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Full Length Research Paper

Influence of water quantity on the yield, water use efficiency, and plant water relations of *Leucaena leucocephala* in arid and semi arid environment using drip irrigation system

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Water is considered an important factor in the arid and semi-arid areas because water shortage affects the agricultural production. The current study aimed to investigate the influence of water application level on the dry matter yield, water use efficiency (WUE), and plant water status in *Leucaena leucocephala*. The treatments consisted of five levels of water applications based on actual evapotranspiration (AET): 0.25, 0.50, 0.75, 1.00 and 1.25 AET respectively. The production was increased from 306.4, 676.3, 724.1, 838.5, to 1172.7 kg/ha as the water application levels increased. The estimated WUE was 2.32, 2.57, 1.83, 1.59 and 1.78 kg/ha/mm for 0.25, 0.50, 0.75, 1.00 and 1.25 AET, respectively. Increasing the water application level did not increase the WUE. Using the irrigation level at 0.50 AET can be used to irrigate *Leucaena* crop without leaving any significant change in dry matter yield compared with 0.75 and 1.00 AET, respectively. There was no significant effect of water application level on each of the leaf water potential *(Ψw)* and leaf relative water content (LRWC). The means of *Ψw* was -2.3, -2.1, -2.2, -2.3, -2.2 MPa at 0.25, 0.50, 0.75, 1.00 and 1.25 AET, respectively. The means of leaf relative water content were 75, 74, 77, 77 and 78% at the water treatment levels, respectively. Under different water application levels, a poor correlation between the *Ψw* and LRWC existed. It is recommended to use 50% of AET as the best irrigation water management treatment for *Leucaena* production.

Key words: Crop productivity, water use efficiency, multipurpose forest tree, plant water relations, drip irrigation.

INTRODUCTION

Improving water productivity will reduce the additional water requirements in agriculture (Nangia et al., 2008). This goal can be obtained by selecting crops that tolerate the drought conditions, methods of irrigation, monitoring the water status and using deficit irrigation. The total water consumption in agriculture is currently near 70% of the available water resources (MIW, 2007). Thus, by applying these methods the efficiency of using water will be increased (WUE) by increasing the agricultural production and reducing the water consumption in agriculture. Several multipurpose crops can be grown in arid and semi-arid lands adding many benefits to soil such as nitrogen fixation and texture improvement. Using the existing vegetation might not provide such benefits while using crops such as *Leucaena Leucocephala* will reach the goal.

Leucaena is an important multipurpose tree used widely for forage production, firewood, and fuel. It can compensate the shortage of grasses and hay in the off season by using it as forage for feeding sheep, goats and cows to meet food needs of the people. It acts as a soil enriching plant and helps in controlling erosion (Winrock, 1985).

Relatively few studies were conducted on *Leucaena* to explore the above benefits especially in the arid and

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semi-arid areas that explain our research approach in comparison with other studies conducted on different crops. Effective irrigation management in arid and semi arid regions, could increase crop yield and improve productivity of scares fresh water resources (Elasu et al., 2009). Under the effective irrigation management, it is important to know how much production per unit of water was applied. Less water consumption by agricultural crops leads to saving water for other purposes in different sectors. Deficit irrigation techniques can save water without affecting the yield (Speer et al., 2008). Applying less water to the soil may cause an increase in water stress in a late period in the season (Kramer and Boyer, 1995).

The crop yield, water use efficiency, plant water status are not same for all crops, because there is variation in the methods of irrigation, water deficit or drought conditions, and soil characteristics. Dry matter production for Acacia was not correlated with WUE (Kireger and Blake, 1994). In woody trees such as mango, the WUE was always significantly higher in the deficit irrigation compared with no irrigation and reported that the yield declined due to deficit irrigation during monitoring of the crops (Speer et al., 2008). Meanwhile, it was reported that *Jojoba* was well adapted to drought, since it can survive long period under water stress. However, there was a linear correlation between plant volume and yield (Benzioni and Nerd, 1984). Leaf water status is intimately related to several leaf physiological variables such as leaf turgor, growth, stomatal conductance and transpiration (Kramer and Boyer, 1995 sited in Yamasaki and Dillenburg, 1999). Leaves that develop under draught conditions require longer periods of imbibitions than those that develop under conditions of high water availa-bility, which may be related to draught-induced structural changes in the leaf tissue (Yamasaki and Dillenburg, 1999). Deficit irrigation under subsurface drip irrigation did not affect clearly the almond water status parameters and their relationships, and produce higher water application efficiency (Romero et al., 2003).

Leaf relative water content (LRWC) percentage and leaf water potential (Ψw) are used widely to estimate the deficits in leaf tissues. LRWC expressed the relative amount of water available on the plant tissue. A study suggests that LRWC% is more sensitive under long term water limitation (Santana et al., 2008).

It was reported by Merima et al. (1997) that the water deficit lowered leaf water potential in seedlings of *Leucaena* planted in pot experiments. Moreover, water deficiency causes a severe drop in the leaf water potential over time. In another study, the response of *Quercus pyrenaica* to soil water deficit showed that no clear water stress situations occurred because no significant variation in Ψw was found (Santana et al., 2008). The Ψw was not different among the three highest water application levels at the later part of the season, but it showed a steady decrease as applied water decreased (Grattan et al., 2006). The objectives of this study are to evaluate the impact of water quantity on dry matter yield, water use efficiency, and plant water status of *L. leucocephala* in arid condition using the drip irrigation system.

MATERIALS AND METHODS

The experiment was conducted during the period from May 2008 to December 2008 at the Jordan University of Science and Technology campus (JUST). It is located 80 km northern of Amman (32° 34' N, 36° 01'E, a.s.l. 520 m). The soil of the experimental area is silty clay soil with hard pan at depth of 0.7 – 1.0 m. Some of the soil properties of experimental area are presented in Table 1.

The plants of *L. leucocephala* were raised in a nursing greenhouse for one month and half in plastic bags with a media of sand, soil, and peatmoss (1:1:1 v/v ratio). The plants were transplanted in rows in the permanent experimental area in June 22nd, 2008, when they reached approximately 30 cm in height. The starting date for water application to the plants at different levels was in July 16th, 2008. The sampling for the soil water content, leaf water potential, and leaf relative water content started at the end of July. The area of the experiment is cultivated and leveled for 10 rows of trees with 2 × 2 m spacing. The length of each row is 12 m and contained 5 trees. Each treatment was replicated four times with each replicate contained two trees. Each treatment was assigned to 10 trees, where every 5 trees are irrigated with one lateral line. One tree from each replicate was used for monitoring the Ψw and the other for measuring the LRWC%. *L. leucocephala* trees were irrigated with fresh water once a week. The soil water content was taken from any one of the 5 trees. The leaf samples for Ψw and LRWC% were taken one day before irrigation.

The experiment was conducted under surface drip irrigation system using the flow meter, valves, pressure gauge, lateral pipes, main line, and emitters. Each plant of *Leucaena* was irrigated using 2 emitters of a water discharge of 8 L/h each. The applied volume of water was controlled by using stop watch, flow meter, and a valve at the beginning of each lateral. The pressure was set to be 10 psi at the beginning of each lateral and not less than 9 psi at the end of the laterals.

Irrigation water was applied at five levels: 25, 50, 75, 100 and 125% of the actual evapotranspiration (AET). The AET was calculated based on the evaporation pan readings using a pan coefficient Kp (0.65) and a crop coefficient Kc (0.75). The actual evapo-transpiration during the growing season was estimated and presented in Figure 1. The pan location is 5 m far from the border of the experimental area. The irrigation was performed weekly during the morning of every Wednesday, where all the treatments are irrigated at the same time.

Soil samples were taken before and after irrigation for measuring the soil water content to maximum depth of 45 cm with a 15 cm depth of each interval within 10 to 15 cm distance from the plant.

The lateral line of drip irrigation was near the center of the plant, including two on-line emitters were spaced 30 cm. The soil water depletion from the root zone was estimated on the basis of the differences in water content before and after irrigation. The soil samples were taken by auger for estimating the gravimetric water content, and multiplied by the bulk density to get the volumetric water content.

L. leucocephala biomass was weighted after cutting and drying the leaves in the oven for 24 h at 70°C. The water use efficiency (kg/ha^{-1} mm^{-1}) was estimated as the total dry weight per hectare divided by the total amount of irrigated water for each treatment. Ψw was measured by using the pressure chamber technique. The LRWC% is expressed in the percentage of the water content at a given time to the water content at full turgor as:

LRWC% = (FW -DW)/(TW-DW) (Salisbury and Ross, 1992).

Table 1. Soil properties of the field experiment site located at Jordan University of Science and Technology Campus.

Clay (%)	Sand (%)	Silt (%)	Soil type	Bulk density (gm/cm^3)	Field capacity	Wilting point	Infiltration rate (cm/h)	pH	EC (µS/cm)
44	10	46	Silty clay	1.5	0.35	0.19	1.2	8.6	461

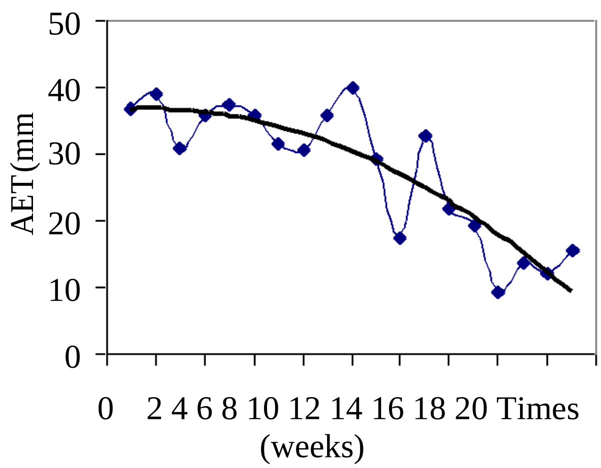

Figure 1. Actual evapotranspiration AET (mm) during the growing season from 16/7/2008 to 26/11/2008.

The analysis of variance (ANOVA) of the collected data (dry matter yield, WUE, *Ψw*, and LRWC%) were generated using SAS system version 8.2. The means for the effect of each water level treatment on these parameters of *Leucaena* were separated by Least Significant Difference (LSD) at P = 0.05.

RESULTS AND DISCUSSION

Water deficit and depletion

The soil water depletion under each treatment of water level application is presented in Figure 2. The main effect of different application levels of water on soil water depletion values was not significant. The main effect of the time (weeks) on soil water depletion was significantly different. This was due to changes in evapotranspiration during the growing season. Furthermore, the interaction between the treatments and weeks on the soil water depletion was not significant. The volumetric depletion of water content (DVWC) varied as 0.08 - 0.30, 0.10 - 0.40, 0.11 – 0.35, 0.15 - 0.30, 0.15 - 0.35 at 0.25, 0.50, 0.75, 1.00 and 1.25 AET, respectively. The results showed that the trend line of soil water depletion over the weeks started a decrease in the treatments 0.25, 1.00 and 1.25 AET (Figures 2a, d and e), respectively. The trend lines of the soil water depletion tended to increase in treatments 0.50 and 0.75 AET (Figures 2b and c). These results showed that soil water depletion increased as the water application level increased in both 0.50 and 0.75 AET compared to 1.00 and 1.25 AET in which the soil water depletion did not increase. These results might be due to soil variation in water distribution around the plants as observed during the experiment application.

Crop yield

Figure 3 represents the dry matter yield of *L. leucocephala* at different treatments. The results showed that the highest dry matter yield was obtained at 1.25 AET with an average yield of 1172.7 kg/ha. The dry matter yield of *L. leucocephala* showed a significant increase as water quantities increase. *Leucaena* production was 306.4, 676.3, 724.1, 838.5, 1172.7 kg/ha at 0.25, 0.50, 0.75, 1.00 and 1.25 AET, respectively. The means of dry matter yield were not significantly different among 0.50, 0.75 and 1.00 AET of water application treatments. However, they were significantly different between 0.25 and 1.25 AET. The rate of increase in the mean of *Leucaena* dry matter yield was 120% (0.50 over 0.25 AET), 7% (0.75 over 0.50 AET), 16% (1.00 over 0.75 AET) and 40% (1.25 over 1.00 AET). The relationship between the dry matter yield (kg/ha) and AET (mm) can be expressed as Y = 1.4X + 175.1 (R^2 = 0.60).

The results of this study showed that increasing the water application level in respect to the AET caused an increase in the dry matter yield. However, the changes in the yield due to deficit irrigation were minor and mostly not significant (Speer et al., 2008). The results indicated that the water application at 0.50 AET gave higher dry matter yield (676.3 kg/ha), which was not significant than those at 0.75 and 1.00 AET that scored 724.1 and 838.5 kg/ha, respectively (Figure 3). Moreover, the main conclusion is that it is possible to reduce the irrigation by 50%, without significantly decreasing the *Leucaena* yield. This result is recommended in arid and semi arid fields, where the annual average rainfall and water resources are limiting the growing conditions.

Water use efficiency

The results presented in Figure 4 represent the water use efficiency (WUE) for *Leucaena* which are grown under different water application levels. The main effect of water application levels was significant with respect to WUE. The WUE was estimated as the dry weight of *Leucaena* per hectare divided by the amount of water applied in millimeter depth at each water application level. The esti-mated WUE was 2.32, 2.57, 1.83, 1.59 and 1.78 kg/ha/mm

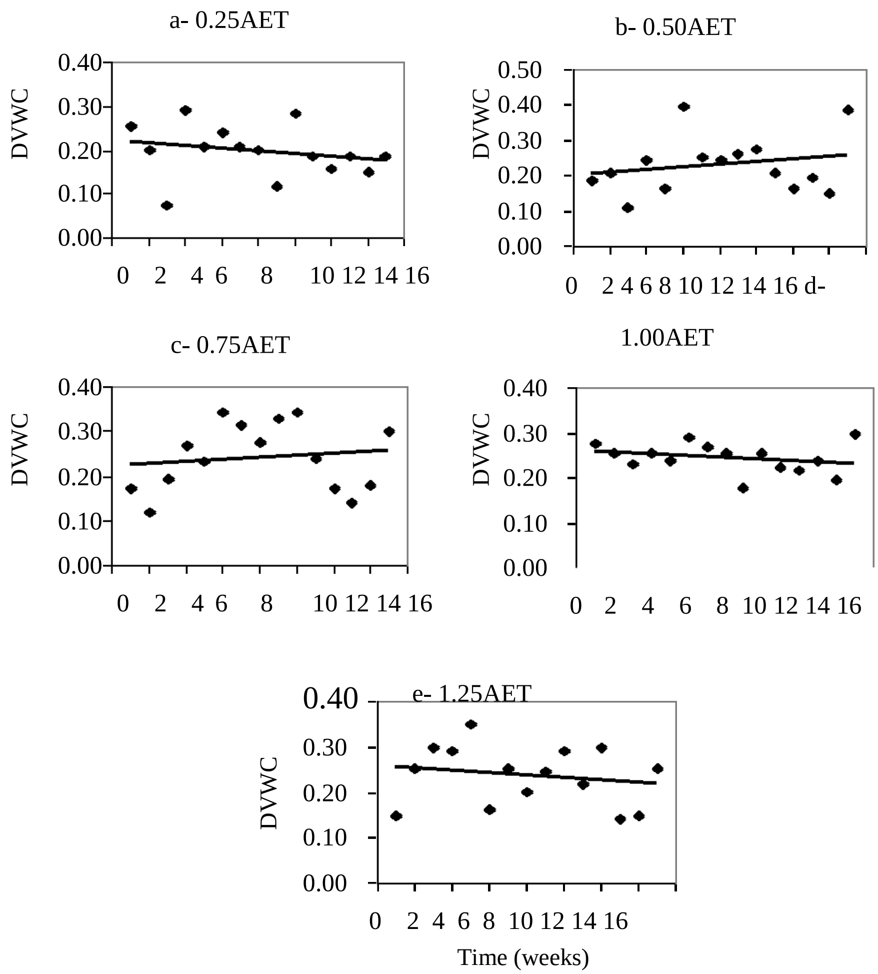

Figure 2. The volumetric depletion of soil water content under different water levels of AET

1 applied to *L. leucocephala* in the field under drip irrigation condition.

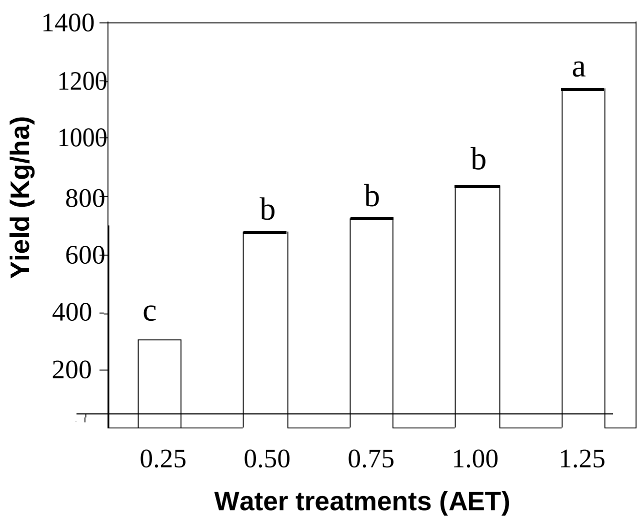

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Figure 3. *L. leucocephala* dry matter yield (kg/ha) grown under different water levels. Means with same letters are not

Figure3 3. *Leucaena*significantly*Leucocephala*differentat Pdry=0matter.05(LSD-yield=231) .(kg/ha) grown under different

water levels. Mean

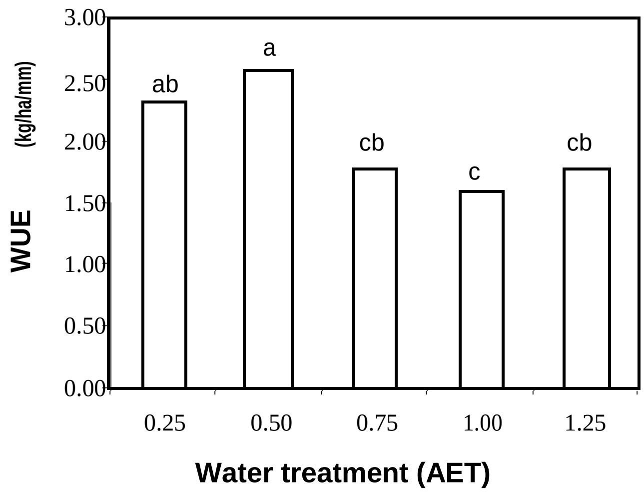

Figure 4. The water use efficiency (WUE) of *L. leucocephala* grown under different water levels. The mea-ns with same letters are not significantly different at P = 0.05 (LSD = 0.72).

for 0.25, 0.50, 0.75, 1.00 and 1.25 AET, respectively. The means of WUE at 0.25 and 0.50 AET levels were not significantly different from the others. Also, the mean of WUE was significantly different from that at 1.00 AET only. And, the mean of WUE at 0.50 AET was different from those means at 0.75, 1.00 and 1.25 AET, whereas the means at the last three water application levels were not significantly different from the others (Figure 4). The WUE was highest at 0.50 AET and lowest at 1.00 AET compared to other treatments.

The rate of increase or decrease in WUE was +11% (0.50 over 0.25 AET), -28% (0.75 over 0.50 AET), -13% (1.00 over 0.75 AET) and +13% (1.25 over 1.00 AET). These results showed that irrigation of *Leucaena* at 0.50 AET gave the highest value of WUE, leading to saving of 50% of irrigation water. Reducing the irrigation by 0.50 AET for *Leucaena* crop without relative reduction in pro-ductivity and allowing the water authorities and farmers to utilize the rest of supply water in irrigating other crops, increased the cropping area, and saved water for other sectors. The water use efficiency (Kumar et al., 2007) depends on the crop yield and water application level. And water use efficiency decreased as the water appli-cation level increased. Our study found a poor correlation (R^2 = 0.24) between the WUE and water application level which indicate that increasing the water application did not always increase the WUE as it was reported in previous studies (Kireger and Blake, 1994; Speer et al., 2008).

Leaf water potential and relative water content

Leaf water potential (*Ψw*) and relative water content (LRWC%) of *Leucaena* were monitored in the midday time. The results demonstrated in Figure 5 showed the (*Ψw*) and L RWC% over the twenty weeks of growth under different water application levels. There was no significant effect of water application level on the *Ψw*. The means of *Ψw* were -2.3, - 2.1, -2.2, -2.3 and -2.2 MPa at 0.25, 0.50, 0.75, 1.00 and 1.25 AET, respectively. The interaction of water level application treatments and time showed a significant effect on the *Ψw*. The trend lines (Figure 5) indicated that the *Ψw* slightly became more negative over time. Previous study (Merima et al., 1997) stated that water stress over time showed more negative leaf water potential in *Leucaena* seedlings planted in pots experiment. In this experiment, no clear differences in *Ψw* were found among the treatments of water application levels (Figures 5 and 6a). A similar study (Santana et al., 2008) on the response of *Q. pyrenaica* to soil water deficit found that no clear water stress situations occurred because no significant varia-tion in *Ψw* was found. This was explained by absorption of water from the deep soil layers and the water content in the plant was stable due to the availability of water. (Romero et al., 2003) reported that there were no significant differences in the soil water content and plant water status where minimum values of *Ψw* ranged between -1.95 and -2.52 MPa. They concluded that the deficit irrigation under subsurface drip irrigation did not affect clearly the almond water status parameters and their relationships, and produced higher water application efficiency.

Comparing the values of *Ψw* at different levels of water application over weeks showed that at 0.25 AET the *Ψw* was less negative for 6 weeks out of 20 weeks. The *Ψw* was more negative at 0.50 AET for 8 weeks out of 20 weeks compared to 1.00 AET that scored *Ψw* more negative for 3 weeks out of 20 weeks. The *Ψw* values at all water application levels became more negative at the beginning of the season due to high values of AET. At the end of the season, the *Ψw* values were close to each other due to low values of AET and water availability and the slow growth of the plant (Grattan et al., 2006). Three ranges approximately of *Ψw* values occurred during the growing season of 20 weeks (Figure 6) as -1.2 to -2.0, -1.2 to -3.1 and -1.8 to - 2.8 MPa, for the week's 1 to 4, 5 to 11, and 12 to 20, respectively.

According to the LRWC%, the water level application has no significant effect on the LRWC%. The interaction of the water level application treatment and weeks on LRWC% was significant. The means of LRWC% were 75, 74, 77, 77 and 78% at 0.25, 0.50, 0.75, 1.00 and 1.25 AET, respectively. The mean values LRWC% at 0.50 and 1.25 AET were significantly different, where other treat-ments are not significant. The minimum values of LRWC% were approximately 58, 55, 60, 60 and 55% and the maximum values 84, 90, 86, 90 and 91% at 0.25, 0.50, 0.75, 1.00 and 1.25 AET, respectively.

The mean effects of LRWC% at 0.50 and 1.25 AET were significantly different from the others. However, each one of them was not significantly different from those at 0.25, 0.75 and 1.00 AET. Based on Figure 5, the trend lines

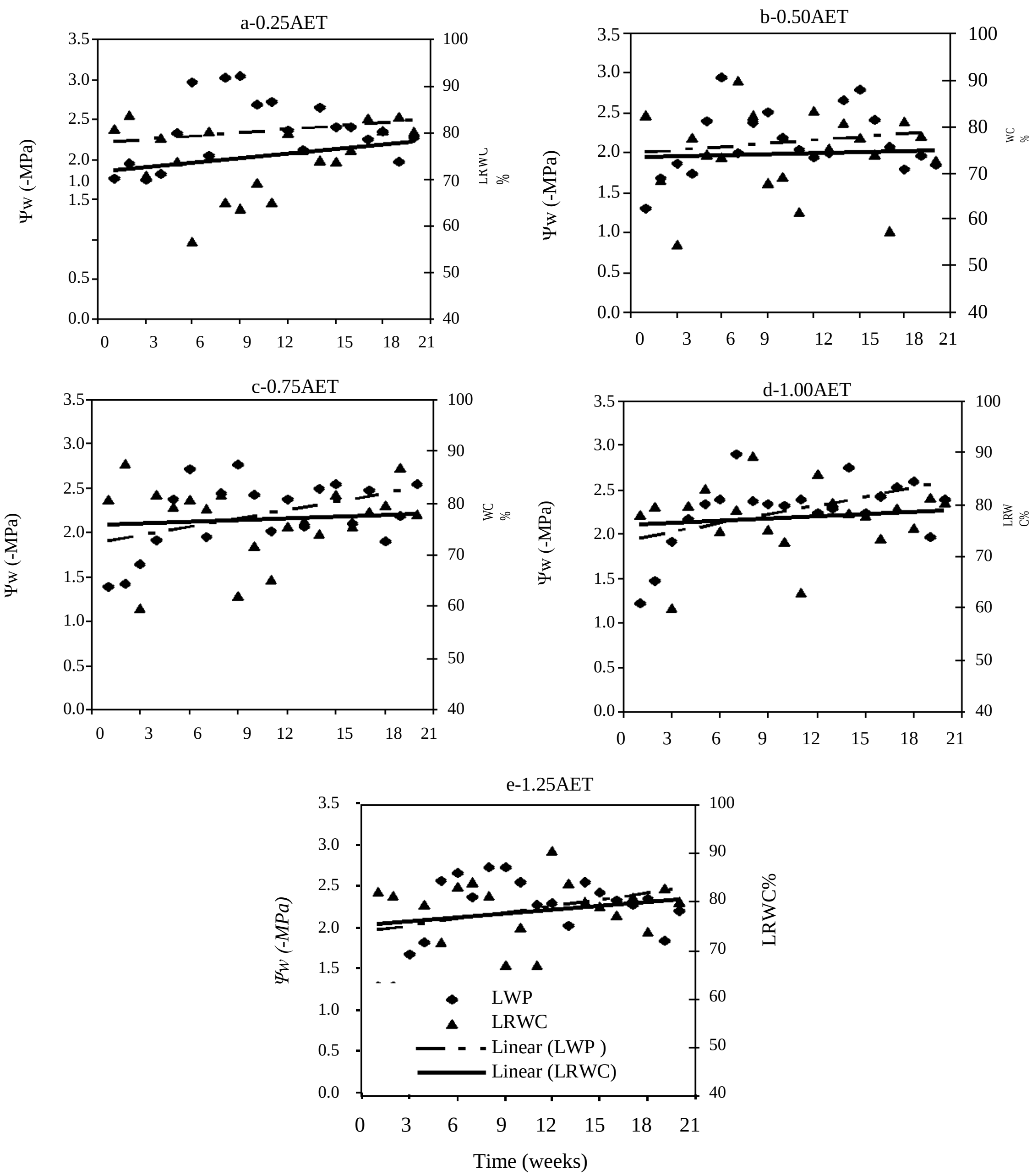

Figure 5. The relationship between the leaf water potential (-MPa) and the leaf relative water content during the time of growing season for *L. leucocephala*.

indicated that there is a slight increase in the LRWC% over weeks. The values of LRWC% over the weeks were the highest for three to five weeks out of 20 weeks. Two ranges of LRWC (%) were noticed (Figure 6) as 50 - 90 and 70 - 88 in the week's period from 1 - 11 and 12 - 20, respectively.

According to the correlation analysis between treatments and time regarding *Ψw* and LRWC%, the correlation coefficient was significantly weak for both *Ψw* (r = 0.26) and LRWC% (r = 0.10). The water application levels showed a variation in the correlation in respect to *Ψw* and LRWC%. The first treatment showed a satisfactory negative correlation (r = 0.76) between *Ψw* and LRWC% compared to other treatments that showed a weak correlation indicating more stress less relative water content.

The values of LRWC% are more sensitive under long term of water limitation (Santana et al., 2008). LRWC% as described earlier (Cha-un et al., 2006) increased as the water application level increased. Also, the decreases in LRWC% with decreasing the water application level was expected as the water stress increased.

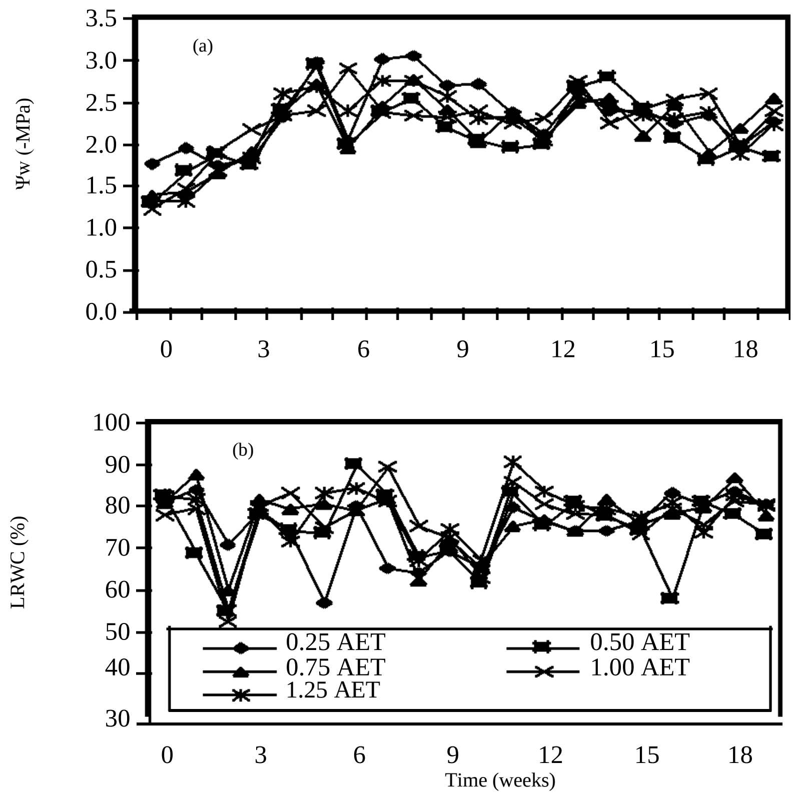

Figure 6. The Leaf water potential and the leaf relative water content of *L. leucocephala* grown under different water application levels during the time of growing season for *L. leucocephala*. The standard errors for *Ψw* and LRWC are 0.17 and 4.61, respectively.

Table 2. Depth of water applied (mm) at each water application treatment weekly.

Week #	date	AET (mm)	0.25 AET	0.50 AET	0.75 AET	1.0 AET	1.25 AET
1	16/7/2008	37	9	19	28	37	46
2	23/7/2008	39	10	20	29	39	49
3	30/7/2008	31	8	16	23	31	39
4	6/8/2008	36	9	18	27	36	45
5	13/8/2008	38	9	19	28	38	47
6	20/8/2008	36	9	18	27	36	45
7	27/8/2008	32	8	16	24	32	40
8	9/3/2008	31	8	15	23	31	38
9	9/10/2008	36	9	18	27	36	45
10	17/9/2008	40	10	20	30	40	50
11	24/9/2008	29	7	15	22	29	37
12	29/9/2008	18	4	9	13	18	22
13	8/10/2008	33	8	16	24	33	41
14	15/10/2008	22	5	11	16	22	27
15	22/10/2008	20	5	10	15	20	24
16	29/10/2008	9	2	5	7	9	12
17	5/11/2008	14	3	7	10	14	17
18	12/11/2008	12	3	6	9	12	15
19	26/11/2008	16	4	8	12	16	20
Total (mm)		527	132	263	395	527	658

All over this study, it is noticed that when the *Ψw* becomes more negative, the LRWC% increased over all treatments (0.25, 0.75, 1.00 and 1.25 AET) which might be explained that some plants can withstand some degree of drought through the control of leaf water potential and relative water content using stomatal opening and closure mechanism in which loss of water is controlled and water content kept within minimal change. There were no clear differences in each parameter values of Ψw and LRWC% over weeks at different treatments of water applications. This situation may have occurred because the irrigation is taking place weekly, and by that time the *Ψw* is becoming less negative. Also, the more negative of *Ψw* affect the stomatal openings and decrease the photothensis and turgor (Benzioni and Nerd, 1984; Kaufmann, 1981). The slight differences in *Ψw* and LRWC% are due to the no significant differences in the soil water depletion values (Figure 2). Moreover, it might be related to the absorption of water from the deeper layers, which was similar to the reported results by Santana et al. (2008), although the differences in *Ψw* and LRWC% could be observed if the irrigation interval was longer than one week.

Conclusions

The overall results from this experiment showed that increasing the water application level caused an increased *L. leucocephala* dry matter yield. The water application level at 0.75 AET and higher did not show an increase in water use efficiency (WUE). The WUE scored a high significant value at 0.50 AET compared to the other treatments. Thus, the water application level at 0.50 AET was recommended to be used for irrigation compared to 0.75 and 1.00 AET where the dry matter yield was not significantly changed. As a result, the water saving is increased allowing the water authorities and farmers in the local societies to maintain water in arid and semi arid regions to be utilized for living and industry uses to face the water crises. There was no significant effect of water level application on the *Ψw* and LRWC% values. A poor correlation was found between *Ψw* and LRWC% under different water application levels using drip irrigation method.

The drip and deficit irrigation can be used to increase the crop yield and WUE, leading to saving water for other purposes in arid and semi arid regions.

This research recommended using *the* multipurpose forest tree species *(L. leucocephala*) and saving much water instead of planting forages that consume a lot of water during short growing season.

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