Determination of crop water requirements and irrigation scheduling of wheat using CROPWAT at Koga and Rib irrigation scheme, Ethiopia

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Abstract

Background

Population growth, high water competition, and the effect of climate change have caused water shortage problems in the Nile basin, Ethiopia. Proper water management improves water efficiency; determining the water requirement of field crops is an option for improving water productivity.

Methods

In this study, the CROPWAT 8.0 model, local climate, and soil data were used to determine crop water requirement (CWR) and irrigation scheduling of wheat at Koga and Rib irrigation scheme, Nile basin. The Penman-Monteith and United States Department of Agriculture (USDA) soil conservation service methods were used to compute the reference evapotranspiration (ETo) and effective rainfall. Five levels of water depth (50%, 75%, 100%, 125%, and 150%) of the model and two irrigation intervals (14 and 21 days) were arranged in a Randomized Completely Block Design (RCBD).

Results

The results showed that at Koga, irrigating 75% of CROPWAT simulated water depth (9.3 mm, 22.9 mm, 44.1 mm, and 25.8 mm at initial, development, middle and late-stage respectively) gave 3.37 t ha$^{-1}$ wheat yield and 1.01 kg m$^{-3}$ water productivity. The result at Rib showed that irrigating 75% of the model (9.1 mm, 23.6 mm, 47.2 mm, and 34.2 mm at initial, development, middle, late-stage) respectively) gave 4.27 t ha$^{-1}$ yield and 1.81 kg m$^{-3}$ water productivity of wheat. The reference evapotranspiration was varied from 4.86 mm day$^{-1}$ to 3.14 mm day$^{-1}$ at Koga and from 4.67 mm day$^{-1}$ to 2.36 mm day$^{-1}$ at Rib scheme. The irrigation requirement of wheat at Koga was 376.9 mm dec$^{-1}$ while at Rib was 379.9 mm dec$^{-1}$.

Conclusions

This study showed that the CROPWAT model is an important tool to compute the crop water requirement of field crops in irrigated agriculture.

Introduction

Water is the main production inputs in agriculture to maintain the development of irrigation agriculture (Dinar et al., 1997). Irrigated agriculture plays an important role in food security, poverty reduction, and economic growth, thus effective management is an important issue in an irrigation system (Mozumdar, 2012). Comprehensive irrigation water management practices are essential to improve water management and eliminate the associated problems (Al-Kaisi et al., 1997). Agriculture is the backbone of Ethiopia but most of the cultivated land is under a rain-fed agriculture system (Awulachew et al., 2007). Even though
Ethiopia has abundant water resources from precipitation, surface, and subsurface source, it suffered from severe drought, high temporal and spatial variations of water resources for the last four decades (Muktar and Yigezu, 2016). Farmers in Ethiopia produce crops under high spatial and temporal variation of rainfall which causes crop production failures (Awulachew et al., 2010). The population is growing rapidly and is expected to continue growing, which inevitably leads to increased food demand (Awulachew et al., 2005). Farmers in Ethiopia face challenges including high competition for water, unpredictable rainfall, limited financial capacity, and climate change. By realizing such challenges, the government of Ethiopia take initiative and allocating huge investments for irrigation infrastructure development during the last two decades (Abate, 1994). Tana Beles, Megech, Koga, and Rib are some of the irrigation projects located in the Blue Nile Basin, Ethiopia.

Appropriate water (crop water requirement) application in crops production can improve nutrient availability, prevent land degradation, improve crop yield and water use efficiency (Gaafer and Refaie, 2006). It improves the moisture content of the fruit, survival rate, and better fruit test (Raviv and Blom, 2001). Soil moisture conditions affect nutrient availability to the crops (Choudhury and Kumar, 1980). Good irrigation management is critical for wheat productivity, a significant grain yield and tillers were observed using optimal and suboptimal crop water requirements (Sharma et al., 1990). The proper amount and timing of irrigation water applications is a crucial decision for a farm manager to prevent yield loss and maximize the irrigation water use efficiency (Allen et al., 1998). Crop water requirements are the depth of water needed to meet the water loss through evapotranspiration, being disease-free, growing in large fields under non-restricting in soil, water, and fertility, and achieving full production potential under the given growing environment (Doorenbos and Pruitt, 1977).

Several empirical methods were developed around the world from the simplest and oldest (Blaney Criddle method) to the most recent and accurate (FAO Penman-Monteith method) to determine crop water requirement ranging. The Penman-Monteith method has been recommended as the appropriate combination method to determine reference evapotranspiration (ETo) based on climatic data (Allen et al., 1998). CROPWAT is a tool developed by FAO used for irrigation planning and management and is widely used to estimate reference evapotranspiration (ETo) and crop water requirement (Abdalla et al., 2010). It allows for the development of improved irrigation practices, planning of irrigation schedules, and assessment of production under rained/irrigation conditions (Clarke et al., 2001).

Irrigation agriculture is widely expanded in the Blue Nile basin like Koga and Rib irrigation schemes. Farmers can irrigate crops based on traditional know-how causing nutrient leaching, waterlogging, and severe water shortage problems in the study area. Wheat is the most dominantly cultivated cereal crop under irrigation in the Koga irrigation command area while in Rib, it is the newly introduced cereal crop by farmers (Tewabe et al., 2020). However, crop water requirements and irrigation schedules of wheat were not done in the study site (Koga and Rib) irrigation scheme. Therefore, the objectives of this study were to determine the crop water requirement and irrigation scheduling of wheat using the CROPWAT model for optimal resource allocation and to increase yield and water productivity.

Materials And Methods
Study Area

Koga irrigation scheme is located in the Tana Basin under Mecha district, south of the Amhara Region, Ethiopia. It lies between 11°20’ to 11°32’ North Latitude and 37°02’ to 37°11’ East Longitude. Koga irrigation scheme is located 41 km to the West of Bahir Dar city and 543 km to the North of the capital city, Addis Ababa at 37°7’29.72” Easting and 11°20’57.85” Northing and 1953 m a.s.l. The average annual rainfall of the area is 1124 mm. The mean maximum and minimum temperatures are 26.8 °C and 9.7 °C respectively (Fig. 1). Rib irrigation scheme is located inside Tana Basin in Fogera district Northwest of Ethiopia, 60 kilometers to the East of Bahir Dar city and 648 km North of the capital city, Addis Ababa at 37°25’ to 37°58’ Easting and 11°44’ to 12°03’ Northing and an altitude of 1803 m a.s.l. It receives 1400 mm mean annual rainfall. The mean daily maximum and minimum temperature of the area is 30°C and 11.5°C.

To verify the CROPWAT model generated water depth, field experiments were carried out for two consecutive years (2015 and 2016) at both locations. The field experiments were arranged in a randomized complete block design (RCBD) with three replications. The crop wheat; a variety of TAY was used and planted on 0.2 m spacing between row and were applied by drilling 150 kg ha\(^{-1}\) seed rate. DAP was applied at a rate of 100 kg ha\(^{-1}\) at planting and 138 kg ha\(^{-1}\) Urea (the half at planting and a half at 45 days after planting) were applied. All the agronomic practices were applied equally for all treatments as per agronomic recommendations (Ayana et al., 2016). Local rainfall data, reference evapotranspiration (ET\(_o\)), soil data, and crop data have been used as input for the CROPWAT model. Crop water requirement and irrigation water requirement were computed using the CROPWAT 8.0 model. Climate data for sixteen years (2000–2016) for the Koga irrigation scheme were taken from Koga and Bahir Dar meteorological stations while for the Rib irrigation scheme Addis Zemen meteorological station was used. The crop data for wheat (root depth, crop coefficient, critical depletion, yield response factor, and length of plant growth stage) was obtained from FAO irrigation and drainage paper 56 (Allen et al., 1998). The planting date under irrigation in the study area was started in mid-November. Information on soil properties i.e., field capacity (FC), permanent wilting point (PWP), infiltration rate, initial soil moisture depletion were done at Adet Agricultural Research Center soil laboratory using the gravimetric method. Reference evapotranspiration (ET\(_o\)), the crop evapotranspiration (ET\(_c\)), and irrigation water requirement (IWR) were estimated using FAO penman-Monteith method; equations 1, 2, and 3 respectively. The United States Department of Agriculture (USDA) Soil Conservation Service method was used for the estimation of effective rainfall (Doorenbos and Pruitt, 1977).

\[
\text{ET}_o = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34U_2)} \quad \text{(eqn. 1)}
\]

Where: \(\text{ET}_o = \) reference evapotranspiration [mm day\(^{-1}\)], \(R_n = \) net radiation at the crop surface [MJ m\(^{-2}\) day\(^{-1}\)], \(G = \) soil heat flux density [MJ m\(^{-2}\) day\(^{-1}\)], \(T = \) mean daily air temperature [°C], \(U_2 = \) wind speed at 2 m height [m s\(^{-1}\)], \(e_s = \) saturation vapour pressure [kPa], \(e_a = \) actual vapour pressure [kPa], \(e_s - e_a = \) saturation vapour pressure deficit [kPa], \(\Delta = \) slope vapour pressure curve [kPa °C\(^{-1}\)], \(\gamma = \) psychrometric constant [kPa °C\(^{-1}\)]
The crop water requirement (CWR) is the water lost from a cropped field through evapotranspiration (ET) and it is expressed as the rate of ET in mm/day. The CWR is derived from crop evapotranspiration (ETc) and estimated by the following equation (Ewaid et al., 2019). The differences in crop evapotranspiration (ETc) during the growth stages, crop coefficient (Kc) for wheat was varied over the development stage (initial development, mid-season, and late-season) (Allen et al., 1998, Ewaid et al., 2019). Irrigation scheduling determines when and how much irrigate the specific field crop (Ewaid et al., 2019).

\[
\text{ETc} = \text{ETo} \times \text{Kc} \quad \text{(eqn. 2)}
\]

Where, ETc = Crop Evapotranspiration (mm day\(^{-1}\)), ETo = Reference Crop Evapotranspiration (mm day\(^{-1}\)), Kc = Crop coefficient

The irrigation requirement (IR) is the main parameter for the planning, design, and operation of irrigation and water resources systems (Savva and Frenken, 2002). It is important to the optimal allocation of water resources for policy and decision-makers during the operation and management of irrigation systems. Missed management of irrigation requirements may lead to inappropriate capacities storage reservoirs, low water use efficiency, reduction of the irrigated area, and increased development costs (Savva and Frenken, 2002). The irrigation requirement is therefore determined by the following equation.

\[
\text{IRn} = \text{ETc} - (\text{Pe} + \text{Ge} + \text{Ws}) + \text{LR} \quad \text{(eqn. 3)}
\]

Where, IRn = Net irrigation requirement (mm), ETc = Crop evapotranspiration (mm), Pe = Effective dependable rainfall (mm), Ge = Groundwater contribution from water table (mm), Ws = Water stored in the soil at the beginning of each period (mm) and LR = Leaching requirement (mm)

The on-farm trial was conducted in the dry season (November to April) with ten treatments. Two fixed irrigation intervals of 14 and 21 days and five water depths (50, 75, 100, 125, and 150 %) of CROPWAT 8.0 generated depth were arranged in Randomly Completed Block Design (RCBD) (Table 1). During crop water requirement determination 70 % application efficiency was applied at both locations.

| Treatment | Depth and Interval | Treatment | Depth and Interval |
|-----------|-------------------|-----------|-------------------|
| T1        | 50% CWR at 14 days| T6        | 50% CWR at 21 days|
| T2        | 75% CWR at 14 days| T7        | 75% CWR at 21 days|
| T3        | 100% CWR at 14 days| T8        | 100% CWR at 21 days|
| T4        | 125% CWR at 14 days| T9        | 125% CWR at 21 days|
| T5        | 150% CWR at 14 days| T10       | 150% CWR at 21 days|
Results And Discussion

The soil sample was taken before the planting of wheat takes place and analyzed using laboratory procedure. The particle size of the sample was determined using the hydrometer method (Bouyoucos, 1962). The result as shown the soil texture was varied in the study site (Table 2). It showed that the texture was laying under the clay soil texture class at Koga according to (Hazelton and Murphy, 2016) and the other physical characteristics were similar with (Abiyu and Alamirew, 2015). The soil analysis at Rib has shown that a light clay classification and has high alluvial deposited that comes from a mountainous area upstream of the Rib River (Table 2). Data of wheat planting and harvesting date, critical depletion level, root depth, crop growing period (Table 3), and soil characteristics of the study area (Table 2) were used to compute crop evapotranspiration.

| Site | FC (%) | WP (%) | Sand (%) | Silt (%) | Clay (%) |
|------|--------|--------|----------|----------|----------|
| Koga | 30.8 ± 1.7 | 18.9 ± 1.2 | 20.2 ± 4.8 | 22.4 ± 2.7 | 57.3 ± 4.5 |
| Rib  | 59.0 ± 1.3 | 21.0 ± 1.4 | 24.0 ± 2.4 | 36.0 ± 3.5 | 40.0 ± 5.2 |

Table 3
Input data for the CROPWAT model in the study area

| Crop | Planting and Harvesting Date | Root depth (m) | Depletion fraction (P) | Yield response factor ($K_f$) |
|------|------------------------------|----------------|------------------------|-----------------------------|
|      |                              |                |                        | Initial | Development | Middle | Late  |
| Wheat| Mid-November                 | 0.6–1.5        | 0.55                   | 0.20   | 0.60        | 0.50   | 0.50  |
| Month      | Temperature (°C) | Relative Humidity (%) | Wind speed (km day⁻¹) | Sunshine hours | Radiation (MJ/m²/day) | ETo (mm/day) |
|------------|------------------|-----------------------|-----------------------|----------------|-----------------------|--------------|
|            | Min              | Max                   |                       |                |                       |              |
| January    | 8.2              | 27.1                  | 48                    | 61             | 9.5                   | 20.9         | 3.45        |
| February   | 10               | 29.1                  | 43                    | 69             | 9.7                   | 22.6         | 4.01        |
| March      | 12.7             | 30.1                  | 41                    | 86             | 9.2                   | 23.3         | 4.56        |
| April      | 14.4             | 30.3                  | 42                    | 95             | 9.1                   | 23.6         | 4.86        |
| May        | 15.2             | 29.7                  | 52                    | 86             | 8.5                   | 22.3         | 4.62        |
| June       | 14.2             | 27.8                  | 66                    | 86             | 6.9                   | 19.5         | 4.00        |
| July       | 14               | 24.4                  | 76                    | 69             | 4.6                   | 16.2         | 3.21        |
| August     | 13.9             | 24.8                  | 84                    | 69             | 4.6                   | 16.4         | 3.14        |
| September  | 13.4             | 25.8                  | 73                    | 69             | 6.3                   | 18.8         | 3.57        |
| October    | 13.7             | 26.8                  | 64                    | 69             | 8.7                   | 21.4         | 3.96        |
| November   | 11.2             | 26.9                  | 57                    | 61             | 9.7                   | 21.4         | 3.72        |
| December   | 8.5              | 26.8                  | 52                    | 61             | 9.7                   | 20.6         | 3.41        |
| Average    | 12.4             | 27.5                  | 58                    | 73             | 8                     | 20.6         | 3.88        |

The reference evapotranspiration (ETo) obtained using the input data at the Koga irrigation scheme was high between February and June (4.0–4.86 mm day⁻¹) due to the high temperature (Table 4). It decreases after July and the lowest value was 3.14 mm day⁻¹ in August due to low temperature in the area. The average reference evapotranspiration was 3.88 mm day⁻¹ (Table 4). The reference evapotranspiration value at Rib irrigation scheme showed that a high evaporation rate was observed in March (4.67 mm day⁻¹) while the lowest evaporation (2.36 mm day⁻¹) was recorded in July (Table 5). In the study area June, July, August, and September are the rainy seasons. The lowest rainfall and effective rainfall was observed starting from November to May (Table 5). The average rainfall of the last sixteen years (2000–2017) was used as input and the USDA soil conservation service was applied to estimate effective rainfall and to compute the wheat water requirement and irrigation scheduling. The average annual rainfall at Koga and Rib irrigation scheme was 874.3 mm and 1032.0 mm while the effective rainfall was 539.2 mm 623.1 mm respectively (Table 6). The monthly reference evapotranspiration (ETo) exceeds the monthly rainfall from January to May and from November to December on both locations (Fig. 2 and Fig. 3). These indicate that irrigation water is substantial during these months in the study area.
Table 5
Climate characteristics of Rib irrigation scheme

| Month  | Temperature (°C) | Relative Humidity (%) | Wind speed (km day⁻¹) | Sunshine hours | Radiation (MJ/m²/day) | ETo (mm/day) |
|--------|------------------|-----------------------|-----------------------|----------------|-----------------------|-------------|
|        | Min              | Max                   |                       |                |                       |             |
| January| 9.8              | 27.7                  | 156                   | 8.3            | 19.1                  | 3.57        |
| February| 10.8             | 29.5                  | 156                   | 9.3            | 21.9                  | 4.25        |
| March  | 11.8             | 29.7                  | 147                   | 9.2            | 23.2                  | 4.67        |
| April  | 12.1             | 29.2                  | 130                   | 8.3            | 22.3                  | 4.57        |
| May    | 12.1             | 29.5                  | 156                   | 6.8            | 19.8                  | 4.12        |
| June   | 12.0             | 26.8                  | 156                   | 5.6            | 17.7                  | 3.37        |
| July   | 12.1             | 23.7                  | 104                   | 2.0            | 12.4                  | 2.36        |
| August | 12.0             | 24.0                  | 86                    | 2.2            | 12.8                  | 2.40        |
| September| 11.6             | 25.2                  | 104                   | 6.7            | 19.4                  | 3.38        |
| October| 10.8             | 27.2                  | 138                   | 8.4            | 20.9                  | 3.69        |
| November| 10.3             | 27.2                  | 138                   | 9.1            | 20.4                  | 3.56        |
| December| 10.3             | 27.6                  | 112                   | 8.8            | 19.2                  | 3.40        |
| Average| 11.3             | 27.3                  | 132                   | 7.1            | 19.1                  | 3.61        |
Table 6
Rainfall and Effective characteristics of the study irrigation scheme

| Month   | Rainfall (mm) | Eff. Rainfall (mm) |
|---------|---------------|--------------------|
|         | Koga | Rib | Koga | Rib |
| January | 0.0   | 6.0 | 0.0   | 5.9 |
| February| 0.0   | 2.0 | 0.0   | 2.0 |
| March   | 0.1   | 0.0 | 0.1   | 0.0 |
| April   | 0.0   | 11.0| 0.0   | 10.8|
| May     | 7.3   | 32.0| 7.2   | 30.4|
| June    | 122.0 | 110.0| 98.2 | 90.6|
| July    | 314.8 | 355.0| 156.5| 160.5|
| August  | 274.4 | 319.0| 152.4| 156.9|
| September| 137.9| 129.0| 107.5| 102.4|
| October | 17.8  | 51.0| 17.3  | 46.8|
| November| 0.0   | 13.0| 0.0   | 12.7|
| December| 0.0   | 4.0 | 0.0   | 4.0 |
| Total   | 874.3 | 1032.0| 539.2| 623.1|

The monthly water requirement and irrigation requirement of wheat planted in mid-November shown that crop water demand in both locations was varied within the same month. The maximum crop water requirement was obtained in February which was 46.3 mm dec$^{-1}$ at Koga and 50.2 mm dec$^{-1}$ at Rib irrigation scheme (Table 7 and Table 8). This variation comes from high-temperature variation between the two study sites (Table 5 and Table 4).
Table 7: Crop water requirement and irrigation requirement of wheat at Koga irrigation scheme

| Month | Decade | Stage | Kc (Coeff.) | ETc (mm/day) | ETc (mm/dec) | Eff rain (mm/dec) | Irr. REq. (mm/dec) |
|-------|--------|-------|-------------|--------------|--------------|-------------------|-------------------|
| Nov   | 2      | Init  | 0.30        | 1.12         | 6.7          | 0                 | 6.7               |
| Nov   | 3      | Init  | 0.30        | 1.09         | 10.9         | 0                 | 10.9              |
| Dec   | 1      | Init  | 0.30        | 1.05         | 10.5         | 0                 | 10.5              |
| Dec   | 2      | Dev   | 0.36        | 1.23         | 12.3         | 0                 | 12.3              |
| Dec   | 3      | Dev   | 0.64        | 2.20         | 24.2         | 0                 | 24.2              |
| Jan   | 1      | Dev   | 0.94        | 3.24         | 32.4         | 0                 | 32.4              |
| Jan   | 2      | Mid   | 1.15        | 3.96         | 39.6         | 0                 | 39.6              |
| Jan   | 3      | Mid   | 1.16        | 4.21         | 46.3         | 0                 | 46.3              |
| Feb   | 1      | Mid   | 1.16        | 4.42         | 44.2         | 0                 | 44.2              |
| Feb   | 2      | Mid   | 1.16        | 4.63         | 46.3         | 0                 | 46.3              |
| Feb   | 3      | Late  | 1.08        | 4.53         | 36.2         | 0                 | 36.2              |
| Mar   | 1      | Late  | 0.83        | 3.62         | 36.2         | 0                 | 36.2              |
| Mar   | 2      | Late  | 0.54        | 2.47         | 24.7         | 0                 | 24.7              |
| Mar   | 3      | Late  | 0.34        | 1.60         | 6.4          | 0                 | 6.4               |
| Total |        |       |             |              | 377          | 0.1               | 376.9             |
Table 8
Crop water requirement and irrigation requirement of wheat at Rib irrigation scheme

| Month | Decade | Stage | Kc (Coeff.) | ETc (mm/day) | ETc (mm/dec) | Eff rain (mm/dec) | Irr. REq. (mm/dec) |
|-------|--------|-------|-------------|--------------|--------------|------------------|-------------------|
| Nov   | 2      | Init  | 0.30        | 1.07         | 6.4          | 1.9              | 4.9               |
| Nov   | 3      | Init  | 0.30        | 1.05         | 10.5         | 2.5              | 8.0               |
| Dec   | 1      | Init  | 0.30        | 1.04         | 10.4         | 2.0              | 8.4               |
| Dec   | 2      | Dev   | 0.36        | 1.23         | 12.3         | 0.9              | 11.4              |
| Dec   | 3      | Dev   | 0.65        | 2.25         | 24.8         | 1.2              | 23.6              |
| Jan   | 1      | Dev   | 0.96        | 3.38         | 33.8         | 1.9              | 31.8              |
| Jan   | 2      | Mid   | 1.17        | 4.18         | 41.8         | 2.2              | 39.6              |
| Jan   | 3      | Mid   | 1.18        | 4.48         | 49.3         | 1.7              | 47.6              |
| Feb   | 1      | Mid   | 1.18        | 4.75         | 47.5         | 1.1              | 46.5              |
| Feb   | 2      | Mid   | 1.18        | 5.02         | 50.2         | 0.6              | 49.6              |
| Feb   | 3      | Late  | 1.10        | 4.85         | 38.8         | 0.4              | 38.4              |
| Mar   | 1      | Late  | 0.84        | 3.82         | 38.2         | 0.0              | 38.2              |
| Mar   | 2      | Late  | 0.55        | 2.57         | 25.7         | 0.0              | 25.7              |
| Mar   | 3      | Late  | 0.34        | 1.60         | 6.4          | 0.0              | 6.3               |
| Total |        |       |             |              | 396.1        | 16.5             | 379.9             |

An optimal irrigation water requirement and irrigation schedule improve irrigation management in the field (Gaafer and Refaie, 2006). Effective irrigation management is managing the amount of water applied and timely application of water efficiently. In the study area, farmers applied irrigation water through furrow irrigation (dominantly) and flooding irrigation (minor) systems. The application efficiency in the study area was taken as 70 % to determine irrigation requirements. The total gross and net irrigation water requirement for wheat at the Koga irrigation scheme was 529.2 mm and 370.5 mm respectively while at the Rib irrigation scheme was 635.8 mm and 445 mm respectively (Table 9).
Table 9
Irrigation scheduling of wheat at Koga irrigation scheme

| Date   | Day | Stage | Rain (mm) | Ks (fract.) | Eta (%) | Depl (%) | Net Irr (mm) | Deficit (mm) | Loss (mm) | Gr. Irr (mm) | Flow (l/s/ha) |
|--------|-----|-------|-----------|-------------|---------|----------|--------------|--------------|-----------|--------------|---------------|
| 28-Dec | 44  | Dev   | 0         | 1           | 100     | 56       | 58.0         | 0            | 0         | 82.8         | 0.22          |
| 18-Jan | 65  | Mid   | 0         | 1           | 100     | 56       | 70.7         | 0            | 0         | 101.0        | 0.56          |
| 04-Feb | 82  | Mid   | 0         | 1           | 100     | 57       | 71.9         | 0            | 0         | 102.7        | 0.70          |
| 20-Feb | 98  | Mid   | 0         | 1           | 100     | 58       | 72.8         | 0            | 0         | 104.0        | 0.75          |
| 20-Mar | 126 | End   | 0         | 1           | 100     | 77       | 97.1         | 0            | 0         | 138.7        | 0.57          |
| 24-Mar |     | End   | 0         | 1           | 0       | 4        |              |              |           |              |               |
Table 10
Irrigation scheduling of wheat at Rib irrigation scheme

| Date      | Day | Stage | Rain (mm) | Ks (fract.) | Eta (%) | Depl (%) | Net Irr (mm) | Deficit (mm) | Loss (mm) | Gr. Irr (mm) | Flow (l/s/ha) |
|-----------|-----|-------|-----------|-------------|---------|----------|--------------|--------------|-----------|------------|--------------|
| 28-Nov    | 14  | Init  | 0         | 0.82        | 92      | 64       | 45.1         | 0            | 0         | 64.5       | 0.53         |
| 12-Dec    | 28  | Init  | 0         | 1           | 100     | 26       | 24.3         | 0            | 0         | 34.7       | 0.29         |
| 26-Dec    | 42  | Dev   | 0         | 1           | 100     | 29       | 33.5         | 0            | 0         | 47.9       | 0.4          |
| 09-Jan    | 56  | Dev   | 0         | 1           | 100     | 37       | 50.4         | 0            | 0         | 72.0       | 0.6          |
| 23-Jan    | 70  | Mid   | 0.9       | 1           | 100     | 40       | 57.9         | 0            | 0         | 82.6       | 0.68         |
| 06-Feb    | 84  | Mid   | 0         | 1           | 100     | 44       | 63.0         | 0            | 0         | 90.0       | 0.74         |
| 20-Feb    | 98  | Mid   | 0         | 1           | 100     | 48       | 68.6         | 0            | 0         | 98.0       | 0.81         |
| 06-Mar    | 112 | End   | 0         | 1           | 100     | 43       | 61.3         | 0            | 0         | 87.6       | 0.72         |
| 20-Mar    | 126 | End   | 0         | 1           | 100     | 28       | 40.9         | 0            | 0         | 58.5       | 0.48         |
| 24-Mar    |     | End   | 0         | 1           | 0       | 3        |              |              |           |            |              |

The crop needs optimal moisture conditions to achieve maximum yield. The total available moisture (TAM) and readily available moisture (RAM) (Fig. 4 and Fig. 5) are media that the plant can get from the root zone with no water stress (Some et al., 2006). The result showed that the crop water requirement of wheat varies in place, month, and growth stage in the study area. In general optimal irrigation application considering soil water holding capacity and crop water requirement (especially during critical stages of wheat) is essential to improve water shortage problems and to enhance yield and water productivity of the study area.

The result showed that the yield and water productivity of wheat for irrigation interval and depth have significantly affected at both locations. The result showed that an optimal yield of 3.37 t ha\(^{-1}\) and 1.01 kg m\(^{-3}\) water productivity of wheat were obtained under 75 % CWR within 14 days irrigation interval at Koga (Table 11). The yield showed an increasing trend with the increase of water depth. However, a further increase in irrigation level hurt the grain yield of wheat. The production was low compared to other productive areas of northwestern Amhara this is due to the soil condition (acidic soil) of the Koga command area. Besides, the soil at Koga has very low organic matter content and available phosphorus as
This result is in line with Ali and Yasin (1991), they reported adequate nutrient supply and optimum water gave a maximum yield of wheat. The yield of wheat at Rib showed that 4.54 t ha\(^{-1}\) of wheat yield and 0.95 kg m\(^{-3}\) of water productivity were obtained at 125 % CWR within 14 days irrigation interval (Table 11). However, at Rib scheme 4.27 t ha\(^{-1}\) yield and 1.81 kg m\(^{-3}\) of water productivity were achieved using 75% of CROPWAT generated depth within 21 days irrigation interval. Therefore, the application of the CROPWAT generated depth of irrigation water within 21 days of irrigation interval is another option for the study area. The soil at Rib is alluvial deposited which comes from the upper catchments which have good nutrient content Tewabe et al. (2020) results in the yield of wheat at Rib was higher than at the Koga scheme.

Table 11

| Treatment | Yield (ton ha\(^{-1}\)) | Water productivity (Kg m\(^{-3}\)) |
|-----------|-------------------------|-----------------------------------|
|           | Koga | Rib | Koga | Rib |
| 14D x 50% | 2.06 | 3.67 | 0.92 | 1.88 |
| 14D x 75% | 3.37 | 4.25 | 1.01 | 1.47 |
| 14D x 100% | 3.54 | 3.99 | 0.66 | 1.04 |
| 14D x 125% | 3.61 | 4.54 | 0.64 | 0.95 |
| 14D x 150% | 3.33 | 4.13 | 0.62 | 0.72 |
| 21D x 50% | 2.94 | 3.98 | 1.02 | 2.38 |
| 21D x 75% | 3.36 | 4.27 | 1.07 | 1.81 |
| 21D x 100% | 2.87 | 4.14 | 0.68 | 1.34 |
| 21D x 125% | 2.95 | 4.03 | 0.96 | 0.95 |
| 21D x 150% | 2.09 | 3.96 | 0.33 | 0.91 |
| CV        | 8.9  | 5.2  | 7.6  | 7.4  |
| LSD (5%)  | **   | **   | ns   | *    |

Note that: D = Day, * = significant, ns = no significant and ** = highly significant

Conclusion And Recommendations

This study showed that monthly crop water requirement and irrigation water requirement of wheat have high spatial and temporal variation. Simulation of crop water requirement and scheduling of wheat using the CROPWAT model was specific to the study area owing to a high seasonal and spatial variation. The study showed that at Koga, irrigating 75% CWR with 14 days intervals gave 3.36 t ha\(^{-1}\) yield and 1.07 kg m\(^{-3}\) water productivity. At Rib, irrigating 75% CWR within 21 days irrigation interval gave 4.27 t ha\(^{-1}\) yield
and 1.81 kg m$^{-3}$ water productivity. This study showed that the CROPWAT generated water depth is a good tool to determine the crop water requirement of field crops. The study will help to improve the management of water resources and the productivity of wheat. CROPWAT tool can help to assess crop water requirement and irrigation scheduling of field crops in areas where water resource is limited. This study may a reference for decision-making for future planning.

**Declarations**

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**Availability of data and materials**

The data used to support the findings of this study can be accessed from the corresponding author upon request.

**Ethics approval and consent to participate**

Not applicable.

**Consent for publication**

Not applicable.

**Competing interests**

The authors declare there is no competing interest.

**References**

1. Abate Z (1994) Water resources development in Ethiopia: an evaluation of present experience and future planning concepts. Ithaca press
2. Abdalla N, Zhang X, Ishag A, Gamareldawla H (2010) Estimating reference evapotranspiration using CROPWAT model at Guixi Jiangxi Province. *State Key Laboratory of Hydrology and Water Resources and Hydraulic Engineering, Hohai University, China, vol*

3. Abiyu A, Alamirew T (2015) Assessment of Stage-Wise Deficit Furrow Irrigation Application on Maize Production at Koga Irrigation Scheme, Blue Nile River Basin, Ethiopia. *Assessment, 6*

4. Al-Kaisi MM, Berrada A, Stack M (1997) Evaluation of irrigation scheduling program and spring wheat yield response in southwestern Colorado. *Agric Water Manag 34:137–148*

5. Ali R, Yasin M (1991) Response of wheat to nitrogen and phosphorus. Chhonkar PK and Tilak BR 1997. Biofertilizers for sustainable agriculture gaps and future needs. *Efficiency and Policy Issues, 52–66*

6. Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao Rome 300:D05109

7. Awulachew SB, Erkossa T, Namara RE (2010) Irrigation potential in Ethiopia. In: Constraints and Opportunities for Enhancing the System; International Water Management Institute. *Addis Ababa, Ethiopia*

8. Awulachew SB, Merrey D, Kamara A, Van Koppen B, De Vries P, F. & Boeele E (2005) Experiences and opportunities for promoting small-scale/micro irrigation and rainwater harvesting for food security in Ethiopia. IWMI

9. Awulachew SB, Yilma AD, Louseged M, Loiskandl W, Ayana M, Alamirew T (2007) Water resources and irrigation development in Ethiopia. International Water Management Institute (IWMI)

10. Ayana G, Abdo A, Merine Y, Jobie T, Bekele A, Mekonnen D, Mekibib F, Tabor G, Amare M, Eshete M (2016) Plant variety release. Protection and seed quality control directorate. Ministry of agriculture and natural resources of Ethiopia, Addis Ababa

11. Bouyoucos GJ (1962) Hydrometer method improved for making particle size analyses of soils 1. *Agron J 54:464–465*

12. Choudhury P, Kumar V (1980) The sensitivity of growth and yield of dwarf wheat to water stress at three growth stages. *Irrig Sci 1:223–231*

13. Clarke D, Smith M, El-Askari K (2001) CropWat for Windows: user guide. IHE

14. Dinar A, Rosegrant MW, Meinzen-Dick R (1997) Water allocation mechanisms: principles and examples. *The World Bank*

15. Doorenbos J, Pruitt W (1977) Crop water requirements. FAO irrigation and drainage paper 24. *Land and Water Development Division, FAO, Rome, 144*

16. Ewaid S, Abed S, Ansari N (2019) Crop water requirements and irrigation schedules for some major crops in Southern Iraq. *Water 11:756*

17. Gaafer S, Refaie K (2006) Modeling water effects on growth and yield of melon cv. reticulates. *Egypt J Appl Sci 21:682–693*

18. Hazelton P, Murphy B (2016) Interpreting soil test results: What do all the numbers mean? CSIRO publishing
19. Mozumdar L (2012) Agricultural productivity and food security in the developing world. Bangladesh Journal of Agricultural Economics 35:53–69

20. Muktar B, Yigezu T (2016) Determination of Optimal Irrigation Scheduling for Maize (Zea Mays) at Teppi, Southwest of Ethiopia. Irrigation & Drainage Systems Engineering, 5

21. Raviv M, Blom TJ (2001) The effect of water availability and quality on photosynthesis and productivity of soilless-grown cut roses. Sci Hort 88:257–276

22. Savva AP, Frenken K (2002) Crop water requirements and irrigation scheduling. FAO Sub-Regional Office for East and Southern Africa Harare

23. Sharma D, Kumar A, Singh K (1990) Effect of irrigation scheduling on growth, yield and evapotranspiration of wheat in sodic soils. Agric Water Manag 18:267–276

24. Some L, Dembele Y, Ouedraogo M, Some BM, Kambire FL, SANGARE S (2006) Analysis of crop water use and soil water balance in Burkina Faso using CROPWAT. CEEPA DP36, University of Pretoria, South Africa

25. Tewabe D, Abebe A, Enyew A, Tsige A (2020) Determination of bed width on raised bed irrigation technique of wheat at Koga and Rib Irrigation Projects, North West, Ethiopia. Cogent Food & Agriculture, 1712767

Figures
Figure 1

Location of the study site

Figure 2
Reference evapotranspiration (ETo), rainfall, and effective rainfall at Koga scheme

Figure 3

Reference evapotranspiration (ETo), rainfall, and effective rainfall at Rib scheme

Figure 4

Irrigation scheduling of wheat at Koga irrigation scheme
Figure 5

Irrigation scheduling of wheat at Rib irrigation scheme