Effect of Deficit Irrigation on Yield - Water Relation of French Bean in Rift Valley – Njoro Nakuru County- Kenya

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Abstract: This research experiment was conducted from January to March 2017, at the Agricultural Engineering Department Demonstration farm/ Egerton University Nakuru Kenya. The objective of the study was to investigate the effect of deficit irrigation scheduling on yield and water relation of French bean (Phaseolus Vulgaris L). The modified FAO Peneman Montieth Method was used to calculate ETo by adapting ETo calculator, crop coefficient was used to calculate evapotranspiration Etc, the water application levels were 100% of evapotranspiration (Etc), 80% Etc, 60%Etc, and 40%Etc. Based on these irrigation levels. The experiment was laid out in RCBD with four treatments and three replications. Data collection during the experiment was irrigation depth and crop data (pod yield), Crop water use and Irrigation water use. The deficit irrigation levels applied throughout the growing season of French bean had significantly (P < 0.001) affected pod weight. From the result the highest yield was found in treatment 100%Etc (10.008 t/h) and the lowest yield was found in treatment 40%Etc (3.203 t/ha) the deficit irrigation was throughout the season except crop establishment (initial stage), the highest and lowest crop water use efficiency (3.07 kg/m³) and (2.25kg/m³) were found in 80%Etc and 40%Etc, and the highest irrigation water use efficiency was 2.76 and 2.03 in treatments 80%Etc and 40% Etc). Therefore in water scars areas irrigation water for French beans can be reduced by 20% water requirement with less effect in yield reduction.

Key word: Deficit irrigation. Water use efficiency. Evapotranspiration. French bean

I. Introduction

Irrigation is considered the greatest user of water resources in the world, with 70% total withdrawals and over 80% of consumptive use [9]. Water scarcity is due to physical constraints of fresh water resources and inefficient use and poor [17] The increasing demand for water made widen gap between supply and demand in most parts of the world [18]. Furthermore, the increasing worldwide shortage of water and costs of irrigation are leading to an emphasis on developing irrigation techniques that economize the water use and maximize its use efficiency [10]. As water resources around the world are threatened by scarcity it is important to improve our ability to produce more food with less water. Therefore, there is an urgent need to develop and adopt suitable water conservation measures. This should be taken as a major approach in the design of irrigation water distribution and management systems. It can be accomplished by improving water use efficiency through implementation of appropriate technologies. Adoption of modern water-saving technologies is often help as the key to increasing water use efficiency while maintaining current levels of production [3].

The lack of proper irrigation scheduling decisions and appropriate evaluation of their performance and economic impacts at farm level are the main constraints for adoption of efficient irrigation strategies [2]. Deficit irrigation technique is an irrigation scheduling strategy in which only a fraction of seasonal net crop water requirement is achieved through applied irrigation water [7]. It matches the level of irrigation, the amount of land and the crop mix, which maximizes the benefits of irrigation. Correct application of deficit irrigation requires the understanding of yield and economic impact of reduction of harvested produce [5]. According to Blum [1] where less water than required is applied during growing season, high yield can still be obtained by supplying the required amount of irrigation water during sensitive crop growth stage.

Food insecurity in Kenya like in many other sub-Saharan African countries continues to loom. With demand for more food increases more water is being used to recurrent problem to alleviate persistent recurrent food shortage. Water use by agriculture must be decreased to 33 present by the year 2025. In ASALs. Many of the existing irrigation systems do not use water efficiently, thus prompting the need for the current study. The purpose of the current study therefore, will be to determine the effectiveness of adopting efficient, economical
irrigation water application techniques and developing water management technologies, the objective of the study was to investigate the effect of deficit irrigation on yield – water relation of French bean.

II. Materials and methods

The experiments were conducted in dry season from January to April 2017 at the Agricultural Engineering Research Field of Egerton University, Njoro, Kenya. The field lies at latitude of 0°23 S, longitude 35°35 E and altitude of 2200 m.a.s.l. under rain shelter the data for maximum and minimum temperature, evaporation and rainfall were presented in figure below:

![Weather data from January to April 2017.](image)

A Soil characteristics

Soil samples from the study area were collected from 0-15 cm and 15 – 30 cm depth to characterize the soil in term of physical characteristics such as textural class (soil texture). PH. Organic matter and the average bulk density. And the soil parameter were analysed at the soil laboratory of Egerton University and Kenya Agricultural and Livestock Research Organization (KALRO) Njoro. The table 1 below showed the soil characteristics:

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Soil texture</th>
<th>Soil type</th>
<th>FC %</th>
<th>PWP %</th>
<th>TAW %</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15</td>
<td>64</td>
<td>26.5</td>
<td>9.5</td>
<td>SL</td>
<td>19.65</td>
<td>11.5</td>
</tr>
<tr>
<td>15-30</td>
<td>59</td>
<td>29</td>
<td>12</td>
<td>SL</td>
<td>20.65</td>
<td>10.7</td>
</tr>
</tbody>
</table>

SL= Sandy loam, FC = field capacity, PWP = permanent wilting point, TAW = total available water

The average soil separate values obtained are 64% sand, 26.5 silt and 9.4 clay. The soil texture class is sandy loam textured throughout the profile investigated on USDA soil textural classification triangle. The soil moisture content at field capacity is ranged from 20.65-19.65 % at the depth of 0-30 cm. the permanent wilting point values obtained is ranged 10.7- 11.5% and the total available water is 8.5%. And the pH of the soil at the experimental site is 5.84 indicate that the soil still suitable for growing the French bean.

B Experimental design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with four treatments replicated three times. The treatments were watered at the level of 100%, 80%), 60(% and 40% ETc throughout the season, crop growth stages were four . The size of each experimental plot was 2x2 m. The plots and replications were separated by a path of 1 meter and the total numbers of experimental plots were 12. The spaces between plants were 15cm, and between the lines were 45cm. The French bean seeds cultivars Source were sourced from Amiran Kenya. Source is a determinate variety and one of the most popular among the French bean grower in Kenya. Each plot had five irrigation drip lines spaced at 45cm and 15cm between plants.
C Agronomic practices
The planting dates was first January 2017, planting density were 14 plants per m\(^2\), the nutrient requirements were determined based on soil analysis and were done by fertilizer application DAP 50 kg/acre (18.46.0), weed were controlled by hand when it appeared.

D Crop water requirement and irrigation management
The daily crop water requirements were calculated by multiplying the reference evapotranspiration values with the French bean crop coefficients (0.5, 0.75, 1.15 and 0.9) initial, development, mid and late stage respectively
\[
I = ET_C = ET_O \times K_C \times K_S
\]
Where:
- \(I\) = irrigation water requirement (mm)
- \(ET_c\) = crop water requirement (mm),
- \(ET_o\) = reference crop evapotranspiration (mm),
- \(K_c\) = crop coefficient that varies by crop development stage (range 0 to 1),
- \(K_s\) = coefficient for each irrigation treatment level in the experiment.

The reference evapotranspiration \(ET_o\) was determined using FAO Blaney-Criddle method. For purposes of creating irrigation schedules historical weather data of 15 years (2000-2015) was collected from Egerton University Meteorological Department. Values of crop coefficients \(K_c\) were selected from the table according to FAO Irrigation and Drainage Paper no 24 by Doorenbos and Pruitt [6]. The coefficient of each irrigation treatment \(K_s\) (1) = 100% of \(ET_c\) no stress, \(K_s\) (0.8) = 80% of \(ET_c\), \(K_s\) (0.6) = 60% of \(ET_c\), \(K_s\) (0.4) = 40% of \(ET_c\).

Water was applied by drip irrigation on the same day as that of fully irrigated plot, but the irrigation depths will be reduced to 80%, 60%, and 40%, of the full irrigation for T2, T3, T4, treatments respectively. The seasonal amount of irrigation water from each treatment was recorded.

<table>
<thead>
<tr>
<th>Date</th>
<th>Stages</th>
<th>(ET_o)</th>
<th>(K_c)</th>
<th>(ET_c)</th>
<th>Days</th>
<th>Total (ET_c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/1 – 24/1/017</td>
<td>Initial</td>
<td>4.3</td>
<td>0.5</td>
<td>2.15</td>
<td>20</td>
<td>43</td>
</tr>
<tr>
<td>25/1 – 31/1/17</td>
<td>Development</td>
<td>4.3</td>
<td>0.75</td>
<td>3.23</td>
<td>7</td>
<td>22.61</td>
</tr>
<tr>
<td>1/2 – 23/2</td>
<td>Development</td>
<td>4.4</td>
<td>0.75</td>
<td>3.3</td>
<td>23</td>
<td>75.9</td>
</tr>
<tr>
<td>24/2 – 30/2</td>
<td>Mid-season</td>
<td>4.4</td>
<td>1.15</td>
<td>5.06</td>
<td>7</td>
<td>35.42</td>
</tr>
<tr>
<td>1/3 – 23/3</td>
<td>Mid-season</td>
<td>4.7</td>
<td>1.15</td>
<td>5.4</td>
<td>23</td>
<td>124.315</td>
</tr>
<tr>
<td>24/3 – 31/3</td>
<td>Late season</td>
<td>4.7</td>
<td>0.9</td>
<td>4.23</td>
<td>8</td>
<td>33.84</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>26.5</td>
<td>5.2</td>
<td>23.03</td>
<td>88</td>
<td>335.085</td>
</tr>
<tr>
<td>Gross Irrigation</td>
<td></td>
<td>294.21</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For optimal condition the total water requirement of French bean was 335.08 mm table. Adopting irrigation efficiency to be 85%, the gross water requirement was 394mm.

E Crop parameters
Final yield was determined at the end of the season after the crop was harvested. An electronic balance (0.001g sensitivity) was used to weigh the pods from various treatments at each harvest time. Water use efficiency for each treatment was determined by dividing the harvested pod yield by its seasonal water use.

\[
CWUE = \frac{Ya}{CWU}
\]
Where \(CWUE\) = Crop water use efficiency (kg ha\(^{-1}\) mm\(^{-1}\)), \(Ya\) = Actual yield (kg ha\(^{-1}\)), \(CWU\) = Crop water use (mm). Irrigation water use efficiency was calculated from the ratio of fruit yield and irrigation water applied:

\[
IWUE = \frac{Ya}{IW}
\]
Where \(IWUE\) = Irrigation water use efficiency (kg ha\(^{-1}\) mm\(^{-1}\)), \(Ya\) = Actual yield (kg ha\(^{-1}\)), and \(IW\) = Gross Irrigation water applied (mm)

F Yield water relation
Development of Yield water relation (crop water-production) function was involve full and deficit irrigation scheduling and crop yield response data from deficit irrigation were fitted the following linear equation [15]

\[
(1 - Y_a \times Y_m^{-1}) = K_y \left(1 - ET_a \times ET_m^{-1}\right)
\]
Where
- \(Y_a\) = maximum yield (t ha\(^{-1}\)) from 100% water requirement,
- \(Y_a\) = actual yield (t ha\(^{-1}\)) from different level of water requirement,
- \(ET_a\) and \(ET_m\) = the maximum and actual evapotranspiration (mm),
- \(K_y\) = a yield response factor indicate the response of French beans to deficit irrigation.
G Statistical Analysis
The data was analysed statistically using analysis of variation (ANOVA) procedure of SAS 9.1.3. Mean separation was being done using Tukey's at significant level at 0.5.

III. Results and discussions

A Crop water use efficiency
The mean values of crop water use efficiency (CWUE) are presented in Table 3. The analysis of variance on irrigation water levels showed that the variability among irrigation level treatments were statistically significant (at P<0.001) on the mean CWUE values. The crop water use efficiency of French bean varied from 2.23 kg/m$^3$ to 3.24 kg/m$^3$.

Maximum mean CWUE was obtained when 80%ETc was applied throughout the growth season. Plots which received 100%ETc throughout the growth season resulted in second largest CWUE [16] reported that, French bean had greater potential to increase water use efficiency under deficit irrigation. According to [8] they reported that deficit irrigation increase water productivity for various crops. From Table 3, the second lowest mean value of CWUE (2.39 kg/m$^3$) was found when 40%ETc was imposed. The pod yield of French bean is severely affected by soil moisture stress at flowering and pod filling stages and then ultimately the crop water use efficiency. Therefore, application of adequate water during flowering and pod development was the most significant factor in bean irrigation [14].

B Irrigation water use efficiency
The calculated value of irrigation water use efficiency (IWUE) is presented in Table 3. IWUE as the ratio of total pod yield to the total gross irrigation water applied. The analysis of variance showed that the effect of irrigation levels throughout on irrigation water use efficiency was significantly (p < 0.001) different. From this result, it is clear seen that irrigation applied with 80% ETc can increases the irrigation water use efficiency with lower yield reduction (Table 3). Therefore, when irrigation water is plenty, the French bean can be irrigated at the level of 100%ETc but when water source is scarce, French beans can be irrigated at the lower water level (80% ETc) taking economic conditions into consideration.

Increasing the amount of water used by the plant or increasing the growth and yield of the plant can change water use efficiency [13][18].

Table: 3 Average applied water, crop water use and irrigation water use efficiency of French bean under DI practices

<table>
<thead>
<tr>
<th>Irrigation level</th>
<th>Net Irrigation (m3)</th>
<th>Gross Irrigation (m3)</th>
<th>Yield (kg/ha$^{-1}$)</th>
<th>CWUE (kg ha$^{-1}$ m$^{-1}$)</th>
<th>IWUE (kg ha$^{-1}$ m$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40%ETc</td>
<td>1340</td>
<td>1488</td>
<td>3200 d</td>
<td>2.39 c</td>
<td>2.15 c</td>
</tr>
<tr>
<td>60% ETc</td>
<td>2010</td>
<td>2233</td>
<td>4490 c</td>
<td>2.23 d</td>
<td>2.00 d</td>
</tr>
<tr>
<td>80% ETc</td>
<td>2680</td>
<td>2977</td>
<td>8702.00 b</td>
<td>3.24 a</td>
<td>2.92 a</td>
</tr>
<tr>
<td>100% ETc</td>
<td>3350</td>
<td>3722</td>
<td>9660 a</td>
<td>2.88 b</td>
<td>2.60 b</td>
</tr>
<tr>
<td>R²</td>
<td></td>
<td></td>
<td>0.99</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>CV%</td>
<td>0.043</td>
<td></td>
<td>0.27</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>RMSE</td>
<td>2.40</td>
<td></td>
<td>0.007</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>6312.38</td>
<td></td>
<td>2.58</td>
<td>2.25</td>
<td></td>
</tr>
</tbody>
</table>

*Means followed by the same letter within a column and a parameter are not significantly different according to Tukey's honestly significant difference test at p≤0.05.

C Crop-water-production functions

![Figure 2 Yield and irrigation water applied](image-url)
Crop water production functions show the rate of transformation of production functions to yield. The mathematical functions of ETc and yield that better fit the production obtained with the water volume received [12]. It is noted that there is no CWPF universally applicable to all crops, growing seasons and climatic zones. The coefficient of determination of the regressed equation was 0.93, which shows good correlation between applied water and yield. The good relationship obtained in this study between crop performance and seasonal irrigation water demonstrates that, accurate estimates of water requirement on a seasonal basis can be valuable in irrigation management decisions and scheduling. The maximum yield (9660 kg ha⁻¹) was obtained when the optimal gross irrigation water depth was 3722 m³/ha.

D Yield – Water Relationship
The relationship between yield (kg ha⁻¹) and the depth of irrigation water for each treatment is presented in Table (4). The average yield under deficit irrigation is about 8702 kg ha⁻¹. One also should notice that treatment 80% ETc that received 241 mm irrigation water throughout the growing season produced 8702 kg ha⁻¹. The yield reduction in 80% ETc was much less than those observed in the treatment 60% to 40%, and 20% ETc had shown the yield reduction of 45.61, 61.81 and 80.72%, respectively as compared to the 80% ETc treatment resulted in yield reduction of 9.92 respectively.

From the above result it can be observed that the yield reduction is lower if the crop is 20 and 40% deficit rather than 60 and 80% deficit the crop throughout the growing season. Similarly, [14] was reported that 34% less water supply resulted in yield reduction of 42% and 20% less water resulted in yield reduction of 27%. This consistent decrease in the pod yield production with the decrease in the amount of water could be explained by the fact that when full crop water requirement is not met, water deficit in the plant causes stomata closure for the plant to save water, but at the expense of photosynthesis and biomass production [11].

Table 5 Yield response factor of deficit irrigated French bean

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yield (kg/ha)</th>
<th>Net Irrigation (mm)</th>
<th>1-Ya/Ym</th>
<th>I-ETa/ETm</th>
<th>ky</th>
</tr>
</thead>
<tbody>
<tr>
<td>40%ETc</td>
<td>3200</td>
<td>134</td>
<td>0.67</td>
<td>0.6</td>
<td>1.12</td>
</tr>
<tr>
<td>60%ETc</td>
<td>4490</td>
<td>201</td>
<td>0.53</td>
<td>0.4</td>
<td>1.33</td>
</tr>
<tr>
<td>80%ETc</td>
<td>8702</td>
<td>268</td>
<td>0.1</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>100%ETc</td>
<td>9660</td>
<td>335</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The yield response factor (ky) was derived from the relationship of relative yield reduction (1-Ya/Ym) and relative evapotranspiration deficits (1-ETa/ETm) for the whole growing period and are given in Table 5. According to this relationship, water stress throughout the growth stage, 80% ETc had limited effect on French bean. Observed yield response factors. (ky) for French bean yield production ranged between 0.5 and 1.33, the lowest and highest being for 80% and 60% ETc irrigation levels, respectively Table 5. Deficit irrigations level, 80% ETc of the full irrigation in this experiment is therefore useful in saving irrigation water.

V. Conclusions
In Kenya most of the farmers depend on rain-fed agriculture. However, the amount of rainfall is low or its distribution is uneven, very erratic, and drought occurs very frequently. Water scarcity remains the major limiting factor in intensifying agricultural production especially in arid and semi-arid areas like most of the Kenya areas, where shortage of water is the major constraint to stabilize crop production. Efficient use of irrigation water using appropriate irrigation systems and management is an important consideration in the drought prone areas of the region for improved crop production.

All the yield attributes and yield of French bean were significantly (P < 0.001) influenced by the effect of deficit irrigation levels. Plants received 100% and 80% ETc resulted in the higher total pod yield, and lower total pod yield was obtained from 40% ETc deficit levels as compared to full irrigation throughout the growing season. The irrigation water use efficiency and crop water use efficiency which obtained from 80%ETc irrigation levels was relatively higher than the 100%, 60%, and 40% ETc. All deficit irrigation applications increased the crop water use efficiency from a minimum of 2.23 kg ha⁻¹ mm⁻¹ to a maximum of 3.24 kg ha⁻¹.

DOI: 10.9790/2380-1010040712 www.iosrjournals.org
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mm-1 compared with the full irrigation. The highest IWUE was obtained from irrigation water application at 80% ETc. Considering the highest water saving and maximum pod yield, irrigation water application at 80% ETc levels could be considered as optimal irrigation management as compared to other deficit treatment. Observed yield response factors (ky) for French bean production ranged between 0.75 and 1.18, the lowest and highest being for 80% and 60% ETc applications, respectively.

IV. Recommendation

It can be concluded that good performance of French bean in relation to water use efficiency can be achieved as far as the deficit irrigation level does not exceed 80% of full crop evapotranspiration and under Njoro condition and similar area to Njoro, it is better to irrigate French bean either with 100% ETc during the water available/ rain fall is abundant area or application of 80% ETc at water scarcity area. Therefore, further works should be done by applying different amount of deficit irrigation at different growth stages of the crop and repeated for more seasons so that sufficient information could be obtained in order to develop proper deficit irrigation scheduling and reach at sound conclusions and recommendations. And application Aqua Crop model for simulation of French bean is important to reduce the number of field research in other areas, and other research will be done in investigation of deficit irrigation on French bean nutrients

References

[1] F. A. Blum, Effective use of Water (EUW) and not Water-use Efficiency (WUE) is the Target of Crop Yield under Drought Stress. Field Crop Res. 12, 2009, 112-119.


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