IRRIGATION SCHEDULING FOR SOME SELECTED VEGETABLES CROP AT THE GALMA PILOT IRRIGATION SCHEME

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ABSTRACT
The possibility of improving efficient use of water and energy by applying the right amount of water to cropland at the right time and thereby increasing the extent of irrigation to other areas is not only relevant but calls for urgent attention. The study aims at determining irrigation scheduling for vegetable crops at Galma Pilot Irrigation Scheme of the Ministry of Mater Resources, Zaria Kaduna State. The moisture contents at field capacity and wilting point were obtained from the soil water characteristics software named hydraulic properties calculator (HPC) using the details of the particles size analyses and bulk density obtained from the study area. The crop water requirement for each vegetable crop was estimated based on average of ten years weather data. Water application depth and irrigation interval were calculated based on the initial stage, crop development stage, middle stage and late stage. The irrigation interval for the initial stage for the different crops ranges between 3 – 5 days , crop development stage 4 -6 days, mid season stage 4 – 8 days and 4 -8 days at maturity. The water application depth ranges from 13 -20mm at the initial stage for the different crops, 14 – 22mm at the development stages, 19 -35mm at the middle stage and maturity stage.

KEYWORDS: Irrigation, vegetable crops, wter application, maturity, moisture content

Background of the Study

Vegetables are among the most important food of mankind as they are not only nutritious but also indispensable for the maintenance of health. From the point of view of the agriculturist also, it is of great importance as the is assured of high returns from its cultivation even on a small scale. The present vegetable production in the World is around one million tons per year, 70% of which is produced during the cool season (Ali, 2000). Production of summer vegetables is constrained by lack of suitable and high-yielding varieties, high rainfall, humidity and temperature, while vegetable production in winter is favored by suitable climate (Ali, 2000).

The farmers' irrigation are characterized by poor water management irrigation is applied at very high moisture content. The implication of this practice will be over irrigation, which will lead to water wastage and may likely affect the crop grown. Doorenbos and kassam (1979) warned that over irrigation of vegetables lead to poor yield. Over irrigation can also result in waterlogging of the farm, leading to build up of the water table and soil salinity. Adequate irrigation scheduling therefore needs to be designed for vegetable crops so as to improve their growth and yield.

Statement of the Problem

The Galma pilot scheme is a division of Zaria irrigation scheme in Kaduna state which is located 16km along new Zaria – Jos road. The purpose of establishing the pilot scheme was to train local farmers on when and how to irrigate their farmland. It was also meant to assist in putting the vast fertile land along the river Galma under crop production. Check basin is the most common method of irrigation observed by farmers growing vegetables like Carrot, Spinach, onion Lettuce, Cabbage in the scheme etc. The problem encountered in the scheme is the lack of trained personnel to effectively guide farmers on how to schedule Irrigation on their farmland.

Justification of the study

Most famers that produce vegetables depend on traditional methods of production. It is generally recognized that such production techniques do not put into consideration the amount of water applied to the crop, how frequent and how much water could be used by the crop. This has brought the need to effectively design the irrigation scheduling for Galma irrigation scheme which is required to reduce the excess water being wasted and put more in to production.

Objectives

To develop irrigation scheduling for some selected vegetable crops at Galma irriation scheme these crops include: Carrot, Cabbage, Onion, Spinach and Lettuce.

The specific objective include;

1. To determine appropriate water application depths for selected vegetables in the study area.
2. To determine appropriate irrigation intervals for the selected vegetables in the study area.

LITERATURE REVIEW

Irrigation Scheduling

Irrigation Scheduling is a process of determining when to irrigate, and how much water to apply per irrigation. Irrigation scheduling is important in achieving higher yields, good quality of farm products, water and energy conservation and to lower production cost. Some irrigation water is stored in the soil to be removed by crops and some is lost by evaporation, runoff or seepage. The amount of water lost through these process is affected by the irrigation system design and irrigation management. Prudent scheduling minimizes runoff and percolation losses, which in turn usually maximizes irrigation efficiency by reducing energy and water use (Robert, 1996). Irrigation scheduling is carried out, either to maximize yield per unit depth of water applied, or to maximize yield per unit area of land. Scheduling for maximum yield per land area becomes imperative when water supply is readily available and irrigation cost are low, while scheduling for maximum yield per unit depth of water I s justified when irrigation water is limited in supply and cost of irrigation increases with use.

The factors that affect irrigation interval include water supply, climatic setting, crop and crop stages, irrigation system, soil, weather and the economics of irrigation interval based on fixed number of days requires the simplest and cheapest approach, often handled by unskilled workers. Plant water use change with crop stage and weather, and so it is not constant throughout the growing season. Fixed interval treatment can be either too wet or too dry at different plant stages for precise scheduling, information on the rate of water applied and crop water use are require.

Selected Vegetable

1. **Cabbage-** (Brassica Olera Cea Ver Capitata): cabbage is sown thinly in nursery bed or in boxes. Seed germinates 4-10 days after sowing. It is then transplanted on a bed when seedlings are 8-10cm in height. Depending on the variety, cabbage is ready for harvest in 12-18 weeks. (Sekyere, 1997).
2. **Carrot**- (Daucus): Carrot grows well on a light soil and seeds are sown on beds 1cm deep. Seeds germinate in 7 -14 days. Carrot is harvested 10-14 weeks after planting. (Sekyere, 1997).
3. **Lettuce-** (Lactuca Sativa): Lettuce seeds are sown sparsely in nursery beds or boxes. They are transplanted and the crop is ready for harvest in 6-10 weeks. (Sekyere, 1997).
4. **Onion**-(Allium Cepa): Onions are very sensitive to both temperature and length of day. Onion is sown in a nursery bed and geminates in 7-21 days. They are transplanted when seedlings are 5-8cm tall and spaced at 10cm away. Bulbs mature in 3-4 months. The crop may be harvested green in 6-8 weeks after transplanting or left till leaves turn brown. (Sekyere, 1997).
5. **Spinach-** (Basella Aba): Spinach is sown in situ in rows at a distance 60cm by 30cm. leaves are harvested when young.

The selected vegetables have different growth stages, rooting zones and water requirement. Summary of these are shown in table 1

The Check Basin Irrigation System

Slobbers (1971) reported that the most common irrigation method in many parts of the world especially in food plains is the check basin method. It is used in both small sizes to grow vegetables and large sizes to grow cereal crops. The distinguishing features of the various uses of the check basin method of irrigation involve the size and shape of the basin and whether irrigation is accomplished by intermittent or continuous pounding of water in the basins. The basin size is highly dependent on the prevailing slopes.

According to Michael (1978) check basin irrigation is suited for smooth, gentle and uniform land slopes and for soil having moderate to low infiltration rates. It is also suitable in very permeable soil but the basins must be covered with water rapidly to prevent excessive deep percolation losses at the upstream end. The design of check basin is often limited by sized and height of practical basin ridges used to confine water in the basin.

Design Daily irrigation Requirement

James (1988) defined Design Daily Irrigation Requirement (DDIR) as the rate at which an irrigation system must supply water to achieve the desired level of irrigation. In some situations, the largest daily irrigation requirement is associated with land preparation (like rice paddy formation) and not evapotranspiration (ET) The DDIR for an irrigation system depend on the crop, climate, and soil of the farm. Farm located in climates with high daily ET rates and low precipitation have the largest DDIR.

Generally, $DDIR_S$ for crops grown in soils with low water holding capacities such as sand are higher than those for crops grown in finer textured soils with higher water holding capacities. This is because the interval between irrigations increase with water holding capacity and the average daily irrigation requirement is smallest for longer irrigation intervals. DDIR Is expressed as (James, 1988):

$$DDIR = \frac{AD}{11_{min}} \quad \ldots\ldots 1$$

Where:

Ad = Allowed depletion of soil water between irrigations (mm);

11_{min} = Minimum irrigation interval during irrigation season (days).

Approaches to Irrigation Scheduling

The requirement regarding the number of irrigations and their timing vary for different crops. Under field experimental conditions the criteria of soil water availability plays and important role in scheduling of irrigation. This leads to the concept of evapotranspiration, maximum allowable deficiency (MAD), irrigation frequency etc, which can be used as the criteria for irrigation timing.

Irrigation should be scheduled by observing soil moisture level, and not by observation of the crop (Michael, 1978). A summary of the common irrigation scheduling techniques as presented by Rujov et al (1973) includes:

a. Measurement or observation of water deficit in plants,
b. Monitoring soil moisture content until the critical point is reached,
c. Irrigation scheduling on evapotranspiration rates,
d. Calculating irrigation schedules or irrigation guides.

Crop Coefficient

The crop coefficient K_C, relates the actual rate at which a crop uses water (ET) to reference evapotranspiration (ET_O). Burman et al, (1983) defined K_C as the ration of ET occurring for a specific crop at a specific stage of growth to the potential ET at that time. James (1988) stated that values of K_C for field and vegetable crops generally increase gradually from an initial low value to a peak plateau and then declines as the plant progresses to its maturity stage. Coefficient K_C and growth stage information for several other field vegetable crops are available in Doorenbos and Pruitt (1977).

Reference Crop Evapotranspiration (ET_O)

ET_O may be either potential ET or reference ET. Potential ET is the maximum rate at which water, if available, can be removed from soil and plant surface, and varies from day to day (James, 1988). Doorenbos and Pruitt (1977) defined reference crop ET as the, "ET from an extensive surface of 8-15cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water". Potential ET varies from crop to crop, while reference crop ET is defined for a specific crop. Therefore, reference crop ET is preferred over potential ET (James, 1988).

Several methods have been developed for computing ET_O. One of such method is the hargreaves ET_O equation, expressed as (Allen et al 1998).

$$ET_O = 0.0023\,(T_{mean} + 17.8)\,(T_{max} - T_{min})^{0.5} R_a \quad \ldots\ldots 2$$

Where:

T_{mean}= Mean of the daily maximum (Tm_{ax}) and Minimum temperatures (T_{min}).

R_a = extra terrestrial radiation for daily periods (MJm^{-2} day^{-1}) as detailed by allen et al 1998.

Crop Evapotranspiration (ET_C)

The term crop evapotranspiration refers to the rate of evapotranspiration of a disease-free crop growing in a field under optimal soil condition including sufficient water and fertilizer, and achieving full production potential of the crop under the growing environment (Doorebos and Pruitt, 1977).

$$ET_C = K_C \times ET_O \quad \ldots\ldots 3$$

Where:

K_C = crop coefficient

ET_O = reference crop evaportranspiration (mm/day)

Maximum Allowable Deficiency (MAD)

The concept of maximum allowable deficiency, MAD is also one of the criteria for estimating the amount of water that can be used without adversely subjecting the crop to water stress. MAD gives the critical water content at which irrigation is required. It is defined as the ratio of readily available water to the total available water. That is

$$MAD = \frac{RAW}{TAW} \quad \ldots\ldots 4$$

Where

RAW = readily available water (mm)

TAW = total available water (mm)

Readily available water is defined as the amount of water between field capacity and critical soil water content. Total available water is the amount of moisture held between field capacity and wilting point. MAD depends on soil type as well as crop type. See table 2

Irrigation interval

Michael (1978) defined irrigation frequency as the number of days between irrigation during the period without rainfall. Irrigation frequency depends on the crop consumptive use and also on the amount of moisture stored in the root zone. It is function of crop, soil and climate. The stage of growth of crop with reference to the critical periods of growth is also kept in view while designing irrigation frequency is expressed as (Robert and Juanita 1989):

$$Interval = \frac{RAW}{CRW} \quad \ldots\ldots 5$$

Where;

RAW= readily available water (mm) also known as net depth.

CRW= Crop water requirement (mm/day)

Irrigation period

According to Michael (1978) Irrigation period is the number of days that can be allowed for applying one irrigation to a given area during the peak consumptive use period of the crop being irrigated. It is the basis for irrigation system capacity and equipment design. The irrigation system must be so designed that the irrigation period is not greater than the irrigation interval.

Available Moisture

The major role of soil in supporting agriculture is their function as a reservoir of water and nutrients for plant use. The difference in moisture content of a soil between its field capacity and wilting point is termed the available moisture. This represents the moisture, which can be restored for subsequent use the plants. After irrigation, soil moisture is expected to be restored to field capacity.

Field capacity is defined as the moisture content after drainage of gravitation water has become very slow and the moisture content has become relatively stable. The field capacity varies from one soil type to another. For sandy soil, it attains field capacity within one day; loamy soil about 2 days, whereas clay soil at 3 or more days after thorough wetting. Wilting point is the moisture content at which plants can no longer obtain enough moisture to meet their evapo-transpiration requirements, and remain wilted unless soil moisture is restored. For permanent

Water Application Efficiency

An ideal irrigation is assumed to be the one, which supplies enough water to wet the soil uniformly to field capacity throughout the root zone with negligible losses. Water application efficiency is the ratio of water that is in root zone of soil to the amount of water applied (Michael, 1978). It is expressed as,

$$E_A = \frac{R_S}{W_F} \quad \text{...6}$$

Where;

E_A= water application efficiency (%)
W_S= quantity of water stored in the root zone of plant (mm).
W_F= quantity of water delivered to the field (mm).

Generally, water application efficiency decreases with increasing amount of water applied. Lower application efficiencies below 100% are due to run – off losses from the field and deep percolation below the root zone (Michael, 1978).

Water Application Depth.

Stewart et al. (1990) reported that at the beginning of the growing season, the amount of water given per irrigation application also called the water application depth is small and given frequently. This is due to the low evapotranspiration of young plants and their shallow root depth. During the mid – season, the irrigation depth should be larger and given less frequently due to high evapotranspiration and maximum root depth. In principle, the amount of irrigation water given in one irrigation application is the amount of water used by the plant since the previous irrigation.

Table 1 growing stage, root zone and water requirement of the selected vegetables.

Crop	Initial Length	Development length	Mid length	Late length	Total	Root depth (cm)	*Water requirement (mm)
Cabbage	40	60	50	15	165	0.5	380-500
Carrot	20	30	30	20	100	0.5	380-500
Lettuce	20	30	25	10	85	0.4	200-300
Onion	25	30	10	5	70	0.4	350.500
Spinach	20	20	15	5	60	0.4	250-380

Source: (Allen et al, 1998) * (Robert, 2003)

Table 2: MAD values for the selected vegetables

Crop	MAD
Cabbage	0.45
Carrot	0.45
Lettuce	0.30
Onion	0.30
Spinach	0.30

Source: Allen et al (1998)

MATERIALS AND METHODS

Study Area

The Galma pilot irrigation scheme is a division of Zaria Irrigation Scheme in Kaduna State which is located 16km along the new Zaria – Jos road. It is on latitude 11^0 05 'North and longitude $7^0$44' east, and covers an area of about 250ha. Over 350 farmers are allocated with various sizes of farmland for both dry and raining season farming yearly. The different crops under cultivation are: wheat, okra, hot pepper, tomatoes, sweet potatoes, spinach, garden egg, carrot, onion, maize etc. the source of water for the scheme is Shikka Dam and the Galma river (Musa, 2008).

The climate of Galma is marked by wet and dry a season which is sub – divided into three;

i. The cool, dry season from October to February
ii. The hot, dry season from March to May and
iii. The warm wet season from June to September.

The rainy season usually starts in the month of May and ends in October. Mean monthly temperature normally ranges from 30^0C – 35^0C and a mean relative humidity ranging from 30 – 70% annually.

Soil Physical Properties

Ogbe (2008) provided the details of the soil particle size analysis and bulk density of the study area. These details were used to determine moisture content at field capacity and wilting point with the help of the hydraulic properties soil characteristic software (Sexton, 1994) see table 3

Determination of Crop Evapotranspiration (ET_C)

An average of 10 year weather data was used to determine the reference evapotranspiration (ET_0) using the Hargreaves equation (Eq. 2) The weather data was obtained from the institute for Agricultural Research (IAR). Ahmadu Bello University, Samaru Zaria. The data are temperature, sunshine, relative humidity and wind speed. Hargreatives equation was used to determine the ETo because there were missing data. Crop evapotranspiration was determined by multiplying the average of the year reference evapotranspiration by the crop coefficient of the various stages of development of each crop given in. (Eq. 2.3)

Water application depth

The water application depth (dg) was calculated from the net depth of application using E.q. 8 (Michael, 1978).

$$dg = \frac{dn}{Ea} \quad \ldots\ldots 7$$

Where:

dg = gross depth (water application depth)
dn = net depth of application
Ea = Application efficiency
MAD (FC – PWP) Rz

dn = ……………………………………3.2
100

Where:

MAD = Maximum Allowable Deficiency
PWP = Permanent Wilting point (%)
FC = Field Capacity
R_Z = Root zone depth (mm)

Irrigation interval

The Irrigation interval was calculated based on the stages of development of each vegetable, that is initial stage, development stage, middle stage and last stage. The irrigation interval was obtained base on soil, plant and climatic characteristics as recommended by Robert and Juanita (1989).

$$\text{Interval} = \frac{RAW}{CRW} \quad \text{……9}$$

Where;
RAW = Readily available water (mm) also known as net depth.
CRW = Crop water requirement (mm/day)

Table 3 Average soil properties at different depths
Source: Ogbe (2008), *Saxton (1994)

Depth (mm)	Clay %	Silt %	Sand %	Texture	Bulk density g/cm^3	*Field capacity (% vol)	*Wilting point (% vol)
0.0 – 200	11	53	36	Silt loam	1.40	25.7	9.1
200 – 400	12	53	36	Silt loam	1.62	24.6	9.7
400 – 600	11	47	42	Loam	1.59	20.8	6.9
600 – 800	11	43	46	Loam	1.60	19.7	6.8

RESULTS AND DISCUSSION

Introduction

In order to ensure optimum water management and efficiency in operation, an effective and suitable irrigation schedule for farmers that is practical under local condition should be designed. The results discussed in this chapter are centered on irrigation interval and water application depth for vegetable crops in Galma Irrigation Scheme.

Crop water requirement of the selected vegetables

Table 4 shows the average daily crop water requirement for the four growth stages season for the crops under study (Eq. 3). The crop water requirements were low at the initial stage of the crop that is just after planting. The values increase to a peak at the mid season stage of the crops. This because crop coefficient for the vegetable crops generally increase gradually from initial low value to a peak and then decline as the plant progresses to its maturity. See table 4

Water Application Depth

Farmers cultivating in Galma irrigation scheme do not have suitable means of measuring the amount of water they apply to their crop. Table 4.3 shows the water application depth required to bring the soil to field capacity at the different growth stages. Stewart et al. (1990) recommends 60% water application efficiency for surface irrigation system. This accounts for the amount of water that would be lost in the course of application. The water application depth was found to range from 13 – 20mm at the initial, 14 – 22mm at the development stage, 19 – 35mm at the middle stage and late stages. The water application depth for lettuce, onion and spinach were the same at different stage of development because soil is silt loam and they have the same rooting depth. Also cabbage and carrot have the same application depth at the different stages of crop development because the soil varies from silt loam to loam and have the same rooting depth. The water application depth increases from initial to late stage because the root zone depth keeps increasing See table 5

Irrigation Interval

Table 6 shows the irrigation interval for the selected vegetables at the four stages of development. The irrigation interval for the initial stage for the different crop range between 3-5 days, crop development stage 4 – 6 days, mid season stage 4 – 8days and maturity stage 4 – 8 days, for good crop growth and development the vegetables should be irrigated frequently at the beginning of the growing period because of their shallow root depth. This implies that, applying the same water application depth at the initial stage ,can result in damage to crops, leading to building of water table and soil salinity. Since the water application depth is small, at the initial stage, the irrigation should be applied within a short interval. If farmers irrigate every seven days, it means at all growth stages, the crops will suffer moisture stress except for crop that the interval is less than 7 days.

Comparison between farmers' fixed schedule and design schedule

The irrigation interval observed by the farmers at the study area is 7days. This interval was observed by the farmers irrespective of the growth stage of crop. Farmers have no knowledge of the water use that need to be applied to bring the soil to field capacity.

Growth stages of the selected vegetables where the computed interval is 8 days, the water use that needs to be applied to bring the soil to fil capacity is higher compare to the farmers' water application depth at fix interval farmers schedule will result to water and yield may be affected

Growth stages of the crop where the computed interval was less than 7 days, shows that the water use that applied to bring the soil to field capacity is less than the farmers water application depth at fixed interval. In this case water and energy will wasted by the farmers schedule see table 7

Table 4 Average value of crop water requirement at various growth stages (mm/day)

Crop	Initial	Development	Middle	Late
Cabbage	2.6	3.9	5.0	4.4
Lattuce	2.6	3.5	5.1	5.1
Carrot	3.1	3.7	5.2	4.0
Onion	3.1	3.7	4.7	4.0
Spinach	3.1	3.5	4.8	4.1

Table 4.3: Irrigation water application depth at different stages of development for each application.

Crop	Initial stages(mm)	Development stages (mm)	Middle stage (mm)	Late stages (mm)
Cabbage	20	37	58	58
Carrot	20	37	58	58
Lettuce	13	23	32	32
Onion	13	23	32	32
Spinach	13	23	32	32

Table 4.2 Irrigation interval (days) at different stages of development.

Crop	Initial stage	Development stage	Middle stage	Late stage
Cabbage	5	6	8	8
Carrot	4	6	7	8

Lettuce	3	4	4	4
Onion	4	4	4	4
Spinach	4	4	4	5

Table 7 comparing the farmers the farmer's water application depth at irrigation interval of 7days with the computed interval.

Crop	Stage of development	Farmer's irrigation interval depth (day)	Water use /application interval (days)	Computed irrigation interval (days)	Water application depth (mm)
Cabbage	Interval	7	30	5	20
	Development	7	42	6	37
	Middle	7	54	8	58
	Late	7	50	8	58
Carrot	Initial	7	35	4	20
	Development	7	42	6	37
	Middle	7	58	7	58
	Late	7	53	8	58
Lettuce	Initial	7	30	3	13
	Development	7	48	4	23
	Middle	7	58	4	32
	Late	7	53	4	32
Onion	Initial	7	37	4	13
	Development	7	42	4	23
	Middle	7	57	4	32
	Late	7	43	4	32
Spinach	Initial	7	37	4	13
	Development	7	42	4	32
	Middle	7	55	4	32
	Late	7	50	5	32

Summary

The study was conducted at Galma pilot schem, a Division of Zaria irrigation scheme in Kaduna State. The irrigation scheduling method observed by the farmers growing at the study area is fixed schedule and the irrigation method adopted by farmers is surface irrigation basically check basin. The soil of the study area was found to be silt loam at a depth of 400mm and loam at depths from 400mm to 600mm. an average of ten years weather data was used to compute reference crop evapotranspiration and crop water requirement for the selected vegetable crops was calculated. The irrigation interval and water application depth were calculated based on the growth stage of the selected vegetable crops. These depends on soil type, root depth and climatic data.

CONCLUSION

Irrigation scheduling is important in achieving higher yields, good quality of farm products and to lower production cost.

Farmers in Galma Irrigation Scheme should be effectively guided on how much water to be applied per irrigation and when to irrigate their farmland based on the growing stages of crops. This is because crop water use changes with crop stage and weather.

To maximize yield per unit area of land, appropriate water application and appropriate irrigation intervals must be considered. By virtue of the results of this finding, farmers in Galma Irrigation Scheme should be trained on how to irrigate their farmlands

RECOMMENDATIONS

i. Further study need to be carried out for other crops in the Galma Pilot Irrigation scheme.
ii. Similar study need to be carried out in other locations with soil of different properties.

REFERENCES

Ali, M. 2000. Dynamics of vegetable production distribution and consumption in Asia. vegetable research & Development Centre, 20 AVRDC publication No. 00-498. 470p.

Allen, R. G, Smith, M. Perrer and Pereira, L.S. 1998. crop Evapotranspiration Guidelines for computing Crop water requirements, food and agricultural organization Irrigation and Drainage paper. 196p.

Burman, R.D., R.H. Cueca and A. weiss 1983. Techniques for estimating irrigation water requirement in: advances in irrigation vol. 2 (D. Hillelied) Academic press New York, N: 336 – 391.

Doorenbos, J and A.M. Kassam. 1979. Yield response to water irrigation and drainage paper 33, Food and Agricultural Organisation, Rome. Page 24.

Doorenbos, J and W.O. Pruitt. 1977. Guideline for predicting crop water requirement, irrigation and drainage paper 24, Food and Agricultural Organisation, Rome.

James, L.G. 1988. Principles of farm irrigation system Design, John wiley and sons, New York.

Michael, A.M. 1978 Irrigation, Theory and practice, Indian Agricultural Research institute New Delhi. Page 448 – 451, 480, 507 -512

Ogbe, V. 2008 Evapotranspiration of water Advance Model for furrow Irrigation. M.Eng. Thesis, Department. of Agric Engineering, ABU Zaria.

Rijov, S.N. Hogan and M.J. Aston 1973. Water, plant growth and crop irrigation requirements, in irrigation, Drainage and Salinity. (Kovdi, V.A., C.V. Berg and R.M. Hagan, eds.) Hutchinson and Co ltd: 206.251.

Robert R.Y. and Juanita H. 1989. Design issues in farmer – managed irrigation system.

Robert, Spencer, 2003 Agricutural information centre Albente Agricultural and Rural Development.

Sekyere, D.A. 1997. Better vegetables Ghana Handbook, Ghana Academy of science, Accra. Pages 205 – 208.

Sexton, K.E and Rawls, W.J., 2006. Soil water characteristics estimates by texture and organic matter for hydrological solution. Soil science society of America,

Slobbers, P.J. 1971. Design Criteria for check basin irrigation system FAO published land and water development, irrigation and drainage Div. Paper No. 3 Rome. Page 12 – 14

Stewart B.A and Nelson D.R 1990.Irrigation of Agricultural crops. Publisher Madison Wisconsin USA. Pages 509 - 541

Taylor, S.A 1965. Managing irrigation water on the farm American Society of Agricultural Engineers 8:433-436.

Appendix A1.

Values of crop water requirement, reference evapotranspiration and root zone of lettuce throughout the growing period.

Stage	Day	Month	ET_O (mm/day)	K_C	ET_C (mm/day)	RZ (mm)
Initial	1	11	5.4	0.5	2.7	150
	2	11	5.1		2.5	
	3	11	5.0		2.5	
	4	11	5.2		2.6	
	5	11	5.3		2.7	
	6	11	5.0		2.5	
	7	11	5.2		2.6	
	8	11	5.1		2.6	
	9	11	5.2		2.6	
	10	11	5.1		2.6	
	11	11	5.1		2.5	
	12	11	5.0		2.5	
	13	11	5.1		2.6	
	14	11	5.0		2.5	
	15	11	5.1		2.6	
Development	16	11	5.2	0.7	3.7	300
	17	11	5.1		3.6	
	18	11	5.2		3.6	
	19	11	5.1		3.6	
	20	11	5.1		3.6	
	21	11	5.2		3.6	
	22	11	5.2		3.6	
	23	11	5.1		3.6	
	24	11	5.1		3.6	
	25	11	5.1		3.6	
	26	11	5.1		3.6	
	27	11	5.0		3.6	

	28	11	4.9		3.5	
	29	11	5.1		3.4	
	30	11	5.0		3.5	
	1	12	4.9		3.5	
	2	12	4.9		3.4	
	3	12	4.8		3.4	
	4	12	4.8		3.2	
	5	12	4.6		3.2	
	6	12	4.6		3.2	
	7	12	4.6		5.1	
	8	12	4.6		5.0	
	9	12	4.7		5.1	
Middle	10	12	4.6	1.1	5.1	400
	11	12	4.7		5.1	
	12	12	4.6		5.2	
	13	12	4.5		4.9	
	14	12	4.7		5.2	
	15	12	4.6		5.1	
	16	12	4.5		4.9	
	17	12	4.5		4.5	
	18	12	4.7		4.7	
	19	12	4.7		4.7	
Last	20	12	4.4	10	4.4	400
	21	12	4.5		4.5	
	22	12	4.7		4.7	
	23	12	4.6		4.6	
	24	12	4.5		4.5	
	25	12	4.6		4.6	

Appendix A2.

Values of crop water requirement, reference evapotranspiration and root zone of carrot throughout the growing period.

Stage	Day	Month	ET_o (mm/day)	K_c	ET_c (mm/day)	R_z (mm)
	1	11	5.4		3.2	
	2	11	5.1		3.2	
	3	11	5.0		3.2	
	4	11	5.2		3.2	
	5	11	5.3		3.2	
	6	11	5.0		3.2	
	7	11	5.2		3.2	
Initial	8	11	5.1	0.6	3.2	150
	9	11	5.2		3.2	
	10	11	5.1		3.2	

	11	11	5.1		3.2	
	12	11	5.0		3.2	
	13	11	5.1		3.2	
	14	11	5.0		3.2	
	15	11	5.1		3.2	
	16	11	5.2		3.2	
	17	11	5.1		3.2	
	18	11	5.2		3.2	
	19	11	5.1		3.2	
	20	11	5.1		3.2	
	21	11	5.2		3.2	
	22	11	5.2		3.2	
	23	11	5.1		3.2	
	24	11	5.1		3.2	
	25	11	5.1		3.2	
	26	11	5.1		3.2	
	27	11	5.0		3.2	
	28	11	5.9	0.75	3.2	300
Development	29	11	5.1		3.2	
	30	11	5.0		3.2	
	1	12	4.9		3.2	
	2	12	4.9		3.2	
	3	12	4.8		3.2	
	4	12	4.8		3.2	
	5	12	4.6		3.2	
	6	12	4.6		3.2	
	7	12	4.6		3.2	
	8	12	4.6		3.2	
	9	12	4.6		3.2	
	10	12	4.6		3.2	

	11	12	4.7		3.5	

	12	12	4.6		3.5	
	13	12	4.5		3.3	
	14	12	4.7		3.5	
	15	12	4.6		3.5	
Middle	16	12	4.5	1.15	5.2	500
	17	12	4.5		5.1	
	18	12	4.7		5.4	
	19	12	4.7		5.4	
	20	12	4.4		5.1	
	21	12	4.5		5.2	
	22	12	4.6		5.3	
	23	12	4.5		5.2	
	24	12	4.6		5.2	
	25	12	4.6		5.3	
	26	12	4.4		5.3	
	27	12	4.5		5.0	
	28	12	4.6		5.2	
	29	12	4.8		5.3	
Last	30	12	4.5	0.9	4.2	500
	31	12	4.3		4.3	
	1	1	4.5		4.0	
	2	1	4.4		4.0	
	3	1	4.2		4.0	
	4	1	4.2		3.8	
	5	1	4.3		3.7	
	6	1	4.4		3.9	
	7	1	4.4		4.0	
	8	1	4.4		4.0	

Appendix A3.

Values of crop water requirement, reference evapotranspiration and root zone of spinach throughout the growing period.

Stage	Day	Month	ET_o (mm/day)	K_c	ET_c (mm/day)	R_z (mm)
Initial	1	11	5.4	0.6	3.2	150
	2	11	5.1		3.0	
	3	11	5.0		3.0	
	4	11	5.2		3.1	
	5	11	5.3		3.2	
	6	11	5.0		3.0	
	7	11	5.2		3.1	
	8	11	5.1		3.1	
	9	11	5.2		3.1	
	10	11	5.1		3.1	
	11	11	5.1		3.0	
	12	11	5.0		3.0	
	13	11	5.1		3.1	
	14	11	5.0		3.0	

	15	11	5.1		3.1	
Development	16	11	5.2	0.7	3.7	300
	17	11	5.1		3.6	
	18	11	5.2		3.6	
	19	11	5.1		3.6	
	20	11	5.1		3.6	
	21	11	5.2		3.6	
	22	11	5.2		3.6	
	23	11	5.1		3.6	
	24	11	5.1		3.6	
	25	11	5.1		3.6	
	26	11	5.1		3.6	
	27	11	5.0		3.5	
	28	11	4.9		3.4	
	29	11	5.1		3.6	
	30	11	5.0		3.5	
Middle	1	12	4.9	1.05	5.2	400
	2	12	4.9		5.2	
	3	12	4.8		5.0	
	4	12	4.8		5.1	
	5	12	4.6		4.9	
	6	12	4.6		4.8	
	7	12	4.6		4.9	
	8	12	4.6		4.8	
	9	12	4.7		4.9	
	10	12	4.6		4.8	
	11	12	4.7	0.9	4.2	400
	12	12	4.6		4.1	
	13	12	4.5		4.0	
	14	12	4.7		4.3	
	15	12	4.6		4.2	
	16	12	4.5		4.0	
Last	17	12	4.5		4.0	
	18	12	4.7		4.2	
	19	12	4.7		4.2	
	20	12	4.4		4.2	

Appendix A4.

Values of crop water requirement, reference evapotranspiration and root zone of Onion throughout the growing period.

Stage	Day	Month	ET_o (mm/day)	K_c	ET_c (mm/day)	R_z (mm)
Initial	1	11	5.4		3.2	
	2	11	5.1		3.0	
	3	11	5.0		3.0	
	4	11	5.2		3.1	
	5	11	5.3		3.2	
	6	11	5.0		3.0	

	7	11	5.2		3.1	
	8	11	5.1		3.1	
	9	11	5.2		3.1	
	10	11	5.1	0.6	3.1	150
	11	11	5.1		3.0	
	12	11	5.0		3.0	
	13	11	5.1		3.1	
	14	11	5.0		3.0	
	15	11	5.1		3.1	
	16	11	5.2		3.1	
	17	11	5.1		3.1	
	18	11	5.2		3.1	
	19	11	5.1		3.1	
	20	11	5.1		3.1	
	21	11	5.2		3.9	
	22	11	5.2		3.9	
	23	11	5.1		3.9	
	24	11	5.1		3.9	
	25	11	5.1		3.8	
	26	11	5.1		3.8	
	27	11	5.0		3.8	
	28	11	4.9		3.7	
	29	11	5.1		3.8	
Development	30	11	5.0	0.75	3.7	300
	1	12	4.9		3.7	
	2	12	4.9		3.7	
	3	12	4.8		3.6	
	4	12	4.8		3.6	
	5	12	4.6		3.5	
	6	12	4.6		3.5	
	7	12	4.6		3.5	
	8	12	4.6		3.4	
	9	12	4.7		3.5	
	10	12	4.6		3.5	