	1.625	0.451	13.53	
	105	90-120	36.30	1.633	0.593	17.79	49.29
4	15	0-30	13.98	1.480	0.207	6.21	
	45	30-60	16.15	1.500	0.242	7.26	
	75	60-90	18.75	1.625	0.305	9.15	
	105	90-120	1.633	1.633	0.444	13.32	35.94
6	15	0-30	10.50	1.480	0.155	4.65	
	45	30-60	13.04	1.500	0.196	5.88	
	75	60-90	15.65	1.625	0.254	7.62	
	105	90-120	20.32	1.633	0.332	9.96	28.11
8	15	0-30	7.85	1.480	0.116	3.48	
	45	30-60	9.07	1.500	0.136	4.08	
	75	60-90	11.83	1.625	0.192	5.76	
	105	90-120	15.30	1.633	0.250	7.50	20.82
10	15	0-30	5.72	1.480	0.085	2.55	
	45	30-60	6.50	1.500	0.098	3.94	
	75	60-90	8.75	1.625	0.142	4.26	
	105	90-120	11.40	1.633	0.186	5.58	15.33
12	15	0-30	4.50	1.480	0.067	2.01	
	45	30-60	5.10	1.500	0.077	2.31	
	75	60-90	0.50	1.625	0.106	3.18	
	105	90-120	8.55	1.633	0.140	4.20	11.70
14	15	0-30	3.35	1.480	0.050	1.50	
	45	30-60	4.53	1.500	0.068	2.40	
	75	60-90	5.04	1.625	0.082	2.46	
	105	90-120	6.48	1.633	0.106	3.18	9.54
16	15	0-30	2.50	1.480	0.037	1.11	
	45	30-60	2.87	1.500	0.043	1.29	
	75	60-90	3.70	1.625	0.060	1.80	
	105	90-120	4.85	1.633	0.079	2.37	6.57

*WAP – Weeks after planting
w = Moisture Content
Δz = Soil depth

APPENDIX B

Table B-1. Soil Intake rates at Landzun inland valley (valley top).

Date: 24/10/2003. 1st Trial

	A	B	C	D	E	
Elapsed Time (min)	Final depth (cm)	Initial depth (cm)	Water intake (A-B) (cm)	Cum Infil (cm)	Infil rate D/t (cm/min)	Infil rate Ex 60 (cm/hr).
1	5.9	5.0	0.9	0.9	0.90	54.0
2	6.5	5.9	0.6	1.5	0.75	45.0
5	7.8	6.5	1.3	2.8	0.56	33.6
10	9.4	7.8	1.6	4.4	0.44	26.4
15	10.6	9.4	1.2	5.6	0.37	22.2
20	12.3	10.6	1.7	7.3	0.37	22.2
25	14.2	12.3	1.9	9.2	0.37	22.2
30	15.0	4.2	0.8	10.0	0.33	19.8
45	7.9	5.0	2.9	12.9	0.29	17.4
60	10.7	7.9	2.8	15.7	0.26	15.6
75	13.1	10.7	2.4	18.1	0.24	14.4
90	15.3	13.1	2.2	20.3	0.23	13.8
105	6.5	5.0	1.5	21.8	0.21	12.6
120	8.0	6.5	1.5	23.3	0.19	11.4
135	9.5	8.0	1.5	24.8	0.18	10.8
150	10.9	9.5	1.4	26.2	0.17	10.2
165	12.0	10.9	1.1	27.3	0.17	10.2
180	14.2	12.0	2.2	29.5	0.16	9.6
195	7.0	5.0	2.0	31.5	0.16	9.6
210	9.1	7.0	2.1	33.6	0.16	9.6

Basic infiltration rate = 9.6cm/hr

Table B-2. Soil Intake rates at Landzun inland valley (valley top).

Date: 24/10/2003. 2nd Trial

	A	B	C	D	E	
Elapsed Time (min)	Final depth (cm)	Initial depth (cm)	Water intake (A-B) (cm)	Cum Infil (cm)	Infil rate D/t (cm/min)	Infil rate Ex 60 (cm/hr).
1	6.1	5.0	1.1	1.1	1.10	66.0
2	6.9	6.1	0.8	1.9	0.95	57.0
5	8.5	6.9	1.6	3.5	0.70	42.0
10	10.3	8.5	1.8	5.3	0.53	31.8
15	11.8	10.3	1.5	6.8	0.45	27.0
20	13.8	11.8	2.0	8.8	0.44	26.4
25	7.2	5.0	2.2	11.0	0.44	26.4
30	8.3	7.2	1.1	12.1	0.40	24.0
45	11.2	8.3	2.9	15.0	0.33	19.8
60	14.1	11.2	2.9	17.9	0.30	18.0
75	7.5	5.0	2.5	20.4	0.27	16.2
90	9.8	7.5	2.3	22.7	0.25	15.0
105	11.5	9.8	1.7	24.4	0.23	13.8
120	13.2	11.5	1.7	26.1	0.22	13.2
135	6.7	5.0	1.7	27.8	0.21	12.6
150	8.3	6.7	1.6	29.4	0.20	12.0
165	9.6	8.3	1.3	30.7	0.19	11.4
180	12.0	9.6	2.4	33.1	0.18	10.8
195	7.2	5.0	2.2	35.3	0.18	10.8
210	9.5	7.2	2.3	37.6	0.18	10.8

Basic infiltration rate = 10.8cm/hour.

Table B-3. Soil Intake rates at Landzun inland valley (valley top).

Date: 25/10/2003. 3rd Trial

	A	B	C	D	E	
Elapsed Time (min)	Final depth (cm)	Initial depth (cm)	Water intake (A-B) (cm)	Cum Infil (cm)	Infil rate D/t (cm/min)	Infil rate Ex 60 (cm/hr).
1	6.3	5.0	1.3	1.3	1.30	78.0
2	7.0	6.3	0.7	2.0	1.00	60.0
5	8.4	7.0	1.4	3.4	0.68	40.8
10	10.3	8.4	1.9	5.3	0.53	31.8
15	12.0	10.3	1.7	7.0	0.48	28.8
20	14.3	12.0	2.3	9.3	0.47	28.2
25	7.2	5.0	2.2	11.5	0.46	27.6
30	8.4	7.2	1.2	12.7	0.42	25.2
45	11.5	8.4	3.1	15.8	0.35	21.0
60	14.4	11.5	2.9	18.7	0.31	18.6
75	7.6	5.0	2.6	21.3	0.28	16.8
90	9.7	7.6	2.1	23.4	0.26	15.6
105	11.4	9.7	1.7	25.1	0.24	14.4
120	12.9	11.4	1.5	26.6	0.22	13.2
135	14.3	12.9	1.4	28.0	0.21	12.6
150	6.3	5.0	1.3	29.3	0.20	12.0
165	7.8	6.3	1.5	30.8	0.19	11.4
180	9.1	7.8	1.3	32.1	0.17	10.2
195	10.3	9.1	1.2	33.3	0.17	10.2
210	11.9	10.3	1.6	34.9	0.17	10.2

Basic infiltration rate = 10.2cm/hour.

APPENDIX C

Table C-1: Soil Intake rates at Landzun inland valley (valley bottom).

Date: 26/10/2003. 1st Trial

	A	B	C	D	E	
Elapsed Time (min)	Final depth (cm)	Initial depth (cm)	Water intake (A-B) (cm)	Cum Infil (cm)	Infil rate D/t (cm/min)	Infil rate Ex 60 (cm/hr).
1	5.7	5.0	0.7	0.7	0.70	42.0
2	6.2	5.7	0.5	1.2	0.60	36.0
5	9.2	6.2	1.0	2.2	0.44	26.4
10	8.3	7.2	1.1	3.3	0.33	19.8
15	9.2	8.3	0.9	4.2	0.28	16.8
20	10.4	9.2	1.2	5.4	0.27	16.2
25	11.7	10.4	1.3	6.7	0.26	15.6
30	12.5	11.7	0.8	7.5	0.25	15.0
45	7.9	5.0	2.9	10.4	0.23	13.8
60	10.7	7.9	2.8	13.2	0.22	13.2
75	14.0	10.7	3.3	16.5	0.21	12.6
90	6.5	5.0	1.5	18.0	0.20	12.0
105	7.4	6.5	0.9	18.9	0.18	10.8
120	8.9	7.0	1.5	20.4	0.17	10.2
135	10.1	8.9	1.2	21.6	0.16	9.6
150	11.0	10.1	0.9	22.5	0.15	9.0
165	11.6	11.0	0.6	23.1	0.14	8.4
180	13.7	11.6	2.1	25.2	0.14	8.4
195	7.1	5.0	2.1	27.3	0.14	8.4
210	9.2	7.1	2.1	29.4	0.14	8.4

Basic infiltration rate = 8.4cm/hr.

Table C-2. Soil Intake rates at Landzun inland valley (valley bottom).

Date: 26/10/2003. 2nd Trial

	A	B	C	D	E	
Elapsed Time (min)	Final depth (cm)	Initial depth (cm)	Water intake (A-B) (cm)	Cum Infil (cm)	Infil rate D/t (cm/min)	Infil rate Ex 60 (cm/hr).
1	5.6	5.0	0.6	0.6	0.60	36.0
2	6.0	5.6	0.4	1.0	0.50	30.0
5	7.0	6.0	1.0	2.0	0.40	34.0
10	8.3	7.0	1.3	3.3	0.33	19.8
15	9.2	8.3	0.9	4.2	0.28	16.8
20	10.6	9.2	1.4	5.6	0.28	16.8
25	12.2	10.6	1.6	7.2	0.29	17.4
30	12.7	12.2	0.5	7.7	0.26	15.6
45	7.6	5.0	2.6	10.3	0.23	13.8
60	10.0	7.6	2.4	12.7	0.21	12.6
75	12.1	10.0	2.1	14.8	0.20	12.0
90	13.9	12.1	1.8	16.6	0.18	10.8
105	6.2	5.0	1.2	17.8	0.17	10.2
120	7.3	6.2	1.1	18.9	0.16	9.6
135	8.4	7.3	1.1	20.0	0.15	9.0
150	9.4	8.4	1.0	21.0	0.14	8.4
165	10.2	9.4	0.8	21.8	0.13	7.8
180	12.0	10.2	1.8	23.6	0.13	7.8
195	6.7	5.0	1.7	25.3	0.13	7.8
210	8.3	6.7	1.6	26.9	0.13	7.8

Basic infiltration rate = 7.8cm/hr.

Table C-3. Soil Intake rates at Landzun inland valley (valley bottom).

Date: 27/10/2003. 3rd Trial

	A	B	C	D	E	
Elapsed Time (min)	Final depth (cm)	Initial depth (cm)	Water intake (A-B) (cm)	Cum Infil (cm)	Infil rate D/t (cm/min)	Infil rate Ex 60 (cm/hr).
1	5.7	5.0	0.7	0.7	0.70	42.0
2	6.2	5.7	0.5	1.2	0.60	36.0
5	7.3	6.2	1.1	2.3	0.46	27.6
10	8.6	7.3	1.3	3.6	0.36	21.6
15	10.2	8.6	1.6	5.2	0.35	21.0
20	12.2	10.2	2.0	7.2	0.36	21.6
25	14.0	12.2	1.8	9.0	0.34	20.4
30	5.8	5.0	0.8	9.8	0.33	19.8
45	8.5	5.8	2.7	12.5	0.28	16.8
60	10.8	8.5	2.3	14.8	0.25	15.0
75	13.2	10.8	2.4	17.2	0.23	13.8
90	7.0	5.0	2.0	18.2	0.21	12.6
105	8.3	7.0	1.3	21.2	0.20	12.0
120	9.1	8.3	0.8	22.5	0.19	11.4
135	10.0	9.1	0.9	23.3	0.18	10.8
150	10.9	10.0	0.9	24.2	0.17	10.2
165	11.5	10.9	0.6	24.8	0.15	9.0
180	13.4	11.5	1.9	26.7	0.15	9.0
195	7.1	5.0	2.1	28.8	0.15	9.0
210	9.6	7.1	2.5	31.3	0.15	9.0

Basic infiltration rate = 9.0cm/hr.

APPENDIX D

Table D-1. Inverse auger hole hydraulic conductivity test at the valley top.

Location: valley top   Date: 04/11/2003.

Soil: Sandy

Diameter of auger hole: 50mm

	D = 90.0cm	r = 5.0cm	
Reading No.	Time (secs)	ho (cm)	Ht (cm)
1	600	50.0	28.6
2	600	50.0	53.3
3	600	50.0	38.0
4	600	50.0	42.7
5	600	50.0	47.4

(ho + r/2) = 50 + 2.5 = 52.5. log 52.5 = 1.7200

(ht + r/2) = 47.4 + 2.5 = 49.9 . log 49.9 = 1.6981

$$K = 1.15r \left\{\frac{\log (ho + r/2 - \log (ht + r/2}{t}\right\}$$ (Smedema and Rycroft, 1988)

$$= 1.15 \times 5 \left\{\frac{1.7202 - 1.6981}{600}\right\}$$

$= 7.6 \times 10^{-1}$ $cmhr^{-1}$.

Where, ho is the initial water level at t = 0, ht is the final water level at t = 600secs, r is the radius in cm and D is the depth in cm.

Table D - 2. Measurement of hydraulic conductivity (K) by auger hole method at valley bottom.

Location: valley bottom Date: 05/11/2003.

Soil: loamy sand

Diameter of auger hole: 50mm

D (W +H) = 125cm W = 47cm r = 5cm S = 120cm

Time T (secs)	Water level W + h (cm)	Head H (cm)	Change in head Δh (cm)	Time interval Δt (Secs)
0	102.4	55.4	-	-
30	101.0	54.0	1.4	30
60	99.8	52.8	1.2	30
90	98.8	51.8	1.0	30
120	97.8	50.8	1.0	30
150	96.9	49.9	0.9	30
180	96.1	49.1	0.8	30
210	95.3	48.3	0.8	30
240	94.6	47.6	0.7	30

Calculations (for complete time period)

□h = 55.4 – 47.6 = 7.8cm

□t = 240 – 0 = 240secs

$-h = \frac{55.4 + 47.6}{2} = 51.5\text{cm}$

H = 125 – 47 = 78cm

H/r = 78/5 = 15.6

S/H = 120/78 = 1.5 =2

-W/H = 51.5/78 = 0.7

$K = \frac{C\Delta h}{\Delta t} = 5.10 \times 7.8/240 = 0.16575 \text{ mday}^{-1} = 6.9 \times 10^{-1} \text{ cmhr}^{-1}$

where, H is depth of hole below water table in cm, S is depth to the impermeable subtratum below the bottom of the hole, r is radius of the hole in cm, W is the depth of water table below the ground surface and c is geometry factor (dimensionless); obtained from look-up table based on values of H/r and S/H (Smedema and Rycroft, 1988).

APPENDIX E

Table E-1. Weekly water table measurement below ground surface (cm) at Landzun inland valley.

	Oct	November				December				January					February			
Well	30th	6th	13th	20th	27th	4th	11th	18th	25th	1st	8th	15th	22nd	29th	5th	12th	19th	26th
No	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
1	178	159	172	188	196	204	214	220	223	224	226	230	231	235	241	244	249	253
2	158	145	161	170	176	184	191	196	202	202	203	204	208	213	217	223	228	231
3	95	87	110	116	124	132	138	142	144	145	148	150	153	157	164	166	169	175
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	62
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	95
6	27	33	35	35	38	42	45	45	47	49	50	50	52	53	55	57	59	61
7	46	37	45	55	62	71	74	83	85	90	95	103	105	109	112	116	121	127
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	54
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	108

Well Nos. 1 – 3 (Valley Top, VT) Well Nos. 4 – 9 (Valley Bottom, VB)

APPENDIX E. CONTINUED

	March				April					May				June			
Well No.	4th (19)	11th (20)	18th (21)	25th (22)	1st (23)	8th (24)	15th (25)	22nd (26)	29th (27)	6th (28)	13th (29)	20th (30)	27th (31)	3rd (32)	10th (33)	17th (34)	24th (35)
1	259	262	267	269	272	261	270	231	184	156	165	142	135	124	112	119	120
2	234	237	241	243	246	239	241	215	153	128	130	115	122	107	92	100	89
3	177	179	183	184	187	180	185	143	102	94	87	81	79	72	65	67	70
4	64	67	69	73	75	69	72	55	31	15	6	0	0	0	0	0	0
5	104	106	107	110	114	108	112	95	62	43	22	27	14	8	0	0	0
6	62	64	67	68	69	60	66	48	20	9	0	0	0	0	0	0	0
7	124	126	127	131	134	127	130	113	77	48	25	30	11	0	0	0	0
8	58	59	63	65	66	58	61	46	30	17	10	0	0	0	0	0	0
9	110	115	116	119	123	118	120	102	56	43	20	26	13	0	0	0	0

APPENDIX F

1. MAXIMUM YIELD (Ym)

$$Rs = (0.25 + 0.5n/N)/Ra = 630 cal/cm^2/day$$

The values of n,N and Ra were obtained from Doorenbos and Pruitt (1984) at 10 °N.

where, Rs is the actual measured incoming short wave radiation in $cal/cm^2/day$, Ra is the extra – terrestrial radiation in mm/day, N is the maximum possible sunshine duration in hrs/day and n is the actual measured sunshine duration is hrs/day.

$$F = (Rse - 0.5Rs)/0.8Rse$$

$$= 376 - 0.5(630) \quad /0.8 \times 376 \quad = 0.20$$

where Rse is the maximum active incoming short wave radiation in $cal/cm^2/day$.

Value of Rse was obtained from Doorenbos and Kassam (1981).

At a mean temperature of 26.8°C (Table 3.1), y_m is obtained as 65kg/ha/hr (Doorenbos and Kassam,1981).

Y_m is estimated from equation as follows:

$$Y_o = F(0.8 + 0.01y_m)y_o + (1 - F)(0.5 + 0.025y_m)\ y_c$$
$$= 0.20(0.8 + 0.01x65)236 + (1 - 0.2)(0.5 + 0.025x65)440$$
$$= 816.44 kg/ha/day$$

The values 236 and 440 for y_o and y_c respectively are mean values obtained from Doorenbos and Kassam (1981) at latitude 10 °N.

$$Y_m = cL.\ cN.\ cH\ .\ G\ .\ Y_o$$
$$= 0.5 \times 0.5 \times 0.4 \times 100 \times 816.44 \text{ (equation 20)}$$
$$= 8164.4 kg/ha.$$

2. MAXIMUM EVAPOTRANSPIRATION (ETm)

The ETm was obtained from Table 3.1 as 6.0mm/day.

3. ACTUAL EVAPOTRANSPIRATION (ETa)

Net irrigation (In) at ETm = 189.72 x Ea = 189.72 x 0.75 = 142.3mm (Appendix G)

Actual depth of available moisture (Wb) at the beginning of the month = 15.6mm/m.

Effective rainfall (Pe) = 0 (no rainfall during the research period.

At Etm 6.0mm/day, available soil water index (fraction p) = 0.55mm/day (Doorenbos and Kassam, 1981).

Total available soil water (Sa) over the root depth (D) =D.Sa

=1.2 x 222.0 = 266.4mm/m

Available soil water index (ASI) is then calculated from:

$$ASI = In + Pe + Wb - [(1 - P)\ D.Sa]/ Etm\ (monthly)$$

$$= 142.3 + 0 + 15.6 - [(1 - 0.55)266.4]/ 31 \times 6.0 = 0.204$$

With the computed values of ASI and ETm, ETa was obtained as 3.6mm/day from a look-up table (Doorenbos and Kassam, 1981). At ripening, the yield response factor (ky) is obtained from look-up table as 0.2 (Doorenbos and Kassam, 1981; Berka et al., 2003).

4. ESTIMATED YIELD (Ye)

The Ye was calculated from equation 18 as follows:

$$Y_e = Y_m [1 - ky (1 - \frac{ETa}{ET_m})]$$

Substituting the values of Ym, ky, ETa and ETm gave Ye = 2612.6kg/ha

Average water requirement for growing season = 6.12 x 100 = 612mm

(B) FIELD WATER BALANCE

Gross irrigation required in November (I):

I = IR x No. of days = 6.12 x 27 = 165.2mm

Dec; I = 6.12 x 31 = 189.72mm

Jan.; I = 6.12 x 31 = 189.72mm

Feb.; I = 6.12 x 11 = 67.32mm

Monthly ET over the growing period was computed as:

November; ET = Average ETo Nov. x No. of days = 4.8 x 27 = 129.6mm

Similarly ET for December, January and February were computed as 161.2, 164.3 and 55.0mm respectively.

Run off (Q) = 0.0 (no rainfall during the period)

Deep percolation loss (L) was estimated from equation (17).

L = xI (Aneke, 1988) ; x = 20% of I (Michael, 1995).

For November, L = 0.2 x 165.2 = 33.04mm

ΔS was evaluated from equation (16)

ΔS = I – (Q + ET + L), (Table 4.7).

Table G – 1. Pattern of the water requirements of corn (Jo – 195) during growth period (November, 2003 to February, 2004).

Periods (days)	Growth stage	Water use (mm)
3 – 15	Emergence and establishment	50.49
15 – 40	Vegetative growth	137.70
40 – 60	Tasselling and silking	160.65
60 – 70	Fertilization and fruit set	68.85
70 – 100	Fruit emergence and maturation	41.31