VARIETAL RESPONSE OF IRISH POTATOES TO IRRIGATION SCHEDULING IN THE NORTHERN GUINEA-SAVANNAH ZONE OF NIGERIA

By

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**BEING A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL,
AHMADU BELLO UNIVERSITY, ZARIA; IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE AWARD OF M.Sc. DEGREE IN
AGRICULTURAL ENGINEERING**

APRIL,2005

DECLARATION

I hereby declare that this thesis has been written by me, and that it is a record of my research work. It has not been submitted or accepted in any previous application for the award of Higher Degree anywhere.

All sources of information have been specifically acknowledged by means of references.

DIBAL, JIBRIN MUSA

Signature________________________

Date ________________________

CERTIFICATION

This thesis, entitled "VARIETAL RESPONSE OF IRISH POTATOES TO IRRIGATION SCHEDULING IN THE NORTHERN GUINEA SAVANNAH ZONE OF NIGERIA" by DIBAL, JIBRIN MUSA, meets the regulations governing the award of the degree of Master of Science (Agricultural Engineering) of Ahmadu Bello University, Zaria; and it is approved for its contribution to scientific / technical knowledge and literary presentation.

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DEDICATION

TO: Allahu subhanahu Wa Ta'ala who made it possible for me to commence and accomplish this work.

TO: My parents – Bulama Musa Mari Dibal and Hamsatu Bulama Musa Mari who made immeasurable sacrifices for the sustenance of this work.

TO: My Wife – Hauwa Mohammed Biu

TO: My children.

ACKNOWLEDGEMENT

My highest praise and gratitude first go to the Almighty Allah who made everything possible for me in his infinite mercy and bounties. I wish He will accept my gratitude for seeing me through this work.

I remain most indebted to my project supervisors: DR. A.A. RAMALAN and DR. M.A. OYEBODE, for their guidance, constructive criticisms, suggestions born out of long term experiences and personal sacrifices they made to ensure the success of not only the research project, but my entire M.Sc Programme at large. Thank you Sirs.

Equally, I must express my profound gratitude to all academic and non-academic staff of the Department of Agricultural Engineering, Ahmadu Bello University (A.B.U.), Zaria; for their support, personal assistances/contributions, suggestions and patience extended to me during my stay in the department.

I would also want to acknowledge with deep appreciations the contribution of Dr. Suleiman Sulaudeen of Mass Communication Dept., Ahmadu Bello University (A.B.U.), Zaria and his family for their numerous assistances rendered to me. May God equally reward him and his family abundantly, Ameen.

My thanks also go to Irrigation Research Programme, Institute for Agricultural Research for the provision of some equipments and technical advices which contributed immensely to the completion and success of this project.

I also wish to express my sincere appreciation to my dear friends who assisted me in many ways to see me through the challenging task. They are: Mallam Abdulkadir Inuwa Ahmad, Mallam Sanusi Usman Mohammed, Mr. Donatus Onwegbunam Obiajulu, Mr. Olaosebikan Akanbi Layi, Mallam Ali Gambo and Engr Sumaila Bayo A. Also worthy of mention are Engr. Baba Alkali and Engr. Babagana Mustapha Malumbe, both of Electrical and Electronics Engineering Department, University of Maiduguri.

Similarly I want to acknowledge deeply the contributions of Malam Dalhatu Ibrahim Shika and Sarkin Baka both of Animal science department, A.B.U. Zaria; and that of Malam Dari Dogara Bomo (Mai Unguwa) and Malam Mohammed Sani both of NAERLS, A.B.U. Zaria. The efforts of my field operator, Malam Gambo Kurmin Bomo are also highly appreciated. A big thanks also go to Mr. and Mrs. Joshua Kaye for their support and assistance.

Finally, I want to say “thank you” to my brothers and sisters for the patience and courage they gave to me.

ABSTRACT

The study examined the response of four potato varieties (Pakistan, Nicola, SP, and Dual) to four levels of irrigation scheduling in terms of growth, yield, crop water use and crop water use efficiency. The levels of the irrigation schedules were irrigation at cumulative pan evaporation(CPE 20 mm), CPE 30 mm, CPE 40 mm and irrigating at fixed interval of 7 days. The treatments were laid in a Randomized Complete Block Design on a loamy soil. Irrigation treatments were imposed 35 days after germination. Neutron probe was used to monitor the soil moisture throughout the study.

In general, no significant difference was found among irrigation scheduling in terms of total yield, total number of tubers, tuber size less than 25.4 mm, tuber size between 25.4 mm and 50.8 mm and tuber sizes between 76.2 mm and 101.6 mm in diameter, respectively. However, irrigating at cumulative pan evaporation (CPE) 20 mm had resulted into early flowering, early tuberisation, highest total yield, largest tuber sizes, heavier tubers and highest total number of tubers than all other irrigation scheduling treatments studied.

Using CPE 20 mm as threshold to schedule irrigation has however resulted into very short irrigation interval of 3.17 days, highest seasonal crop water use of 551 mm and highest crop water use efficiency (CWUE) of 48.85×10^{-3} (t/ha-mm). Generally, the CPE-based scheduling exhibited better performance when compared to the fixed 7-days (a rotational method of water supply).

Variety Dual, which tubered earlier than all other varieties studied, appeared to be promising as it generally showed better performance. However, when emphasis is placed on largest tuber sizes, Pakistan demonstrated best performance.

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CHAPTER ONE

1.0 Introduction

Irish potato (*Solannum Tuberosum L.*) is a popular root crop found almost all over the world. It is believed to have originated from the Andes of Peru and Boliva in 1524 (Doorenbos and Kassam, 1979; Harper, 1983; Brown, 1993). It was later introduced into Europe and gradually to the rest of the world. Potato was identified as food since late eighteenth century (Brown, 1993; Dixit, 2003). It also compares favorably with other staple foods such as rice, maize, wheat, etc in terms of calorie, protein, vitamin and mineral contents (Douglas, 1981; Horton and Fano, 1984; Dixit, 2003). It is therefore regarded as food as well as cash crop (Roger *et al*.,2002)

Globally, potato is the fourth most important food crop, with annual production approaching 300 million tons cultivated on over 18 million hectares (Horton and Fano, 1984; Dixit, 2003). Africa has average potato yields of 14-28 t/ha, with Egypt, South Africa and Morocco as the larger producers (Dixit, 2003).

The crop (Irish Potato) was introduced into Nigeria by Europeans in the 1920s; its production rose from mere 180 tons in 1940 to 1,732 tons in 1944 (Rhoades *et al.,* 2002). Production of the crop is concentrated in three states, namely Plateau, Kaduna and Kano States. Yields of over 20 t/ha have been reported from research stations; however, farmers' yields are generally much lower, on average 10 t/ha cultivated on about 10,000 hectares (Obigbesan, 1976, Rhoades *et al.,* 2002).

The chief determining factor of cropping calendar for potato in Nigeria is the availability of water. In general, the two main production systems are rain fed and irrigated. Rain-fed potatoes planting starts from April through August, depending on local condition. Harvest occurs three or four months later. Planting of potatoes under irrigation starts by October through December, again depending on local conditions, and harvest is from February to April (Rhoades *et al.*, 2002). Planting of potato for irrigation is avoided as much as possible between February to September due to high temperatures (Obigbesan 1976; Ifenkwe, 1978; Rhoades *et al.,* 2002).

Although formal potato research in Nigeria dates from 1940 (Rhoades *et al.,* 2002) it is still not yet a staple food (Ifenkwe, 1978; Rhoades *et al*., 2002) that consumption outside production areas is primarily among urban, higher income groups (Rhoades *et al.,* 2002).

Water stress has been identified as one of the constraints to potato production in the tropics (Manrique, 1993). Nigeria fall within the tropics whose two-third of her total land area is arid and semi-arid with mean annual rainfall of 250-1300 mm (Ogunwale and Owonubi, 1998). Armitage (1985) lamented that in arid and semi-arid lands, water is one of the most limiting factors for plants' growth, and rain-fed agriculture has low and unpredicted yields. The arid and semi-arid condition of Nigeria is harsh on crop production. The harsh conditions include unreliable rainfall, high temperatures, high evaporation and fragile soils (Ogunwale and Owonubi, 1998). Okai *et al.* (2000) also reported that crop production; especially in Nigerian Savanna is being adversely affected by insufficient water supply. Many farmers in Nigeria rely solely on rainfall for their crop requirements (Raji, 2001). This explains why Nigeria still has to import food from abroad despite her 69,037,000 agricultural populations (FAO, 1995). Nigeria therefore fall among the developing countries with food deficiency relative to their population (Musa, 1996; FAO-AGL, 2002); and this population is rapidly growing at the rate of 2.7% (PRB, 2002). Efforts should therefore be geared toward sustaining the current food production and prepare adequately for additional food that will soon be needed (Tsutsi, 1993). Irrigation is the only alternative antidote to this problem (Adeniji, 2002).

Irrigation is an agricultural practice designed to compliment and/or supplement the deficiency of climate: the imbalance between water supplied by precipitation and the evaporative demand of the atmosphere. The need for irrigation is most practical in the arid-zones of the world which are characterized by long, hot dry (non-rainy) summers and low amounts of rainfall concentrated in a short rainy period (Fuchs, 1985). Pauw and Adam (2000) reechoed same.

Large-scale irrigation scheme in Nigeria started in the era of River Basin Development Authorities (RBDAs) by the promulgation of RBDAs decree in 1976. This practice met the old age *shaduff* irrigation, which utilizes seasonally flooded land (Fadama) along the rivers and streams (Adewumi, 1990). The large-scale irrigation covers 100kha (10%) and the small scale covered 900kha (90%) of the total land under irrigation in Nigeria (Pradhan, 1993; FAO, 1995). Yet, Mijindadi *et al.* (1993) lamented that about 90% of the total Fadama, resources is unharnessed. Adeniji (2002) also reechoed same.

1.1 Statement of Problem

Until the independence in the 1960, agriculture was the most important sector of Nigerian's economy accounting for more than 50% of her GDP and more than 75% of her exports earnings. The sector entered a relative decline following the rapid expansion of petroleum resources(Adeniji,1990.,FAO-AGL,2002).In spite of the long history of irrigation, targeted at boosting food in Nigeria, food production has not kept pace with the demand for food by the actual and growing population. Population growth rate in Nigeria is estimated at 8% (Olorunfemi *et al*,2004) while food production increases at about 3%(Olorunfemi *et al.*,2004).This could be attributed to crop water stress, water logging and/or diseases among others.

The sources of irrigation water in Nigeria are usually shallow rivers/ponds, lakes, dams and underground water. Most of the rivers/ponds often get dried up untimely; thus inflicting a moisture stress on crops with consequential effect of low yields and economic loss. In many other places, vast tract of fertile irrigable lands are too far from the water resources, making irrigation practice obviously impossible. Lakes and dams (where available) usually provide adequate water for irrigation, but most farmers do over-irrigate thinking that the more they apply, the better the yields (Bashir and Duru, 2000; Mofoke, 2002).This practice leads to soil salinization, water logging, crop diseases and hence reduced yields. Drilling of borehole to adequately supply irrigation water is expensive, thus not affordable by most farmers. Where the borehole is drilled, it usually taps from parched water table, which gets exhausted in a short time due to over-pumping and leaves immature crops wilting on the fields. The over-pumping on the other hand translates to over application, with undesirable results similar to the cases of lakes and dams. The overall result of these situations is yield loss, depression in farmers' economic status and that of their general welfare. This means there is a dwindling availability of irrigation water in appropriate quantity and time. Many crops are sensitive to moisture stress. Potatoes are shallow-rooted crops and are more sensitive to both soil moisture stress and water logging (CSIDC, 2001).

1.2 Justification of the Study

The extensive water loss through evapotranspiration (ET), unskillful handling of irrigation system that often leads to undesired consequence should be reduced. It is therefore essential to develop water management techniques such as irrigation scheduling that would avert water stress on crops and ensure efficient water use.

Mofoke (2000) and Fatai (2001) worked on potato irrigation, but did not recommend any irrigation scheduling for the crop in this region. Therefore there is dearth of information on irrigation water management techniques such as irrigation scheduling and water supply methods for practical purposes.

In Nigeria, potato production is restricted to few locations. This is not unconnected to climatic, soil and water availability problems. In view of the need for increased food production in Nigeria, and potato being a nutritive crop, the demand for it is not met.

1.3 Objectives of the Study

The general objective of this study was to determine the effect of water conserving measures through irrigation scheduling on growth, yield and water use efficiency of Irish Potato.

The specific objectives were:

(i) To determine the optimum moisture required for potato growth and production.

(ii) To develop operational irrigation scheduling for potato in the study area.

(iii) To assess the effect of irrigation scheduling on yield, crop water use and crop water use efficiency of four potato varieties in the study area.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

The increasing demand for clean water (industrial, wildlife, etc) and the increasing environmental awareness and cost of the finite amount of water calls for better management practices. Management can be improved through better irrigation scheduling and prudent field design and operation. The cultural practice of the crop to be planted must also be taken into recognition.

2.2 Irrigation

The primary reason for irrigating crops is to supplement water available from natural sources of water such as rainfall, dew, floods, and ground water (James, 1988; Michael, 1998). The need for irrigation arises where an imbalance occurred between the natural water sources and the evaporative demands of the atmosphere (Fuchs, 1985).

Doneen (1971) and James (1988) both classified irrigation into four broad classes: surface, subsurface, sprinkle, and trickle irrigation. Irrigation is generally concerned with transferring water from a source via conveyance system into the soil within arguable range of root zones of the growing plant (Vipond and Withers, 1974; Shock, 2002).

Surface irrigation is achieved by one of the several water application methods, namely: border, furrow, basin and corrugation. In each of these, water moves freely under gravity over the land surface in an open channel. Sprinkler and trickle systems convey water from the source to the farm under pressure in a network of pipes. While the sprinkler delivers water in form of droplets over the crops, the trickle system on the other hand applies water slowly either directly to the land surface or into the root zone of the crop. The choice of any method is a factor of the soil under consideration, water availability, the type of crop and economy among others (James, 1988).

Sub-irrigation involves the complete control of the water table elevation so that the plants root zone is kept well free from excess water, but is continually supplied with capillary moisture. Soils under such practice must have good vertical and horizontal permeability (Michael 1998). Doorenbos and Kassam (1979) recommended sprinkler and furrow irrigation methods for potato farming. The advantage of one system over the other is determined by adequacy and effectiveness of the system. Irrigation generally involves conception, planning, design, construction, operation and water management (James, 1988).

2.2.1 Furrow irrigation methods

This is accomplished by running water in small channels (furrows) that are constructed along or across the slope of the field. Water infiltrates from the bottom and sides of furrows moving laterally and down wards to wet the soil and to move soluble salts, fertilizers, etc carried with the water (James, 1988). Furrow irrigation works well if the furrow hydraulics is correct for uniformity along the run and if water movement within the soil is predominantly horizontal, into the plant root zone (Vipond and Withers, 1974). Nwokeocha (1995) indicated that the degree of flooding in furrows depends on the shape, size, furrow spacing, land slope and hydraulic roughness of the furrow. The design of furrow irrigation demands the consideration of shape and size of furrows, the advance of the furrows, field slope, and furrow length and field width. While excessively long furrows are discouraged to avoid loss to deep percolation and erosion (Doneen, 1971), high ridges are desirable to avoid overtopping and gives greater volumes of readily drainable soils. It also reduces the damage of root zone due to water logging (Vipond and Withers, 1974). The furrow cross-section ranges from conventional V-shape or trapezoidal shape to flat parabola.

Doneen (1971) reported that the stream should be large enough to allow water run through the furrow rapidly without erosion but should be reduced so that excessive runoff will not occur in the rest of the irrigation. To achieve desirable application uniformity and efficiency in furrow irrigation, the furrow stream size must not exceed the maximum non-erosive stream size which is given by equation (2.1).

$$Q\ max = K/So \qquad (2.1)$$

where:

Q max = Maximum non- erosive stream size (l/m)

So = Furrow slope in the direction of the flow (%)

(2.1)

where:

Q max = Maximum non- erosive stream size (l/m)

So = Furrow slope in the direction of the flow (%)

he flow (%)

K = Unit constant whose value depends on the unit of stream size.

For stream size in l/min, K = 40. (James, 1988).

Nwokeocha (1995) reported that the stream should reach the end of the run in one-fourth of the required contact time to reduce excessive runoff. This is possibly achieved when number of cutback(s) is/are made to the initial flow (Vipond and Withers, 1974). The slope of the furrow should be that which could prevent excessive loss due to deep percolation, runoff and erosion. The choice of slope is largely a function of soil and net depth of water to be applied. Zigzag furrow may be advantageous for heavy soils to slow down the effective advance of the water. For sandy loam and sandy clay loam soil, a slope of 0.40% is recommended (Vipond and Withers, 1974; Melvyn, 1993). The slope should however, be uniform to ensure uniform wetting of the soil and hence maximum irrigation efficiency (Michael, 1998).

Furrow spacing should be done such that it will fit the crops grown and type of machines used. The spacing should be close enough to ensure that water spreads to sides into the ridges and the root zone of the crop to replenish the soil moisture uniformly (Peters, 1994). For crops such as potatoes, maize and cotton; furrows should be spaced between 60 to 90 cm apart (Michael, 1998). The spacing of the furrows is also a factor of the soil type, because water moves down more quickly in less permeable soils than more permeable soils, furrows are therefore to be closer in more permeable soils (Melvyn, 1993).

Generally, furrow irrigation may be classified into straight furrows and contour furrows. Straight furrows are laid along the prevailing land slope; they are best suited when the slope is not more than 0.75 percent. Contour furrows are laid across the slope of the land and are curved to fit the topography of the land (Melvyn, 1993; Michael, 1998). Nwokeocha (1995) indicated that furrow irrigation is further classified based on the method of water application into every furrow irrigation, every furrow with cutback and alternate furrow irrigation. Every furrow irrigation method is the conventional method in which every furrow is irrigated at each irrigation. This method in most cases results into flooding and/or excessive runoff at the lower end of the furrows. To curtail this effect, every furrow irrigation with cutback is recommended, in which the initial stream will be reduced at certain stage of the flow. In the alternate furrow irrigation, water is applied in alternate furrows at successive irrigation events. Thus, during first irrigation, only even numbered furrows are irrigated. Nwokeocha (1995) and Melvyn (1993) reported that alternate furrow irrigation offers the advantage of reducing the total quantity of water applied. It also reduces irrigation duration, labour requirement and plant water stress.

2.2.2 Irrigation scheduling

Water is generally a critical requirement for seed emergence, establishment and consequent performance in terms of crop yield (Afolayan, 1998); the major goal of irrigation is to increase crop production under sustainable system. Irrigation should therefore not only be water application via canals, pipes, etc, but it should include economic utilization of water.

Irrigation offers a considerable direct and/or indirect benefit like alleviating poverty among people and thus raising their standard of living through improved sustainability of crop production. Unfortunately, irrigation commonly fails to yield its promise, fails to repay the investments made into it, and worse still, may directly or indirectly generate serious environmental and/or socio-economic problems. This is due to poor irrigation water management (Barrow, 1993; Ogunwale and Owonubi,1998). For example, Ramalan and Nwokeocha (2000) reported that excessive irrigation results in lack of aeration, surface runoff, deep percolation, build up of water table with consequent decrease in root zone depth, water logging and possibility of salinity. Irrigation water management is therefore very essential.

Mofoke (2000) reported that the operation of farm irrigation system is currently based on either of two principles, both of which seek to answer two classical questions viz.: when to irrigate and how much water to apply per irrigation event. One of the irrigation management principles recommends that irrigation be done as frequently as practicable, if possible, daily; and apply enough water to meet the daily evapotranspiration demand of the crop at hand while preventing salinization of the root zone. This principle is only applicable when water supply is readily available and irrigation/production costs are easily affordable. This is quite difficult in arid and semi-arid zones due to non availability of water. The other principle of irrigation management recommends that water be applied only when the soil moisture content drops to near a “critical point” as influenced by a predetermined Management Allowable Depletion (MAD) and to apply enough water to raise the soil moisture back to field capacity. The critical point varies with crop requirement, soil type and it is influenced by prevailing weather (Melvyn, 1993). This principle is applicable when irrigation water is scarce as consequence of reduced water supply or increasing water cost. This is irrigation scheduling. It determines when to apply water and how much water to apply per irrigation so as to meet the crop water demand (Yonts and Klocke, 1997; Imtiyaz *et al.,* 2000; Stark and King, 2003). Wu and Barragan(1998) therefore added that a well-designed irrigation system cannot achieve its irrigation purpose if the decision on irrigation scheduling is not properly made.

A proper irrigation scheduling is essential for efficient use of limited water resources, energy and other production inputs (James, 1988; Brady and Weil, 1999). The efficient water use translates into increased crop production, decrease in water wastage, and decrease in labour cost and to avoid soil salinization (James, 1988; Ahmad and Heerman, 1992; Michael, 1998; Roger *et al.*, 2002). This means irrigation scheduling offers better crop yields at reduced labour and management costs. It is generally carried out to, either maximize yield per unit applied water or maximize yield per unit land area (Nwokeocha, 1995). This is confirmed by Tama (2002) who said he experienced a dramatic productivity gains in just a space of 12 months and volume of water use reduced by 25% when he changed from the traditional approach of water application to irrigation scheduling; and it is environmentally friendly. Stryker (2001) however, cautioned that improper irrigation scheduling (over- or under-irrigation) generally leads to reduced crop yields, degrade crop quality, encourage disease development and increase in production cost. Roger *et al.* (2002) and Stark and King (2003) reaffirmed same. Irrigation scheduling can therefore transforms a country from a food-deficient to a food surplus nation (Tama,2002; Roger *et al.,* 2002).

2.2.3 Irrigation scheduling approaches.

Rijov *et al.* (1974) presented a summary of irrigation scheduling procedures as follows:

a. Measurements or observations of water deficits in plants.

b. Monitoring soil moisture content until the critical point is reached.

c. Irrigation scheduling based on evapotranspiration rates.

d. Calculated irrigation schedules or irrigation guides.

All of the above procedures are directly or indirectly concerned with soil moisture availability to crops. The plants' growth and appearance, leaf temperature, water potential and stomata resistance are the factors that could be observed from the plants; while the soil factors are soil appearance and feel, soil water potential,and soil water content from the soil. Other factors affecting the decision of irrigation frequency include availability of water supply, crop factors (flowering habit, harvest index and stress sensitivity), irrigation system, soil texture, soil chemical composition, labour and economics (Nwokeocha, 1995). The use of Tensiometers, Neutron Scattering, Cumulative Pan Evaporation, etc are some of the methods of irrigation scheduling. Soil water check book and computer-assisted scheduling are also used (Shock, 2002). Irrigation scheduling is generally based on knowing the crop water use rates and amount of soil water in the root-zone, so that soil water, could be replaced before critical level is reached and over-irrigation is also avoided. This could help ensure better, sustainble, predictable and reliable crop yields.

2.2.4 Cumulative pan evaporation method

Evaporation is the process during which liquid water changes into gas (Michael, 1998). Water will evaporate from land, either bare or covered with vegetation, and also from plants, impervious surface like roofs and roads, open water and flowering stems (Wilson, 1990). Evaporation can be measured directly using evaporation pan. The evaporation pans provide a measurement of the integrated effect of radiation, wind, temperature and humidity on evaporation from specific open water surfaces; plants respond to the climatic variables in a similar fashion (Doorenbos and Pruitt, 1977; Wilson,1990). Not withstanding some differences, with proper settings, the use of pans to predict crop water requirement is still warranted (Doorenbos and Pruitt, 1977; Burman *et al.,*1983).

The British standard pan is 1.83 m in diameter and 610 mm deep filled to a depth of 550 mm and set in the ground so that the rim of the pan projects 76 mm above the ground surface. In the U.S.A., the standard pan (also called class “A” pan) is circular with 1.22 m in diameter and 254 mm deep, filled with water to the depth of 200 mm set on a timber grillage with the pan bottom 150 mm above the ground level. It is made of 22 gauge-galvanized iron (Wilson, 1990; Michael, 1998). The same authors also indicated that the class ‘A’ pan is most widely used and more preferred to others for its accuracy.

The cumulative pan evaporation method for irrigation scheduling is based on selected value of cumulative pan evaporation since the last irrigation. The field is irrigated usually when such selected cumulative pan evaporation value(s) is/are reached. It is based on the fact that the pan evaporation is an estimate of actual crop evapotranspiration (ET crop) (Melvyn, 1993). In a sense, it is a version of soil water budget method, because the selected value(s) of cumulative pan evaporation (CPE) is estimated based on available soil moisture, when the selected value of CPE is reached, it is assumed that the available soil water has been depleted to a level that any further depletion will result into crop water stress and so irrigation is naturally necessary at such level (Melvyn, 1993). Despite its drawback that in assuming no addition to soil moisture by precipitation and/or groundwater, it is suitable for scheduling irrigation for every crop (Cripps *et al.,* 1982; Ahmad and Heerman, 1992; Melvyn, 1993). The reference crop evapotranspiration(ET_O) and the actual crop evapotranspiration(ET_{crop})are obtained from equatrions (2.2) and (2.3) respectively(James,1988)

$$ET_o=k_pE_{pan} \qquad (2.2)$$

And, the actual crop evapotranspiration from

$$ET_{crop}=K_c\,ET_o \qquad (2.3)$$

where :

ET_o = Reference crop evapotranspiration (mm)

K_p = pan coefficient

E_{pan}=Pan Evaporation(mm).

ET_{crop} = Actual crop Evapotranspiration (mm)

K_c = crop coefficient.

Irrigation scheduling, which determines the amount and frequency of irrigation is governed by many complex factors, but climate plays a major role. It is therefore important to develop irrigation scheduling techniques under prevailing climatic conditions. Cumulative pan evaporation method of irrigation scheduling is therefore very suitable(Imtiyaz *et al.,*2000)

2.3 Crop Water Use

Evaporation has been defined in section 2.2.4 and transpiration is the process by which water vapour leaves the body of a living plant and enters the atmosphere (Wilson, 1990). Evapotranspiration (ET) is the term used for the evaporation of moisture from the earth's surface including lakes and streams and the vegetation that cover the land. Consumptive use (CU) otherwise called crop water use (CWU) refers to the combined evaporation and transpiration from vegetation-covered land areas only (Wilson, 1990); but crop water use (CWU) is only 1% greater than evapotranspiration, they are therefore, practically used synonymously(James,1988).

The common cause of water wastage, flood, etc, and the consequent inability of irrigation to contribute significantly in food production, is the failure of the irrigators to take into full account the user's requirement, namely the crop themselves(Adeniji,1992). The knowledge of the rates of crop water use and water-retention characteristic of soil is therefore a fundamental factor in the design of a water supply system and scheduling of irrigation (Vipond and Withers, 1974), this is so because the amount of water applied per irrigation is dependent on the water requirement of the crop at hand (Doorenbos and Pruit, 1977).

Crop water requirement is defined as "the depth of water needed to meet the water loss through evapotranspiration (ET_{crop}) of a disease-free crop, growing in a large field under non-restricting soil conditions including soil water and fertility and achieving full production potential under a given growing environment" (Doorenbos and Pruitt, 1977; Burman *et al.,* 1983). Therefore the knowledge of crop water use is an essential key for irrigation planners and allied workers.

Doorenbos and Pruitt (1977); Burman *et al.* (1980); Wilson (1990) and Michael (1998) contained extensive review of numerous models of estimating the reference evapotranspiration (ET_o). Burman *et al.* (1983);Stocle and Hiller (1994) and Nwokeocha(1995) have identified the combination method as apparently another good approach of calculating ET_o for wide range of climatic conditions due to its strong theoretical basis. Wilson (1990) and Michael (1998) re-echoed some. Potential Evapotranspiration (ET_p) is defined as the maximum rate at which water if fully available, that would be removed from earth's surface, and transpired by actively growing plants that completely shades the ground (Burman *et al.,*1983) The combination method also called modified penman method depends on meteorological measurements.

The original penman equation (Penman, 1948) yielded evaporation from an open water surface, E_o; this was modified to yield evapotranspiration from a grassed land (reference crop evapotranspiration, ET_O) by multiplying E_O by a crop coefficient of about 0.8. The reference crop evapotranspiration is defined as "the rate of evapotranspiration from an extended surface of 8 to 15cm tall green grass of uniform height, actively growing, completely shading the ground and not short of water (Doorenbos and Pruitt, 1977; Wilson, 1990). The modified penman equation is given by equation 2.4 (Doorenbos and Pruitt, 1977., Burman *et al.*, 1983; Wilson, 1990).

$$ET_o=C(W \times Rn + (1-W) X f(a) X (\ell a-\ell d) \qquad (24)$$

where:

C= Adjustment factor

ET_o= Reference crop evapotranspiration (mm/day).

W = Temperature related weighting factor

Rn = Net radiation in equivalent evaporation (mm/day)

F(a)= Wind-related function

(ℓa-ℓd)= Difference between the saturated vapour pressure at mean air temperature and mean actual vapour pressure of the air (mb)

The actual crop evapotranspiration (Crop water requirement) is then determined by equation (2.5) (Wilson, 1990).

$$ET_{crop} = Kc\ ET_o \tag{2.5}$$

Doorenbos and Pruitt (1977) however indicated that equation (2.4) assumes "normal" atmospheric conditions where solar radiation is medium to high (ratio of actual to maximum possible sunshine hours; (n/N) ranging from 0.6 to above 0.8), maximum relative humidity is medium to high (55-70%), and daytime wind speed is moderate (2-5 m/sec) and about double the time wind speed. For climatic conditions other than these, ET_o from equation (2.4) must be adjusted using the adjustment factor (C). The same author has provided a table for the C-values. Kc Values are also available in literatures.

Another approach for directly measuring crop water use that has gained wide acceptance is the soil moisture depletion method. The modern techniques involve the use of neutron probe. This has been discussed in section (2.5.1).

2.4 Stream Size Measurement

Flow measurements in open channels are made possible by creating a control section which causes flow to pass from a sub-critical through critical stage and the discharge become single-valued function of upstream water level. This is possible by the use of flumes (Vipond and Withers, 1974).

A flume is a specially built or installed structure in open channels to obtain a stable stage-discharge relationship for flow measurements (James, 1988). Flumes are generally classified as either short or long throated, depending on the length of the throat section relative to the upstream head.

Kraatz *et al.* (1975) as reported by Abubakar (1992) recommended the use of cutthroat flume developed by Skogerboe *et al.* (1967); that it enables the measurement of irrigation water stream size with greater ease than other flumes. He further urged that cutthroat flume which does not have the longitudinal throat section facilitates stream size measurement and ensures a high degree of accuracy, especially if it is operated under free flow conditions. Equation 2.6 was given for the determination of discharge through the cutthroat flume under free flow conditions.

$$Q = C_f H^n \qquad (2.6)$$

where:

Q = flow rate (m^3/Sec)

C_f = Free flow coefficient

$K_L W^{1.025}$

H = Upstream flow depth (measured at a piezometer tap distance of 2L/9 from flume throat (cm)).

n = Flume exponent (obtained from standard curves of free flow coefficient and exponent for cut-throat flumes).

L = Flume overall length (M)

K_L = Flume length coefficient (obtained from the same curve with'n')

W = flume width (m).

Kraatz *et al*. (1975) also recommended that for accurate discharge measurements, the ratio of flow depth to flume length (Ha:L) should be less equal to 0.4. Higher values of this ratio were found to have resulted into greater inaccuracies.

Abubakar (1992) calibrated a 10 cm cutthroat flume to determine the flow coefficients. Equation (2.6) thus becomes

$$Q = 0.0525Ha^{2.105} \quad (2.7)$$

where:

Q = Stream size (l/s)

H_a = Upstream water depth measured from the installed flume (cm).

2.5 Soil Moisture Instrumentation

2.5.1 Soil moisture determination.

Precise irrigation management depends on soil water monitoring. Soil moisture content is monitored while the field is irrigated when a predetermined deficit is reached. (Vipond and Withers, 1974). Soil moisture can be determined by the methods that determine the soil water content or soil water potential. Soil water content is the amount of water per unit volume of soil or weight of dry soil, and soil water potential is the force necessary to remove the next increment of water from the soil (Shock, 2002). Methods of soil water content determination include Appearance and feel method, Gravimetric, Neutron probe and Electrical resistance. The most widely used is gravimetric method, though accurate and simple, but is destructive, slow, and specific interpretations are necessary (Stewart and Hagan,1974; 1980; Michael, 1998). The appearance and feel method, though fairly reliable and inexpensive, requires significant experience and skills to accurately determine soil moisture levels (Klassen *et al.,* 2003). The Neutron probe (Where available) is another widely used method of soil moisture measurements because it is a rapid means of accurate in-situ measurement of soil moisture (Michael, 1998; Shock (2002). Among the soil moisture measuring techniques, neutron probe method has been identified as the best; it has the advantage of making measurements at various depths of the soil profile, it offers precision in the representatives of the soil water volumes and there is independence of the measurement results from the subjective peculiarities of operators work (Emelyanov *et al.,1*980). The principle of the neutron method is based on the measurement of the number of hydrogen nuclei that are present in a unit volume of soil, the number, being a direct function of the number of water contained in the same volume. When the probe (fast neutron source) is inserted into an access tube, the fast neutrons will collide with nuclei of low atomic weight-the hydrogen in the soil moisture. These fast neutrons will therefore lose energy and are converted into slow neutrons, which are then subjected to scatter and reflection. A detector is used to count these neutrons – the count rate being an indication of the moisture content of the soil. It is necessary to take a standard water count using free water in a container whenever the instrument is to be used in the field for moisture measurements. The actual soil moisture is then computed there from. The instrument must always be calibrated in- situ before field records are taken. A single calibration will be adequate for the season provided the location of use is maintained.

The volumetric moisture content will then be determined using the calibration equation so obtained.

2.5.2 Soil water potential determination

Klassen *et al.,* (2003) indicated that soil water potential has direct correlation with soil moisture content. This means measuring soil water potential implies measuring soil water content. The popular methods of measuring soil water potential include the use of tensiometer, Gypsum blocks, granular matrix sensor, etc (Shock,2002). Tensiometers are the most available instrument among the four listed.

Soil water potential measurement with tensiometer or granular matrix sensors provides a measurement analogous to the force (suction) necessary to extract water from the soil. The force is transmitted from the atmosphere through the plants to the roots. Tensiometer provides a direct measure of the tenacity with which water is held by soil (Michael, 1998). A typical tensiometer consists of a porous ceramic cup filled with water, which is buried in the soil at any desired depth and connected to a water-filled tube to which a vacuum gauge is connected. Before they are installed, a proper hydraulic contact must be ensured between the water in the tube and that in the ceramic cup, this is possibly done by removing all air bubbles in it by allowing it to stay in water for at least 8 hours. This is to avert possible errors in field measurements.

The main draw back of tensiometers is that they have limited range (80Kpa), above which they do not effectively perform (Nwokeocha, 1995). Stryker(2002) advised that tensiometers are temperature sensitive, and readings at different times of the day may vary; as such, readings must be taken consistently at a particular time of the day. Michael (1998) however, indicated that tensiometers do not provide direct information on the amount of water held in the soil; rather they provide information on soil suction only.

Some of the advantages of using tensiometers are the possibility of getting rapid, accurate and non-destructive measurements. And it is probably the best field instrument to use to determine moisture conditions at wet ranges.

2.6 Land Slope Determination

To reduce the effect of erosion, ensure good surface drainage, and unobstructed flow of water infields, land grading is inevitable. It also ensures uniform distribution of water, conserve moisture and increase irrigation system efficiency (Michael, 1998). A suitable Slope should therefore be created in the direction of irrigation. Abubakar (1992) reported equation (2.8) for land slope determination.

$$Sp = \frac{DEP}{DSP} \times 100 \qquad (2.8)$$

where:

Sp = Percent slope (%)

DEP = Difference in elevation between first and last point (mm)

DSP = Horizontal distance between the first and last point (mm)

Safe limits of slope for efficient irrigation are a factor of soil type, irrigation system and hydraulic properties of the channel. Michael (1998) reported 0.05-0.25%, 0.20-0.40% and 0.25-0.65% as the recommended safe limits of land slope for heavy (clay) soils, medium (loam) soils and light (sandy) soil respectively.

2.7 Soil Physical Properties

2.7.1 Soil texture

Benami and Ofen(1984) defined soil texture as the relative proportion of sand, silt and clay contained in a particular soil mass. It is a conventional way of classifying agricultural soils and from which other physical properties such as infiltration capacity, total available water, etc can be estimated or inferred.

Because of variation in soil texture, many soil physical properties that are vital in irrigation planning and execution such as available water (AW), porosity

(P), water holding capacity (WHC), etc differ from one location to another. It is therefore recommended that the soil texture of any project field be determined (Owonubi *et al*., 1994; Klassen *et al*., 2003).

Soil texture determination is made possible by the use of mechanical and wet analysis. The distribution of larger particles can be found by sieve analysis and that of finer particles by settling test based on Stoke's law (equation 2.8) presented by Vickers (1978).

$$V = \frac{H}{T} = \frac{2 \text{ x } (\ell s - \ell_L)\, g\, r^2}{g} \qquad (2.9)$$

where:

V = velocity of fall (cm/sec.)

H = Vertical distance through which the particle falls (cm)

t = Time taken by a particle to fall the vertical distance, H(Sec)

r = Radius of the particle (cm)

V=Viscosity of the liquid (Poise)

ℓs = Specific gravity of the solid particle

ℓ_L = Specific gravity of the liquid

g = Acceleration due to gravity (cm/sec^2)

From Stoke's Law, it is possible to determine the time, t, after which all particles of diameter, D must have settled through a distance, H. When time, t from the start of sedimentation has elapsed, only those particles with diameter less than D will remain at or less than the depth H from the surface. The analysis involves drawing an amount of nine suspensions at a depth H in the suspension container after a time, t and then evaporating to dryness in order to determine the mass of the solid matter. The percentage composition is calculated from the ratio of weight of solid mass in the drawn off sample to the total weight used for the entire suspension. Equation (2.9) is then used to calculate the particle diameter.

The mechanical analysis involves shaking a pre-weight sample in a set of sieves with a mechanical shaker for at least 2 minutes. Samples retained on each sieve will be re-weighed and percentage of each particle size will be taken. The USDA textural triangle is usually used to obtain the textural class of the soil

2.7.2 Total Available Water Capacity

Total available water holding capacity (TAWC) otherwise referred to as Total Available water, water holding capacity(WHC), readily available water(RAW) or simply Available water(AW) is the amount of moisture held between field capacity (FC) and permanent wilting point (PWP). Equation (2.10). (Benami and often, 1984; James, 1988; Michael, 1998).

$$\text{TAWC} = (\text{FC}-\text{PWP}) \times \text{Bd} \qquad (2.10)$$

where:

TAWC = Total available water capacity (mm)

FC = Field capacity (%)

PWP = Permanent Wilting point (%)

Bd = Bulk density of the soil (g/cm^3)

Field capacity is the moisture held in a soil after drainage of gravitational water has become very slow and moisture content has become relatively stable. This situation exists one to three days after rain or irrigation (Michael, 1998). It is regarded as the upper limit of the available moisture range (Roger *et al.*, 2002). It corresponds to soil moisture tension of one- third bars.

Permanent wilting point is the soil moisture content at which plants can no longer draw enough water to meet their transpiration requirements; and remain wilted unless water is added to the soil. It corresponds to soil tension of 15 bars (Michael, 1998; Stryker,2002).

The total available water capacity (TAWC) is the water that is held in the soil by the action of capillary forces. Therefore, fine textured soils have greater TAWC than coarse textured soils because coarse soils release most of their water within narrow range of suction due to predominance of non-capillary microspores.

2.8 Potato Irrigation

2.8.1 Growth cycles and critical stages

Vipond and Withers (1974); Doorenbos and Kassam (1979) and Roger *et al.* (2002) individually indicated that potato has four distinct growth stages. The stages are establishment, vegetative growth, tuber initiation and tuber growth and maturity. The knowledge of the growth stages for every crop is essential in irrigation planning since the crop water requirement differs with growth stage

(Doorenbos and Pruitt, 1977). This will help in reducing risk of possible crop failure or yield depression especially when the critical stages are well taken into consideration.

The critical stage for potato is a factor of grower's/researcher's need. For example for high yield, moisture stress should be avoided during the period of tuber initiation; this however, reduces the average size of tubers considerably (Klassen *et al.,* 2003). Doorenbos and Pruitt (1977) however reported that dry matter formation will be limited if there is water deficit during maturity stage. It is obvious that the grower/researcher has to decide on the quality of potato he is after before starting irrigation scheduling. The general critical stage is from tuber initiation to yield formation.

2.8.2 Irrigation frequency and water requirement

To achieve appreciable crop water use efficiency and high production, the water supply schedules must be adjusted in accordance with the crop water requirements over the growing periods. Shock (2002) reported that irrigating potatoes at less than crop water requirement resulted into sharp decrease in yield, quality grade and profitability. This is in agreement with the fact that irrigation interval is a factor of soil properties, weather, and crop factors (Roger *et al.*, 2002). The soil factors include soil textures, percent organic matter present, soil structure and hence water holding capacity; the weather parameters are temperature, wind speed, relative humidity, solar radiation and sunshine hours.

The crop factors are growth stages, rooting depth, and hence crop water requirement.

Potatoes are shallow feeders and very sensitive to soil moisture stress (Doorenbos and Pruitt, 1977; CSIDC, 2001; Roger *et al.,* 2002) that a mere deviation from optimum water application can lead to considerable decrease in yield, quality and grade (Shock, 2002). Proper irrigations scheduling is therefore necessary to ensure adequate water supply to the crops.

2.9 Evaluation of Irrigation System Performance.

Irrigation systems are designed and operated to supply the individual irrigation requirement of each field on the farm while controlling deep percolation, runoff, evaporation and operational losses (James, 1988). The performance of a farm irrigation system is determined by the efficiency with which water (from the source) is diverted, conveyed and supplied, and by the adequacy and uniformity of application (Doorenbos and Kassam, 1979; James, 1988).

2.9.1 Overall efficiency

The overall efficiency of a farm irrigation system is defined as the percent of water supplied to the farm that is beneficially used for irrigation on the farm.

Farm irrigation systems are designed and operated to supply the individual irrigation requirements of crops on the farm while controlling deep percolation, runoff, and operational losses. The performance of irrigation is determined by its efficiency (Doorenbos and Kassam, 1979; James, 1988).

The application of least amount of water required to bring the root zone back to field capacity is considered as efficient irrigation. If on the other hand, the amount of water applied grossly exceeds that actually needed to replenish soil back to field capacity; the irrigation efficiency is, then very low(Doneen, 1971). Irrigation efficiency therefore measures how well the water supplied to the field is beneficially used by crops (Roger *et al.*, 2002). Stewart and Hagan (1974) and James (1988) defined irrigation efficiency as it is in equation(2.11).

$$\text{Irrigation Efficiency}=\frac{\text{ET (From irrigation water applied)}}{\text{Irrigation water applied}}\text{X}100\% \quad (2.11)$$

Equation (2.11) points that irrigation efficiency would be 100% if all the water applied is used up. Vaux and Pruitt (1983) however, reported that irrigation efficiency may decrease as potential evapotranspiration is approached, and so for potential yield to be achieved, the field water supply must be greater than the potential evapotranspiration (ET_P). Perrier and Salkini (1991) discovered that low irrigation efficiency will also reduce yield, possibly due to water logging, fertilizer leaching, erosion, etc; however, irrigation practices with highest irrigation efficiencies are not always desirable since they do not always maximize net profit (James, 1988). Consequently a satisfactory irrigation practice is not one that necessarily gives a high efficiency approaching 100%, nor the one with very low efficiency. James (1988) lamented that irrigation efficiency in the neighborhoods of 80% is adequate. It is however unlikely that water application would be perfectly uniform. Non-uniform application increases losses due to deep percolation and runoff in over irrigated areas and reduces these losses in under irrigated areas.

2.9.2 Application efficiency.

Water application for irrigated farm is the ratio, in percent, of the volume of water beneficially used by the crop to the volume of water delivered to the area. When translated into depth of water, it is mathematically given as:

$$E_a = \frac{V_b}{V_a} \qquad (2.12$$

where: V_b=Depth of water stored in the plants' root zone (mm).

V_a=Depth of water applied by irrigation (mm)

2.9.3 Application uniformity.

This describes how evenly an application system distributes water over the field. The Uniformity of application is evaluated with the use of Christiansen uniformity coefficient (CU).

2.9.4. Adequacy of irrigation.

This is the percent of the field receiving sufficient water to maintain the quantity and quality of crop production at profitable level. This definition reflects soil, crop and market conditions; so it is redefined as the percent of the field receiving the desired amount of water or more.

2.10 Water Use Efficiency

This is an efficiency index that is used to judge how well crops can attain adequate yields at the least level of water consumption (Ramalan and Nwokeocha, 2000). It was presented as the mass ratio of crop yield to water use (Michael, 1998). The same author indicated the term "water use" could either mean field water use or actual crop water use efficiency hence demarcating between field water use efficiency (FWUE) and Crop water use efficiency (CWUE). Only the crop WUE is reported herein.

Crop water use efficiency (CWUE) can then be expressed mathematically as:

$$CWUE = \frac{Y}{ET_C} \qquad (2.13)$$

where :

CWUE = Crop water use efficiency (kg/ha-cm; t/ha-mm)

Y = Marketable yield (kg/ha; t/ha)

ET_c = Crop water use (cm; mm)

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

The study area, climate of the study area, description of field layout, cultural practices and experimental procedure are presented in the following section. Growth parameters (Days to 50% germination, Days to 50% flowering, Days to 50% tuberisation), Yield and yield components (total yields, size separations, mean tuber weights, and total number of tubers) are presented. Irrigation performance parameters are established.

3.2 Study Area

The field experiment was conducted during the cool dry season of 2003/2004 at Irrigation Research Farm of the Institute for Agricultural Research, Samaru – Zaria. The location is at 11^{o} 11′ N and 07^{o} 38′ E, 686 m above the sea level in the northern guinea Savanna-Nigeria. The climate of the site is described as semi-arid. The cool, dry season begins by October and ends by April.

3.3 Description of Field Layout

The experimental farm comprised of 0.1125 ha size measuring 45 x 25 m. The entire field was ploughed and ridged with furrow spacing of 0.75 m as described in Eberiem *et al.* (1995); Meith *et al.* (1993) and Rhoades *et al.* (2002). It was then divided into four blocks, each running 10 m long. A total of 48 plots were marked out for the study. Each plot consisted of three ridges measuring 22.5 m^2. A ridge was used to separate one plot from the adjacent one. (Figures 1 and 2).

3.4 Experimental Design and Treatments

The experiment consisted of factorial combination of irrigation schedules and varieties of Irish potatoes laid in a randomized complete block design resulting into sixteen treatments. The treatments were randomly assigned to plots and were replicated three times. Each replication was separated from another by two buffer ridges. Irrigation scheduling was at four levels, namely cumulative pan evaporation/irrigation ratios (CPE/IR) of 0.4 for cumulative pan evaporation (CPE) 20 mm, CPE/IR of 0.6 for CPE of 30 mm, CPE/IR of 0.8 for CPE of 40 mm and a fixed interval of 7 days. The four levels of potato varieties were Pakistan, Nicola, SP and Dual. Each treatment had resulted into net depth of application of 50 mm. Daily evaporations from pan were collected at Samaru weather station and added cummulatively, and water was applied to plots whenever the CPE value designated to them was reached since the last irrigation.

The conventional straight furrow irrigation method was used. All plots were irrigated uniformly from planting till treatments were imposed when the plants were fully established.

Two water supply methods were also used. They were on-demand and Rotational. The On-demand consisted of irrigating at CPE of 20 mm, 30 mm and 40 mm while the Rotational was based on 7 days fixed interval as described in Ahmad and Heerman (1992).

3.5 Soil Physical and Chemical Properties

Soil samples were taken from the field at an incremental depth of 15 cm from the soil surface to 90 cm depth. These samples were used for the determination of textual class, bulk density, available moisture (AW), soil pH, electrical conductivity (EC) and cation exchange capacity (CEC).

The core method was used for determination of bulk density. Mechanical analysis was used for textural class determination based on USDA textural classification system.

3.6 Stream Size Measurements

A 100 mm cutthroat metal flume was used to measure the head and hence the volume of water diverted into each plot at each irrigation. A plot was irrigated at a time. Equation (2.7) was used to compute the stream size applied. The flume was calibrated and flow coefficients of the equation were determined.

3.7 Soil Moisture Measurement

Soil moisture measurement was carried out using neutron meter as described by Emelyanov *et al.* (1980). The principles of operation was discussed in (2.5.1). Galvanized access tubes 10 cm in diameter were installed at the center of each plot to a depth of 1 m. Moisture content readings were taken just before every irrigation and two days after irrigations at an incremental depth of 15 cm from the soil surface down to 90 cm. Standard water counts were taken at the beginning of every moisture reading.

3.8 Cultural Practices

The entire field was ploughed and ridged with furrow spacing of 0.75 m. Plots and replicates were marked out and labelled in accordance with the design.

The four potato varieties (Pakistan, Nicola, SP and Dual) were chemically dressed against fungal, bacterial, etc attack and planted by the sides of the ridges; intra spacing was 30 cm, thus, there were 100 stands per plot.

NPK fertilizer (25:10:10) was used at the dose of 100 kgN, 90 kgP and 80 kg K. 50 % of these doses were incorporated with soil during the tillage operations and the remaining 50 % was applied as side dressing four weeks after planting. Weeding was carried out manually three times throughout the growing season. Single harvesting was used.

3.9 Design Calculations

For the loamy soil (Appendix 1)

FC = 19.86% by weight (figure 3)

PWP = 4.96% by weight (figure 3)

Bd = 1.57 g/cm^3

MAD for potatoes = 35% (Roger *et al*., 2002)

Depth of root zone = 60 cm = 0.6 m (Roger *et al*., 2002)

NWR = (FC-PWP) x Bd x Drz x MAD.

$\therefore$NWR =(19.86-4.96) x 1.57 x 10 x 0.6 x 0.35 = 49.13 ≈ 50 mm

where:

NWR = Net water requirement (mm)

FC = Field capacity (% by weight)

PWP = Permanent wilting point (% by weight)

Bd = Bulk density (g/cm^3)

Drz = Depth of Root zone (m)

MAD = Maximum Allowable depletion (%)

3.10 Application Time

Furrow Area = Furrow length x furrow spacing.

$=10\ \text{m} \times 0.75\ \text{m}$

$=7.5\ \text{m}^2$

Volume of water per furrow = Furrow area x net depth of water to be applied.

$=7.5\ \text{m}^2 \times 0.05\ \text{m}$

$=0.375\ \text{m}^3$

$=375\ \text{l}$

$$\text{Application time, } T = \frac{\text{Volume of water applied per furrow (l)}}{\text{Stream size (l/s)}}$$

$$T = \frac{375\text{(l)}}{3\ \text{(l/s)}}$$

$T=125$ sec

$T=2$ min,0.8 sec

$T \approx 2$ min

3.11 Statistical Analysis

All relevant data collected were subjected to statistical analysis of variance as described by Snedecor and Cochran(1967). Differences among the treatment means and their interactions were separated using Duncan's Multiple Range Test (DMRT).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Introduction

The effects of the four levels of irrigation schedules on four varieties of Irish potatoes were examined to determine their responses in terms of growth parameters (Days to 50 percent germination, Days of 50 percent flowering, Days of 50 percent tuberisation), yield components (total yields, tuber sizes: grading (less than 25.4 mm, greater than or equal to 25.4 mm but less than 50.8 mm, greater than or equal to 50.8 mm but less than 76.2 mm, greater than or equal to 76.2 mm but less than 101.6 mm), total number of tubers, mean tuber weights)); water application parameters (irrigation intervals, number of irrigations, seasonal water applied, crop water use, crop water use efficiency and irrigation efficiency.

4.2. GROWTH PARAMETERS

4.2.1 Days to 50%Germination,50% Flowering and 50 % Tuberisation

The results of varietal treatments on days to 50 percent germination since planting are presented in Table 4.1. The Table shows that days to 50% germination were significantly different among the varieties at 1 percent level of significance. Dual used the least number of days to achieve 50 percent germination. This was followed closely by the variety Pakistan.

Table 4.1 Days to 50 % germination, days to 50 % flowering and days to 50% tuberisation as affected by varieties and irrigation schedules.

Treatments	Days to 50% germination.	Days to 50% flowering.	Days to 50% tuberisation.
varieties			
Pakistan	18.17b	63.43b	43.83b
Nicola	18.33b	NF	48.83b
SP	23.67a	70.42a	49.58a
Dual	17.12b	NF	42.58b
Significance	**	**	**
L.S.D.(p=0.01)	99.5	99.1	99.8
Irrigation schedules			
CPE 20 mm	NE	NE	48.58
CPE 30 mm	NE	NE	46.75
CPE 40 mm	NE	NE	46.75
Fixed 7-days	NE	NE	46.75
Significance			NS
L.S.D.(p=0.01)			

Note

* * = Significant at 1 percent level

NE = No Effect.
N F = Non Flowering variety.
NS = Not Significant.

and Nicola, that were statistically at par. SP used the highest number of days to attain 50 percent level of germination. The varietal difference purely accounted for the germination differences.

Irrigation scheduling treatments had no effect on germination, as the schedules were imposed after the germination.

Only two varieties were observed to have flowered among the four varieties studied, this is traced to the genetic properties of the varieties. The Table also shows that flowering was significantly different between the two varieties. Pakistan took least number of days to reach 50 % flowering compared to SP (the second variety that flowered)

Irrigation scheduling treatments again showed no effect on flowering, as flowering started only few days after scheduling treatments were imposed.

Days to 50 % tuberisation was significantly different among the varieties. Dual achieved 50 % tuberisation in the least number of days from sowing, and it was statistically at par with Pakistan and Nicola. SP used up the longest period with additional eight days over that of Dual to attain 50 % tuberisation, it was last to complete its tuberisation. Irrigation scheduling treatments were not statistically different with respect to days to 50 % tuberisation, nonetheless, the fixed 7- days rotational irrigation was found to have resulted into 50 % tuberisation some few days earlier than irrigating at CPE 20 mm. The result of irrigating at CPE 30 mm and CPE 40 mm on 50% tuberisation were similar. The relatively shorter irrigation intervals from the CPE-based irrigation scheduling was found to have encouraged crop vegetative growth, this had led to retardation in tuberisation. Doorenbos and Kassam(1979) and Lynch *et al.*(1995) individually had a similar observation.

4.3 YIELD AND YIELD COMPONENTS

4.3.1 Total Yields

The data in Table 4.2 shows the treatment effects on the total yields. Both varietal and irrigation scheduling treatments are not significant. This is possible due to genetic properties and proper cultural practices. However, Dual yielded highest among all the varieties, followed by Nicola, Pakistan and SP in that order.

The results of all irrigation scheduling treatments were statistically similar with respect to the total yields, but irrigating at CPE 20 mm yielded highest among all the irrigation scheduling treatment. It was also observed that there was yields decrease with increase in cumulative pan evaporation (CPE) values. Fixed 7-days resulted into the least net return with 40% loss when compared to that from irrigating at CPE 20 mm. This was expected, as increase in CPE values directly translates to increase in irrigation intervals, which in turn translates into decrease in available water (AW) with consequence of crop water stress. This result agrees with the findings of Mouromical and Ierna (1995) that discovered that tuber yields were higher with lower irrigation regime. Similarly, Gregory and Simmonds(1992) found that the fresh yield of Irish potatoes are generally proportional to the water they received.

Table 4.2 Main effects and interactions of varieties and irrigation schedules on the total yields of Irish potatoes.

Treatments	**Yields (t/ha)**
Varieties	
Pakistan	3.48
Nicola	3.78
SP	3.32
Dual	4.54
Significance	N.S.
L.S.D. (p = 0.05)	
Irrigation Schedules	
CPE 20 mm	4.89
CPE 30 mm	3.73
CPE 40 mm	3.50
Fixed 7-days	3.49
Significance	N.S
L.S.D (p = 0.05)	
Interactions	
Varieties X Irrrigation schedules	NS

Note

N S = Not significant

They also lamented that increasing water supply increased leaf transpirations, tuber growth, number of tubers and hence higher yield.

The result is also in accord with the observations of Sharma and Dixit (1992), who found that irrigating at CPE 33 mm produced higher tuber yields compared to that of CPE 40 mm, 50 mm and 66 mm respectively. This is because there was a gradual depletion of total available soil water during growth period, which normally showed a consequent result of decrease in yield (FAO-AGL 2002). But both Sharma and Dixit (1992) and Mouromical and Irena (1995) showed that there was no statistical difference among irrigation scheduling treatments. Neibling and Brooks (1994) and Muhammed *et al.* (2002) also reported tuber yield differences due to irrigation scheduling treatments.

4.3.2 Effects of interactions of irrigation schedules with varieties on total yields

The interaction of varieties and irrigation schedules was not significant. Irrigating Dual at CPE 20 mm had resulted in the highest yield (Table 4.3). The worst combination was irrigating Pakistan at CPE 30 mm that produced the least yield. However, irrigation at CPE 30 mm happened to be the optimum irrigation schedule for Nicola and SP. The 7-days rotation had resulted into 50% loss of yields over Pakistan and Dual, but had favoured the yield of SP and Nicola with a difference of 80% when compared to CPE 20 mm. Generally, increasing the CPE value by a step of 10 mm translated to decrease in the total yields.

Table 4. 3 The effects of interactions of irrigation scheduling with varieties on total yields (t/ha).

Irrigation Schedules	**Varieties**			
	Pakistan	**Nicola**	**SP**	**Dual**
CPE 20 mm	4.93ab	3.60c	2.60c	6.40a
CPE 30 mm	2.53c	4.70ab	3.76c	3.93c
CPE 40 mm	2.80c	2.90c	3.60c	4.70ab
Fixed 7-days	3.63c	3.90c	3.30c	3.13c

Note: All means followed by the same letter(s) in the same column are not statistically different.

Table 4.4 Effects of treatments on yields of potatoes (t/ha) in relation to tuber sizes less than 25.4 mm.

Treatments	Tuber sizes less than 25.4 mm
Varieties	
Pakistan	0.18
Nicola	0.22
SP	0.17
Dual	0.24
Significance	N.S.
L.S.D. (p = 0.05)	
Irrigation Schedules	
CPE 20 mm	0.22
CPE 30 mm	0.21
CPE 40 mm	0.19
Fixed 7-days	0.19
Significance	N.S
L.S.D p = 0.05)	

Note

NS = Not significant

4.3.3 Tuber sizes less than 25.4 mm in diameter.

The result of tuber sizes less than 25.4 mm as affected by treatment is presented in Table 4.4. It was observed that both the varietal treatments and irrigation scheduling treatments were statistically similar at 5 percent level of significance. Genetic properties of the varieties could account for this. However, Dual yielded highest and it was followed closely by Nicola, Pakistan and SP in that order.

Irrigation at CPE 20 mm resulted into highest tuber sizes less than 25.4 mm in diameter. The yield decreased with increase in CPE values. Fixed-7days irrigation scheduling gave the least tuber yields of this size. This is similar to the observations of Doorenbos and Pruitt (1977) and Doorenbos and Kassam (1979). Differences in yield between all the treatments were less than 20%.

4.3.4 Interactions of irrigation schedules with varieties on tubers less than 25.4 mm in diameter

The highest yield of this tuber size came from Dual when irrigated at CPE 20 mm, and had out yielded Pakistan by a fctor of 30 % at this CPE value. It had however suffered 100 % loss of yield when irrigated using the 7-days rotational irrigation. Pakistan also performed best at CPE 20 mm and out yielded SP by 90 % and Nicola by 30 %. Its yield was depressed by 70 % when the CPE value was increased by a step of 10 mm. Nicola yielded best when irrigated at CPE of 40 mm but it showed a 100 % yield loss when irrigated at 7-days rotational irrigation.

Generally, there was a trend of reciprocal relationship between irrigating at CPE values and yields of all the varieties, except for Nicola and SP which exhibited their best performance at CPE 30 mm but their yields dropped thereafter.

Table 4.5 The effects of interactions of irrigation scheduling with varieties on yields of potatoes (t/ha) in relation to tuber sizes less than 25.4 mm in diameter.

Irrigation Schedules	Varieties			
	Paskistan	**Nicola**	**SP**	**Dual**
CPE 20 mm	0.25c	0.19c	0.13c	0.32a
CPE 30 mm	0.13c	0.46a	0.19c	0.21c
CPE 40 mm	0.14c	0.25c	0.18c	0.24c
Fixed 7-days	0.21c	0.21c	0.19c	0.16c

Note: All means followed by the same letter(s) in the same column are not statistically different.

Table 4.6 Effects of treatments on yields of potatoes (t/ha) in relation to tuber sizes greater or equal to 25.4 mm but less than 50.8 mm in diameter

Treatments	Tuber sizes greater or equal to 25.4 mm but less than 50.8 mm in diameter
Varieties	
Pakistan	
Nicola	1.49c
SP	2.56b
Dual	2.19b
Significance	3.15a
L.S.D. (p = 0.05)	*
	95.9
Irrigation Schedules	2.24
CPE 20 mm	2.17
CPE 30 mm	2.45
CPE 40 mm	2.54
Fixed 7-days	N.S
Significance	

Note

N.S = Not significant

* = Significant at 5 percent level

4.3.5 Tuber size greater than or equal to 25.4 mm but less than 50.8 mm in diameter

Treatment effects on tuber sizes between 25.4 mm and 50.8 mm in diameter are presented in Table 4.6. It was found that the varietal differences had affected the tuber sizes between 25.4 mm and 50.8 mm in diameter significantly at 5 percent level of significance. Dual was leading and had out yielded Pakistan by a factor of 70%. Nicola and SP statistically were similar.

Irrigation scheduling treatments did not influence tuber size between

25.4 mm and 50.8 mm in diameter. Fixed 7-days scheduling resulted into highest yield of this size range. It was followed by irrigating at CPE 40 mm, CPE 30 mm and CPE 20 mm in that order. Increasing CPE value in step of 10 mm depth did not translate into yield advantage in this size range.

Table 4.7. Effects of interactions of irrigation schedules with varieties on yields of potatoes(t/ha) in relation to tuber sizes greater than or equal to 25.4 mm but less than 50.8 mm in diameter.

Irrigation schedules	**Varieties**			
	Pakistan	Nicola	SP	Dual
CPE 20 mm	1.37c	2.42c	1.50c	3.64a
CPE 30 mm	1.00c	2.37c	2.36c	2.96c
CPE 40 mm	1.16c	2.50c	2.53c	3.60ab
Fixed 7-days	2.44c	2.96c	2.38c	2.39c

Note: All means followed by the same letter(s) in the same column are not statistically different.

Table 4.8 Effects treatments on potato tuber sizes greater than or equal to 50.8 mm but less 72.6 mm in diameter

Treatments.	**Tuber sizes greater than or equal to 50.8 mm but less 72.6 mm in diameter**
Varieties	
Pakistan	1.43a
Nicola	0.98b
SP	0.89b
Dual	1.17b
Significance	**
L.S.D. (p = 0.05)	99.4

Irrigation schedules	
CPE 20 mm	1.53a
CPE 30 mm	1.16b
CPE 40 mm	0.91b
Fixed 7-days	0.79b
Significance	**
L.S.D (p = 0.05)	99.1

Note

NS = Not significant
** = Significant at 1 percent level
* = Significant at 5 percent level.

4.3.6 Interaction effects of irrigation schedules with varieties on tuber sizes greater than or equal to 25.4 mm but less than 50.8 mm in diameter.

Irrigating Dual at CPE 20 mm produced the highest yield of this size range, and had out yielded Pakistan by a factor of 165 %. Similar patterns were observed with other CPE values. However, all the varieties were at par when irrigated at the 7-days interval.

4.3.7 Tuber sizes greater than or equal to 50.8 mm but less than 76.2 mm in diameter

The result of yield of tuber sizes greater than 50.8mm in diameter but less than 76.2 mm in diameter is presented in Table 4.8. The Table indicated that this size range was affected by both varietal differences and irrigation scheduling at 1 percent level of significance. Pakistan produced largest yield of this tuber sizes and this was followed by Dual. Nicola and SP varieties were statistically at par with their yields about 50 % lower than Pakistan. SP yielded least of this tuber sizes.

The differences among the irrigation scheduling treatments were significant at 1 percent level, with the result of irrigating at CPE 20 mm having the overall top yield. Successive increase in CPE values by 10 mm translated to yield decrease. The fixed 7-days rotational irrigation resulted into 94 % yield loss compared to that from CPE 20 mm. The results of irrigating at CPE of 30 mm, CPE 40 mm and the fixed 7-days were however statistically at par.

Table 4.9. Effects of interactions of irrigation scheduling with varieties on potato yields (t/ha) in relation to tuber sizes greater than or equal to 50.8 mm but less than 76.2 mm in diameter.

Irrigation schedules	varieties			
	Pakistan	Nicola	SP	Dual
CPE 20 mm	2.18a	0.91c	0.68c	2.33a
CPE 20 mm	1.12c	1.32ab	1.21c	0.99c
CPE 20 mm	1.23c	0.25c	0.89c	0.79c
Fixed 7-days	1.20c	1.08c	0.77c	0.58c

Note: All means followed by the same letter(s) in the same column are not statistically different.

Table 4.10. Treatment effects on yields of potato (t/ha) in relation to tuber sizes greater than or equal to 76.2 mm but less than 101.6 mm in diameter.

Treatments	Tuber sizes greater than or equal to 76.2 mm but less than 101.6 mm in diameter.

Varieties	0.49a
Pakistan	0.27b
Nicola	0.04b
SP	0.01b
Dual	*
Significance	95.5
L.S.D. (p = 0.05)	
Irrigation Schedules	
CPE 20 mm	0.33
CPE 30 mm	0.26
CPE 40 mm	0.14
Fixed 7-days	0.09
Significance	NS
S.D (p = 0.05)	

Note

NS = Not significant

* = Significant at 5 percent level

* * = Significant at 1 percent level.

4.3.8 Interactions of irrigation schedules with varieties on tuber sizes greater than or equal to 50.8 mm but less than 72.6 mm in diameter.

With exception of Nicola and SP, which showed best perforrmance when irrigated at CPE 30 mm, there was a general trend of yield decrease with increase in CPE values (Table 4.9) However, Dual had the highest yield when irrigatedat CPE 20 mm, but its yield diffrences at CPE 30 mm, CPE40 mm and the fixed 7-days were statistically at par. Also at CPE 20 mm Pakistan was at par with Dual, but had a 95 % yield loss when irrigated at CPE 30 mm. The yields of thwe varieties were statistically similar when irrigated at 7-days rotational basis.

4.3.9 Tuber sizes greater than or equal to 76.2 mm but less than 101.6 mm in diameter

Pakistan produced the overall top yield of this size range(which is the largest tuber size range) at 5 % level of significance(Table 4.10). It was follwed by Nicola, SP and Dual in that order.Dual which topped the total yields (Table 4.2) performed drastically low compared to all other varieties studied at this size range.

Irrigating at CPE 20 mm had resulted into the highest yield of this tuber sizes. But increasing the CPE value by a step of 10 mm translated to successive decraese in yield. The fixed 7-days rotational irrigation exhibited the poorest performance here with 267 % loss compared to that from CPE 20 mm.

Table 4.11. Effects of interactions of irrigation scheduling with varieties on yields (t/ha) of potatoes in relation to tuber sizes greater than or equal to 76.2 mm but less than 101.6 mm in diameter.

Irrigation Schedules	Varieties			
	Pakistan	Nicola	SP	Dual
	1.13a	0.09c	0.00c	0.10c

CPE 20 mm	0.27c	0.78b	0.00c	0.00c
CPE 30 mm	0.27c	0.00c	0.00c	0.07c
CPE 40 mm	0.28c	0.23c	0.03c	0.00c
Fixed 7-days				

Means followed with the same lettter(s) within a column are not different at 5% level.

Table 4.12 Treatment effects on total number of tubers

Treatments	**Total Number of Tubers**
Varieties	
Pakistan	171.33
Nicola	173.00
SP	195.42
Dual	221.42
Significance	NS
L.S.D. (p = 0.05)	
Irrigation Schedules	
CPE 20 mm	203.92
CPE 30 mm	198.00
CPE 40 mm	186.50
Fixed 7-days	181.75
Significance	NS
L.S.D (p = 0.05)	
Interaction	
Irrigation Schedules X Varieties.	
Significance	N.S

Note

NS = Not significant
* = Significant at 5 percent level
** = Significant at 1 percent level.

4.3.10 Interactions effects of irrigation schedules with varieties on tuber sizes greater than or equal to 76.2 mm but less than 101.6 mm in diameter

The best yield of this size range was obtained from Pakistan when irrigated at CPE 20 mm. Its yield differences at CPE 30 mm, CPE 40 mm and fixed 7-days were statistically at par, but lost yields by a factor of 300 % for this size range compared to that from irrigation at CPE 20 mm. The largest tuber sizes of Nicola were obtained when irrigated at CPE 30 mm, at which it out yielded Pakistan by 189%. SP and Dual generally exhibited poorest performance of this size range (Table 4.11)

4.3.11 Number of Tubers

There was no statistical difference among both the varietal and irrigation scheduling treatments with respect to total numbers of tubers. Non-theless, Dual produced the highest overall number of tubers, followed by SP, Nicola and Pakistan in that other (Table 4.12).It was observed that variety Pakistan produced the highest yields of the largest tuber sizes, had low total number of tubers.

There was a decrease in total number of tubers with increase in cumulative pan evaporation (CPE) value; thus irrigating at CPE 20 mm ranked first with the largest number of tubers. CPE 30 mm and CPE 40mm followed immediately. Fixed 7-days rotational irrigation yielded the least total number of tubers. This means the longer irrigation interval did not encourage production of large number of tubers.

All possible interactions of irrigation schedules with varieties on total number of tubers were not significant.

4.3.12 Mean Tuber Weight

The mean tuber weights were generally statistically similar among the varieties studied. However, Dual produced the heaviest tubers (Table 4.13).This was followed closely by Nicola and Pakistan; SP which was 40 % lighter than Dual, had the lowest tuber weight. This could be due to genotypic varietal differences in resistance or tolerance to production environment. Benoit *et al*. (1983) observed same. Shock and Feibert (2002) who lamented that genotypic difference could lead to differences in yield and yield components, buttressed this result.

Table 4.13 also showed that irrigating at CPE 20 mm produced heaviest potato tubers. But increasing the CPE value by 10 mm translated in to decraese in tuber wieghts. There was therefore a general trend of reciprocal relationship between the mean tuber weights and CPE valus. Irrigating at the fixed 7-days resulted in to the least tuber weights.This result is similar to the observations of Miller and Martin (1983) who found that variation in irrigation amount and/or intervals will result into significant reduction in yields and tuber weights. Benoit *et al.* (1983) also stated that relatively drier soils during production periods results in limited number of tubers and lower grades. And yield and grade respond linearly to water application (Shock and Ferbert, 2002).

Table 4.13 Treatment effects on mean tuber weights

Treatments	Mean Tuber Weights (g)
Varieties	
Pakistan	29
Nicola	34
SP	25
Dual	35
Significance	NS
L.S.D. (p = 0.05)	
Irrigation Schedules	
CPE 20 mm	34.00
CPE 30 mm	32.08
CPE 40 mm	31.25
Fixed 7-days	28.33
Significance	NS
L.S.D (p = 0.05)	

Note = Not significant

* = Significant at 5 percent level
* * = Significant at 1 percent level.

Table 4.14 Effects of interactions of irrigation scheduling with varieties on mean tuber weights (g)

Irrigation Schedules	**Varieties**			
	Pakistan	**Nicola**	**SP**	**Dual**
CPE 20 mm	42.00ab	25.67c	20.7c	47.67a
CPE 30 mm	23.77c	44.67ab	32.68ab	27.33c
CPE 40 mm	26.77c	32.67ab	22.00c	32.00ab
Fixed 7-days	26.67c	35.33ab	29.33c	33.67ab

4.3.13 Effects of interactions of irrigation schedules with varieties on mean tuber weights.

Irrigating Dual at CPE 20 mm produced the heaviest tubers, this was followed by Pakistan(Table 4.14). But both of them lost about 70 % weights when irrigated at CPE 30 mm, the level at which Nicola and SP had its heaviest tubers. The least tuber weights were from SP when irrigated at CPE 20 mm. Obviosely, irrigating at CPE 20 mm was too frequent for Nicola and SP, but was optimum for Pakistan and Dual.

4.4.1 Irrigation frequency, seasonal depth of water applied, irrigation intervals, seasonal volume and irrigation efficiency.

The effects of irrigation scheduling on number of application and seasonal depth of water applied are as presented in table 4.15. The number of irrigation applications were statistically different at 1 percent level. Irrigating at cumulative pan evaporation (CPE) 20 mm had the highest number of irrigation events. This is possible because CPE 20 mm could easily be attained in very short days, especially in the semi-arid and arid zone of the tropical region with high temperatures and low humidities respectively. The CPE 20 mm was followed by CPE 30 mm and 40 mm respectively, while the Fixed 7-days schedule used up the least number of irrigations events. This is so because, inspite of the high temperature and humidities (Appendix 4) 7-days irrigation interval was the longest period before the next irrigation, and consequently had the least number of irrigation applications.

Table 4.15 Effects of irrigation scheduling on irrigation frequency, seasonal depth of water applied, irrigation intervals, seasonal volume of water and irrigation efficiency

TREATMENTS	No.of applications	Seasonal depth Of water applied (mm)	Irrigation intervals (Days)	Seasonal volume of water (m^3)	Irrigation Efficiency (%)
Irrigation schedules.					
CPE 20 mm	18a	900a	3.18b	243a	61.522a
CPE 30 mm	16b	800b	3.86b	216b	52.55b
CPE 40 mm	15b	750b	4.67b	202.5b	45.56b
Fixed 7-days	12b	600b	7.0a	162b	48.32b
Significance	**	**	*	*	**
L.S.D.(p=0.05)	99.4	99.7	95.33	97.67	99.2

Note

NS = Not significant

* = Significant at 5 percent level.

** = Significant at 1 percent level.

The Table also showed that the seasonal depth of water applied was statistically different among the levels of irrigations schedule treatments.

Similar to number of irrigation applications, seasonal depth water had a reciprocal fashion to cummulative pan evaporation (CPE) values. The Fixed 7-days which had the least number of irrigation, evidently had the least seasonal depth of water applied.

Irrigating at CPE 40 mm resulted into the longest irrigation interval of 4 days and at CPE 20 mm resulted into the shortest irrigation interval of 3 days. The Fixed 7-days remained 7 days interval. Although the result showed that CPE 20 mm and CPE 30 mm had only one day irrigation difference, they were however statistically different, as 24 hours delay for irrigation is much enough to cause a water stress in crop, which could lead to serious reduction in yield and economic loss. This observation was supported by Stockle and Hiller, (1994); Yonts and Klocke, (1997) and Roger *et al. (*2002). It could be observed that there was a successive increase in irrigation interval with increase in CPE value by a step of 10 mm. This agreed with the findings of Sharma and Dixit (1992), that experienced lowest irrigation intervals with 33 mm and highest interval with CPE 66 mm. FAO-AGL, (2002) also spoke of similar result. The fixed 7-days intervals consumed the least volume of water. Schedules based on CPE values had a reciprocal relationship with the seasonal volume of water applied.

Irrigation at CPE 20 mm significantly resulted in to highest overall irrigation efficiency. The irrigation efficiency of irrigating at CPE 30 mm, CPE 40 mm and the fixed 7-days were lower and were statistically at par

4.4.2 Crop Water Use (CWU) and crop water use efficiency (CWUE).

Statistical differences were observed among the irrigation scheduling treatments. Irrigating at CPE 20 mm had resulted into highest crop water use (CWU), but irrigating at CPE values above 20 mm by a step of 10 mm up 40 mm were observed to have resulted in to lesser crop water use (Table 4.16) The CWU from the fixed 7-days was the least. This was so because, irrigating at CPE 20 mm had the highest application frequency and thus the highest possible soil moisture. This encourages increased leaf transpiration (Mouromical and Ierna (1995). While the fixed 7-days schedule (depending on the weather) forces the stoma to be partially closed, and thus reduced leaf and body transpiration (James, 1988). Sharma and Dixit (1992) experienced similar results. Similarly, Gregory and Simmonds (1992) reported that the degree of wetness of the soil surface is one of the principal factors that determines the amount of water that would evaporate from the soil surface. Nwokeocha (1995) also experienced decrease in crop water use with increase in irrigation interval. Yadiv and Singh (1981) also indicated that increase in irrigation frequency reduces crop water use and crop water use efficiency.

The results of the effects of the irrigation scheduling treatment on crop water use efficiency followed similar patterns.

SP, the variety that had the least total yields, used up the highest amounts of water. The numerical value CWU of Pakistan, Nicola and Dual were statistically at par.

Pakistan, the variety which produced the highest largest tubers, was observed to have the best economic water utilization (highest crop water use efficiency). Nicola, SP and Dual had similar crop water use efficiency values. This is due to variation in climate and weather, and soil type and its heterogeneity, which Doorenbos and Kassam (1979) said could result into changes in crop water use and crop water use efficiency from year to year and from period to period within the same year.

Table 4.16 Treatment effects on crop water Use (mm) and crop water use efficiency(t/ha-mm)

Treatments	Crop water use (CWU) (mm/day)	Crop water use efficiency (CWUE) (t/ha-mm) X 10^{-3}
Irrigation schedules		
CPE20 mm	551a	48.85a
CPE30 mm	420b	18.36b
CPE40 mm	341.2b	12.85b
Fixed 7 days.	289.8b	15.85b
Significance	*	**
L.S.D (p=0.05)	95.1	99.5
Varieties		
Pakistan	399.32	71.79
Nicola	399.33	9.95
SP	409.55	9.95
Dual	388.52	10.93
Significance	NS	NS
L.S.D.(p=0.05)		
Interaction:		
Varieties X Irrigation schedules:		NS

Note

N.S = Not significant
** = Significant at 1 percent level
* = Significant at 5 percent level.

All possible interactions of irrigation scheduling and varieties on CWU and CWUE were not significant.

5.0 Summaries, Conclusion and Recommendations

The effects of Pan Evaporation-based irrigation scheduling and varieties at four levels each on growth, yield and water use efficiency of Irish potatoes were studied, using a factorial design experiment on a loamy soil. The following conclusions were drawn based on the results therefrom.

1. Irrigating Irish potatoes at CPE values up to 40 mm had generally exhibited better performance in terms of total yields, larger tuber sizes, tuber weights, total number of tubers, Crop water use, crop water use efficiency and overall irrigation efficiency than the 7-days rotational irrigation. Lower CPE values resulted in the best results. The 7-days rotational irrigation had however encouraged early tuberisation.
2. Irrigating at CPE values up to 40 mm translated into shorter irrigation intervals, higher irrigation frequency, larger seasonal depth of water applied, and larger seasonal volume of water delivered.
3. Increase in cumulative pan evaporation values to schedule potato irrigation had a reciprocal relationship with yields and yield components, crop water use, crop water use efficiency and irrigation efficiency.
4. The optimum moisture for potato growth and production is a function of climate, soil, and variety; but seasonal moisture should range between 341.3 mm and 551mm
5. Dual, a non- flowering potato variety used up the least number of days to attain 50 percent germination and tuberization. It also performed best in terms

of total yield, tuber weights, total number of tubers and crop water use efficiency when compared to all the three other varieties. However, the largest tuber sizes were produced by variety Pakistan.

6. SP generally showed the worst performance in terms of growth parameters, yield and yield components and water use efficiency.
7. Irrigating at CPE 20 mm was optimum for Pakistan and Dual, and at 30 mm was best for Nicola and SP.

RECOMMENDATIONS

1. Irrigation intervals for potatoes exceeding 4 days should be avoided when 50 mm net depth is used on loamy soils in the arid and semi-arid zones.
2. Pakistan is the best variety when emphasis is laid on large potato tuber sizes. However, when large tuber size is immaterial, variety Dual is the best.
3. Economic viability of CPE-based irrigation scheduling should be evaluated.
4. A similar research should be conducted to evaluate the performance of irrigation scheduling at higher CPE values in the arid and semi-arid zones of Nigeria.
5. Possible measures of evaluating effects of groundwater on irrigation scheduling should be developed to help avoid over-applying even when there is groundwater contribution.

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APPENDIX 1

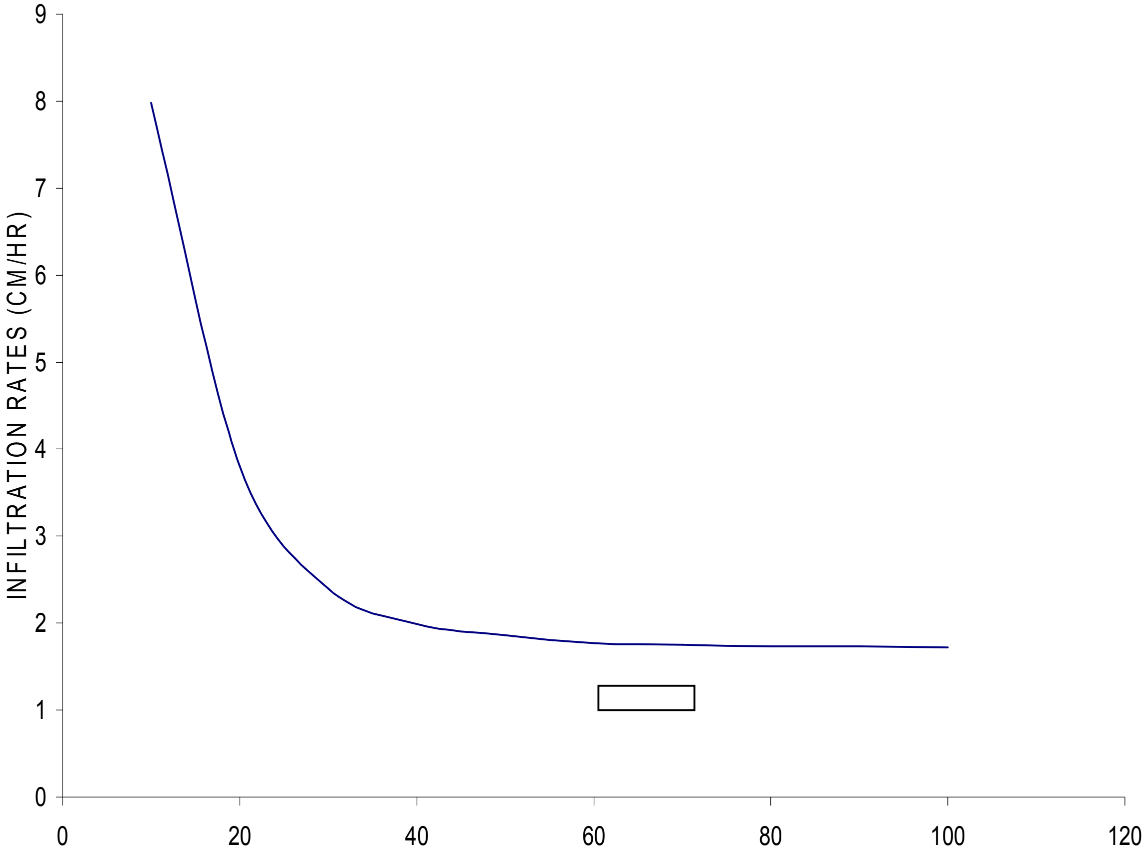
PHYSICAL PROPERTIES OF THE SOILS

Unit	Depth of soil (cm)	Soil Proportions (%)			Textural class *	Mean bulk density (g/cm^3)
		Clay	Silt	Sand		
1.	0-15	18	44	38	Loam	1.43
	15-30	24	38	38	Loam	1.68
	30 – 45	24	34	42	Loam	1.43
	45 – 60	22	39	40	Loam	1.42
2.	0-15	20	44	36	Loam	1.37
	15-30	26	38	36	Loam	1.59
	30-45	28	36	36	Loam	1.49
	45-60	30	38	31	Clay	1.47
3.	0-15	30	36	34	Clay-loam	1.54
	15-30	22	42	36	Loam	1.68
	30-45	24	34	42	Loam	1.64
	45-60	25	36	41	Loam	1.54
4.	0-15	18	44	38	Loam	1.47
	15-30	22	44	34	Loam	1.67
	30-45	26	30	44	Loam	1.68
	45-60	18	44	43	Loam	1.47
5.	0-15	18	50	32	Silty –loam	1.40
	15-30	36	18	46	Sandy-loam	1.52
	30-45	32	38	36	Clay-loam	1.63
	45-60	33	37	40	Clay-loam	1.62

* Based on USDA Textural classification

RESULTS OF SOIL ANALYSIS

The soil at hand was found to be predominantly a loamy soil (Appendix 1) with basic infiltration rate of 2 cm/hr (figure 4). It has the mean pH value of 5.44 (Appendix 2). This corresponds to the pH requirement for potato production (Doorendos and Kassam,1979; FAO-AGL,2002).It has a mean electrical conductivity(EC) of 0.066 ds/m. This may not seriously affect yield, since there would be zero potato yield decrease at EC of 0.017 ds/m(Doorenbos and Kassam, 1979) The percentage carbon and Nitrogen are low(Appendix 2).



TIME (MIN)
INFILTRATION RATES OF THE SOIL
FIGURE 4

<u>G</u>

APPENDIX 2

RESULTS OF EXCHANGEABLE CATIONS PROPERTIES OF THE SOIL

Exchangeable cations	*SAMPLE*		*NUMBER*			
	1	2	3	4	5	***MEAN***
Ca	1.8	2.5	2.5	2.2	2.5	2.3
Mg	0.43	0.59	1.25	0.69	0.69	0.73
K	0.15	0.36	0.32	0.26	0.20	0.26
Na	0.35	0.64	0.44	0.46	0.57	0.50
C.E.C	4.8	6.2	6.8	5.6	6.2	6.0

RESULTS OF CHEMICAL PROPERTIES OF THE SOIL

CHEMICAL PROPERTIES	*SAMPLE*		*NUMBER*			
	1	2	3	4	5	***MEAN***
pH in H_20	5.60	5.8	5.4	4.9	5.5	5.44
pH in 0.01m $CaCl_2$	4.80	4.7	4.3	3.9	4.2	4.38
Electrical conductivity(dsm^{-1})	0.08	0.07	0.050	0.050	0.080	0.066
% Organic carbon	0.079	0.400	0.460	0.320	0.140	0.278
% Total Nitrogen	0.120	0.240	0.240	0.240	0.183	0.205

APPENDIX 3

CALIBRATION OF THE NEUTRON PROBE.

1. A 1 m^2 hole was dug in the field where the experiment was conducted.

2. A 12 cm hole, 1m deep, was augered near the hole and an access tube 10cm in diameter was installed in to it.

3. Moisture readings were taken with the neutron probe from each of the access tube at successive incremental depth of 15cm from the top soil down to 90cm depth. Standard water count was also taken.

4. Soil samples were taken at five different locations horizontally from each successive depth, from which soil moisture contents were determined gravimetrically. Bulk density was also determined.

5. The volumetric moisture content was regressed on count rate ratio (CRR). The equation resulted therefrom was used for computation of the crop water use from the neutron data collected from the field during the experiment..

The table below shows the data used for the Neutron probe calibration**.**

Depth from top soil (cm)	**Neutron counts**	**Count rate ratio**	**Soil moisture (g/g)**	**Bulk density (g/cm^3)**	**Volumetric moisture Content**
15	9481	0.5515	9.5333	1.5133	14.4267
30	9989	0.5810	17.0467	1.4833	25.2854
45	10811	0.6288	20.5833	1.6867	34.7584
60	11499	0.6689	27.0133	1.6067	43.4023
75	11881	0.6911	32.2233	1.5500	49.9461
90	12211	0.7103	38.7600	1.3533	52.4539

Standard water count = 17192

Regression equation usually takes the form of:

Y = $a + bx$ where

Y = dependent variable.

X = independent variable

a = intercept

b = slope of the graph.

Similar to regression equation, the neutron probe computation equation takes the form of $\theta = (n - a)/b$

where:

θ = Soil moisture content (mm)

n = Neutron meter counts.

'a' and 'b' as defined above.

After carrying out step 5 above, the resulting equation was found to be

$Y = -112.97 + 234.39x$ (Figure 5)

$R^2 = 0.9908$ (Figure 5)

Therefore:

$\theta = (n + 112.97) / 234.39$ was the equation used for the computation.

APPENDIX 4

METEOROLOGICAL DATA

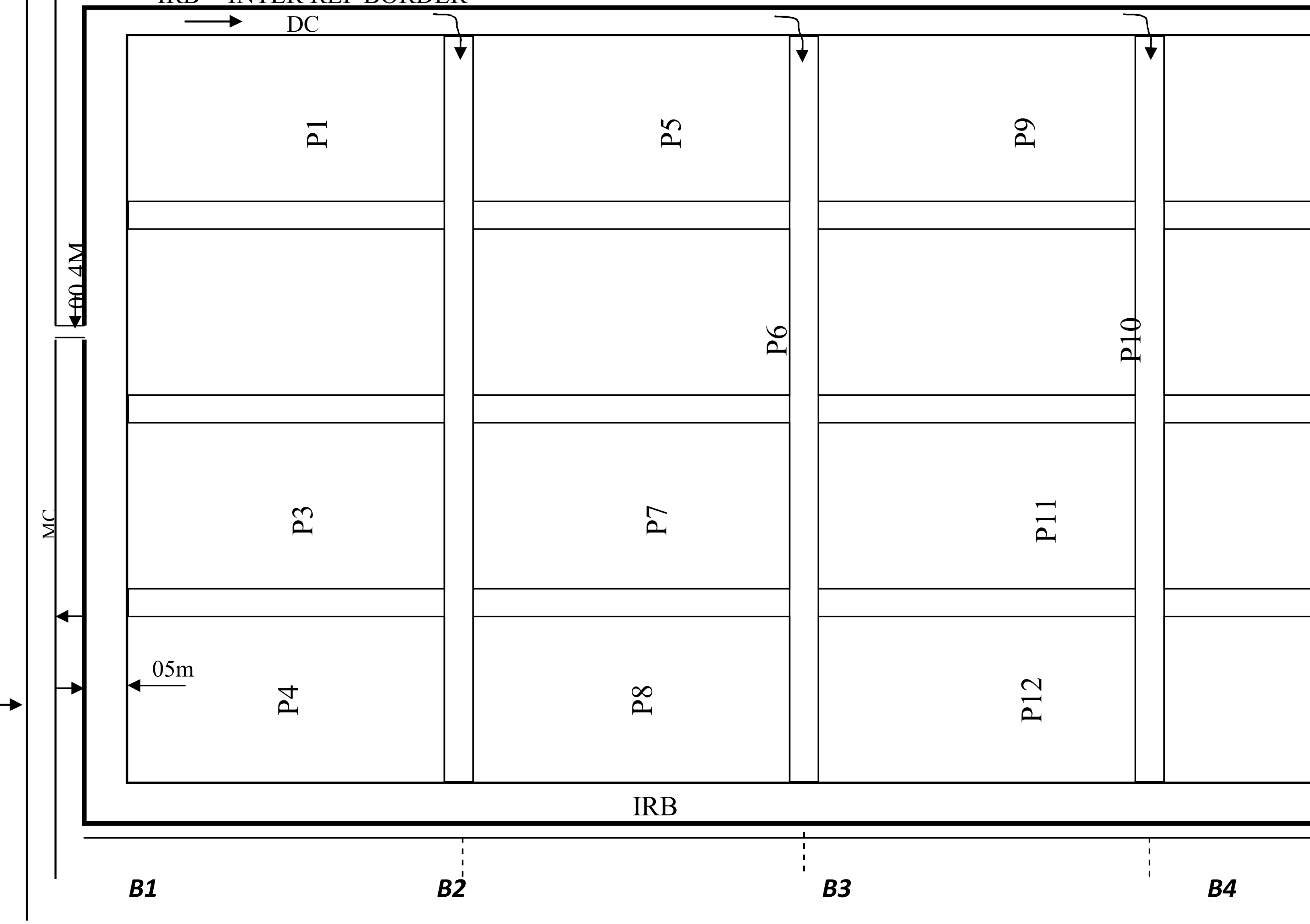
Station:	Samaru Weather Station
Altitude:	686m Above Sea level
Latitude:	11°11’N
Longitude:	07° 38' E
Season:	2003/2004.

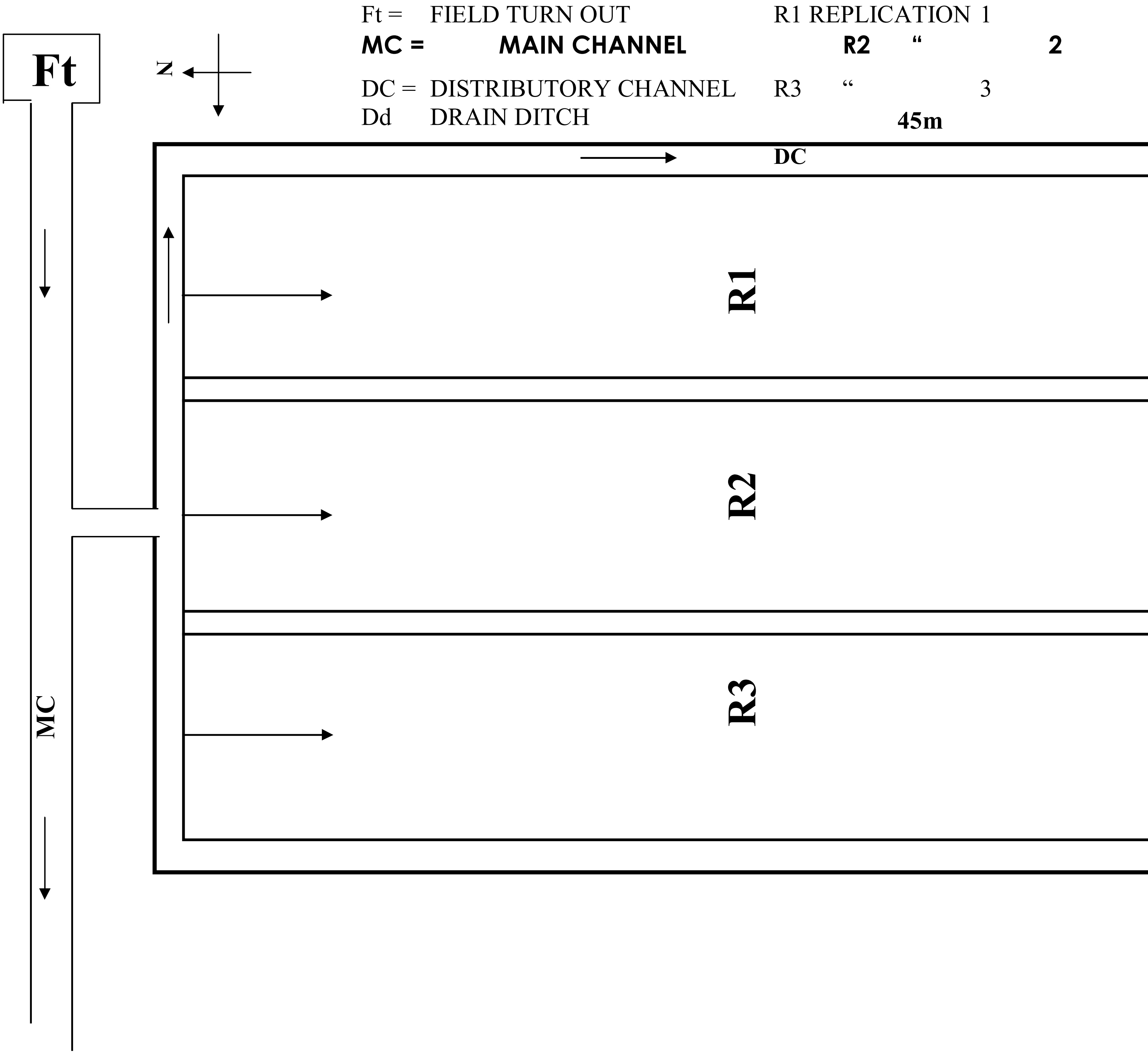
Months	Days. +	Rainfall mm	Pan Evap Mm	Temperature Max °C	Temperature Min °C	RH + %	Wind Run Km/day
Nov;	1-5	Nil	*	34	22	46.6	107.35
2003	6-10	Nil	*	34	20	34.2	108.64
	11-15	Nil	*	34	18	24.2	127.27
	16-20	Nil	*	40	19	19.4	204.22
	21-25	Nil	*	33	16	18.0	135.47
	26-30	Nil	*	34	19	16.2	132.16
Dec;	1-5	Nil	*	33.4	16.2	15.6	18.82
2003	6-10	Nil	*	31.6	14.4	14.0	201.53
	11-15	Nil	*	34.0	15.8	19.6	139.71
	16-20	Nil	*	30.2	16.2	25.2	222.19
	21-25	Nil	*	30.0	16.0	18.4	215.06
	26-31	Nil	*	28.4	15	16.3	239.27
Nov;	1-5	Nil	*	30.5	14.0	18.8	93.25
2004	6-10	Nil	*	29.8	18.2	18.0	300.10
	11-15	Nil	*	29.4	14.2	15	276.90
	16-20	Nil	*	32.2	15.8	9.8	188.53
	21-25	Nil	*	32.0	14.8	14.0	180.18
	26-31	Nil	9.8	33.0	13.8	10.7	187.98
Feb;	1-5	Nil	11.18	28.6	14.2	16.2	375.82
2004	6-10	Nil	10.94	29.8	14.2	15.6	294.22
	11-15	Nil	12.6	35.0	16.8	9.8	256.30
	16-20	Nil	11.6	32.0	16.6	12.6	268.25
	21-25	Nil	*	32.4	18.2	14.0	230.71
	26-29	Nil	5.52	31.25	13.5	13.5	108.55
Mar;	1-5	Nil	10.82	35	20.8	*	240.84
2004	6-10	Nil	12.5	28.6	15.8	*	318.25
	11-15	Nil	13.22	34.6	18.0	*	212.95
	16-20	Nil	15.5	35.4	20.8	8.4	314.34
	21-25	Nil	10.52	35.4	19.6	9.0	226.67
	26-31	Nil	14.62	37.0	22	19.3	171.24

+ = 5 days averages * = Instrument disorder

MC = MAIN CHANNEL
DC = DISTRIBUTION CHANNEL
Dd = DRAIN DITCH
IRB = INTER REP BORDER

P1 – P16 = PLOTS 1 – 16
B1 – B4 = BLOCKS 1 – 4
IPB = INTER PLOT BORDER




Ft = FIELD TURN OUT
MC = MAIN CHANNEL
DC = DISTRIBUTORY CHANNEL
Dd DRAIN DITCH
R1 REPLICATION 1
R2 “ 2
R3 “ 3
Ft
N
45m
DC
R1
R2
R3
MC