Irrigation Scheduling Based on Evapotranspiration and Soil Water Balance Estimation for Papaya (*Carica papaya* L.) Fruit Production in the Central Rift Valley of Ethiopia

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ABSTRACT

Papaya is a fast-growing, softwood, short perennial plant with large succulent foliage. It requires a consistent supply of optimal irrigation throughout the year for successful plantation growth. The Central Rift Valley of Ethiopia is the primary region for papaya production, supplying fresh fruits to Addis Ababa and surrounding markets year-round. However, the areas are hot and dry with short rainy periods, requiring irrigation water for crop production for more than nine months in a year. To determine the optimal irrigation needs for a specific location, estimating water balance and quantifying local evapotranspiration is one of the simplest methods for irrigation scheduling. The objective of this paper is to calculate on-site decadal ETc from long-term climate data and estimate water requirements (ETc) for papaya growing areas such as Batu, Bora, Koka, and Melkassa for first and subsequent years. The estimations showed that the annual decadal ETc was 2750.7 mm for Batu, 2993.1 mm for Bora, 3201.9 mm for Koka area, and 2984.2 mm for Melkassa for papaya production in the first year. The estimated annual net irrigation requirement was at 2099.5 mm for Batu, 2439.9 mm for Bora, 2598.0 mm for Koka, and 2468.1 mm for Melkassa areas for the first year of papaya production. The annual gross irrigation of 3520.1mm for Batu, 4066.5mm for Bora, 4330mm for koka and 4113.5mm for Melkassa areas also estimated for first year of papaya production. Volume of irrigation water of 39988.3m^3/ha, 46195.6m^3/ha, 49188.8m^3/ha and 46729.7m^3/ha were estimated for Batu, Bora, koka and Melkassa in first year of production. This evapotranspiration (ET) and soil water balance-based irrigation scheduling approach could be used until more suitable irrigation scheduling methods are developed for papaya growers in the study areas.

***Keywords**: Crop water requirement, decadal, effective rainfall, evapotranspiration, long-term weather data, papaya, water balance*

INTRODUCTION

Papaya (Carica papaya L.) is widely cultivated in the mid-altitude areas of Ethiopia, primarily concentrated in the irrigated central Rift Valley area of the country. It contributes 5.07% to the total national fruit production (CSA, 2020/21) and have producer of an estimated 921,066 private smallholders' farmers. Papaya gives yield year-round regardless of season as long as they get optimum agronomic managements (Ayele et al., 2017).

The area covered by papaya fruit is estimated to be 50,596.09ha, resulting the total production of 720,077.68 quintals (CSA,2020/21). Papaya has the highest productivity of 141 q/ha among cultivated fruits in Ethiopia (CSA, 2020/21).

Papaya is a short-lived perennial fruit with rapid vegetative growth (Chávez-Pesqueira & Núñez-Farfán, 2017) and quick flowering, fruit development, and continuous harvesting (Paull & Duarte, 2011). The papaya plant has shallow roots and cannot tolerate excessive wetness or standing water, as well as dry conditions. Drought leads to rapid shedding of new flowers and older leaves, as well as poor fruit sets (Paull & Duarte, 2011). Water scarcity has the potential to be tremendously harmful to papaya, as it has high water requirements (Goenaga et al., 2004, 2008; Santana et al., 2008; Campostrini et al., 2018). On other hand, papaya is extremely sensitive to collar rot under flood irrigation where water comes in direct contact with the root. Science-based irrigation management is the key to ensure a supply of adequate water for this fast-growing plant (Bayabil et al., 2020).

The Central Rift Valley areas of Ethiopia, including Batu(ziway), Bora (Bote), Koka, Tibilla, and Melkassa, have ideal climates, soils, and irrigation water resources that support year-round papaya harvests. This makes papayas a great choice for production, and many growers and value chain actors are actively participating in the papaya industry (Shafi et al., 2014).

Although all papaya farmers in the central Rift Valley of Ethiopia irrigate their papaya fields throughout the dry season, most of the papaya growers use the local method of irrigation, where water is applied in either excessive or limited amounts. This indicates that there should be a constant and optimal supply of irrigation water and nutrients, along with other comprehensive crop protection management practices throughout the year, depending on the local climate and soil types.

Irrigation scheduling is a critical factor that influences the agronomic and economic viability of papaya farms (MOA, 2011). The goal of enhancing irrigation scheduling is to save and utilize water more effectively, enhance crop yields and quality, potentially increase crop yield per unit of water used, minimize leaching of water, nutrients, and chemicals below the root zone, and ultimately provide user-friendly irrigation scheduling methods that do not escalate labor or irrigation costs (Bayabil et al., 2020).

Implementing a method for quantifying evapotranspiration-based irrigation scheduling is an easy approach that could save water and potentially reduce energy costs without compromising crop yields (Davis & Dukes, 2010). From a managerial point of view, the advantages of using ET-based irrigation planning are that it eliminates the need for installing and maintaining soil moisture detectors. Instead, it utilizes easily accessible near-instant or historical ETo data combined with Kc values of papaya crops to determine the required amount of irrigation water (Allen et al., 1998; USDA, 1997). The objective of this paper is to estimate site specific decadal ETc, to estimate annual water requirements (ETc) and irrigation scheduling for papaya fruit in the Central Rift Valley areas of Ethiopia from long-term climate data.

MATERIALS AND METHODS

Description of the study areas and climate data

The study was conducted on four potential papaya growing areas in Batu, Bora (Bote, Meki), Koka, and Melkassa Oromia regional state, Ethiopia. The locations are located in the Central Rift Valley of Ethiopia which used the Awash River, underground water, Ziway Lake, and Meki River as sources of irrigation water. The locations are characterized by moisture stress and erratic rainfall. But they are potentially papaya-producer areas in Ethiopia. The geographical descriptions of each study areas and altitudes are indicated in Table 1.

Table 1: Descriptions of geographical locations of study areas

Locations	Long.	Lat.	Altitude
Batu	7°50’0’’- 8°20’0’’N	38°40’0’’ - 39°10’0’’E	1643
Bora (Bote)	8°6’0’’- 8°26’0’’N	38°40’0’’ - 39°0’0’’E	1611
Koka	8°20’0’’- 8°28’0’’N	38°56’0’’ - 39°12’0’’E	1602
Melkassa	8°23’30’’- 8°26’30’’N	39°18’0’’E - 39°22’0’’E	1550

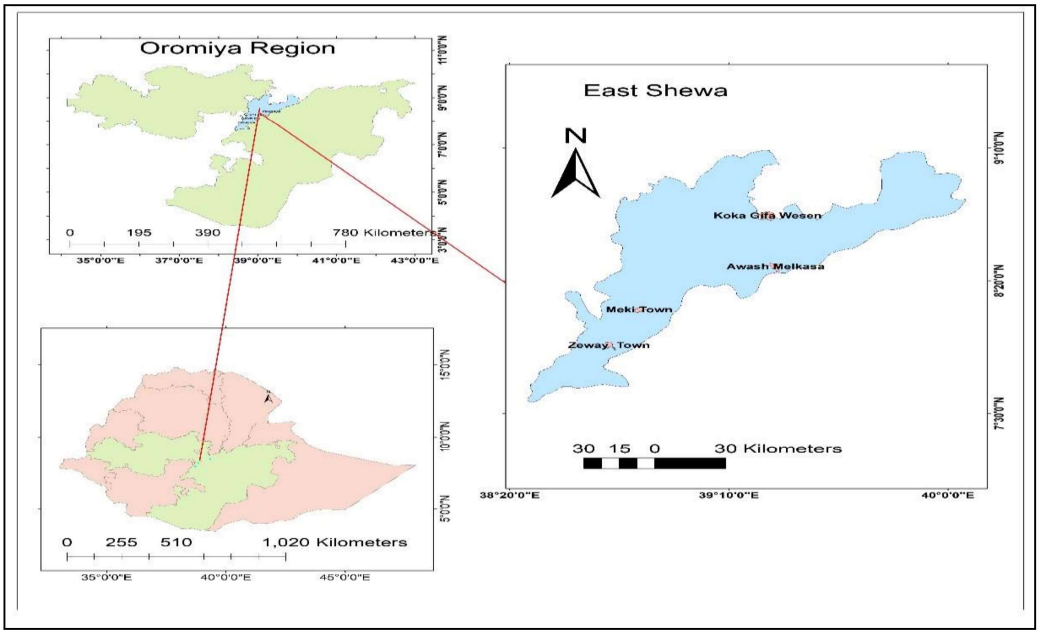


Figure 1: Map of the study areas (Batu, Bora, Koka and Melkassa)

Empirical formula used for evapotranspiration-based irrigation scheduling

The following empirical formulas were used in this study to estimate the parameters.

1. Estimation of reference evapotranspiration (ETo)

Reference Evapotranspiration (ETo) was calculated using the FAO Penman–Monteith equation from the weather data. The Penman–Monteith equation form is as follows (Allen *et al*., 1998).

$$ETo = \frac{0.40\Delta(Rn-G)+\gamma\frac{900}{T+273}U2(es-ea)}{\Delta+\gamma(1+0.34u2)}$$

Where, ETo = Reference evapotranspiration (mm/day), Rn = Net radiation at the crop surface (MJ/m^2/day), G = Soil heat flux density (MJ/m^2/day), T = Mean daily air temperature at 2 m height (°C), U2 = Wind speed at 2 m height (m/s), es = Saturation vapor pressure (kPa), ea = Actual vapor pressure (kPa), es – ea = Saturation vapor pressure deficit (kPa), Δ = Slope of vapor pressure curve (kPa/°C), ϒ = Psychrometric constant (kPa/ °C). The equation uses standard climatological records of solar radiation (sunshine), air temperature, humidity, and wind speed. The rest of the empirical formulas used for the study are indicated in Table 2 below.

Table 2: The empirical formulas used to estimate each parameter.

Parameter	Equation	Symbol	citetion
2.Water balance equation	$ETc = Pe + I + C - \Delta S - D$	ETc = Crop evapotranspiration, Pe = Effective rainfall, I = Applied net irrigation, C= capillary contribution or water from shallow groundwater, ΔS = Soil water storage in the root zone at a given time and D= Water was lost due to deep percolation.	(USDA, 1997).
3. Total available soil water	$TAW=1000\ (\theta_{FC} - \theta_{WP})\ Zr$	TAW= Amount of water that a crop can extract from its root zone (p), and its magnitude depends on the type of soil and the rooting depth (Zr)	Allen *et al.*, 1998
4. Readily available soil water	$RAW = \rho\ TAW$	RAW is the readily available soil water in the root zone [mm], p average fraction of total available soil water (TAW) that can be depleted from the root zone before moisture stress (reduction in ET) occurs (0 – 1).	Allen *et al.*, 1998
5. Net irrigation (Net IR)	$I = ETc - PE$	Assuming C, ΔS, and D in the root zone is zero	
6.Evapotranspiration rat (ETc)	$ETc = Kc * ETo$	Kc = crop coefficient, ETo = Reference Evapotranspiration	Allen *et al.*, 1998
7. Effective rainfall	$Pe = 0.8\ P - 24$ were $P > 70 mm/month$ $Pe = 0.6\ P - 10$ were $P < 70 mm/month$	Pe = Effective rain falls(mm) and P = Dependable rainfall (mm)	Dastane, 1978
8. Application efficiency	$Ea = \frac{d}{\text{Water Applied (gross)}} \times 100$	Ea = application Efficiency d = Water stored in the rootzone and Water Applied (gross) is the irrigation water.	USDA, 1997
9. Gross Irrigation Water Requirement	$GI = \frac{ETc - Pe}{Ea}$	GI = Gross irrigation, Pe = Effective rainfall (mm), and Ea = application Efficiency	(USDA, 1997
10. Irrigation intervals	$\text{Irrigation interval (I)} = \frac{\text{Net IR}}{ETc}$	I = Irrigation Interval (days), Net IR = Net irrigation requirement (mm), ETc = Irrigation water requirement (mm/days).	
11.Volume of water	$V=A*D$	V = Volume of water in m^3, A = Area in m^2, D = depth of water in m.	

Papaya irrigation water requirement and real-time irrigation scheduling

Papaya irrigation scheduling is done in two stages: the first year of plantation when Kc varies, and from the 2^{nd} to the 4^{th} year of well-managed papaya plantations when Kc remains constant. For the sake of simplicity in estimating and calculating the decadal ETc, net irrigation water requirement, decadal gross irrigation, decadal irrigation volumes, and decadal irrigation intervals for papaya in four production areas are prepared and presented below:

Kc and papaya growth characteristics

The Kc ini and Kc end for evergreen non-dormant fruit trees are often similar when climatic conditions do not vary much, as is common in tropical climates (Allen et al., 1998). Under these conditions, seasonal adjustments for climate may therefore not be required since variations in ETc depend mostly on variations in ETo (Allen et al., 1998). The Kc values for papaya were adjusted by plant age as follows: 1.0, 1.2, and 1.5 for 0–3 months old, 4–6 months old, and 7 months and older, respectively. These values were derived from various published reports (Bayabil et al., 2020; Rao et al., 2019) and were adjusted according to Ethiopian papaya transplanting calendars (Table 2).

The whole papaya production in the study areas of Ethiopia is typically transplanted at the beginning of July and ends late September. This is followed by the application of irrigation water until the end of the dry rainy season, which ends on July 1st. Once transplanted, papaya plants must receive either rainfall or irrigation up to mid-season (June). Once established, papaya fruits yield continuously for at least three to four years under good field management practices in the study areas of Ethiopia (Paull & Duarte, 2011). For this reason, a constant crop coefficient (Kc) of 1.5 was maintained after 7 months of transplanting. The root length of papaya was recorded as 0.60 cm (Masri, 1993). Although Allen et al. (1998) suggested 0.35 MAD for papaya, this study used 0.3 MAD of papaya, taking into account that papayas have a critical stage at all stages throughout the year and in all areas.

Table 2: Typical crop coefficients (Kc) for papaya fruit transplanted in the first week of July in Ethiopia (days after transplanting)

Month	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
Kc	1.0			1.2			1.5 (7 months old and greater)					
Growth characteristics	Newly planted and young plants			Plants begin to flower and set fruit; several fruits develop period			Mature plants continue to flower while other fruits are developing, and harvesting continues on the same tree					

Sources: Bayabil *et al*., (2020) and Rao *et al*., (2019)

Data collections

This study used both primary and secondary data collected from each location in the study areas. Long-term weather data (30 years, 1987-2017) were obtained from the Ethiopian Institute of Agricultural Research (EIAR) and nearby weather stations in Batu, Bora, Koka, and Melkassa. The long-term weather data from the study areas were used to calculate decadal reference evapotranspiration, annual net irrigation, annual gross irrigation, and annual irrigation volume, as well as irrigation intervals for each specific area. The decadal weather data from the study areas were used to calculate the reference evapotranspiration (ETo) for the specific area. Soil's physical and water-holding characteristics are also determined from both primary and secondary sources.

Soil water-holding characteristics of the study areas

The soil textural class of the areas was collected from various studies and reports (Beshir et al., 2015; Nagash and Mohammed, 2014; JICA Report; Dirirsa et al., 2021). The table below indicates the field capacity (FC) and permanent wilting point (PWP) of the soil for each site.

Table 3: The soil water holding properties of the dominant soil types in the study areas

Study location	Dominant soil characteristics			
	Texture	FC (m^3/m^3)	PWP (m^3/m^3)	BD (gm/cm3)
Batu	Sandy loam (Beshir *et al*., 2015)	0.28	0.16	1.44
Bora	Sandy Loam (JICA Report)	0.23	0.11	1.44
Koka	Clay loam (Nagash and Mohammed, 2014)	0.36	0.22	1.28
Melkassa	sandy loam(Dirirsa *et al*., 2021)	0.34	0.18	1.28

FC = Field capacity, WP = Wilting point, BD = Bulk density

Batu has sandy loam dominant soil texture which has a field capacity of (0.28 m^3/m^3) and a permanent wilting point of 0.16 m^3/m^3. Papaya has a 0.6 m effective root depth. Using this information the total available water around Batu is 1000 (0.28-0.16) * 0.6= 72 mm/m. By using the depletion fraction of the papaya crop as 0.3. Readily available water is 72 mm/m *0.3= 21.6 mm; that means 21.6 mm of water is required per 0.6m root depth of papaya per irrigation interval. Depending on the water holding capacity of the soil, irrigation interval for July 21.6 mm/5.1 mm/day = 4 days.

RESULTS

General features of the climate in the study areas

Based on thirty years of climatic data (1987-2017), areas experience dry and wet seasons. The wet season starts in June and lasts until around October. Batu has a maximum temperature of 28.1°C and a minimum temperature of 11.5°C. Similarly, Bora, Koka, and Melkassa have maximum temperatures of 24.7°C, 27°C, and 30.2°C, and minimum temperatures of 11.7°C, 9.1°C, and 12.5°C, respectively. Relationships between potential evapotranspiration and rainfall over thirty years were illustrated in Figure 2(a), (b), (c) and (d) for four locations. Figures 2a, 2b, 2c and 2d indicate that rainfall does not meet evapotranspiration for Melkassa, Koka, Bora and Batu except for two months (July and August). So, estimating irrigation water requirement is important for crop production to full fill the deficit crop water requirement based on decadal, months and over the years. For all papaya transplantations, it is recommended to start during the rainy season (first week of July).

Figure 2: Long term rainfall and potential evapotranspiration of each study areas

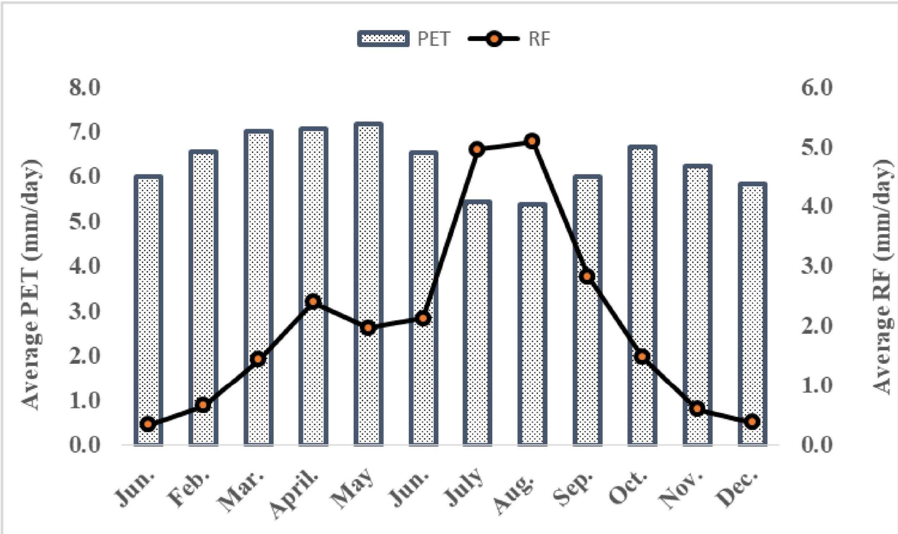


Figure 2(a), Melkassa

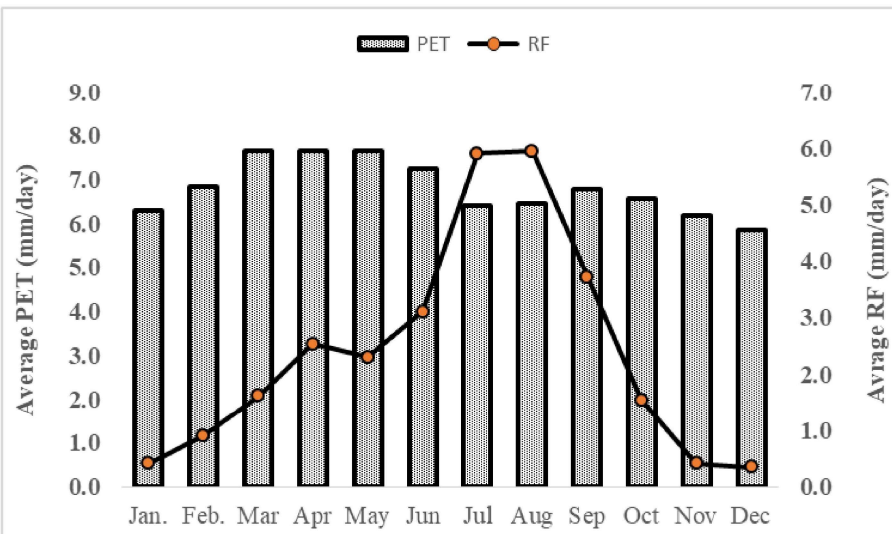


Figure 2(b), Koka

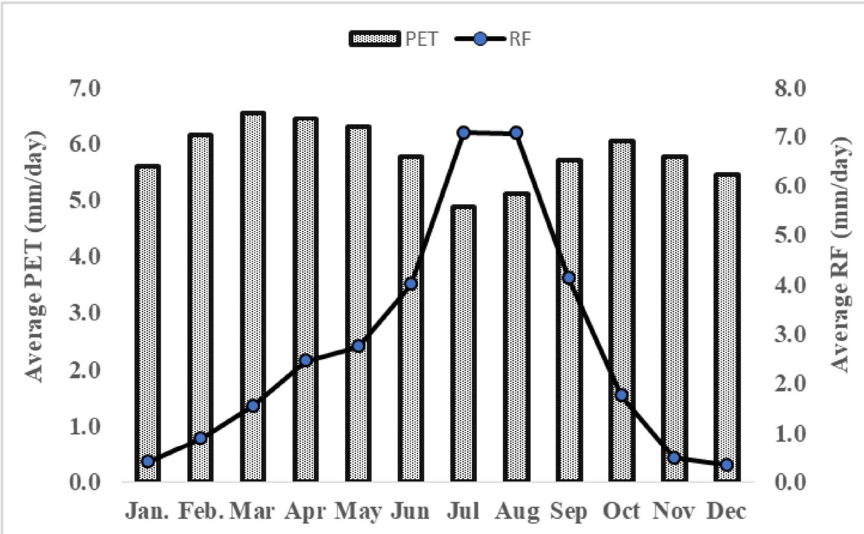


Figure 2 (c), Bora

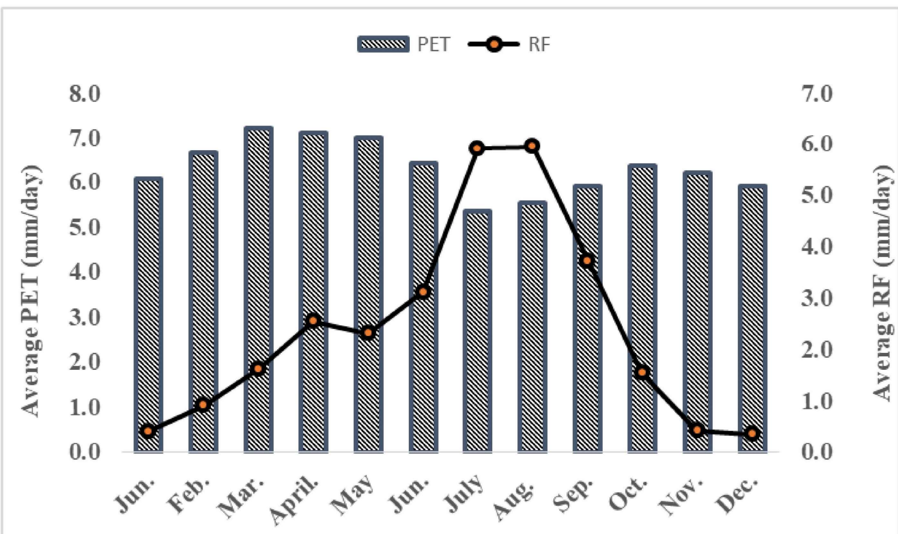


Figure 2(d), Batu

Evapotranspiration and effective rainfall

The long-term average total annual rainfall around Batu is 668.8 mm/year, while the total decadal ETc for papaya production in this area requires approximately 2750.7 mm/ha/year during the first year, as illustrated in Figure 3a below. Total annual ETc of 3154.0 mm/dec was also estimated during the second and subsequent years at Batu. The highest evapotranspiration (>90 mm/dec) was estimated from January to June, while the lowest evapotranspiration (48 mm/dec) was estimated in the second and third decades of July. The lowest effective rainfall of 2.8mm was estimated in December, while the highest of 70mm/dec was estimated in July and August as shown Figure 3a. This indicates that irrigation is necessary when rainfall does not fulfill the crop water requirement of papaya.

Bora receives an estimated effective annual rainfall of 547.8 mm. The total annual decadal evapotranspiration rate of 2983.1 mm/dec also estimated during the first year of papaya production and increases to 3415.5 mm/year in subsequent years. The highest decadal ETc, at 100 mm/dec, was estimated from January to June, as shown in Figure 3b below. The highest effective rainfall was also estimated in July and August in Bora as shown in Figure 3b below.

From long-term rainfall data, Koka receives an estimated effective rainfall of 603.9 mm annually. The total decadal ETc is 3201.9 mm annually and 3678 mm annually for the first and subsequent years of papaya production, respectively. Figure 3c below shows the decadal distribution and amount of effective rainfall, as well as the estimated ETc for the first and subsequent years of papaya production in Koka. Koka receives the highest effective rainfall in the first decade of August, followed by the third decade of August. The highest ETc is greater than 80 mm/dec in all months except for July and August in Koka.

Similarly, Melkassa receives an estimated annual rainfall of 763 mm according to long-term climatic data, and papaya requires a total of annual 2984.2 mm/dec ETc during the first year of production (Figure 3d). Again, a total of annual 3418.5 mm/dec of papaya ETc was computed for the second and subsequent production years. The Estimated ETc of papaya ranges 53mm/dec during rainy and humid months to highest 108mm/dec at dry months in year of production. Similarly, the estimation of decadal ETc ranges from 79 mm/dec during the rainy month decades to the highest 100 mm/dec during dry month decades during the second and following consecutive papaya production years at Melkassa The estimation of decadal effective rainfall at Melkassa ranges from highest 61 mm/dec during the rainy decades to the lowest 2 mm/dec during the dry season. All figures 3a-d show that the crop water requirement of papaya was greater in the second and subsequent years of production, varying by season and production location.

Decadal evapotranspiration in the first year for all locations is lower than the decadal evapotranspiration in the second year of papaya production. This indicates that the crop water requirement for the second year was greater than that for the first year of production.

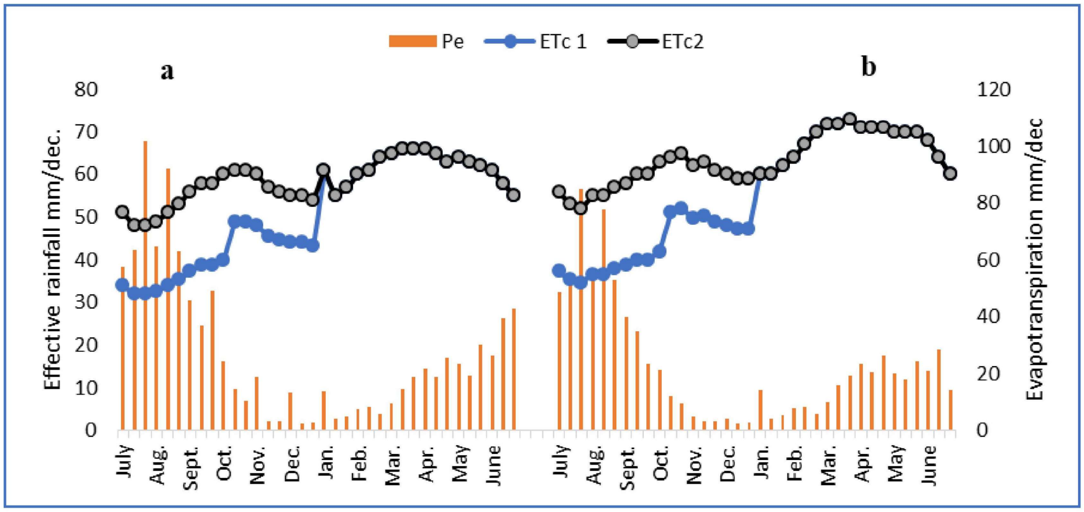


Figure 3 (a & b) Decadal Evapotranspiration and effective rainfall

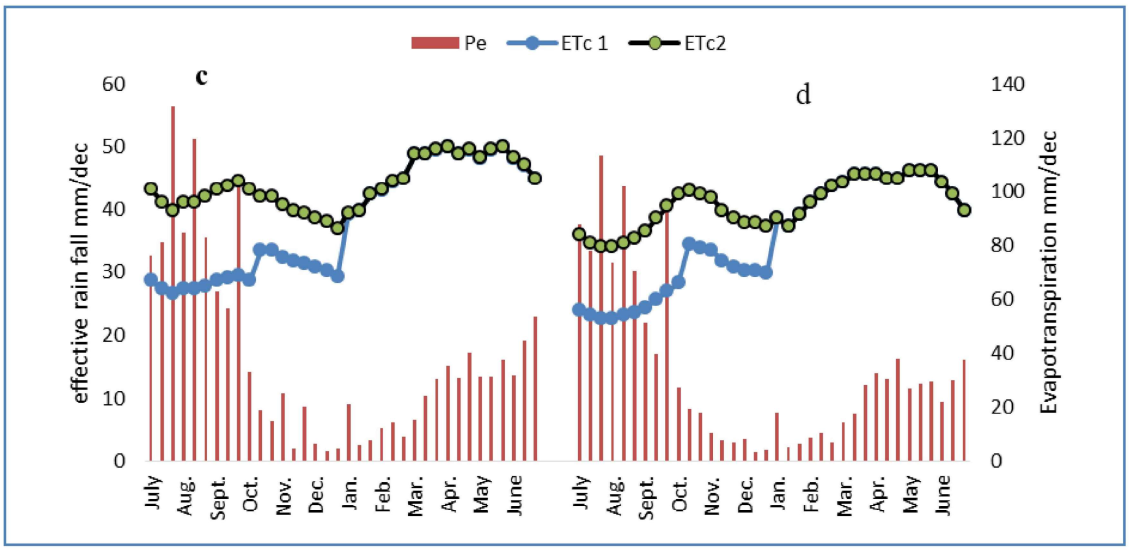
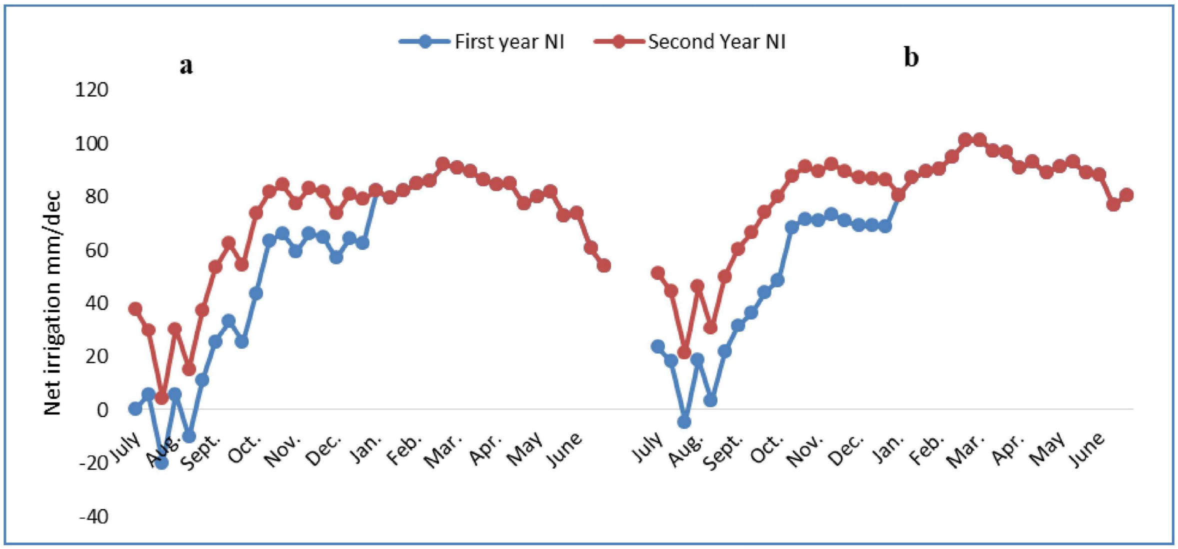


Figure 3(c & d). Decadal Evapotranspiration and effective rainfall

Net irrigation

Net irrigation of 2099.5 mm/year was estimated for papaya production in the first year, while 2485.7 mm/year was estimated for the second and subsequent years in Batu. Figure 4a shows the estimated decadal net irrigation water requirement for first and subsequent years of papaya production at Batu. The estimation of decadal net irrigation (I) high from December up to May with as high as 90 mm/ dec and low during other remaining months decades. In the first year of papaya production, a lower net irrigation water requirement is estimated from July to January compared to the subsequent years of production. The total decadal net irrigation water requirement was estimated at 2439.9 mm/year for the first year and 2867.7 mm/year for the second and subsequent years of papaya production in Bora. The calculated decadal net irrigation around Bora showed a maximum of 98 mm/dec during January to May. Decadal net irrigation requirement distribution was shown in figure 4b. The estimated net irrigation water requirement at Koka is 2439.9 mm annually for the first production year and 2867.7 mm annually for the second and subsequent years.

The net water requirement for an annual is a total of 2468.1 mm/year, with 2818.1 mm/year for the first year and the second year of papaya production at Melkassa. It ranges from 0 mm during the rainy season to 96 mm during the dry months, such as from January to June, in the first year of production. Similarly, the estimation of decadal net irrigation during the second and follow-up production years showed ranges from 4 mm during the rainy season to 98 mm/dec during the dry season as shown in figure 4d.



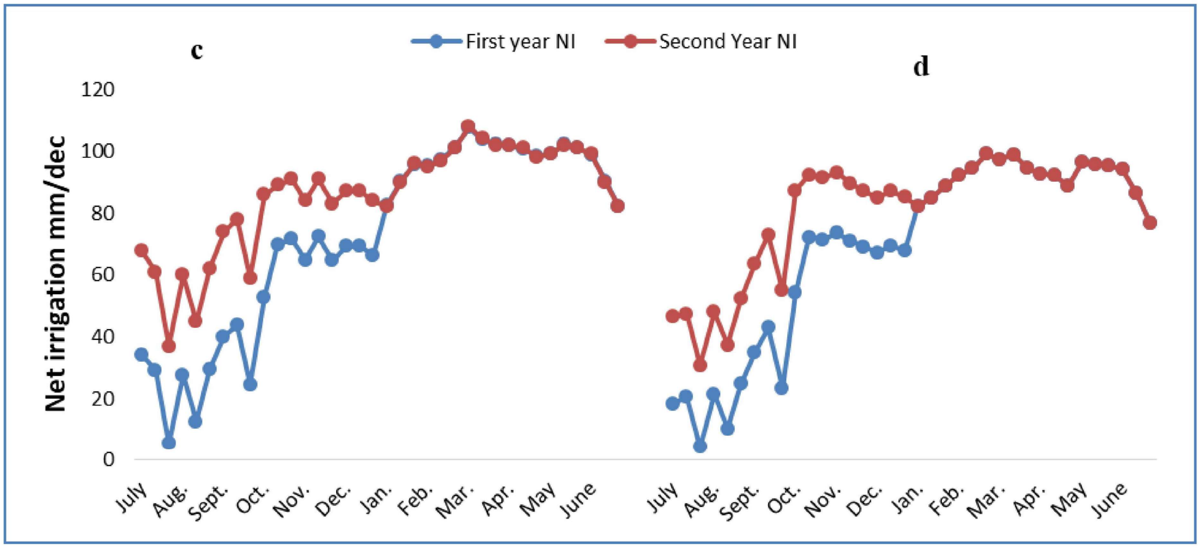


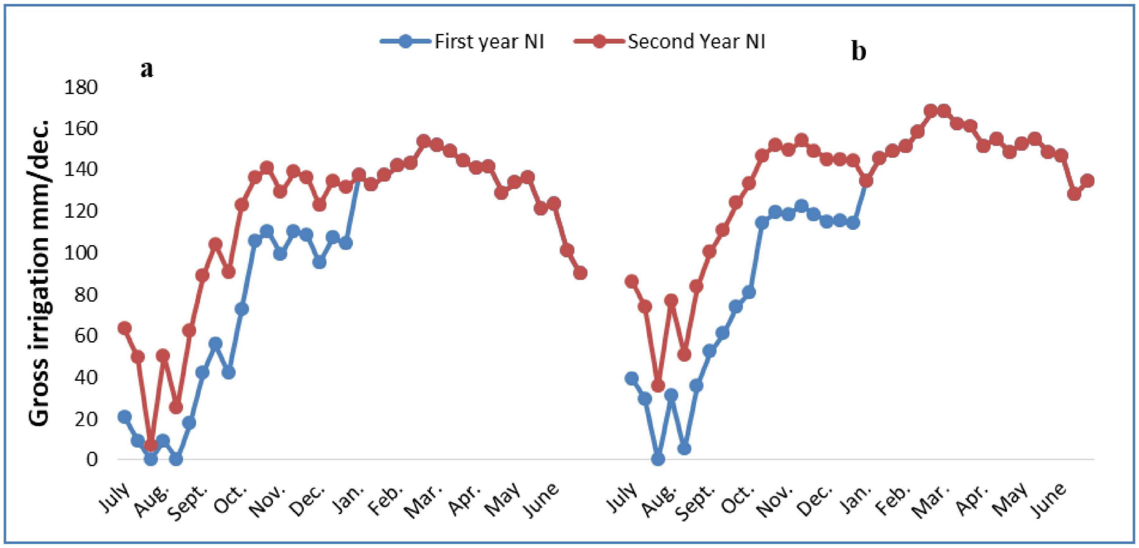
Figure 4. Decadal net irrigation

Gross irrigation

The estimated decadal gross irrigation requirements for papaya production at Batu were 3520.1 mm/year in the first year of production and 4142.9 mm/year in the second and subsequent years of production. The lowest decadal gross irrigation was 0 mm in August and highest decadal gross irrigation was estimated in Feb. with 150 mm/ dec during the first year of papaya production as shown in 5a. At Bora, the estimated decadal gross irrigation for papaya production was around 4066.5 mm/year for the first cycle and 4779.6 mm/year for subsequent cycles of papaya production.

Around the Koka area, the estimated gross irrigation is 4330.0 mm/year during the first production year and 5125.0 mm/year for the second production year.

Similarly, the estimation of gross irrigation for Melkassa resulted in a total of 4113.5 mm/year and 4837.4 mm/year for the first and subsequent years of papaya production. Distribution of estimated decadal gross irrigation requirements across each location are shown in figures 5(a), (b), (c), and (d).



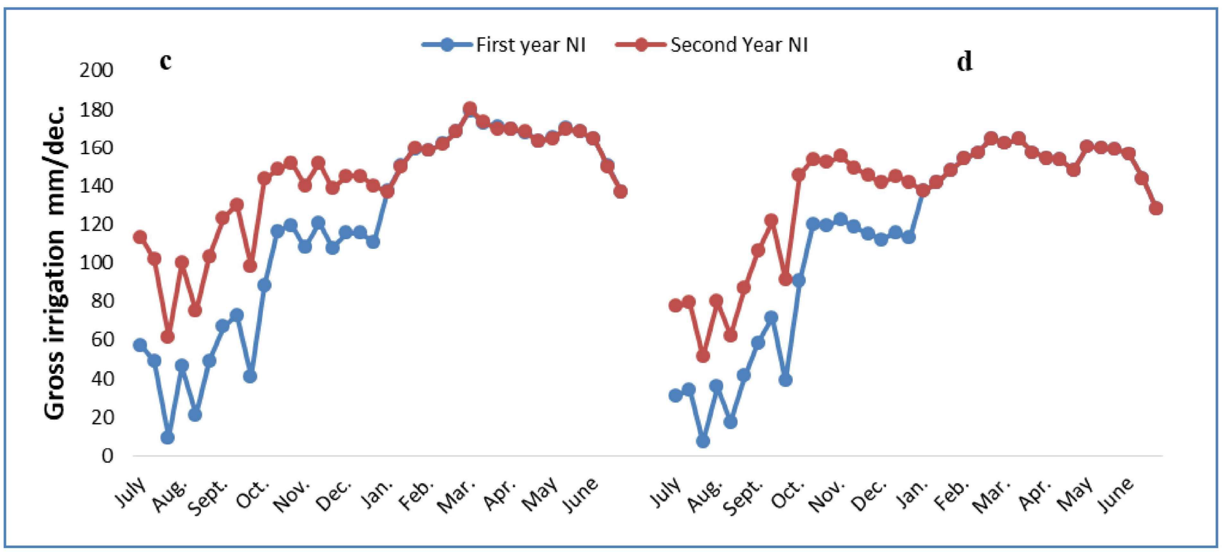
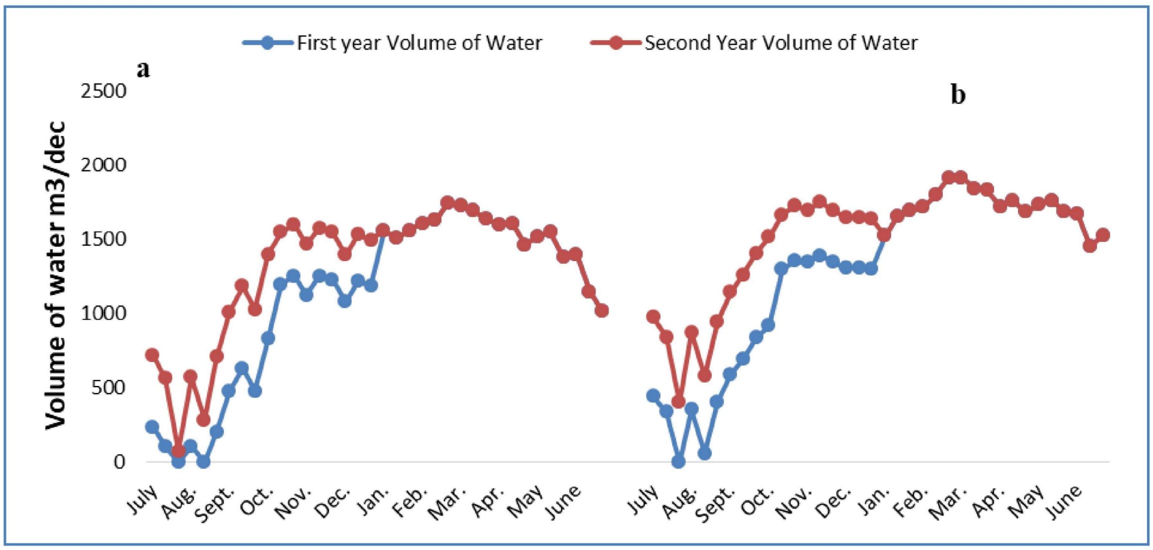


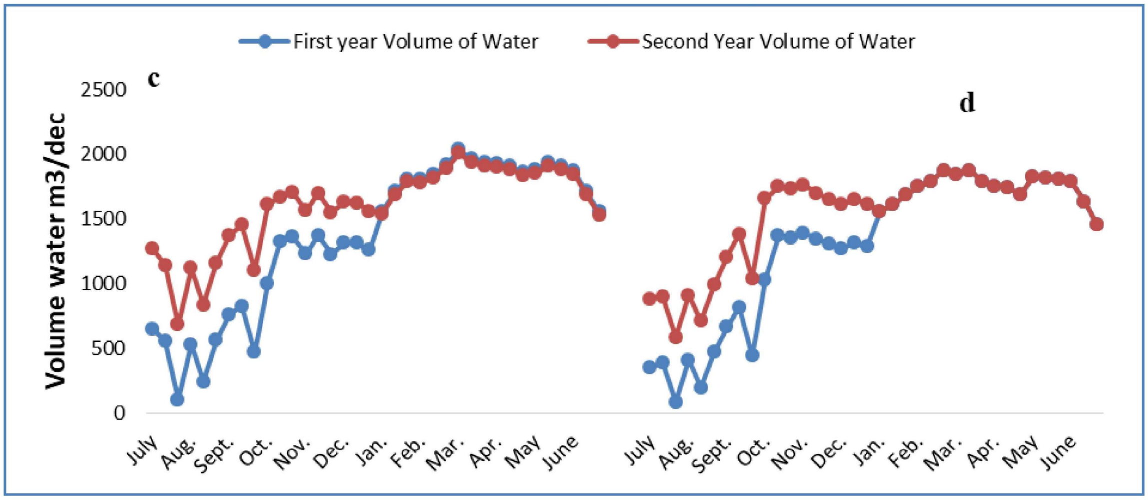
Figure 5

Volume of water

The estimated decadal volume of irrigation water in Batu was consistently high, exceeding 600 m^3/ha in all February and March decades throughout the years of papaya production, totaling 39998.3 m^3/ha of irrigation water for the first year. An estimated 47063.7 (m^3/ha/year) amounts of irrigation water are required for the second and consecutive years in Batu for papaya production. The decadal calculated volume of water required for papaya production around Bora showed that it could reach as high as 1920 m^3/ha from February to March, with a total of 46195.6 m^3/ha during the first production year and 542960.0 m^3/year during the second and subsequent production years.

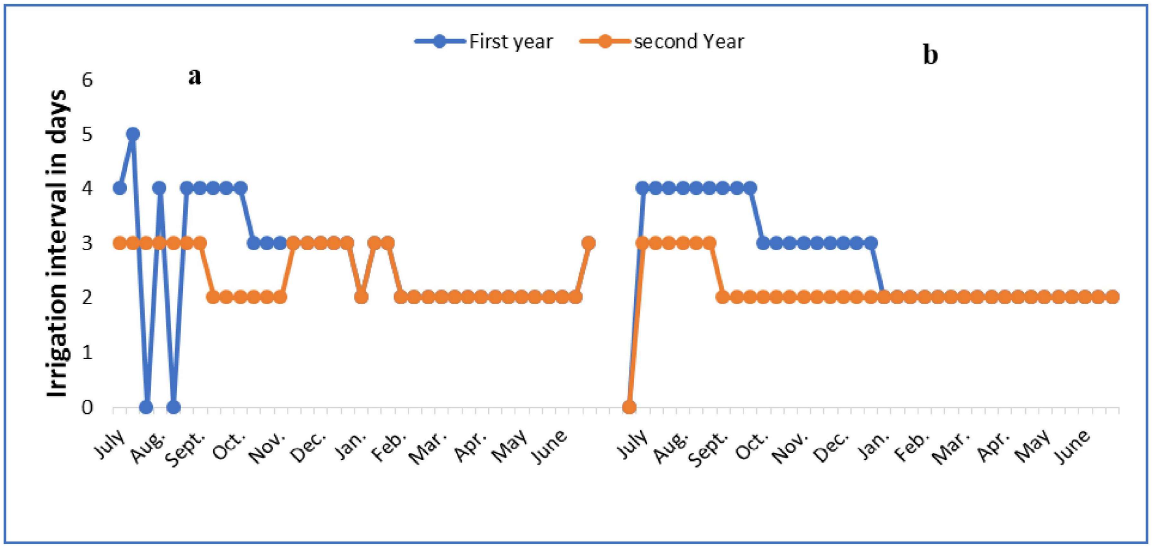
In Koka, the estimated volume of irrigation water for papaya production is 49188.8 m3/ha for the first production year and 57385.1m^3/ha for the second and consecutive production years. The estimated decadal volume of water required for papaya production at Melkassa ranges from 0 m^3/dec during the rainy decades to 1873.3 m^3/dec during the dry months, with a total of 46729.7 m^3/ha/year during the first year of production. Similarly, the estimation of the decadal volume of irrigation water required for papaya production at Melkassa during the second year is estimated to be a total of 5495.2.5 m^3/ha/year. The distribution of the estimated volume of water for Batu 5(a), Bora 5(b), Koka 5(c), and 5(d) is shown below.

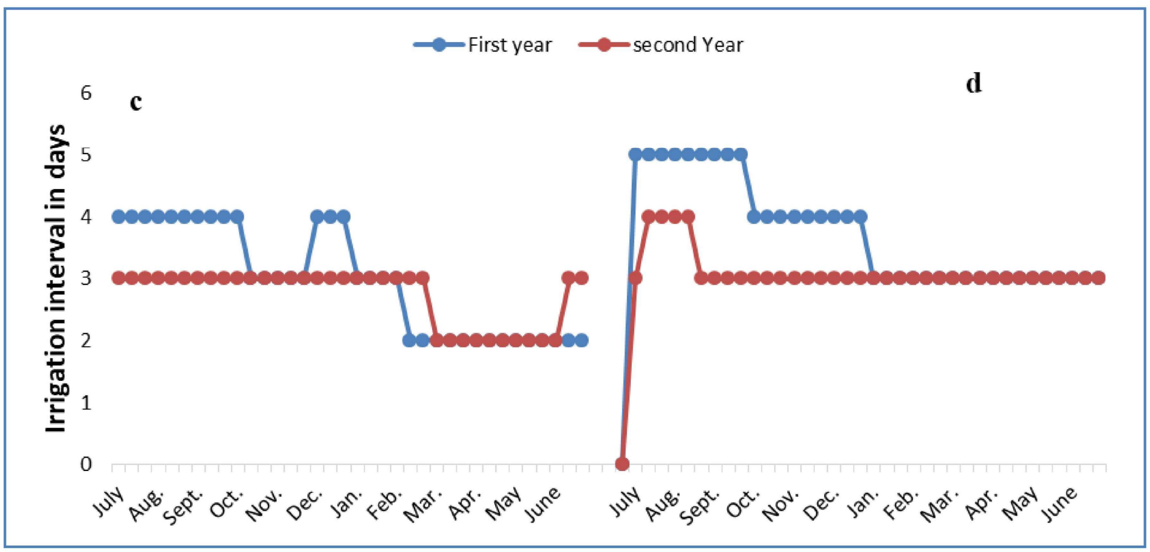




Irrigation interval

Irrigation interval estimation depends on the maximum root depth of papaya, not on the specific root depth with growth stages. The estimated irrigation interval varies in the first and subsequent production years of papaya. In Batu, the estimated decadal irrigation interval suggests that papaya fields should be irrigated every 2 days during the dry seasons and either every 4 or every 5 days in each decade, as illustrated in Figure 6(a). The irrigation interval in the first year of production was estimated to be between 2 and 5 days at Batu. The estimated decadal irrigation intervals for papaya production at Bora range from 2 days during dry decades to 3 days during wet season decades. Moreover, it varies by production year and can reach up to 4 days in the first year of production (Figure 6b). Estimated Irrigation interval at Koka also reaches from 2 days to days as shown 6(c). The calculated irrigation intervals for papaya production at Melkassa range from 4 days during the rainy seasons to 2 days during the dry periods, as shown in Figure 6(d).





DISCUSSIONS

Papaya fruit is cultivated in the Rift Valley of Ethiopia under irrigation, consuming a large quantity of irrigation water. The crop water requirements of papaya crops have not been well studied and estimated in Ethiopia. The amount of moisture required for papaya growth varies in different locations, depending on the ecological characteristics of the area. Factors such as rainfall, temperature, light exposure, wind patterns, soil composition, and elevation are crucial in determining the optimal moisture levels necessary for keeping papaya trees healthy and productive. Additionally, the age of the plant is a significant factor that influences the specific moisture requirements needed for its growth and development.

The study aimed to estimate decadal water requirements (ETc) and develop irrigation scheduling for papaya fruit production in the Central Rift Valley areas of Ethiopia. The results showed that the annual ETc was 2750.7 mm for Batu, 2983.1 mm for Bora, 3201.9 mm for Koka, and 2984.2 mm for Melkassa areas for papaya production in the first year. Similarly, for the second and consecutive production years, the annual ETc of 3154.5 mm, 3415.5 mm, 3201.9 mm, and 3418.5 mm of ETc were estimated for Batu, Bora, Koka, and Melkassa, respectively. The annual net irrigation requirements were estimated to be 2099.5mm, 2439.9mm, 2598.0mm, and 2468.1mm for Batu, Bora, Koka, and Melkassa during the first year of production. Similarly, the annual net irrigation was estimated at 2485.7 mm for Batu, 2867.7 mm for Bora, 2598.0 mm for Koka, and 2902.4 mm for Melkassa areas for the second and consecutive years of papaya production. Gul et al., (2023) suggested that papaya ETc was between 1478 and 1766 mm with a ground water contribution of 7–18% at 1.50–2.50 m. The papaya is adapted to a wide range of rainfall conditions ranging from 35 cm to 250 cm annual precipitation (Soorianathasundaram, 2005). The variation in the results is due to factors affecting crop water requirements.

Net irrigation of 2099.5 mm/year and 2485.7 mm/year was estimated for the first year and the second and subsequent years of papaya production in Batu. The total decadal net irrigation water requirement was estimated at 2439.9 mm/year for the first year and 2867.7 mm/year for the second and subsequent years of papaya production in Bora. The estimated net irrigation water requirement at Koka is 2439.9 mm annually for the first production year and 2867.7 mm annually for the second and subsequent years. The net water requirement for annual is a total of 2468.1 mm/year, with 2818.1 mm/year for the first year and the second year of papaya production at Melkassa.

The annual estimated gross irrigation was 3520.1 mm for the Batu area, 4066.5 mm for the Bora area, 4330.0 mm for the Koka area, and 4113.5 mm for the Melkassa area for the first year of papaya production. The annual estimated gross irrigation is 4142.9 mm for Batu, 4779.6 mm for Bora area, 4330.0 mm for Koka area, and 4837.4 mm for Melkassa area for the second and consecutive years.

The annual estimated volume of irrigation water was 39,988.3 m^3/ha for Batu area, 46,195.6 m^3/ha for Bora area, 49,188.8 m^3/ha for Koka area, and 46,729.7 m^3/ha for Melkassa area for the first year of papaya production. The decadal annual volume of irrigation water was estimated as follows: 47,063.3 m^3/ha for the Batu area, 54,296.0 m^3/ha for the Bora area, 49,188.8 m^3/ha for the Koka area, and 54,952.5 m^3/ha for the Melkassa area during the second and consecutive papaya production years.

CONCLUSIONS AND RECOMMENDATIONS

Based on estimated results, each location has different estimated parameters such as crop evapotranspiration, net irrigation requirement, gross irrigation requirement, volume of irrigation water, and irrigation intervals. These parameters also lower in first year of production when compared to second year of production due to growth stages of papaya. Irrigation scheduling by the water balance and atmospheric based quantifications evapotranspiration approach is based on estimates and are not always exactly accurate. Thus, monitoring of the soil water content in the field and papaya fruit plants with appropriate device, sensors and comparisons with other irrigation scheduling methods and approaches requires further investigations. This information could be used by papaya producer farmers and extension workers until more accurate irrigation scheduling is worked out.

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