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# Influence of irrigation schedules on growth, yield and water use efficiency in aloe (*Aloe barbadensis*)

MIR AWSAF AHMAD[1], L M GUPTA[2], MEENAKSHI GUPTA[3] and N K GUPTA[4]

*Sher-e-Kashmir University of Agricultural Sciences and Technology, Main Campus, Chatha, Jammu, J&K 180 009*

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ABSTRACT

Climatic parameters play an important role in governing water need of crops and the assessment of water need based on day-to-day weather parameters, seems to be more rational than any other method. Various IW/CPE ratios were attributed to achieve higher yield of aloe (*Aloe barbadensis* Mill.). The objective of this study was to evaluate the effect of different irrigation rates on the growth and yield and water use efficiency (WUE) for the production of leaf biomass and gel. Among the irrigation schedules, crops irrigated at $IW_{40mm}/CPE_{40mm}$=1 ($T_7$) registered mean higher value for growth and yield parameters whereas minimum values were recorded under rainfed conditions ($T_1$). Maximum gel yield per leaf (99.06 g), gel yield per plant (0.71 kg) and leaf yield per plant (1.21 kg) were recorded by following irrigation scheduling at $IW_{40mm}$: $CPE_{40mm}$= 1 ($T_7$) and $IW_{40mm}/CPE_{50mm}$=0.8 ($T_6$) as compared to other irrigation schedules. Treatment $T_6$ ($IW_{40mm}$: $CPE_{50mm}$= 0.8) and $T_7$ ($IW_{40mm}$: $CPE_{40mm}$= 1) recorded highest values of WUE (4.21 and 4.13 kg/$m^3$). Subjecting Aloe plants to irrigation of 40 mm depth at IW: CPE ratio of 0.8 and 1 gave the maximum aerial biomass and gel production per unit of water utilized, and thus the greatest water use efficiency.

**Key words**: *Aloe barbadensis*, Gel yield, Irrigation, Leaf yield, Water use efficiency

Aloe (*Aloe barbadensis* Mill.), a drought resistant species with crassulacean acid metabolism (CAM) (Rodríguez-Garcia *et al.* 2007) is a perennial species; its biomass is represented mainly by leaves, growth occurs in a rosette around a small portion of stem no greater than 5 cm. The leaves are simple, triangular, succulent, thick, with narrow lanceolate mucro tip, 30–60 cm long, and 5–12 cm wide at the base and 0.8–3 cm thick (Anez and Vásquez 2005). Flowers 2.5–3 cm long, yellow, grouped in clusters on a single erect stem about 1 m long. *Aloe vera* is an important industrially cultivated species, from which is extracted a gel of proven pharmacological and medicinal value (Hamman 2008). The gel is found in a clear internal zone located between the abaxial and adaxial mesophyll. The gel has a complex chemical composition, composed primarily of soluble sugars, anthraquinones, polysaccharides, amino acids, vitamins and proteins, many of which are enzymes (Chun-hui *et al.* 2007). Biomass production in plant species depends directly upon the availability of water and the seasonal fluctuations in its abundance; water is a selective force in the evolution of these plants, stimulating morphological and physiological responses or adaptations. Gel yield of aloe improves with a low frequency of watering and a high dose of fertilizer. Abundant water generates greater leaf biomass, although the relation between water, biomass and gel production is unknown. Irrigation scheduling is one of the most important tools for developing best management practices for irrigated areas (Al-Jamal *et al.* 1999). If shortage of readily available soil water is eliminated and the technological and biological characteristics of the crop are taken into account, it is possible to achieve high and stable yields of aloe by proper irrigation. There is only a small amount of agronomic and physiological information on aloe as most of the extensive research is oriented to the promotion and marketing of products which includes the gel (Zhao-Pu *et al.* 2006), so the present research was undertaken to study the effect of irrigation scheduling on the growth, yield and water use efficiency (WUE) in aloe in sub-tropical zone of Jammu and Kashmir. Among the various approaches to standardize irrigation scheduling, climatological approach, which is based on irrigation water depth (IW) and cumulative pan evaporation (CPE) proves rational.

[1]Research Scholar (e mail: mirawsaf17@gmail.com), Faculty of Forestry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Benihama, Ganderbal 191201. [2]Associate Professor (e mail: guptalm@gmail.com)[3]Assistant Professor (e mail: meenakshi2001@gmail.com), Division of Agroforestry, [4]Senior Scientist (e mail: nkgupta03@rediffmail.com), Water Management Research Centre, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu 180 009.

## MATERIALS AND METHODS

A field experiment was carried out at Experimental Farm of Division of Agroforestry, Sher-e-Kashmir University of Agricultural Sciences and Technology, Chatha, Jammu, during 2011 and 2012 on sandy-clay loam soil with pH 7.6, low available N (253.26 kg/ha), medium in P (16.07 kg/ha) and K (165.32 kg/ha). The farm is located at an altitude of 332 m above mean sea level. The experimental site falls under sub-tropical zone of Jammu division of Jammu and Kashmir State, with hot dry summers, hot humid rainy and cold winter months. The maximum temperature rises upto 45°C during May and June and minimum falls to 1°C during winter. The experiment was conducted under randomized block design with seven treatments and three replications (Table 1). Raised beds of size 1.8 × 1.8 $m^2$ were prepared and plantlets were planted at a spacing of 60 cm × 45 cm accommodating 12 plant per plot. Irrigations were scheduled based on two irrigation water depths, *i.e.* 30 mm and 40 mm which were used to achieve IW and CPE ratio of 0.6, 0.8 and 1 in each depth in respective plots. Daily pan evaporation was recorded from the open pan evaporimeter available at the meteorological observatory of the research station and cumulative figures were calculated subtracting the rainfall. In 30 mm water depth, a total of 10, 14 and 16 irrigations were applied and in 40 mm water depth 7, 9 and 12 irrigations were given. Irrigations were applied as per treatments when CPE reached at respective level and the quantity of water was measured with the help of parshall flume. Observations with respect to growth and yield parameters were recorded on 15 randomly selected plants per treatment (5 plants per replication). Evapotranspiration per treatment was calculated as per the formula of Simsek *et al.* (2005). Water use efficiency (WUE) was defined as fresh matter production per unit water applied as rainfall, plus irrigation, plus change in soil moisture content (Howell 2001).

ETo ($m^3$/ha) = (No. of irrigations × depth of irrigation water) + Rainfall received

$$\text{Water use efficiency (kg/m}^3) = \frac{\text{Leaf yield (kg/ha)}}{\text{Eto (m}^3\text{/ha)}}$$

Data reported for growth, yield, yield components and water use efficiency was analyzed using software package SPSS. The statistical significance was assessed at P< 0.05 and Fisher's LSD test was used for significant differences between the means.

Table 1 Influence of irrigation scheduling on growth parameters of aloe

| Treatment | Plant spread (cm) | No. of suckers plant | Leaf length (cm) | Leaf width (cm) | Leaf thickness (cm) | No. of leaves/ plant |
|---|---|---|---|---|---|---|
| $T_1$ (Rainfed) | 43.50 | 2.00 | 39.67 | 4.97 | 1.12 | 9.78 |
| $T_2$ ($IW_{30mm}$/ CPE=0.6) | 67.11 | 5.44 | 47.05 | 5.76 | 1.13 | 12.22 |
| $T_3$ ($IW_{30mm}$/ CPE=0.8) | 70.34 | 5.89 | 49.42 | 5.80 | 1.17 | 13.11 |
| $T_4$ ($IW_{30mm}$/ CPE=1) | 60.28 | 3.11 | 53.86 | 6.54 | 1.19 | 10.67 |
| $T_5$ ($IW_{40mm}$/ CPE=0.6) | 54.16 | 6.11 | 50.00 | 6.13 | 1.15 | 11.44 |
| $T_6$ ($IW_{40mm}$/ CPE=0.8) | 62.44 | 4.11 | 56.24 | 6.97 | 1.20 | 12.78 |
| $T_7$ ($IW_{40mm}$/ CPE=1) | 73.22 | 3.89 | 60.25 | 7.80 | 1.24 | 14.22 |
| CD (P = 0.05) | 8.96 | 1.31 | 5.72 | 1.14 | NS* | 1.70 |
| SEm (P<0.05) | 2.90 | 0.42 | 1.86 | 0.38 | 0.07 | 0.55 |

*Non-significant

## RESULTS AND DISCUSSION

*Growth and yield attributes*

The data of experiment on irrigation scheduling indicated positive and profound influence of irrigation scheduling with different IW/CPE ratios on growth and yield of aloe. Among the different irrigation schedules, irrigation with $T_7$ ($IW_{40mm}$: $CPE_{40mm}$= 1) recorded maximum plant spread (73.22 cm), leaf length (60.25 cm), leaf width (7.80 cm) and number of leaves/plant (14.22), whereas the minimum value of plant spread (43.50 cm), suckers/plant (2.00), leaf length (39.67 cm), leaf width (4.97 cm) and number of leaves/plant (9.78) was recorded under rainfed condition ($T_1$). However, the maximum number of suckers/plant (6.11) were recorded in $T_5$ which was at par with $T_3$ (5.89) and $T_2$ (5.44) (Table 1).

Yield and yield attributes were significantly affected by irrigation scheduling with different IW/CPE ratios. Analysis of data revealed that maximum value of number of harvestable leaves/plant (7.01), fresh weight/leaf (170.79 g), wet latex/plant (3.18 g), and dry latex/plant (1.50 g) were registered in $T_7$ ($IW_{40mm}$: $CPE_{40mm}$= 1), whereas the rainfed condition ($T_1$) recorded the minimum value of number of harvestable leaves/plant (5.18), fresh weight/leaf (110.96 g), wet latex per plant (1.06 g) and dry latex per plant (0.54 g). Further, irrigation scheduling with $IW_{40mm}$: $CPE_{40mm}$= 1 ($T_7$) was statistically at par with irrigation scheduling at $IW_{40mm}$/CPE=0.8 ($T_6$). Moreover, no significant effect of irrigation scheduling was noticed on wet latex per leaf and dry latex per leaf with maximum value recorded in treatment $T_7$. Maximum gel yield per leaf (99.06 g), gel yield per plant (0.71 kg), leaf yield per plant (1.21 kg) and leaf yield per hectare (44.73 t/ha) were recorded by following irrigation scheduling at $IW_{40mm}$: $CPE_{40mm}$= 1 ($T_7$) which was at par with scheduling irrigation at $IW_{40mm}$/

$CPE_{50mm}$=0.8 ($T_6$) as compared to other irrigation schedules. Increase in the gel and leaf yield of Aloe is about 2 times higher in $T_7$ than in rainfed (control) condition. However, maximum leaf: gel ratio of 1.94 was observed in rainfed ($T_1$) whereas the minimum leaf: gel ratio of 1.69 g was recorded in $T_7$ which was statistically at par with $T_6$ (1.75), $T_3$ (1.79) and $T_5$ (1.80), respectively (Table 2). The increased growth and yield attributes might be attributed to the ample supply and presence of moisture at critical stages of growth in $T_7$ ($IW_{40mm}$: $CPE_{40mm}$= 1) and $T_6$ ($IW_{40mm}$: $CPE_{50mm}$=0.8) which in turn increased the development of roots resulting in increased uptake of nutrients and thereby, enhanced growth by promoting cell elongation. Cell growth is one of the most drought-sensitive physiological processes due to the reduction in turgor pressure (Taiz and Zeiger 2006). Under severe water deficiency, cell elongation of higher plants can be inhibited by interruption of water flow from the xylem to the surrounding elongating cells (Nonami 1998). The other treatments might have caused water stress at critical stages because of less water availability, thereby leading to decreased growth and yield. Inhibition of plant growth under water stress condition is a result of reduction in cell enlargement (Singh 2009). Compared to less frequency of irrigation in $T_7$ than in $T_3$ ($IW_{30mm}/CPE_{37.5mm}$=0.8) and $T_4$ ($IW_{30mm}/CPE_{30mm}$=1), which received 14 and 16 irrigations, respectively, the higher growth and yield in $T_7$ can be attributed to greater irrigation water depth (40 mm) which kept the soil profile moist for a longer period, compensating for evapo-transpiration losses (Silva *et al.* 2010). The results were in close agreement with the findings of Rao *et al.* (2008), who reported higher biomass yield in *Aloe barbadensis* when irrigation was given at $IW_{50mm}$: $CPE_{62.5mm}$=0.8 compared to IW: CPE ratios of 0.4 and 0.6.

*Water use efficiency (kg/m$^3$)*

A perusal of data indicated that irrigation and rainfed evapotranspiration (ET) values ranged from 602.95 to 1082.95 m$^3$/ha respectively. The highest value of ET (1082.95 m$^3$/ha) were recorded by scheduling irrigation at $IW_{40mm}/CPE_{40mm}$=1 ($T_7$) and $IW_{30mm}/CPE_{30mm}$=1 ($T_4$). Control treatment recorded the lowest value of ET (602.95 m$^3$/ha). Irrigation WUE values clearly defined the growing period as favorable for plant production, mostly depending on amount of precipitation and its distribution. The data on water use efficiency for leaf yield of Aloe is presented in Table 3. The data indicated that scheduling irrigation with different IW/CPE ratios had significant effect on the water use efficiency. Irrigation scheduling

Table 3 Influence of irrigation scheduling on water use efficiency (WUE) of Aloe on leaf yield basis.

| Treatment | Preci-pitation | Evapo-transpiration (m$^3$/ha) | No. of irrigations | Leaf yield (t/ha) | WUE kg/m$^3$ |
|---|---|---|---|---|---|
| $T_1$ (Rainfed) | 602.95 | 602.95 | 0 | 21.77 | 3.61 |
| $T_2$ ( $IW_{30mm}$/CPE=0.6) | 602.95 | 902.95 | 10 | 27.35 | 3.03 |
| $T_3$ ($IW_{30mm}$/CPE=0.8) | 602.95 | 1022.95 | 14 | 33.33 | 3.26 |
| $T_4$ ($IW_{30mm}$/CPE=1) | 602.95 | 1082.95 | 16 | 30.35 | 2.80 |
| $T_5$ ($IW_{40mm}$/CPE=0.6) | 602.95 | 882.95 | 7 | 31.48 | 3.57 |
| $T_6$ ($IW_{40mm}$/CPE=0.8) | 602.95 | 962.95 | 9 | 40.54 | 4.21 |
| $T_7$ ($IW_{40mm}$/CPE=1) | 602.95 | 1082.95 | 12 | 44.73 | 4.13 |
| CD (P=0.05) | | | | 7.23 | 0.57 |
| SEm (P<0.05) | | | | 2.33 | 0.19 |

Table 2 Influence of irrigation scheduling on yield parameters of Aloe

| Treatment | No. of harvestable leaves/plant | Fresh weight/ leaf (g) | Latex/leaf (g) | | Latex/plant (g) | | Gel yield/ leaf (g) | Gel yield/ plant (kg) | Leaf: gel ratio | Leaf yield/ plant (kg) | Leaf yield (t/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Wet | Dry | Wet | Dry | | | | | |
| $T_1$ (Rainfed) | 5.18 | 110.96 | 0.20 | 0.10 | 1.06 | 0.54 | 58.81 | 0.32 | 1.94 | 0.59 | 21.77 |
| $T_2$ ($IW_{30mm}$/CPE=0.6) | 6.22 | 122.30 | 0.34 | 0.15 | 2.11 | 0.93 | 67.27 | 0.41 | 1.86 | 0.74 | 27.35 |
| $T_3$ ($IW_{30mm}$/CPE=0.8) | 6.33 | 135.82 | 0.35 | 0.15 | 2.23 | 0.96 | 76.06 | 0.49 | 1.79 | 0.9 | 33.33 |
| $T_4$ ($IW_{30mm}$/CPE=1) | 5.52 | 148.03 | 0.4 | 0.19 | 2.21 | 1.05 | 81.42 | 0.45 | 1.82 | 0.82 | 30.35 |
| $T_5$ ($IW_{40mm}$/CPE=0.6) | 5.93 | 140.60 | 0.39 | 0.17 | 2.30 | 1.00 | 78.74 | 0.47 | 1.80 | 0.85 | 31.48 |
| $T_6$ ($IW_{40mm}$/CPE=0.8) | 6.71 | 165.10 | 0.42 | 0.20 | 2.86 | 1.36 | 94.11 | 0.66 | 1.75 | 1.09 | 40.54 |
| $T_7$ ($IW_{40mm}$/CPE=1) | 7.01 | 170.79 | 0.46 | 0.22 | 3.18 | 1.50 | 99.06 | 0.71 | 1.69 | 1.21 | 44.73 |
| CD (P=0.05) | 1.10 | 13.45 | NS | NS | 0.42 | 0.23 | 9.54 | 0.17 | 0.11 | 0.22 | 7.23 |
| SEm (P<0.05) | 0.36 | 4.37 | 0.05 | 0.04 | 0.14 | 0.07 | 3.13 | 0.05 | 0.04 | 0.07 | 2.33 |

with $IW_{40mm}$: $CPE_{50mm}$=0.8 ($T_6$) recorded highest value of WUE (4.21 kg/$m^3$) which was statistically at par with $T_7$ ($IW_{40mm}$: $CPE_{40mm}$= 1) which recorded WUE of 4.13 kg/$m^3$. Control treatment recorded higher value (3.61 kg/$m^3$) of WUE compared to $T_2$ ($IW_{30mm}$/CPE=0.6), $T_3$ ($IW_{30mm}$/CPE=0.8), $T_4$ ($IW_{30mm}$/CPE=1) and $T_5$ ($IW_{40mm}$/CPE=0.6). A high WUE may be associated with a low growth and yield (Clavel *et al.* 2005, Fengjun *et al.* 2006, Wu *et al.* 2008). However, our results show that a high WUE may be associated with a high productivity in terms of leaf biomass. The determination of WUE is important, because it gives an idea of the intra-specific variation in the capacity of a plant species to produce higher yield under limiting water conditions. The lowest value of water use efficiency (2.80 kg/$m^3$) was recorded by scheduling irrigation at $IW_{30mm}$/CPE=1 ($T_4$) followed by a value of 3.03 kg/$m^3$ recorded with $IW_{30mm}$/CPE=0.6 ($T_2$). Martinez *et al.* (2003) suggested that high yields under conditions of limited water availability are associated with low WUE values, due mainly to high rates of evapotranspiration. Higher WUE with 40 mm CPE in $T_6$ and $T_7$ is attributed to favorable effect of water supply at shorter interval and greater depth thereby improvement in yield contributing characters and ultimately higher leaf yield in relation to other treatments (Silva *et al.* 2010). Evaporative atmospheric demand had a negative influence on the value of WUE due to water excess, in $T_4$ while as expected, the lower water availability had a negative influence on WUE in the plants of $T_2$, due to deficit. Blum (2005) concluded that it is mainly constitutive characters which affect water use and avoid dehydration under stress, and that a high WUE is more a function of low water use than a net improvement in the production in biomass and/or the biochemistry of assimilation.

From the present investigation, it is concluded that scheduling irrigation at $IW_{40mm}$: $CPE_{50mm}$= 0.8 ($T_6$) and $IW_{40mm}$: $CPE_{40mm}$= 1 ($T_7$) significantly improved growth, yield attributes and yield (gel and leaf yield) of Aloe by improving water use efficiency through enhanced availability of water to the plant. However, $T_6$ ($IW_{40mm}$: $CPE_{50mm}$= 0.8) is better than $T_7$ in terms of comparable leaf yield, lees water consumption and higher water use efficiency.

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