Optimizing irrigation frequency and amount on yield and water productivity of snap bean (*Phaseolus Vulgaris* L.) in NW Amhara, Ethiopia: A case study in Koga and Ribb irrigation scheme

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Abstract: This study has investigated the effects of different irrigation frequency and depth on yield and water productivity of snap bean at Koga and Ribb irrigation scheme, NW Amhara, Ethiopia. It was done in a factorial experiment laid out in split-plot design with three replications of two irrigation intervals and five variable irrigation depths. Irrigation depth had shown a significant effect on marketable pod yield, and irrigation water productivity whereas irrigation frequency hadn't shown a significant effect. The interaction effect hadn’t shown a significant effect on marketable pod yield and response for irrigation water productivity of snap bean at Koga. At Koga, the application of 75% ETc gave an optimum marketable yield of 10.66 t ha⁻¹ and irrigation water productivity of 2.89 kg m⁻³. At Ribb, marketable pod yield and irrigation water productivity had no significant effect on irrigation frequency while marketable pod yield and irrigation water productivity had shown a significant effect on irrigation depth and the interaction effect. At Ribb, the
application of 100% ETc gave an optimum marketable yield of 13.16 t ha$^{-1}$ and irrigation water productivity of 2.69 kg m$^{-3}$. Therefore, to attain an optimum yield and water productivity, at Koga and Ribb snap bean can be irrigated with 75% ETc and 100% ETc at 7 days irrigation interval respectively.

**Subjects:** Agriculture & Environmental Sciences; Soil Sciences; Agronomy; Conservation - Environment Studies

**Keywords:** irrigation scheduling; snap bean; Koga; Ribb

1. Introduction

In Ethiopia, the population is growing rapidly and is expected to continue growing, which inevitably leads to increased food demand. To maintain self-sufficiency in the food supply, one viable option is to raise the production and productivity per unit of land through irrigation. Proper amount and timing of irrigation water applications is a crucial decision for a farm manager to meet the water needs of the crop to prevent yield loss and maximize the irrigation water use efficiency resulting in beneficial use and conservation of the local water resources (Allen et al., 1998).

Recently precision agriculture in humid areas is already being used to increase yield and water productivity thereby making irrigation feasible (Dejonge & Kaleita, 2006). If there is proper irrigation management i.e., schedule irrigation timing and amounts based on accurate crop water use, irrigation has a positive effect on yield provided planted crops are not stressed before water application. In countries with large rainfall amounts over years and within the same year, temporal variation in storm frequency does not always coincide with crop needs at critical periods. Hence, irrigation scheduling remains one of the critical needs for efficient water management in crop production in humid areas (Thomas et al., 2004). Irrigation scheduling and yield have a positive correlation (Al-jamal et al., 1999; Rockstrom, 2001). The relationship between the total quantity of water applied and the yield of a specific crop is a complicated one which Upton and Martin (1996) agree may vary in frequency and amount. Problems associated with the sequential nature of irrigation water inputs stem from the fact that the crop-yield response depends on the timing and adequacy of individual water applications. Applying optimum amounts at the right time as well as at critical growth stages have a crucial impact (Abebe, 2001; Upton & Martin, 1996). Thus, to attain stable crop yields with unpredictable storm frequency variability, irrigation scheduling is often necessary.

Irrigation scheduling is planning when and how much water to apply to maintain healthy plant growth during the growing season. It is an essential daily management practice for a farm manager growing irrigated crops. Proper timing of irrigation water applications is a crucial decision for a farm manager to 1) meet the water needs of the crop to prevent yield loss due to water stress; 2) maximize the irrigation water use efficiency resulting in beneficial use and conservation of the local water resources, and 3) minimize the leaching potential of nitrates and certain pesticides that may impact the quality of the groundwater.

Effective irrigation is possible only with regular monitoring of soil water and crop development conditions in the field, and with the forecasting of future crop water needs. Delaying irrigation until crop stress is evident, or applying too little water, can result in substantial yield loss. Applying too much water will result in extra pumping costs, wasted water, and increased risk for leaching valuable agrichemicals below the rooting zone and possibly into the groundwater.

Irrigation criteria, in terms of frequency of irrigation and amount of application per irrigation, seasonal net irrigation requirement, and gross irrigation requirement for most of the lowland crops that are grown in the middle awash region of Ethiopia have been quantified by Melka Werer research center. However, there was little effort undertaken in the highlands of Ethiopia especially...
in the Amhara region. Crop water use studies which were conducted in some other area are not adopted because of its highly location-specific.

As a cash crop, snap bean is produced worldwide for the export and canning industry. In Ethiopia, different plant types of diverse pod character of the crop production for export purposes. According to Dessalegn et al., (2003) Snap bean production steadily increasing; due to the involvement of state horticulture enterprises, local and foreign private investors, and farmers and thus occupies the highest share (94%) of export potential among all vegetables (Dessalegn et al., 2006). In the last five years, there have been 12 fold increases in export potentials. Besides its export value, the crop is becoming important in local markets, big hotels, and festivals, and in making various dishes (Dessalegn et al., 2006). However, such promising endeavors are not fully supported by the research system. The net irrigation requirements and irrigation schedule of the snap bean are not yet known. Using climatic data is one of the quickest and fairly reliable means of crop water requirements. In the study area as such, there is no attempt to determine crop water requirements of irrigated crops. Therefore this study is initiated to determine irrigation schedules of snap bean and to statistically determine the effect of variable irrigation scheduling on yield and water productivity in a humid tropical environment using the CROPWAT computer model and verify the result with a field trial in Koga and Ribb irrigation project area.

2. Material and method

2.1. Description of the study area
The trial was conducted from 2010/11 to 2011/12 at the experiment field of Adet agricultural research center in Koga irrigation schemes and farmers field at Ribb irrigation command area. Koga irrigation scheme is located in Mecha district; 543 km to the North of the capital city, Addis Ababa (37°7′29.721″ Easting and 11°20′57.859″ Northing and at an altitude of 1953 m a.s.l). The average annual rainfall of the area is about 1118 mm in the rainy season. The mean maximum and minimum temperatures are 26.8 °C and 9.7 °C respectively. The soil type is generally light clay nit soil in its nature.

Rib irrigation site is located in Fogera district, 603 km to the North of the capital city, Addis Ababa (37°25′ to 37°58′ Easting and 11°44′ to 12°03′ Northing and at an altitude of 1774 m a.s.l). It receives 1400 mm mean annual rainfall during the rainy season. The mean daily maximum and minimum temperature of the study area was 30°c and 11.5°c. The area is characterized as mild altitude agro-ecology. The soil at the experimental site is fluvisoil (an alluvial deposit).

| Soil properties          | Irrigation schemes | Koga       | Rib        |
|--------------------------|--------------------|------------|------------|
| FC (%)                   |                    | 32         | 59.25      |
| PWP (%)                  |                    | 18         | 21.0       |
| Total nitrogen (%)       |                    | 0.21       | 0.003      |
| PH (1:2.5 H2O)           |                    | 4.75       | 6.7        |
| CEC (cmol kg⁻¹)          |                    | 2.88       | 33.4–36.25 |
| Available Phosphorus (ppm)|                    | 8.7        | 24.32–36.71|
| Soil texture             |                    | Light clay | Heavy clay |
2.2. Physicochemical properties of soil and irrigation water

Most of the chemical parameters are found to be within the guideline values given by the FAO. It is considered as “good” throughout the canals. In both locations, the results of the analysis indicated that salinity had little or no effect on the growth and yield of plants (Tables 1 and 2).

The electrical conductivity of soil (ECe) value less than 2 mmhos cm$^{-1}$ has little or no effect on the growth and yield of plants. The electrical conductivity of irrigation water (ECw) less than 0.75 mmhos cm$^{-1}$ has little or no hazard to crop (El-Swaify, 2000). Similarly, the Soil Extract Salinity (ECe) values for Ribb irrigation project site vary between 0.15–0.795 mmhos cm$^{-1}$ which is the lower value.

The soil pH for Koga was moderately acidic whereas for Ribb it was for the optimum range. The pH of the irrigation water for both locations in the optimum range (little or no effect on the growth and yield of plants).

### Table 2. Chemical composition of irrigation water at Koga irrigation scheme

| Parameters                        | Koga      | FAO threshold value |
|-----------------------------------|-----------|---------------------|
| Electrical conductivity(μscm$^{-1}$) | 124.9     | <250                |
| Sodium (mg L$^{-1}$)               | 3.7       | -                   |
| PH(1:2.5 H$_2$O)                  | 8.17      | 6.5–8.4             |
| Sodium absorption ratio (SAR)     | 0.18      | <12                 |
| Nitrate (mg L$^{-1}$)             | 1.13      | <50                 |
| Phosphate (mg L$^{-1}$)           | 0.15      | <0.4                |
| Chloride (mg L$^{-1}$)            | 15        | <70                 |
| Calcium (mg L$^{-1}$)             | 18.5      | <100                |

Source: D.F. Densaw et al. (2016)

2.3. Estimation of crop water requirement

CROPWAT 8.0 for Windows was used to estimate daily reference crop evapotranspiration and generate the crop water requirement and the irrigation schedule for snap bean in the study areas. Calculations of the crop water requirements and irrigation schedules were carried out taking inputs of climate, soil, and crop data. To estimate the climatic data (wind speed, sunshine hours, relative humidity, minimum and maximum temperature) LOCClim, local climate estimator softwareFAO (1992) was used both at Koga and Ribb where there is no class A meteorological stations. The estimator uses real mean values from the nearest neighboring stations and it interpolates and generates climatic data values for the study site. Assuming 90 and 70 % application efficiency at Ribb and Koga respectively, the gross water requirement was calculated. The demand for water during the plant’s growing season varies from one growth stage to another and from crop to crop. The values of potential evapotranspiration (ET$_o$) estimated were adjusted for actual crop ET.

Principally, CROPWAT outputs generated by default were used to identify irrigation timing of when 100% of readily available moisture occurs and application depth where 100% of readily available moisture status is attained. To verify the CROPWAT output, field experiments were carried out for two consecutive years in both locations.

2.4. Treatments

The on-farm trial was conducted in the dry season with ten different treatments in both locations at Ribb and Koga. Two irrigation intervals i.e. 7 and 10 days and five irrigation intervals (50, 75,100,125, and 150 % ETc) of variable depths at four growth stages are selected based on CROPWAT 8.0 and farmers traditional practices in the area.
2.5. Experimental design
The experiment was arranged as split-plot with two levels of irrigation frequencies as main plots and five irrigation depth levels in sub-plots with three replications and carried out from December to April. The test crop snap bean a variety of LP was used and sown 3 m by 6 m plot size at Koga and Ribb. Spacing between treatments and each block was 1 m and 1.5 m respectively. The test crop was snap bean with 0.5 m x 0.1 m spacing between row and plants respectively. DAP fertilizer was applied at a rate of 100 kg ha\(^{-1}\) at planting and 100 kg Urea ha\(^{-1}\) was applied half at planting and the remaining half at 45 days after planting. All the agronomic practices were equally done for each treatment.

2.6. Collected data
Agronomic data such as stand count, pod length, marketable and total yield were collected. Irrigation water productivity was calculated as the ratio of crop yield (marketable yield) and applied irrigation water.

2.7. Data analysis
The means of the above parameters were subjected to analysis of variance (ANOVA) using SAS version 9 computer software. Mean comparison was done by using the least significant difference test at 5% probability level.

3. Result and discussion

3.1. Effect of irrigation frequency and irrigation level on pod yield and water productivity of snap bean
Effect of different irrigation scheduling treatments on crop growth parameters, yield, and water productivity at Koga irrigation scheme is presented in (Table 3). The ANOVA table showed that the pod length had shown significant effect for irrigation frequency and the interaction effect but, not respond for irrigation depth. Whereas marketable pod yield and irrigation water productivity were not responded by irrigation frequency and respond for irrigation depth. Irrigation water productivity had an interaction effect while marketable pod yield not responds to the interaction effect.

| Irrigation frequency (day) | Irrigation depth (% ETc) | Pod length (cm) | Marketable pod yield (t ha\(^{-1}\)) | Irrigation water productivity (kg m\(^{-3}\)) |
|---------------------------|-------------------------|----------------|--------------------------------------|---------------------------------|
| 7                         | 50                      | 10.1           | 10.13                                | 3.34                            |
| 7                         | 75                      | 9.84           | 10.66                                | 2.89                            |
| 7                         | 100                     | 9.54           | 10.34                                | 2.36                            |
| 7                         | 125                     | 8.88           | 11.04                                | 1.14                            |
| 7                         | 150                     | 10.2           | 10.54                                | 0.84                            |
| 10                        | 50                      | 7.7            | 8.3                                  | 2.94                            |
| 10                        | 75                      | 7.3            | 9.89                                 | 2.6                             |
| 10                        | 100                     | 7.9            | 10.87                                | 2.2                             |
| 10                        | 125                     | 8.2            | 8.96                                 | 1.45                            |
| 10                        | 150                     | 7.7            | 9.63                                 | 1.12                            |

LSD (5%)
Frequency 57.4** 4.2 ns 0.1 ns
Depth 0.4 ns 4.5* 10.2**
Frequency x Depth 1.95* 2.4 ns 0.33*
CV 8.6 11.9 15.1
At Ribb, pod length, marketable pod yield, and irrigation water productivity had no significant effect for irrigation frequency at (p < 0.05) while marketable pod yield and irrigation water productivity had shown significant effect for irrigation depth and the interaction effect (Table 4).

3.2. Pod length
At Koga, the Irrigation depth hadn’t shown significant effect for the pod length of snap bean at (P < 0.05). The effect of irrigation frequency on marketable pod yield and interaction of irrigation depth and frequency were not significant at P < 0.05. The lowest (7.3 cm) and the highest (10.2 cm) marketable pod length of snap bean were obtained at 75 and 150% ETc at 10 and 7-day irrigation intervals, respectively.

At Ribb, irrigation frequency, irrigation depth, and interaction of irrigation depth and frequency had not shown a significant (P < 0.05) effect on the pod length of snap bean. The lowest (8.07 cm) and the highest (8.6 cm) pod length of snap bean were obtained at 50 and 100% ETc at 7 and 10-day irrigation intervals, respectively.

The pod length is low in both locations as compared to the central rift valley of Ethiopia which is in a range of, 10.6–12.8 cm (Beshir et al., 2015); this might be due to outdated variety LP and lack of monitoring the soil-water regime.

3.3. Marketable pod yield
At Koga, the irrigation depth showed a positive response for marketable pod yield of snap bean at (P < 0.05). The effect of irrigation frequency on marketable pod yield and interaction of irrigation depth and frequency were not significant at P < 0.05. The lowest (8.3 t ha⁻¹) and the highest (11.04 t ha⁻¹) marketable pod yield of snap bean were obtained at 50 and 125% ETc irrigation depth, at 10 and 7-day irrigation interval, respectively.

At Ribb, irrigation frequency had not shown significant effect (P < 0.05) on marketable pod yield of snap bean. The effect of irrigation depth (level) and interaction of irrigation depth and frequency on the marketable pod yield had shown significant effect at P < 0.05. The lowest (9.6 t ha⁻¹) and

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### Table 4. The effect of irrigation frequency and depth for pod length, marketable yield, and water productivity result of snap bean at Ribb

| Irrigation frequency (day) | Irrigation depth (% ETc) | Pod length (cm) | Marketable pod yield (t ha⁻¹) | Irrigation water productivity (kg m⁻³) |
|---------------------------|--------------------------|-----------------|-------------------------------|--------------------------------------|
| 7                         | 50                       | 8.07            | 9.96                          | 4.90                                 |
| 7                         | 75                       | 8.13            | 9.14                          | 3.05                                 |
| 7                         | 100                      | 8.56            | 13.16                         | 2.69                                 |
| 7                         | 125                      | 8.59            | 13.38                         | 2.63                                 |
| 7                         | 150                      | 8.33            | 10.78                         | 1.87                                 |
| 10                        | 50                       | 8.2             | 9.6                           | 4.57                                 |
| 10                        | 75                       | 7.91            | 11.23                         | 4.10                                 |
| 10                        | 100                      | 8.6             | 10.52                         | 2.42                                 |
| 10                        | 125                      | 7.9             | 11.28                         | 2.07                                 |
| 10                        | 150                      | 8.23            | 12.1                          | 1.85                                 |
| LSD (5%)                  | Frequency                | ns              | ns                            | ns                                   |
|                           | Depth                    | ns              | 1.57*                         | 4.5*                                 |
|                           | Frequency x Depth        | ns              | 1.35*                         | 0.79*                                 |
|                           | CV                       | 5.6             | 17.1                          | 12.1                                 |

At Ribb, pod length, marketable pod yield, and irrigation water productivity had no significant effect for irrigation frequency at (p < 0.05) while marketable pod yield and irrigation water productivity had shown significant effect for irrigation depth and the interaction effect (Table 4).
The highest (13.38 t ha\(^{-1}\)) marketable pod yield of snap bean were obtained at 50% ETC and 125% ETC at 7 and 10-day irrigation interval, respectively.

The production is low as compared to the central rift valley of Ethiopia which is in a range of, 12.17–21.23 (Beshir et al., 2015); this might be due to the soil climate of Koga. Suitable PH for the snap bean is in a range of 5.5–7 while 4.63–5.1 at Koga and Ribb. Also, the soil at Koga has very low organic matter content and available phosphorus content according to the category by (Clements & Mcgowen, 1994).

Saleh et al. (2018) revealed green bean productivity was affected by the volume of irrigation water. Most plant growth parameters and pod yield increased with increasing water application from 60 to 80% of ET, without any additional increase up to 100% of ET.

Our results are similar to those previously reported by (El-noemani et al., 2010) concluded that 80% of ET was quite enough to achieve the maximum productivity for green beans. They noted that increasing the irrigation amount up to 100% of ET prompted the highest growth, although the maximum pod yield was achieved by 80% of ET. Under stress conditions, water deficit had a significant impact on plant growth, leading to a decline in growth, leaf area development, and photosynthetic capacity (Bayuelo-jiménez et al., 2003).

Abdel-mawgoud (2006) recorded a linear correlation between snap pod yield and water application up to 120% ETC. He found that vegetative growth parameters and yield components responded positively to water increasing up to 120% ETC. Therefore, irrigation management can positively affect the profitability of bean productivity.

3.4. Irrigation water productivity
Water use efficiency (WUE) is the product of total yield produced over the amount of water applied for each treatment. The highest value was 3.34 and 4.9 kg m\(^{-3}\) under 50% ET crop regime within a 7-day irrigation interval for Koga and Ribb irrigation scheme respectively. For optimum yield and water productivity, irrigation water requirements of snap bean were found to be 345.7 mm and 326.6 mm net irrigation requirement corresponding to 13 and 9 irrigation applications at Koga and Ribb irrigation scheme respectively.

In general, the trends for the WUE related to the total amount of irrigation water and the and the production of total fresh pod yields for the various treatments showed that the lower the amount of irrigation water received, the higher the water use efficiency.

In both locations, irrigation frequency had no significant effect on irrigation water productivity of snap bean. Irrigation depth and the interaction effect between irrigation frequency and irrigation depth had shown a significant influence on water productivity of snap bean (P ≤ 0.05) in both locations (Tables 1 and 2). The water productivity, however, decreased with increasing depth of irrigations.

4. Conclusion and recommendation
The effects of irrigation scheduling were assessed by examining their effects on yield and water productivity of snap bean. The result of the current study revealed that irrigation depth had a significant effect on marketable yield, and water productivity than irrigation frequency both at Koga and Ribb irrigation schemes. Pod length had a positive response for irrigation frequency as well as their interaction at Koga; while not at Ribb. At Ribb, the marketable yield had a positive correlation with irrigation depth up to 125% ETC at a 7-day irrigation interval. However, a further increase in depth showed a negative response. Water productivity showed a decreasing trend where irrigation depth increase from 50 to 150% ETC at 7 and 10 day irrigation intervals both at Koga and Ribb irrigation schemes. Hence from the foregoing statistical analysis results, if irrigation scheduling is aimed at maximizing yields per unit of irrigated area, 125% ETC at 7-day interval at Ribb with an optimum yield 13.38 t ha\(^{-1}\) and water productivity 2.63 kg m\(^{-3}\) and similarly 125% ETC irrigation depth at Koga with
a high yield of 11.04 t ha\(^{-1}\) and water productivity 1.14 kg m\(^{-3}\). Also, if the scheduling objective is to maximize yield per depth of water applied as a result of water is a limiting resource 50% ETC at 7-day interval gave optimal yield 10.13 t ha\(^{-1}\) and water productivity 3.34 kg m\(^{-3}\) at Koga and 50% ETC at 10-day irrigation interval gave optimal yield 9.6 t ha\(^{-1}\) and water productivity 4.57 kg m\(^{-3}\) at Ribb similar agro-ecology is recommended. Saved water will help to cultivate more land and increase production for the teeming human population in Ethiopian highlands.

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