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Research Article

Effects of Deficit Irrigation and Furrow Application Methods on Yield and Yield Components of Artemisia annua L. at Koka, Ethiopia

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ABSTRACT

The study was conducted at Wondo genet Agricultural Research Center Koka Research Station, Ethiopia, 8°26' N latitude, 39°02' E longitude and 1602 m.a.s.l. for three consecutive years with the objectives to determine deficit irrigation levels and furrow irrigation water application techniques on yield and water productivity of Artemisia annua L. The experiment consists of three-level of deficit irrigation (100%, 75%, and 50% ETc), and three furrow irrigation water application techniques (alternate, fixed, and conventional furrow) were used in combination. The study revealed that the deficit levels and the furrow application techniques were statistically affected artemisia plant height, fresh leaf weight, fresh and dry biomass, essential yield, and water use efficiency during the whole years. The pooled mean result indicated that the maximum economic yields which are fresh leaf weight (7.11 t ha-1) and essential oil yield (16.06 kg ha-1) were obtained from the combined treatment of 100% ETc and conventional furrow application technique. However, the maximum water use efficiency (5.83 kg m-3) was recorded from a combined treatment of 50 % ETc and alternate furrow application technique. Based on the study for the maximum yield achievement in an area of no limited water resource 100 % ETc and conventional furrow application technique can be used. Whereas in an area where limited water resource is available the maximized water use efficiency can be obtained from 50% ETc and alternate furrow application technique at Koka and similar agro ecology.

Keywords: Deficit irrigation; Furrow application techniques; Water use efficiency; Artemisia

INTRODUCTION

The competition for scarce water resources has increased in many world regions due to population growth, economic development, and environmental concerns. It is anticipated that irrigation water demand will continue to increase in the coming future [1]. The limited availability of water in many parts of the world is the reason for the global interest in this natural resource and trial for improving the management of water resources. The fact that the basic consumer of available water resources is the irrigated agriculture necessitates water management in the agricultural sector [2].

The fact that water stress effects on growth and yield of species and variety dependent are well known [3]. Under such situations, farmers often receive water allocations below the maximum crop evapotranspiration needs (ETc) and either have to concentrate the supply over a smaller land area or have to irrigate the total area with levels below full ETc [4]. It is important, therefore, to make an effort to enhance the use of irrigation water in the agricultural sector.

Deficit irrigation is a scheduling method where irrigation is purposefully carried out not to fully meet water requirements of the crop, and plants are allowed to extract soil moisture beyond readily available water in the plant root zone is the key to conserving water and improving irrigation performance and sustainability of irrigated agriculture [5,6]. The goal of deficit irrigation is to increase crop water use efficiency by reducing the amount of water at irrigation or by reducing the number of irrigation events [7].

However, deficit irrigation usually entails a risk of negative impacts to crop yield and quality. Consequently, this has to be balanced against the benefits from the alternate uses for the saved water as well as an understanding of the yield and quality trade-offs to optimize productivity and economic returns to the grower rather than maximizing yields [8]. An understanding of crop and particular varietal response to water stress is key to the beneficial use of deficit irrigation.

Artemisia annua L. is aromatic and medicinal belonging to the Asteraceae family which yields artemisinin. Artemisinin is a central component that is currently the most effective malaria drug and World Health Organization recommended it for the treatment of

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drug-resistant and cerebral malaria [9,10].

In many arid and semi-arid areas of developed and developing countries, deficit irrigation has been widely studied and practiced for improving crop yield and/or increasing irrigation water use efficiencies [11]. Besides deficit irrigation and conventional furrow method alternate and fixed furrow application techniques can enhance water use efficiency without significant yield reduction [12,13].

The variations in the reports of the effect of deficit irrigation on crops only imply that the effects of deficit irrigation for the same crop may vary with location. The climate of the location, which dictates the evaporative demand on the crop, and the soil type, which dictates the available water for plant uptake, play vital roles in dictating the influence of deficit irrigation [5]. With this regard, the study was conducted to improve water productivity under deficit irrigation and different furrow application techniques for Artemisia annua L. production.

MATERIALS AND METHODS

Experimental conditions

The study was conducted at Wondo Genet Agricultural Research Center, Koka research station, central rift valley of Ethiopia, 8°26' N latitude, 39°02' E longitude, and 1602 m.a.s.l. for three consecutive dry seasons (2016/17 and 2018/2019). The soil at the experimental site was clay in textures with field capacity and permanent wilting point of 35% and 19%, respectively. The study area receives an annual average of 831.1 mm which is characterized as semi-arid with uni-modal low and erratic rainfall pattern. About 71.2% of the total rainfall of the area falls from June to September. The mean maximum temperature varies from 26.3 to 30.9C while the mean minimum temperature varies from 11.0 to 15.5°C (Table 1).

Experimental design and procedure

The field experiment was carried out using a randomized complete block design with three replications [14]. Each experimental unit had 3 m in length and 3 m in width with spacing of 1.50 m between each unit and 3.00 m between blocks. The experiment consists of three-levels of deficit irrigation (100%, 75%, and 50% ETc), and three furrow irrigation water application techniques (alternate, fixed, and conventional furrow) were used in combination. Alternate furrow technique used by watering selective half furrow from the entire plot alternatively during each irrigation event. Fixed furrow techniques are used by watering half of the entire furrows during all irrigation events and conventional furrows irrigating the whole furrows in every irrigation event.

After the experimental land prepared Artemisia annual L. seedling was planted in a row and plant spacing of 0.6 by 0.6 m, respectively. Regular field management like weeding and hoeing has been in the study during the experimental period for all plots uniformly. Irrigation water was applied based on the treatment variation after it is calculated using CROPWAT 8.0 software using necessary input data. In CROPWAT, the FAO Penman-Monteith method is used to estimate reference evapotranspiration (ETo). The ETo (mm/day) by the FAO Penman-Monteith method is as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T + 273}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

Where Rn is the net radiation at the crop surface (MJ $m^{-2}day^{-1}$); G is the soil heat flux density (MJ m^{-2} day^{-1}); T is the mean daily air temperature at 2 m height (°C); γ is the psychrometric constant; u2 is the wind speed at 2 m height (m s^{-1}); es and e a are the saturation vapor pressure and the actual vapor pressure, respectively (kPa).

Crop water requirement is calculated as same as the crop evapotranspiration (ETc) assuming there are no other water losses. The ETc is calculated by multiplying the ETo by crop coefficient, Kc, i.e.

$$ETc = Kc \times ETc \quad (2)$$

Then, the gross irrigation depth was applied using a 2-inch Parshall flume for each treatment based on the deficit level throughout the growth stage. The soil moisture dynamics were monitored by the gravimetric method by collecting the soil before and after irrigation events.

Data collection

The data collection was conducted after 120 days of transplanting artemisia. For the yield and yield component of artemisia five plants were randomly selected from the central part of the plot excluding the border. The plant height was measure at the field. Fresh biomass of artemisia 30cm above the ground at the edge of the leaf was harvested manually using a sickle. Data on moisture content and essential oil content were collected after the sample was extracted at Wondo Genet Agricultural Research Center, Natural Product Laboratory using the hydrodistillation method.

Moreover, based on the obtained essential oil yields and amount

Table 1: Long-term climatic data of the study area.

Month	Tmax (°C)	Tmin (°C)	Relative humidity (%)	Wind speed (m/s)	Sunshine hour (%)	Rainfall (mm)
January	27.4	11.3	54	4.04	75	13.5
February	28.3	12.6	52	4.08	76	26.1
March	30.0	14.4	51	4.64	74	51.5
April	30.3	15.2	54	3.80	71	58.5
May	30.9	15.1	53	3.98	68	48.5
June	30.0	15.5	57	4.91	65	72.7
July	26.7	15.0	67	4.30	54	212.7
August	26.3	15.1	68	3.15	53	202.4
September	27.8	14.9	66	2.30	57	104.3
October	28.3	12.7	56	3.50	73	21.1
November	27.4	11.3	52	4.09	83	9.9
December	26.1	11.0	54	4.19	76	9.9

of irrigation used, water use efficiency was calculated using the following formula.

$$WUE = \frac{EOY}{TW} \quad (3)$$

Where: WUE is water use efficiency (kg m^{-3}); EOY: is the essential oil yield (kg ha^{-1}); TW: is the seasonal total water use (m^3 ha^{-1}).

Data Analysis

The data collected were statistically analyzed using Statistical Analysis System (SAS) software version 9.4 using the General Linear Programming Procedure (GLM). Mean comparison was carried out using the Least Significant Difference (LSD) at 5% probability level to compare the differences among the treatment mean.

RESULTS AND DISCUSSIONS

Plant height and fresh leaf weight

The plant height was highly significantly (p<0.001) influenced by different levels of deficit and furrow irrigation techniques during the 2016/17 and 2018/19 production years. Similarly, the plant height was significantly (p<0.01) affected during 2017/18. The result shows that as the deficit level increased from 100% to 50% of ETc the plant become short at all furrow application techniques. The pooled mean analysis indicated that the maximum plant height of 116.36 cm was recorded on 100% ETc conventional furrow method however, it is statistically similar with 75% of conventional furrow method which is 111.24 cm. The lowest pant height 83.64 cm was recorded on 50% ETc of fixed furrow application method but statistically similar with 50% alternate furrow application method (Table 2). Elias *et al.*, [15] reported that maize plant height has been significantly affected by different furrow application techniques.

Moreover, the study showed that fresh leaf weight was highly significantly (p<0.001) affected by different deficit levels under furrow techniques in all three consecutive years. The highest fresh leaf weight was obtained from 100% conventional irrigation technique which 7.11 t ha^{-1} during the three consecutive years. The lowest fresh leaf weight was recorded on 50% of ETc under fixed furrow application technique 3.11 t ha^{-1} during the three consecutive years. This minimum fresh leaf weight statistically similar with 50% ETc with alternate furrow application technique.

Fresh biomass and dy biomass

Both fresh biomass and dry biomass of artemia were significantly (p<0.001) affected by deficit levels and furrow application methods during all consecutive production years. The maximum fresh biomass 21.51 t ha^{-1} and dry biomass 11.21 t ha^{-1} obtained from conventional furrow application method with 100% ETc (Table 3). However, the poled mean indicated that 75 and 50% ETc with conventional furrow irrigation technics were statistically similar. On the other hand, the lowest fresh biomass 10.29 t ha^{-1} and dry biomass 5.89 t ha^{-1} of artemia recorded on 50% ETc of fixed furrow irrigation technique which is statistically similar with 50% ETc with alternate furrow.

The highest fresh biomass and dry biomass in conventional furrow application method is associated with the higher amount of water applied as compared with the rest methods. As the applied water reduced from 100% conventional furrow to 50% fixed furrow application technique the fresh biomass and dry biomass reduced by 52 and 47%, respectively. This finding is in line with Elias *et al.*, [16] who reported that fresh and dry biomass decreased as the applied depth of water reduced from 100% conventional furrow to 50% fixed furrow application technique in lemongrass production. Leithy *et al.*, [17] deported that increasing levels of water stress reduce rosemary growth and yield due to reduction in photosynthesis and plant biomass. Generally, under increasing water-stress levels photosynthesis was limited by low CO_2 availability due to reduced stomatal. Plants under drought reduce their biomass production and contribute more biomass to roots to decrease consumption and increase water absorption [18].

Essential oil yield

The study revealed that the essential oil yield of artemia was highly significantly (p<0.001) affected by different levels of deficit irrigation and application techniques in the three consecutive years. The essential oil yield trends decrement as the deficit level increased and the furrow application technique changed from conventional to fixed and alternate furrow. The maximum essential oil yield of 16.06 kg ha^{-1} was obtained from 100% ETc of conventional application technique. The minimum essential oil 6.94 kg ha^{-1} was recorded from 50% of ETc under fixed furrow application techniques. However, these are statistically similar

Table 2: Artemisia yield and yield component response to deficit irrigation and furrow application techniques.

Treatments	PH (cm)				FLW (t ha^{-1})			
	2016/17	2017/18	2018/19	mean	2016/17	2017/18	2018/19	mean
100% AF	87.9^{bcd}	106.8^{ab}	119.07^{ab}	104.58^{bc}	4.4c	6.25^{bc}	4.36^{bc}	5.01^{c}
75% AF	86.9^{cd}	97.5^{bc}	109.27^{b}	97.91^{cd}	3.5de	5.32^{cd}	3.77^{cd}	4.21^{de}
50% AF	81.6^{de}	94.7^{bc}	85.40^{d}	87.24^{ef}	2.5f	4.88^{cd}	2.55^{e}	3.31^{fg}
100% FF	80.9^{de}	106.1^{ab}	117.53^{ab}	101.49^{cd}	3.4de	5.94^{bc}	4.28^{bc}	4.54^{cd}
75% FF	77.0^{de}	97.3^{bc}	105.93^{bc}	93.42^{de}	2.7ef	5.10^{cd}	3.44^{d}	3.74^{ef}
50% FF	70.9^{e}	87.7^{c}	92.40^{cd}	83.64^{f}	2.1f	4.44^{d}	2.79^{e}	3.11^{g}
100% CF	103.2^{a}	115.3^{a}	130.53^{a}	116.36^{a}	6.2a	8.48^{a}	6.62^{a}	7.11^{a}
75% CF	97.4^{abc}	110.9^{a}	125.47^{a}	111.24^{ab}	5.4b	7.42^{ab}	4.59^{b}	5.79^{b}
50% CF	98.1^{ab}	106.8^{ab}	110.27^{b}	105.04^{bc}	3.9cd	6.24^{bc}	4.13^{bc}	4.75^{cd}
CV (%)	7.4	7.2	7.1	4.7	13.0	14.3	9.2	7.7
LSD0.05	11.1	12.8	13.6	8.1	0.9	1.5	0.6	0.6
P value	***	**	***	***	***	***	***	***

NB: - PH: plant height, FLW: fresh leaf weight. Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at p<0.05 level of significance. ***: very highly significant at p<0.001 level of probability, **: highly significant at p<0.01 level of probability.

Table 3: Artemisia yield and yield component response to deficit irrigation and furrow application techniques.

Treatments	FBM (t ha-1)				DBM (t ha-1)			
	2016/17	2017/18	2018/19	mean	2016/17	2017/18	2018/19	mean
100% AF	12.1cd	18.49bc	17.69bc	16.11cd	6.58cd	9.31abc	9.55ab	8.48cd
75% AF	11.1de	14.24de	17.63bc	14.34ef	6.58cd	8.50cd	9.87ab	8.32cd
50% AF	9.3efg	13.82de	11.05d	11.39g	5.32de	7.45d	5.98c	6.25ef
100% FF	9.6ef	18.23bc	17.16bc	14.98de	5.42de	8.68cd	9.46ab	7.85d
75% FF	7.9fg	16.33cd	15.46c	13.23f	4.50e	7.44d	8.71b	6.88e
50% FF	7.0g	12.66e	11.16d	10.29g	4.14e	7.26d	6.26c	5.89f
100% CF	22.5a	21.37a	20.70a	21.51a	12.20a	10.54a	10.86a	11.20a
75% CF	14.9b	20.52ab	18.13abc	17.86b	7.88bc	10.27ab	9.47ab	9.21bc
50% CF	14.0bc	16.99c	18.38ab	16.46bc	8.70b	8.98bc	10.66a	9.45b
CV (%)	11.1	9.2	10.2	5.5	12.1	9.6	11.4	6.3
LSD0.05	2.3	2.7	2.9	1.4	1.4	1.4	1.8	0.9
P value	***	***	***	***	***	***	***	***

NB: - FBM: fresh biomass, DBM: dry biomass. Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at p<0.05 level of significance. ***: very highly significant at p<0.001 level of probability.

Table 4: Artemisia yield and yield component response to deficit irrigation and furrow application techniques.

Treatments	EOY (kg ha-1)				WUE*1000 (kg m-3)			
	2016/17	2017/18	2018/19	mean	2016/17	2017/18	2018/19	mean
100% AF	8.0bcd	14.01bc	10.87b	10.94bc	2.12bc	6.36cde	4.84ab	4.32cd
75% AF	7.5bcd	12.60c	8.20cde	9.42c	2.66ab	7.62bc	4.51ab	4.93bc
50% AF	6.0cde	10.40c	5.89ef	7.43de	3.20a	9.44ab	4.86a	5.83a
100% FF	6.9cd	11.09c	9.47bc	9.16cd	1.84bc	5.03de	3.91bc	3.59def
75% FF	5.7de	11.06c	5.49f	7.43de	2.04bc	6.69cd	3.02cd	3.92def
50% FF	3.8e	10.86c	6.20def	6.94e	2.00bc	9.86a	5.12a	5.66ab
100% CF	13.0a	18.50a	16.66a	16.06a	1.74c	4.20e	3.44cd	3.12f
75% CF	10.0b	17.47ab	10.29b	12.60b	1.78bc	5.28de	2.83d	3.30ef
50% CF	8.7bc	14.16bc	8.53bcd	10.46c	2.32bc	6.43cd	3.52cd	4.09de
CV (%)	22.0	17.8	15.2	10.6	23.0	18.7	13.7	11.3
LSD0.05	3.0	4.1	2.4	1.8	0.9	2.2	0.9	0.8
P value	***	***	***	***	*	***	***	***

NB: - EOY: essential oil content, WUE: water use efficiency. Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at p<0.05 level of significance. ***: very highly significant at p<0.001 level of probability, *: significant at p<0.05 level of probability.

with 75% and 50% ETc fixed and alternate furrow application techniques, respectively (Table 4).

The reduction of water from 100% ETc of conventional furrow to 50% ETc fixed furrow application technique leads 54% yield reduction in essential oil. The study revealed that the essential oil yield increased as the applied water depth increase and vice versa is true. This might be due to fresh leaf production increased at higher irrigation water application depth this in agreement with Joy *et al.*, [19] and Elias *et al.*, [16] report. Following the current study, Alinian and Razmjoo [20] reported that the essential oil yield and yield components of cumin accessions decreased as a result of water stress levels increased. According to the report of Misra and Sricastatva [21] essential yield of Japanese mint reduced as the water stress level increased. Similarly, Henok *et al.*, [22] reported essential oil production of lemongrass was reduced by water stress as the soil moisture depletion level increased.

Water use efficiency

The study revealed that deficit levels and furrow application techniques had significantly (p<0.001) affected the water use efficiency of artemia production during 2017/18 and 2018/19. Likewise, the water use efficiency was significantly (p<0.05) affected by different deficit levels and furrow application techniques during 2016/17 (Table 4). As the study showed that the water uses efficiency and deficit level had a negative relationship which is as the deficit level increased from 100% ETc to 50% ETc the water efficiency has improved. The current study is in line with the findings of Elias *et al.*, [23] who reported that higher water productivity is achieved when lower irrigation depth was applied and lower water productivity associated with higher irrigation water application for lemongrass. The maximum water use efficiency of 5.83 kg m^{-3} was obtained from 50% ETc under alternate furrow application technique.

However, this maximum water use efficiency was statistically similar with 50% ETc under fixed furrow application technique. Whereas, the minimum water use efficiency of 3.12 kg m^{-3} was recorded from 100% ETc under conventional furrow application technique. However, this minimum water use efficiency has statistically similar with 75% and 100% ETc fixed and 50% ETc alternate furrow application techniques. The current finding is similar to the report of Elias *et al.*, [22] that maximum and minimum water use efficiency based on essential oil yield was achieved due to 100% ETc in conventional furrow and deficit irrigation level under alternate furrow irrigation techniques on spearmint plant, respectively.

As the study indicated that the water use efficiency shows a trend of linear increase with a decrease in water use. The study revealed that the reduction of water from 100% ETc of conventional furrow to 50% ETc alternate furrow application technique leads to an improvement in the water use efficiency of artemisia production by 47%. The current study is similar to the findings of Elias et *al.*, [16]; Henok *et al.*, [22]; Singh *et al.*, [24], these reported that as the applied water depth decreased the water use efficiency get improved.

CONCLUSION

The current study revealed that all yield and yield components of Artemia annua L. maximum at no deficit irrigation which is the application of 100% ETC irrigation water with conventional furrow technique. While the water use efficiency improved as the deficit level increased. Based on the study for the maximum yield achievement which is essential oil yield and fresh leaf weight in an area where no limited water resource 100% ETc and conventional furrow application technique can be used. Moreover, using alternate furrow technique can enhance the water-saving and give an optimal yield of artemia. Whereas in an area where limited water resource is available the maximized water use efficiency can be obtained from 50% ETc and alternate furrow application technique at Koka and similar agroecology.

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