Research Article
Volume 10:3, 2021

Irrigation and Drainage
Systems Engineering

ISSN: 2168-9768 Open Access

Using Drip Irrigation to Mitigate the Effects of Drought in Food Production: A Case Study of Production of Beans during Dry Spells in Uasin Gishu County, Kenya

Rioba DO*, Kosgei JR and Kipkorir EC

Department of Civil & Structural Engineering, School of Enginering, Moi University, Eldoret, Kenya

Abstract

Over 80 percent of Kenya's freshwater withdrawals are utilized in agricultural production. The increase in human population means that even more water will be channeled towards food production. Improving water productivity is the most appropriate strategy for increasing food production for a fast growing population due to its consideration of the sustainability of water resources. Kenya predominantly depends on rain-fed agriculture for its food production, and this exposes the country to acute food shortages during droughts. Beans (*Phaseolus vulgaris L.*) are the primary source of protein for most households in Kenya. Despite this fact, there is a supply deficit during dry spells. An irrigation project was carried out at Moi University with an objective to study the effect of deficit irrigation as a mitigation measure to curb the shortage of beans during dry spells while ensuring sustainable use of water resources. This was carried out through modelling of water productivity (WP) and yield (Y) of beans using the FAO AquaCrop model. Field experiments were set up in a Randomized Complete Block Design (RCBD) arranged in split plots and replicated three times. Two water treatment strategies were employed (deficit irrigation, full irrigation). In the full irrigation supply, the crop was kept at 100% of irrigation requirement (T100) and data collected from these plots was used in Aqua Crop model calibration. There were three levels of deficit irrigation used: 80%, 60%, and 50% of irrigation requirement (T80, T60, T50), these were used in model validation. The highest WP, as well as the lowest yield reduction of 2.4%, was observed in the T80 treatment, this signifies water savings of up to 20%, which translates to 750 m3/ha. The highest yield reduction of 59.8% was obtained in T50 treatment, coupled with a drop in WP. Deficit irrigation results in yield reduction as observed in this study, but the amount of water saved can be used to irrigate more land or be utilized elsewhere. Consequently, it is necessary for Kenya to adopt deficit irrigation to ensure food security during dry spells while at the same time ensure sustainable water use.

Keywords: Bean crop • Deficit irrigation • Water use efficiency • Water productivity

Introduction

Background

Agriculture constitutes about 70% of global freshwater withdrawals and in most fast-growing economies it is projected to reach 90%[1]. In Kenya, the figure was estimated to be 80% by the year 2003 [2]. Agriculture is not only a source of food but is also the primary source of employment and contributor to Kenya's Gross Domestic Product (GDP) [3].The population has increased from 37.7 million people as per the 2009 Kenya National Population and Housing census [4] to 47.6 million people in 2019 (KNBS, 2019). The growth in human population translates to more mouths to feed and translates to increased pressure to land and water. Consequently, more water resources will be channelled towards food production. As it stands, Kenya is a water scarce country with a per capita renewable amount of fresh water of less than 647 m^3 per year [4]. Due to various factors such as climate change and population pressure this figure is projected to fall to 245 m^3 by the year 2025. Both these figures are well below the UN recommended benchmark of 1000 m^3 per year (*ibid*). This scenario paints a very grim picture of Kenya's economic future and ability to feed her growing population.

Furthermore, Kenya primarily depends on rain-fed agriculture for its food production; this makes the country susceptible to acute food shortages attributed to the high temporal and spatial variability of rainfall. Irrigation is twice as productive as rain-fed agriculture, but water resources remain limited [5]. Reducing irrigation in order to increase water availability for other uses is unthinkable due to the challenge that lies in growing demand for food. However, Kenyan government (read the ruling Jubilee Party) has recently launched four development pillars dubbed the "Big Four Agenda" viz. ensuring food security, affordable housing, manufacturing and affordable healthcare. Some of these pillars have competing interests for water and according to Salemi [6] water availability for crop production is always reduced in favor of rapidly increasing water uses for industry, drinking and environmental purpose, thus governments face a challenge to produce more food with less water. As water scarcity becomes more acute in many parts of the world, increasing the effectiveness with which agricultural water resources are used is a priority for enhanced food security [7]. Consequently, the solution lies in identifying ways to improve agricultural water use through the acquisition of relevant knowledge. This could include measures to cope with droughts and water scarcity in semi-arid climates in irrigated agriculture and identification of irrigation scheduling strategies that minimize the water demand with acceptable impacts on yields [8]. This action will lead to irrigation practices that improve water use efficiency while still achieving enough crop yields to sustain the increasing population, the "more crop per drop" paradigm [9].

Dwindling water resources and weather variability present two of the major limiting factors for irrigated agriculture and there is a dire need to understand the trends and fluctuations in crop yields due to water scarcity to help producers make better irrigation and crop management decisions. According to Greaves and Wang , judicious planning [10] is required as supplying crops with less than their water requirement can significantly affect crop growth and development, inevitably affecting yield, especially if water stress occurs during the susceptible growth stage. The current study proceed to propose Deficit Irrigation (DI) as a strategy for increasing agricultural water productivity whose benefits could be intensified when coupled with crop simulation modeling to investigate multiple water scarcity alternatives. Fereres and Soriano refer DI as the application of water below the crop evapotranspiration (ET) requirements [11]. After reviewing many field crops under DI, the authors concluded that there is potential for improving water productivity in many field crops and thus documented sufficient information for defining the best deficit irrigation strategy for many situations. Mila conducted field experiments on yield, water productivity and economics on sunflower production. [12] Results

***Address for Correspondence:** Rioba DO, Department of Civil & Structural Engineering, School of Enginering, Moi University, Eldoret, Kenya, Tel:+2545343170; Email: riobaduncan@gmail.com*

Received 21 February 2021; **Accepted** 10 March 2021; **Published** 17 March 2021

indicated that DI treatments at vegetative and pre-flowering stages gave the highest water productivity, irrigation water productivity, and net financial returns. The FAO Aqua Crop simulation model provides a sound theoretical framework to investigate crop yield response to environmental stress [10,13].

There exist numerous possibilities when investigating and imposing a DI management plan. Some of these include growth-stage-specific DI, intermittent DI (irrigation is applied on specific days), and root zone soil moisture depletion. In each case, different water amounts can be applied. Owing to their cost and time effectiveness, crop simulation models is ideally suited for the evaluation of irrigation strategies where there are various alternatives. In the present study, beans (*Phaseolus Vulgaris L.*) also known as common/dry bean, being the most widely cultivated type of bean in Kenya [14] was used to evaluate the effect of deficit irrigation on the water productivity and yield of beans. This was achieved by calibrating Aqua Crop for beans and using it to obtain results on yield output and water productivity under varying irrigation strategies.

According to Dua significant challenge for agriculture is to provide the world's growing population with a sustainable and secure supply of sufficient, safe [7], nutritious food that meets dietary needs and food preferences for an active and healthy life. In 2007, the total yield of common beans in Kenya was 417,000 tons against a demand of over 500,000 ton [15]. This disparity is due to complex biological and physical stresses (such as rainfall variability, insect pests and diseases and declined soil fertility) which keep the yield at less than 25% of potential yield [16]. Recent studies [17] reported that the yield of beans is estimated to have shrunk by 68%. This could be due to decline in long rains and increasing drought spells brought about by climate variability (Figure 1) among other factors. Thus, there is a need to tackle the problem of the declining bean yields while at the same time ensuring that the available water resources are used sustainably. This study focused on the effect of water stress on the yield and water productivity of beans in Uasin Gishu County, Kenya.

Improving water productivity is the most appropriate strategy for increasing food production for a fast growing population due to its consideration of the sustainability of water resources. The region is located in western Kenya where the rainfall distribution is bimodal with the farmers preferring to grow the beans in the long rainy seasons (Figure 1). Cultivation in the short rainy seasons is avoided due to the risk associated with rains that cannot adequately satisfy the crop water requirements. This leads to low yields and a supply deficit of beans.By using drip irrigation as a means of meeting crop water demands during the dry spell, the effect of water stress on the yield and water productivity of beans was studied. This enabled further understanding into how to optimize yields while ensuring water sustainability.

This study was intended to provide a decision-support tool which can be used to advise the farmers on the effect of various irrigation strategies on the yield and water productivity of dry beans. This will assist in ensuring that proper irrigation scheduling is carried out leading to increased water productivity thus promoting water conservation. In so doing, more land can be brought into production, thus addressing food insecurity. The amount of water savings depends upon the irrigation water requirements and in this case the extent to which DI may be applied within acceptable drop in crop yields and thus Water Use Efficiency (WUE).

Irrigation water requirements and deficit irrigation

Irrigation water requirement is the amount of water supplied to the plants to prevent stress and yield reduction. It is essential to apply irrigation water at the right time and in the right quantity. Under or overwatering can lead to reduced yields, lower quality and inefficient use of nutrients. The application depth is affected by the soil type, crop type, stage, and climate and irrigation method. Therefore, the textural class of the soil has to be determined in order to establish its hydraulic properties. Short-term irrigation requirements, when combined with soil water holding characteristics, enable specification of when and how much water to apply (irrigation scheduling). This forms the basis of deficit irrigation (DI), an irrigation strategy whereby water is applied only during the drought-sensitive growth stages of a crop [18]. Although this technique may results in reduction in the crop yield, Kipkorir et al. pointed out that the amount of water saved can be used to irrigate more land on the same farm, or be utilized by other water users [5]. Hence, the high opportunity cost of water compensates for the economic loss due to reduction in yields. However, this notwithstanding, it can be argued that deficit irrigation does not necessarily lead to reduction in yields because the issue at hand is not that of maximizing yields, rather it is that of striking a balance between improved yields and water productivity in order to simultaneously address issues of water scarcity and food shortages.

Crop yield, water use efficiency and water productivity

Water productivity is defined as "the physical mass of production or the economic value of production measured against gross inflows, net inflow, depleted water, process depleted water, or available water".In terms of agriculture, water productivity is regarded as the ratio of the mass of marketable yield (Y_a) to the volume of water evapotranspired (consumed) by the crop (ET_a) [19,20], expressed by equation 1.

$$WP = \frac{Y_a}{ET_a} \quad (1)$$

Where, WP is water productivity (kg/m^3), Y_a is mass of marketable yield (kg), and ET_a is the actual volume of water evapotranspired on the field (m^3).

The water use efficiency (kg/ha-mm) as stated by Sinclair in Hallu et al. (2018) is the ratio of [21,22] the total biomass or grain yield to water supply or evapotranspiration or transpiration on a daily or seasonal basis, as illustrated in Equation 2:

$$WUE = \frac{Y}{ET_c} (2)$$

Where, WUE is the water use efficiency (kg/ha-mm), Y is the yield (kgha^{-1}), and ET_c is the evapotranspiration (mm).

Crop Models

The challenges facing food production coupled with the problems of limited water resources are diverse. Reliance on long-term experiments will not provide quick solutions that are promptly needed. Consequently, crop models are useful to better understand and formulate innovative technologies. Crop models are predominantly used for interpretation of experimental results.

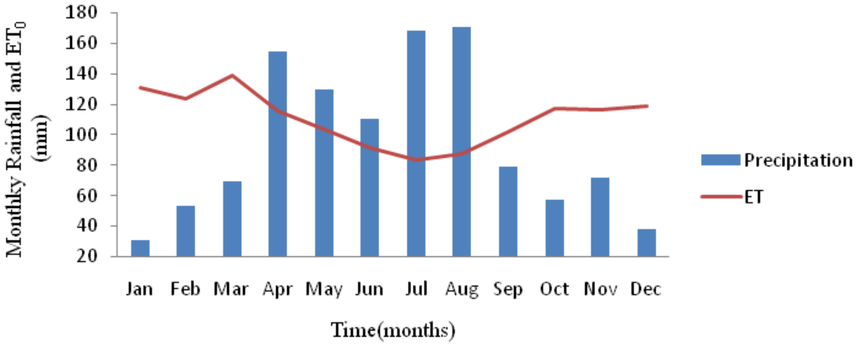

Figure 1. Mean precipitation and the reference evapotranspiration (ET_0) distribution for Eldoret (Source: FAO New_LocClim, 2005).

According to Steduto et al., (2009), extensive and costly experiments can be pre-assessed through a well-proven model to refine field tests and reduce their overall costs [23]. Additionally, models can be used as decision support tools for optimum management practices, planning and policymaking.

Depending on the purpose and objectives of the crop model, two main modelling approaches can be distinguished: scientific and engineering [23]. The scientific approach mainly aims at improving the users understanding of crop behaviour, its physiology, and response to environmental change while the latter attempts to provide sound management advice to farmers or predictions to policymakers (Passioura, 1996). The choice of a suitable model is critical to any study. Some models present considerable complexity for the majority of targeted users, such as extension personnel, water use associations, consulting engineers, irrigation and farm managers, and economists. Additionally, others required extended number of variables and input parameters not easily available for the various range of crops and locations around the [9]. Typically, these variables are much more familiar to scientists than to end users. To tackle these concerns Aqua Crop [20,23,24], was developed by FAO.

Aqua Crop is a canopy-level model, mainly focused on simulating the attainable crop biomass and harvestable yield in response to the water applied [23]. The model emphasizes on water because it is a key driver of agricultural production (*ibid*). The input requirements are commonly available and the numbers of parameters required are relatively few. Consequently, it strikes a balance between simplicity, accuracy and robustness [20].This being a study involving the investigation into the effects of deficit irrigation on the production of beans, Aqua Crop was thus selected as the most appropriate model to undertake this task.

Objective of Study

The primary objective of this study was to evaluate the effect of deficit irrigation on the yield and water productivity of beans using Aqua Crop. Field experiments were set up in a complete randomized system from April to July 2014 at Moi University, Kenya. The beans were subjected to four water treatments of the irrigation water requirement (100%, 80%, 60% and 50%).

Materials and Methods

Study area and climatic conditions

The study was carried out at Moi University, main campus (0 °17' N, 35°20' E, altitude 2240 m above sea level) in Uasin Gishu County about 35 km South East of Eldoret town (Figure 2). Rainfall in this region is characterized by two seasons, long rains from April to September and the short rains season starts from October to December (Figure 1).The field experiments were carried out at the university's irrigation farm between 18th April and 20th July 2014.

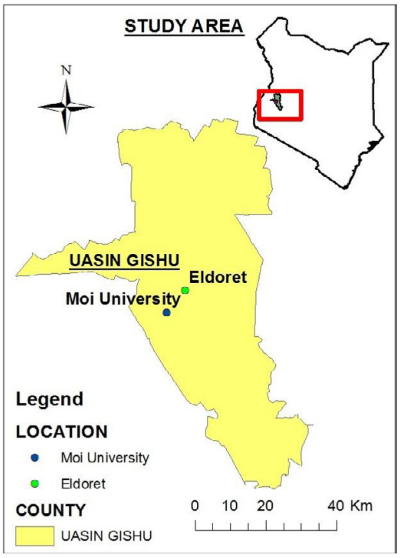

Figure 2. Location of the study area and meteorological stations.

Experimental design and treatments

The field experiments were carried out in a Randomized Complete Block Design (RCBD) arranged in split plots in three replicates. As illustrated in Figure 3, the size of the experimental plots was 10 m^2 (5 m x 2 m) with a spacing of 0.5 m between the plots, and a spacing of 1.0 m between the replicates. Rain shelter was incorporated to cut off rain on the experimental plots during a rain event. This was based on a similar research by Tsegay [24].

Four different water treatments were applied. There was one full irrigation treatment where the crop was kept at 100% of irrigation requirements (T100); soil moisture and crop data was collected from these fields throughout the season and was used for Aqua Crop calibration. In the other three treatments, the crops were subjected to deficit irrigation, where the crops were kept at 80%, 60% and 50% of irrigation requirements (T80, T60, and T50). Data collected from these water-stressed fields was used for model validation. The four treatments were replicated thrice resulting in 12 plots (Figure 3). In the T100 treatment, the estimated root zone was refilled to field capacity (FC) when soil water in the root zone approached 45% of total available water [14]. In the deficit-irrigated treatments, irrigation occurred on the same day as the fully irrigated plots, but the irrigation depth was reduced to 50% (T50), 40% (T60), and 20% (T80) of the T100 treatment. The experiment was set up in such a manner that the only water input considered was from the irrigation water applied.

Irrigation water applications

Water was supplied to the beans via a drip irrigation system. The system consisted of a PVC main line and sub-main lines of diameters 50 mm and 32 mm, respectively. Polyethylene drip lines (laterals) of 25 mm in diameter were used to irrigate the beans. The drip lines had built in emitters with a nominal discharge of 1.2 l/hr spaced 20 cm from each other. Additionally, control valves were installed at the entry of each plot to adjust and control the amount of irrigation water delivered to each plot (Figure 3).

In order to apply water in the right quantity and at the right time, a soil water balance equation described by and given in equation 3 was used [25]. First, historical climatic data of the area was used to estimate daily evapotranspiration (ET_0) by means of the FAO Penman-Monteith equation. [26,27] Thereafter, the crop evapotranspiration (ETc) was calculated with the crop coefficient (K_c) and reference evapotranspiration (ET_0) using Equation 3.

$$ET_C = K_C ET_0 \ (3)$$

Soil water levels in the root zone were used as a measure of when to start and stop irrigation events. Adequate soil water is critical for beans during emergence. The amount of irrigation water was scheduled throughout

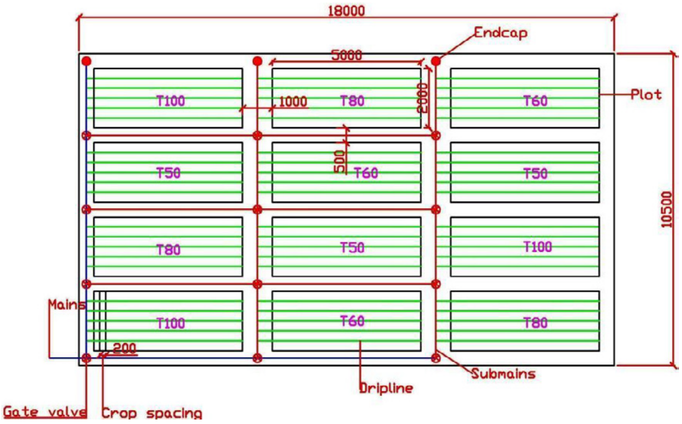

Figure 3. Layout of the drip irrigation system under full irrigation (T100) and Deficit irrigation (T80, T60, and T50). Units (mm).

the growth season by use of the soil-water-atmosphere balance equation (Equation 3). At the beginning of the season, the soil moisture was determined to be close to permanent wilting point (SW_0 = PWP). Therefore, in the first irrigation treatment, the root zone was refilled to field capacity (FC) in all the treatments. Equation 4 determined the depth of the irrigation application while Equation 5 estimated the amount of water in the root-zone at any given time.

$$I_{T1} = (Wr_{Fc} - Wr_{T0}) + \left(\sum_{T0}^{T1} ET_C - \sum_{T0}^{T1} RF - I_{T0} \right) (4)$$

$$Wr_{Fc} - Wr_{T0} = 1000\ (\theta_{Fc} - \theta_{T0})\ Zr\ (5)$$

Where

ET_c = crop evapotranspiration under no water stress conditions

K_c = crop coefficient

ET_0 = reference evapotranspiration

I_{T1} = irrigation depth required at time T1 (mm),

Wr_{FC} = soil water content in root zone at field capacity (mm),

Wr_{T0} = soil water content in root zone at time T_0 (mm),

I_{T0} = irrigation depth at time T_0 (mm),

θ_{FC} = moisture content at field capacity (vol %),

θ_{T0} = moisture content at time T_0 (vol %),

RF = effective rainfall (zero due to rain shelter) (mm),

Zr= rooting depth (m).

Water Use Efficiency and Water Productivity

WUE and WP were computed using Equation 1 and Equation 2, respectively.

Aqua Crop model

To use Aqua Crop to derive DI schedules, Geerts, et al. (2010) proposed and discussed at length four steps viz.[19].

1). After correctly calibrating and validating Aqua Crop to the specific crop with a long series of historical data, the crop development from sowing to the start of growth sensitive stages is simulated under rain fed conditions.

2). Simulation results are statistically analyzed to obtain indicative degrees of crop development that can be expected at the start of the sensitive growing stages for different type of years. Here, a frequency analysis of the simulated above ground, dry biomass production (B) at the start of the sensitive stages, is done. Three characteristic years with B levels similar to the tabulated B with 20, 50 and 80% probability of exceedance at the start of the sensitive growing stages are selected.

3). Simulations are then run for the complete growing cycles for the three selected years. During the sensitive growing stages irrigation applications are generated in aqua Crop by selecting the 'depth' and 'time' criteria and no-rainfall is assumed during these stages. Irrigation method, crop and soil characteristics are factors considered while selecting a fixed irrigation dose (depth criterion), the time criterion is achieved through selection of an allowable depletion level of the root zone at which irrigation should be triggered and normally coincides with the crop's sensitivity to drought stress. A parameter, Harvest Index (HI) is used to simulate the B portioning into harvestable yield and is usually adjusted to the timing and intensity of the drought stress. aqua Crop allows the user to visualize the combined positive and negative effect of the drought stress on the HI and to derive mathematically optimal level of depletion during the sensitive growth stages. By selection an allowable depletion level that avoids severe drought stress during sensitive growth stages, HI and WP can be maximized.

4). the generated schedules with varying irrigation intervals during sensitive growing stages are simplified and translated into an easy readable chart.

Climatic data

Aqua Crop requires daily minimum and maximum temperatures, daily reference evapotranspiration (ET_0), daily rainfall data and annual CO_2 concentration as input in its climatic file. During the experiment period, daily weather data (daily maximum and minimum temperature, average wind speed at 2m height, mean relative humidity) was collected from the Moi University weather station for calculation of the daily ETo. The rainfall was considered as zero on the experimental plots since the rain shelter was used. A software, the ETocalculator [25] which uses the FAO Penman-Montecito equation [26], aided in the computation. The annual CO_2 concentration levels are already incorporated into the model by default. The values are obtained from the Mauna Loa Observatory in Hawaii. Mauna Loa is regularly used as an illustration of rising carbon dioxide levels because it is the longest, continuous series of directly measured atmospheric CO_2[27-29]. Consequently, CO_2 data from Mauna Loa can be used as a proxy for global CO_2 levels because CO_2 mixes well throughout the atmosphere. Therefore, the trend in Mauna [30,31] Loa CO_2 (1.64 ppm per year) is statistically indistinguishable from the trend in global CO_2 levels (1.66 ppm per year) [28,32].

Results and Discussions

Climatic data analysis

In this study, the proposed season for growing the beans is during the short rainy season. The average seasonal rainfall (October-December) and evapotranspiration (ET_0) for 22 years (1990-2011) was about 220 mm and 415 mm, respectively (Figure 4). This suggests that during this period rainfall could only meet slightly over 50% of the reference evapotranspiration.

During this period, the evaporative demand of the atmosphere, ET_0, is much greater than the rainfall. It is important to note that the water requirement for maximum production of the beans is between 300 - 500 mm [14]. Due to this apparent water deficit, there is clear need for another source of water to

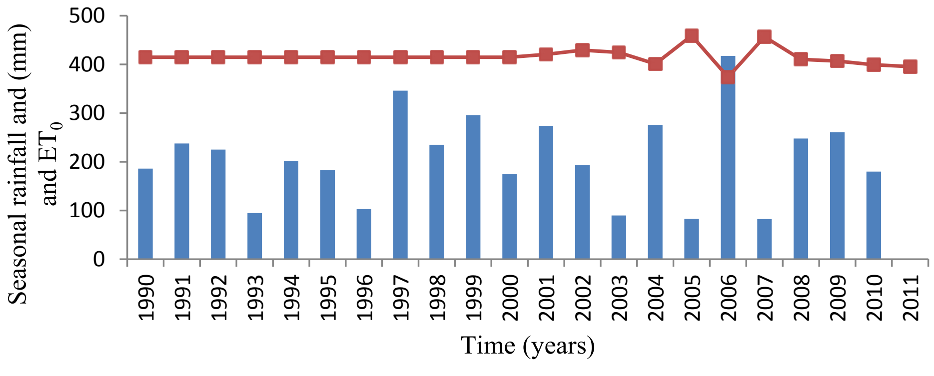

Figure 4. Rainfall (bars) and ET_0 (full line) during the short rains season (October- December). (Source: Moi University weather station, data observed from 1990- 2011).

ensure optimum production of beans during this season.

Irrigation

There were a total of 22 irrigation events with the total irrigation water being 3.970 m^3, 3.220 m^3, 2.460 m^3 and 2.080 m^3 for treatments T100, T80, T60, and T50 respectively. A total of 1173 mm of irrigation water was used in all the four treatments (Table 1). The amount of irrigation water was added every three days based on crop water requirement calculations.

The water applied for the treatments for T100, T80, T60 and T50 during the initial stage was 14.9%, 15.2%, 17.9% and 18.8%, respectively of the total water applied for each treatment. The difference in the percentages is as a result of the constant 19 mm that each treatment received at the beginning as pre-irrigation to raise the root zone soil moisture to field capacity. During the remaining stages, the average percentage amount of water applied in all treatment was 18.9%, 43.8% and 22.5%, respectively, of the total water applied for each treatment. In all treatments, the water demand was highest at the mid-season growing stage (Table 1); this is when the crop is at the flowering and yield formation period and thus has a great bearing on the final grain yield.

The total amount of irrigation water applied was 180.1%, 146.4%, 111.8% and 94.6% of the expected rainfall in the season (Figure 4) for the treatments T100, T80, T60 and T50, respectively. Since rainfall can only meet slightly over 50% of the reference crop evapotranspiration, any water application that is less than 100% ET_c, corresponding to 397 mm in this study, will cause reduction in yield.

Evaluation of yield and water productivity

The observed and simulated yield and water productivity for all the irrigation treatments are presented in Table 2.

The mean yield obtained from the treatments were 4.24, 4.14, 2.25 and 1.7 t/ha from treatments T100, T80, T60 and T50, respectively (Table 2). This represented a 2.4%, 46.8% and 59.8% yield reduction when the T100 treatment, yield of 4.24 t/ha is considered to be the optimum yield. This non-linear relationship between yield reduction and amount of water applied is very useful in the management of deficit irrigation. A farmer may choose to lose a certain percentage of yield for a reduced amount of irrigation water application.

The model prediction of bean yield showed a good agreement with observed values with an R^2 of 0.83 (Figure 5). The Wilmot's index of agreement was 0.97 and root mean square error was 0.4 t/ha.

The T100 irrigation treatment had the highest yield as compared to the other treatments due to lack of water stress. Explainthat solar radiation is the driving force between biomass production and transpiration [23]. Plants need to satisfy the evapotranspiration demand of the atmosphere. In order

Table 1. Amount of irrigation water added throughout the season.

Irrigation treatments							
Dates	**K_c**	**Growth Stage**	**Interval (days)**	**T100 (mm)**	**T80 (mm)**	**T60 (mm)**	**T50 (mm)**
17/4/2014			0	19	19	19	19
21/4/2014	0.4	Initial	3	8	6	5	4
25/4/2014	0.4		3	8	6	5	4
29/4/2014	0.4		3	8	6	5	4
3/5/2014	0.4		3	8	6	5	4
7/5/2014	0.4		3	8	6	5	4
11/5/2014	0.75	Development	3	14	11	8	7
15/5/2014	0.75		3	14	11	8	7
19/5/2014	0.8		3	15	12	9	8
23/5/2014	0.9		3	16	13	10	8
27/5/2014	0.9		3	17	14	10	8
31/5/2014	1.15	Mid-season	3	22	17	13	11
4/6/2014	1.15		3	22	17	13	11
8/6/2014	1.15		3	22	17	13	11
13/6/2014	1.15		3	22	17	13	11
17/6/2014	1.15		3	22	17	13	11
21/6/2014	1.15		3	22	17	13	11
25/6/2014	1.15		3	22	17	13	11
29/6/2014	1.15		3	22	17	13	11
3/7/2014	1.1	Late season	3	21	17	13	11
7/7/2014	1.1		3	21	17	12	10
11/7/2014	0.95		3	19	15	12	10
15/7/2014	0.88		3	17	14	10	9
19/7/2014	0.3		3	13	10	8	6
Total				397	322	246	208

Table 2. Observed and simulated yield and water productivity under different irrigation treatments.

Irrigation treatments	**Yield (t/ha)**		**PD (%)**	**WP (kg/m^3)**	
	Observed	**Simulated**		**Observed**	**Simulated**
T100	4.238	4.387	-3.516	1.01	1.12
T80	4.138	3.952	4.495	1.29	1.23
T60	2.254	2.848	-11.691	0.92	1.01
T50	1.702	2.179	-28.026	0.77	0.98

PD% = percentage difference between observed and measured yield.

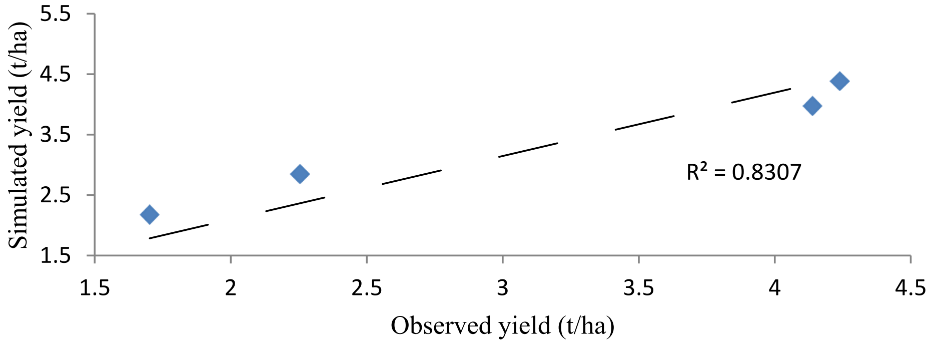

Figure 5. Observed and simulated yield of beans under the different levels of irrigation treatment.

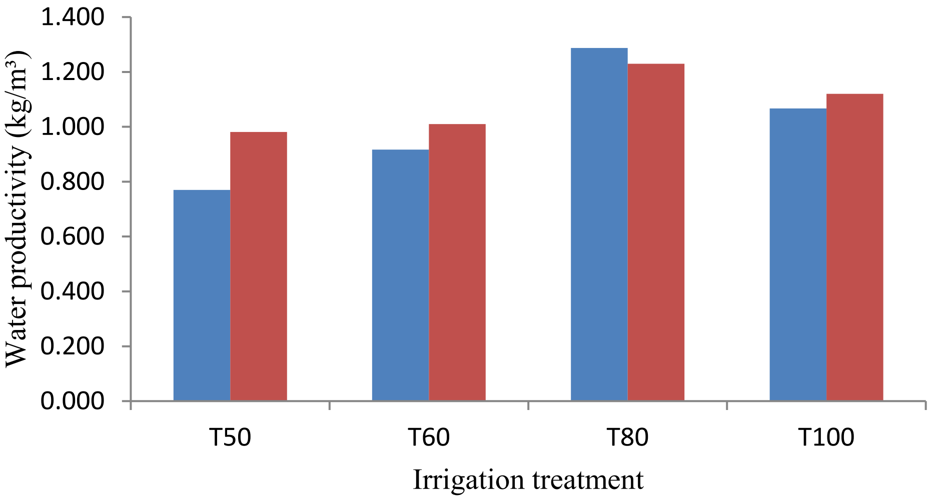

Figure 6. Observed (blue bars) and simulated (red bars) water productivity for beans under the different levels of irrigation treatment.

tocapture carbon dioxide, stomata need to be open for evaporation to take place. If there is water stress, stomata closes thus reducing the rate of photosynthesis and consequently transpiration is reduced thus ultimately affecting the yield. The T80, T60, and T50 irrigation treatments had lower yields because of the reduced evaporation rate due to the closure of stomata, which retarded growth.

Water productivity was, however, highest in the T80 treatment in both the observed and simulated values (Figure 6). This was an indication that the yield output per amount of water applied was highest in this treatment. The lowest yield reduction was also obtained in the T80 treatment, where saving 20% of full irrigation, which translates to 750 m^3/ha reduced bean yield by 2.4% and 9.3% in the observed and simulated results, respectively (Table 3). Whereas, the highest yield reduction was obtained in T50 irrigation treatment i.e. 59.8% and 50.3% in the observed and simulated results, respectively. This is consistent with the fact that common beans with a yield response factor Ky>1 are sensitive to severe water stress. Therefore, the lower drop in yield in the T80 treatment is attributed to the fact that the crop experiences significantly less stress during the drought sensitive stages as compared to the T60 and T50 treatments (Figure 6,Table 3).

PR% represents the percentage reduction between T100 and the respective treatment observed and simulated yield.

Conclusions and Recommendations

Conclusions

The following conclusions were drawn from the study:

1. The successfully calibrated model was used to simulate water productivity and yield response of the four water treatments (100%, 80%, 60% and 50%). From the results obtained, it was deduced that the 80% deficit irrigation treatment had the highest water productivity with the least decline in yield in comparison with the 100% water supply. However, the 60% and 50% deficit irrigation treatments had a considerable drop in yield while at the same time having a decline in water productivity. This was attributed to the fact that in these treatments there was considerable water stress during the flowering stage especially in the 50% treatment. Irrigation schedules were generated (Table 1) which can be used to determine the most favourable irrigation strategy with the prevailing water availability. Therefore, a powerful decision-making tool was produced to advise farmers on attaining reasonable yield while at the same time ensuring conservation of water resources. Increasing water productivity is a primary goal and should be accomplished to maintain food security and water sustainability.

Table 3. Observed and simulated yield under different irrigation treatments.

Irrigation treatments	Yield (t/ha) Observed	PR (%)	Yield (t/ha) Simulated	PR (%)
T100	4.238	0	4.387	0
T80	4.138	2.360	3.952	9.323
T60	2.254	46.815	2.848	35.081
T50	1.702	59.840	2.179	50.331

2. The calibrated model was able to satisfactorily predict the water productivity and yield of beans under different irrigation treatments. Therefore, it can be used as a powerful tool for enabling farmers to obtain profitable yields while ensuring water use efficiency. This scenario will ensure food security during drought while at the same time ensure water security.

3. The study confirmed Aqua Crop is robust, simple and applicable, as it tries to keep the balance between accuracy and input requirements. It requires

only limited input parameters that can easily be determined in the field.

Recommendations

From the results obtained, and general observations made, the following recommendations were made:

1.Relying on the short rains (October-December) season for growing beans poses a substantial risk of crop failure due to the high temporal and spatial variability of rainfall. Therefore, farmers should embrace the deficit irrigation strategy to ensure reasonable yields while at the same time ensure water conservation.

2.The effects of climate change are with us, leading to the unpredictability of climatic conditions and severe droughts. Aqua Crop can be used to carry out further simulations on various scenarios of climate change and effect they will have on the crop yield and irrigation water demand now and in the future.

References

1. WWAP (World Water Assessment Programme). The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. *Paris, UNESCO*, (2012).
2. Land & Water. “Food and Agriculture Organization of the United Nations (FAO)” *ETo Calculator. Rome, Italy* (2013).
3. Poulton Colin and Karuti Kanyinga. "The politics of revitalizing agriculture in Kenya." *Dev Policy Rev* 32 (2014): s151-72.
4. Kilele AKM. "Kenya National Bureau of Statistics (KNBS)." Kenya facts and figures (2008).
5. Kipkorir E, Dirk Raes and Labadie J. "Optimal allocation of short-term irrigation supply." *Irrig Drain* 15 (2001): 247-267.
6. Salemi Hamidreza, Mohd Amin Mohd Soom, Teang Shui Lee and Sayed Farhad Mousavi, et al. "Application of AquaCrop model in deficit irrigation management of winter wheat in arid region." *Afr J Agric Res* 6 (2011): 2204-2215.
7. Du Taisheng, Shaozhong Kang, Jianhua Zhang and William J Davies. "Deficit irrigation and sustainable water-resource strategies in agriculture for China’s food security." *J Exp Bot* 66 (2015): 2253-2269.
8. Abdelaziz Zairi, Hacib El Amami, Slatni A and LS Pereira, et al. "Coping with drought: deficit irrigation strategies for cereals and field horticultural crops in Central Tunisia." *Tools for drought mitigation in Mediterranean regions*, Springer, Dordrecht (2003):181-201.
9. Giordano Meredith, Rijsberman Frank R, Saleth R Maria. "More crop per drop: Revisiting a research paradigm: Results and synthesis of IWMI's research 1996-2005,." *Water Intelligence Online* (2006):02284.
10. Greaves Geneille E, and Yu-Min Wang. "Assessment of FAO AquaCrop model for simulating maize growth and productivity under deficit irrigation in a tropical environment." *Water* 8(2016): 557.
11. Fereres Elias and María Auxiliadora Soriano. "Deficit irrigation for reducing agricultural water use." *J Exp Bot* 58(2007): 147-59.
12. Mila Afrin Jahan, Md Hossain Ali, Abdur Razzaque Akanda and Md Harun Rashid, et al. "Effects of deficit irrigation on yield, water productivity and economic return of sunflower." *Cogent Food & Agriculture* 3 (2017):1287619.
13. Farahani Hamid J, Gabriella Izzi and Theib Y Oweis. "Parameterization and evaluation of the AquaCrop model for full and deficit irrigated cotton." *Agron J* 101 (2009):469-476.
14. Doorenbos J and Kassam AH "Yield response to water." *Irrig Drain* 33 (1979): 257.
15. Katungi Enid, Sperling L, Karanja D and Farrow A, et al. “Relative importance of common bean attributes and variety demand in the drought areas of Kenya.” *J Dev Agric Econ 3*(2011):411-22.
16. Odendo MS David, Kalyebara R, Ostyula R and Buruchara R. "The key role of beans in poverty alleviation: Lessons from the impact of Improved bean varieties in western Kenya." *Occas Public* 43 (2004).
17. Michira MOSES. UN scientists predict global warming to deal Kenya severe blow by 2030,(2014).
18. Geerts Sam and Dirk Raes. "Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas." *Agric Water Manag* 96 (2009):1275-1284.
19. Geerts Sam, Dirk Raes and Magali Garcia. "Using AquaCrop to derive deficit irrigation schedules." *Agric. Water Manag.* 98 (2010):213-216.
20. Dirk Raes, Steduto Pasquale, Theodore C Hsiao and Elias Fereres. "Aqua Crop—The FAO Crop Model to Simulate Yield Response to Water: II. Main Algorithms and Software Description.” *Agron J* 101(2009):438-447.
21. Sinclair, Thomas R, Tanner CB and Bennett JM. "Water-use efficiency in crop production." *Bioscience* 34(1984):36-40.
22. Zhang Rui, Zhuhuang Zhou, Weiwei Wu and Chung-Chih Lin, et al. "An improved fuzzy connectedness method for automatic three-dimensional liver vessel segmentation in CT images." *J Healthc Eng* (2018):1-18.
23. Steduto Pasquale, Theodore C Hsiao, Dirk Raes and Fereres E. “Aqua Crop—The FAO Crop Model to Simulate Yield Response to Water: I. Concepts and Underlying Principles.” *Agron J 101*(2009)426–437.
24. Beyene Alemtsehay Tsegay. "Improving crop production by field management strategies using crop water productivity modeling: Case study of tef (Eragrostistef (Zucc.) Trotter) production in Tigray, Ethiopia"(2012).
25. Land & Water. “Food and Agriculture Organization of the United Nations (FAO)” *ETo Calculator. Rome, Italy* (2009).
26. Allen Richard G, Luis S Pereira, Dirk Raes and Martin Smith. "Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56." *Fao, Rome* 300 (1998):D05109.
27. Food and Agriculture Organization of the United Nations (FAO), *Local Climate Estimator. TheNew_LocClim software*. Rome, Italy, (2005).
28. Oteki Duncan Rioba. "Evaluation of Deficit Irrigation on Water Productivity and Yield Response of Beans Using Aqua Crop in Eldoret, Kenya", Moi University, (2015).
29. Theodore C Hsiao, Lee Heng, Pasquale Steduto and Basilio Rojas-Lara, et al. “AquaCrop—The FAO Crop Model to Simulate Yield Response to Water: III. Parameterization and Testing for Maize.” *Agron J* 101 (2009): 448–459.
30. Masasi Blessing, Saleh Taghvaeian, Prasanna H Gowda and Gary Marek, et al. "Validation and application of Aqua Crop for irrigated cotton in the Southern Great Plains of US." *Irri Sci* 38 (2020): 593-607.
31. Mugai Elisha Njue. "Salinity characterization of the Kenyan saline soils." *J Soil Sci Plant Nutr* 50(2004): 181-188.
32. Stockle CO. "Environmental impact of irrigation: A review." (2013)

How to cite this article: Rioba DO, Kosgei JR and Kipkorir EC. Models Using Drip Irrigation to Mitigate the Effects of Drought in Food Production: A Case Study of Production of Beans during Dry Spells in Uasin Gishu County, Kenya. *Irrigat Drainage Sys Eng* 10 (2021): 260.