Open Access

Growth Analysis and Responses of Cowpea [*Vigna Sinensis* (L.) Savi Ex Hassk.] and Redroot Pigweed (*Amaranthus retroflexus* L.), Grown in Pure and Mixed Stands, to Density and Water Stresses

Jamal R. Qasem*,[1] and Kedir N. Biftu[2]

[1]*Plant Protection Department, Faculty of Agriculture, University of Jordan, Amman, Jordan*

[2]*Sinana Agricultural Research Center, P.O. Box 208, Robe-Bale, Ethiopia, Africa*

Abstract: The effects of water stress and planting density on the competitive relationships, yield performance, and dynamics in canopy dominance of cowpea [*Vigna sinensis* (L.) Savi ex Hassk] and redroot pigweed (*Amaranthus retroflexus* L.) grown in pure and mixed stands were investigated under glasshouse and field conditions. Results showed that water stress at early growth stages reduced plant height, shoot dry weight, leaf area, leaf dry weight and lowered pod dry weight of cowpea, and inflorescence dry weight of *A. retroflexus*. The effect on both species was more pronounced at high planting densities as a result of severe intraspecific competition. In pure stands, cowpea was affected more than *A. retroflexus* and the effect was more pronounced on reproductive organs development. Growth analysis of both species grown in pure stands for different periods indicated that leaf area was the most descriptive variable in shoot dry weight and total dry weight of both species at early growth stage. *A. retroflexus* grew at a faster rate with higher net assimilation rate per unit leaf area and allocated more resources to leaves and roots than did cowpea. Results showed that *A. retroflexus* was stronger competitor than cowpea. Competition reduced growth and competitive abilities of both species mainly by reducing leaf area early in growth but the effect was more pronounced on cowpea.

Keyword: *A. retroflexus*, *Vigna sinensis*, development, inter-specific competition, intra-specific competition, stress responses.

INTRODUCTION

Competition is a dynamic process that depends on amount of resources acquired by the competing species and their efficiency in converting resources to biomass [1]. Growth rates and other components of plant size and function may influence competition [2]. Understanding conditions that affect growth and competitive relationships of crops and weeds might lead to development of production practices that maximize crop growth and minimize weed competition [3].

Cowpeas (*Vigna* spp.) are grown for dry seeds and as leafy vegetables in different parts of the world [4]. They resist drought stress and can recover rapidly during vegetative growth stage by re-watering because of their efficiency in using soil water [5].

Redroot pigweed (*Amaranthus retroflexus* L.) is a troublesome weed that exhibits a wide range of ecological tolerance from dry to moist conditions [6]. It is a prolific seed producer of up to 300, 000 seeds per plant [6, 7].

A. retroflexus is a dominant weed throughout a large area in the Jordan Valley and the highlands areas where summer crops, such as cowpea, are produced. It is abundant and found at high densities (70 plant/m^2) in different regions in the country [8]. Soil water is the most limiting growth factor in semi-arid regions. In Jordan, annual rainfall is markedly low, and the country greatly suffers from water shortage for agriculture.

*Address correspondence to this author at the Plant Protection Department, Faculty of Agriculture, University of Jordan, Amman, Jordan; Tel: +962 6 5355000-22515; Fax: +962 6 5300806; E-mail: jrqasem@ju.edu.jo

Cowpea and *A. retroflexus* are summer grown species associate together under field condition in different locations in the country. Cowpea is well known that tolerates water shortage while the weed has been reported as of high water use efficiency [9]. The advantage conferred by C_4 photosynthesis pathway and concomitant high water use efficiency of *A. retroflexus* would be well expressed in hot, dry and high light environments, where water stress is often a problem. Literature on *A. retroflexus* competition for water, response to density stress and on its growth and competitive relationships with cowpea are lacking. Competition between both species for limited soil water is expected to be severe and may determine their growth and competitive relationships. Therefore the present work was carried out to determine (1) the growth and performance of cowpea and *A. retroflexus* under various water stress treatments and plant density, and (2) the growth characteristics and development of cowpea and *A. retroflexus* grown separately or in mixture for different periods, and the effect on their competitive relationships.

MATERIALS AND METHODS

2.1. Experimental Procedure

Three pot experiments were carried out: one was under glasshouse conditions and the other two were in the field at the University of Jordan, for the period from March to June 2002. A clay-loam field soil [57.6% (w/w) clay, 30.7% (w/w) silt, 12% (w/w) sand] with 12.25% (w/v) $CaCO_3$, pH of 8.1, organic matter content [2.03% (w/w)] and phosphorus (0.025 mg g^{-1}) was used. Cowpea seeds (California Blackeye 3891 Bean; Modesto Seed Company, Modesto, California, USA) were obtained through the Abd-Al-Hafiz Agricultural Company (Amman, Jordan). *A. retroflexus* seeds were collected in 1998 growing season from vegetable fields in the Jordan Valley and stored in brown plastic bottles in cardboard box at room temperature in the laboratory.

2.1.1. Experiment 1. Effect of Water Stress on Growth of A. retroflexus and Cowpea Grown in Pure Stands

This experiment was conducted to study the effect of water stress imposed at different growth stages on growth of both species grown separately at different densities. Uniformly mixed field soil was filled into 25 cm diameter by 22 cm deep pots. All pots were sown by seeds of either species on 25th March, 2002. Excess of seeds was used to insure germination and later to manage seedlings spatial arrangement of both species. When cowpea and *A. retroflexus* seedlings reached two or four leaf stages, respectively, seedlings of the two species were thinned into 2, 4, 6, 8, 10, and 12 plants per pot with the same spatial arrangements kept for both species in different treatments. Plants were grown under unconditioned glasshouse at 30/19^{o} C average day/night temperature.

Treatments were laid out in a randomized complete block within a split-plot design at which three water stress treatments were considered as main-plots and six seedling densities per species as sub-plots and all were replicated four times. Treatments included exposed plants of both species to water stress started at the vegetative stage (at four and two-leaf stage of cowpea and *A. retroflexus*, respectively), stress started at flowering, and no water stress. In stress treatments, water was withheld until tensiometer reading reached 60 cent bar and plants showed visible wilting symptoms, then water was applied to field capacity. The dry-down and re-watering process continued until maturity. In the no water stress treatment, plants were watered daily with an amount of water equal to that evaporated from a nearby pot that had no plants.

For crop and weed species, plant height, leaf length and width were measured and number of leaves, branches and senescent leaves per plant were counted at seven day intervals starting 26 days after emergence until harvest. Temperature in the glasshouse was recorded daily to calculate temperature in degree days. Number of flowers, pods and seeds for cowpea and inflorescence branches of *A. retroflexus* per pot were counted at weekly intervals until maturity.

At maturity, all plants per pot were cut at the soil level on 25th June, 2002. Stem, leaves and inflorescences were separated. Leaf area was measured using a "Square centimeters, Model LI-3100 area meter, Sr. No. LAM 247-7809, Input 108-126/216-252 VAC, 48-66 Hz 100 WATT, USA". All plant parts were oven dried at 70 ºC for 72 h to a constant weight. *A. retroflexus* inflorescence and cowpea pods were weighed, counted, and cowpea seeds per pot and per plant were recorded.

Coefficients that relate measured leaf area, and leaf length and width were obtained from 144 samples, and used to calculate leaf area from leaf length and width collected over season to estimate leaf growth. Best curves were fit to estimate relative leaf area expansion and plant elongation rates based on number of days after emergence. Leaf area was used to estimate growth of cowpea while height was used to estimate that of *A. retroflexus*.

2.1.2. Experiment 2. Growth Analysis of Cowpea and A. retroflexus Grown in Pure Stands

This experiment was conducted to study growth and development of crop and weed plants grown in pure stands for different periods after emergence. Thoroughly mixed field soil was filled into pots similar to those used in Experiment 1. All pots were sown with sufficient number of seeds of either species in the pot center on 25th March, 2002 and placed under natural conditions in the field. The average day/night temperature during the experimental period, from April to late June 2002, was 27/18^{o}C and day/night relative humidity was 26.8% and 38.2%, respectively.

Treatments included the harvesting of weed and crop plants at different intervals after emergence and were arranged in a randomized complete block design with six replicates. At 2-leaf stage of *A. retroflexus* and 4-leaves of cowpea, seedlings were thinned to one per pot. Twelve harvests were made at seven-day intervals from 10th of April until 25th of June 2002 and started 10 days after seedlings emergence.

Data on plant height, numbers of leaves, branches and senescent leaves were recorded at each harvest. The above ground parts were cut at soil level, partitioned into 10 cm height layer. Each layer was separated into leaves, stem and reproductive organ depending on the stages of the crop and weed, leaf area of each layer was measured then all were oven-dried at 70 °C for 72 h and their weights were determined. At each harvest, roots were gently washed with tap water, harvested, oven dried as above and their dry weights determined.

Total dry weight (W) and leaf area (A) per plant were obtained by summing the dry weight and leaf area of each layer, respectively. Relative growth rate (RGR) was obtained using linear regression of the natural logarithm (ln) of total dry weight per plant against weeks after emergence. Net assimilation rate (NAR) was calculated by dividing RGR to leaf area ratio (LAR). Leaf area ratio was the product of leaf weight ratio and specific leaf weight [10].

2.1.3. Experiment 3. Growth of Cowpea and A. retroflexus Grown in Pure Stands and in Competition

This experiment was conducted to study growth of the two species grown in pure stands and in competition. Field soil was filled into pots similar to those used in the above experiments. Pots were sown with sufficient seeds of each species separately placed in the pot center or seeds were arranged in a manner at which each plant of either species was surrounded by five plants of the other species in mixture. All pots were sown on 25th March, 2002. When cowpea and *A. retroflexus* seedlings reached 2 and 4-leaf stages, respectively, they were thinned to one seedling per pot of either species in pure stands or to density proportions of 1 cowpea: 5 *A. retroflexus* and 5 cowpea: 1 *A. retroflexus* in mixtures and considered as treatments.

Treatments were arranged in a randomized complete block design with six replicates. All plants were left to grow under natural conditions in the field and pots were irrigated with tap water when needed.

The experiment was terminated on 25 June 2002 by harvesting plants from the above soil level. Pods of cowpea were counted and shoots of both species were oven-dried at 70 °C for 72 h and their dry weights were determined. Relative yield (RY) and relative yield total (RYT) of both species were calculated [2] from the following formula:

$$RY = \frac{\text{Yield of a species in mixture}}{\text{Yield of the same species in pure stand}}$$

Relative yield total (RYT) was calculated by adding the relative yields of the two species for the same treatment.

2.1.4. Statistics

Data on *A. retroflexus* and cowpea were summarized and species were subjected to ANOVA and regression analysis separately using MSTATC and SPSS software [11], respectively to test for significance ($P \leq 0.05$). The homogeneity and normality of error variance between treatments was tested before conducting any analysis and both were not significant. The main effects and interaction between treatments were calculated. Regression analysis has been suggested as an appropriate method to relate plant growth parameters to weed density [12]. Yield potential and intraspecific competition coefficient in monoculture were obtained by fitting the inverse of yield to seedling density in first experiment ($1/w = a + bN$ where w is yield per plant, a is the inverse of yield in absence of competition, b is intraspecific competition and N is number of plants per pot).

For growth analysis experiment, natural logarithm transformation was employed to linearilize the growth function curve: plant variables growth (Yt), ($\ln(Yt) = a + b*DAE$ where y is yield per plant at time t; a is initial yield, b is RGR and DAE is days after emergence) and regression analysis was conducted on transformed data.

Stepwise regression was employed to select variables to retain in the model when more than one independent variable was considered. The selection of the best multiple linear regression models was performed by starting with maximum independent variables and by eliminating terms with a forward stepwise analysis. Regression of independent variables on other independent variables resulting in a high R^2 indicates multicollinearity among the variables [13]. Variables with higher tolerance and lower multicollinearity significant partial regression coefficients ($P \leq 0.05$) were retained in the model.

RESULTS

3.1. Experiment 1. Effect of Water Stress on Growth of *A. retroflexus* and Cowpea Grown in Pure Stands at Various Densities

3.1.1. Effect on Cowpea

Water and density stress significantly reduced cowpea shoot dry weight and leaf area per plant (Fig. **1a** and **d**) and

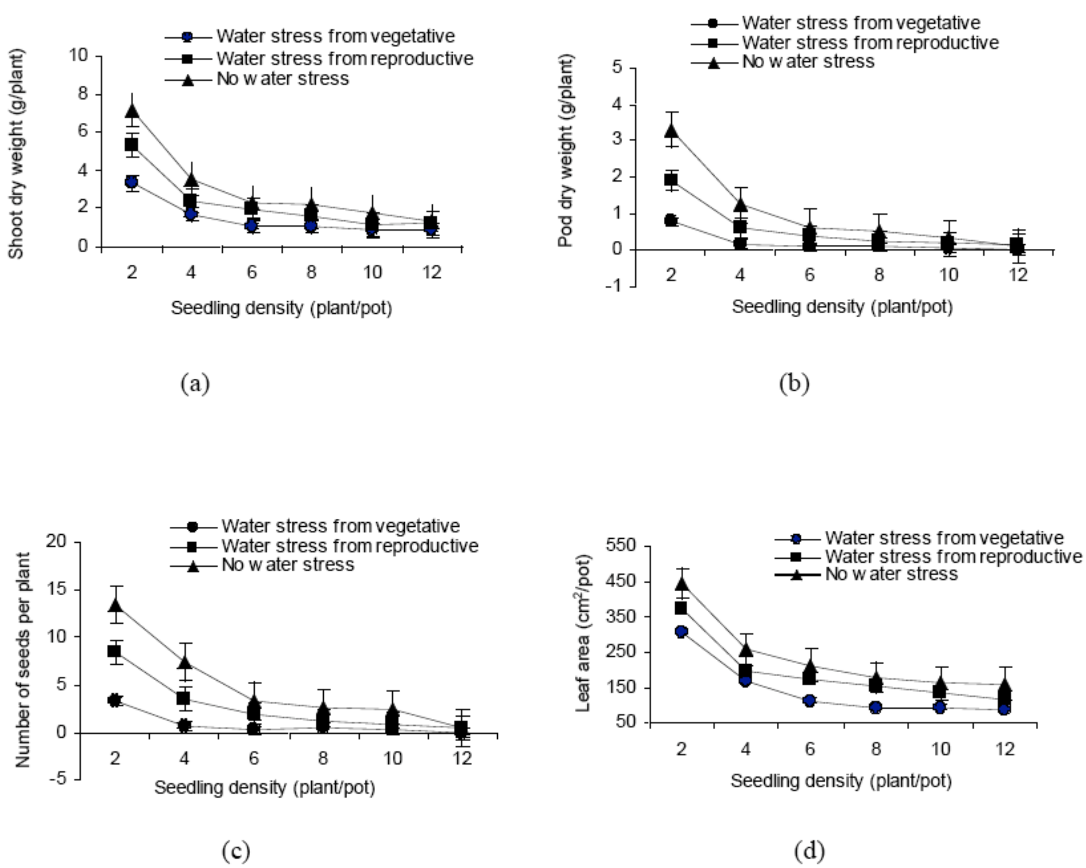

Fig. (1). Effect of different levels of water stress and seedlings density on **a**) shoot dry weight, **b**) pod dry weight, **c**) number of seeds and **d**) leaf area of cowpea. Error bars indicate SE of the means.

Table 1. Effect of Water Stress at Different Growth Stages on Model of Leaf Area Production and Shoot Dry Weight Per Plant of Cowpea and on Plant Height, Shoot Dry Weight and Inflorescence Dry Weight Per Plant of *A. retroflexus*

Method	Time of water stress	Function	R^2	P	N
Cowpea					
Growth	From vegetative to maturity	Ln (leaf area) = 2.77 + 0.12*WAE Ln (shoot dry weight) = 0.26+0.073* WAE	0.99 0.98	0.000 0.000	24 24
Growth	From flower to maturity	Ln (leaf area) = 3.26+0.11*WAE Ln (shoot dry weight) = 0.5+0.08* WAE	0.85 0.99	0.000 0.000	24 24
Growth	Optimum water during the season	Ln (leaf area) = 3.52+0.12*WAE Ln (shoot dry weight) = 0.86+0.088* WAE	0.99 0.97	0.000 0.000	24 24
A. retroflexus					
Growth Inverse	From vegetative to maturity	Ln (plant height) = 0.54 + 0.26*WAE Ln (shoot dry weight) = -0.29+0.24* WAE 1/Y(inflorescence dry weight) = 1.14*SD	0.95 0.95 0.95	0.000 0.000 0.0002	24 24 24
Growth Inverse	From flower to maturity	Ln (plant height) = 0.56 + 0.27*WAE Ln (shoot dry weight) = 0.0026+ 0.26* WAE 1/Y (inflorescence dry weight) = 0.92*SD	0.87 0.88 0.94	0.000 0.000 0.003	24 24 24
Growth Inverse	Optimum water during the season	Ln (plant height) = 0.59+ 0.29*WAE Ln (shoot dry weight) = -0.25 +0.27* WAE 1/Y(inflorescence dry weight) = 0.41*SD	0.88 0.88 0.97	0.000 0.000 0.0001	24 24 24

WAE = week after emergence.

Table 2. Effect of Seedling Density on Model of Leaf Area Production and Shoot Dry Weight Per Plant of Cowpea, and on Shoot Dry Weight and Plant Height of *A. retroflexus*

Method	Density (plants/pot)	Function	R^2	P	N	Function	R^2	P	N
		Cowpea				*A. retroflexus*			
Growth	2	Ln (leaf area) = 3.93 + 0.12*WAE Ln (shoot dry weight) = 0.83+0.096* WAE	0.99 0.99	0.000 0.000	24 24	Ln (plant height) = 0.42 + 0.32*WAE Ln (shoot dry weight) = -0.41+0.3* WAE	0.89 0.91	0.000 0.000	24 24
Growth	4	Ln (leaf area) = 3.41 + 0.12*WAE Ln (shoot dry weight) = 0.55+0.087* WAE	0.98 0.98	0.000 0.000	24 24	Ln (plant height) = 0.62 + 0.28*WAE Ln (shoot dry weight) = 0.26* WAE	0.89 0.91	0.000 0.000	24 24
Growth	6	Ln (leaf area) = 3.2 + 0.12*WAE Ln (shoot dry weight) = 0.44 + 0.079* WAE	0.99 0.99	0.000 0.000	24 24	Ln (plant height) = -0.14 + 0.24*WAE Ln (shoot dry weight) = 0.72 + 0.26* WAE	0.92 0.92	0.000 0.000	24 24
Growth	8	Ln (leaf area) = 2.97 + 0.12*WAE Ln (shoot dry weight) = 0.35 + 0.074* WAE	0.98 0.99	0.000 0.000	24 24	Ln (plant height) = 0.84 + 0.24*WAE Ln (shoot dry weight) = 0.22* WAE	0.90 0.92	0.000 0.000	24 24
Growth	10	Ln (leaf area) = 2.89 + 0.11*WAE Ln (shoot dry weight) = 0.32 + 0.068* WAE	0.98 0.98	0.000 0.000	24 24	Ln (plant height) = 0.88 + 0.23*WAE Ln (shoot dry weight) = 0.63 + 0.21* WAE	0.92 0.93	0.000 0.000	24 24
Growth	12	Ln (leaf area) = 2.7 + 0.12*WAE Ln (shoot dry weight) = 0.22 + 0.071* WAE	0.98 0.98	0.000 0.000	24 24	Ln (plant height) = 0.7 + 0.23*WAE Ln (shoot dry weight) = 0.21* WAE	0.92 0.93	0.000 0.000	24 24

WAE = week after emergence.

the effects were interdependent (Table **1**). When water stress started at early vegetative stage, shoot dry weight of cowpea decreased at a slow rate up to a density of 8 plants per pot and remained constant thereafter. When stress started at flowering and under no water stress, shoots dry weight was dropped sharply with density as a result of reduction in leaf area absolute and relative growth rates (Fig. **1a**, Tables **1** and **2**). Long low water stress increased the intensity of intra-specific competition (Table **3**). The relationship between leaf length and width of cowpea and leaf area was linear and independent of water stress and seedling density (R^2 = 0.93, P ≤0.001).

Both low water and density stresses affected cowpea pod and seed yield. With no water stress, pod dry weight increased by 5.5 and 1.76 times and number of seeds/plant by 7 and 4 times compared to stress started at early vegetative and flowering stage, respectively. Cowpea pod dry weight and number of seeds per plant were inversely related to seedling density (Fig. **1b** and **c**). The differences in water stress effect were higher at lower planting densities. The relationship between seedling densities and number of seeds per plant is negatively correlated (R^2 = 0.99, 0.91 and 0.98, P< 0.001, under water stress at vegetative and flowering stages, and no stress, respectively).

Neither low water stress nor high seedling densities had significant effect on seed weight. Number of seeds per pot was highly correlated with pod dry weight (R^2= 0.97, P<0.001) while pod dry weight was associated with seeds per pod (R^2 = 0.91, No. 72) and somehow to pod length (R^2 = 0.73).

3.1.2. Effect on A. retroflexus

Water and seedling density stresses significantly reduced initial absolute plant height, shoot dry weight and relative growth rate of *A. retroflexus* (Tables **1** and **2**). Water stress started at vegetative growth stage resulted in the lowest weed RGR. The variation in growth rates due to water and density stresses over growing season resulted in differences in plant height and shoot dry weight of the weed (Fig. **2a** and **b**). Intraspecific competition coefficients were dependent on water treatments and increased with prolonged water stress over the growing season (Table **3**). Shoot dry weight of *A. retroflexus* was highly associated with its leaf area at early growth stages (R^2 = 0.99). However, under all water treatments, shoot dry weight of *A. retroflexus* was negatively correlated with the intensity of intraspecific competition.

Water stress imposed at growth stages and seedling density significantly affected inflorescence dry weight of *A. retroflexus* (Fig. **2c** and Table **1**). Water stress at vegetative and flowering stages increased intensity of the weed intraspecific competition by about 3.2 and 2.7 times, respectively, compared with no water stress. Inflorescence dry weight obtained under optimum conditions was about 2 and 1.5 times higher than that when stress started at early and at flowering stages, respectively.

The effect of both water stress and seedling density on inflorescence dry weight was interdependent (Fig. **2c**). Differences in water effect were higher at lower than at higher densities. The inverse model was fitted for all three water conditions with R^2 ranging from 0.94 to 0.97 (Table **1**). However, inflorescence dry weight was associated with stem dry weight and number of reproductive branches per plant (R^2 = 0.91).

3.2. Experiment 2. Plant Growth Analysis of Cowpea and *A. retroflexus*

Analysis of different growth parameters of both species are shown in Table **4**. Relative elongation rate of *A. retroflexus* was 4 times higher than that of cowpea. Cowpea grew taller than *A. retroflexus* only during the first three weeks after emergence (Fig. **3a**). Two-third of *A. retroflexus* height elongation occurred after its leaf area and root growth were ceased (Fig. **3a** and Table **5**).

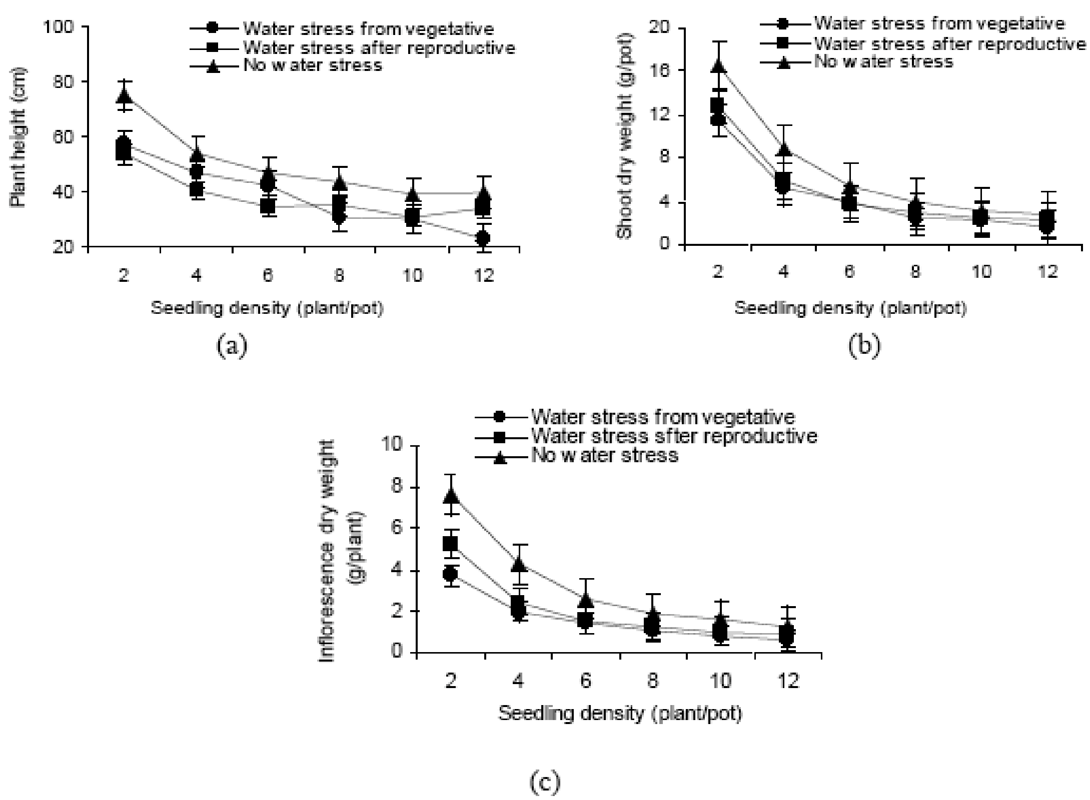

Fig. (2). Effect of different levels of water stress and seedlings density on **a**) plant height, **b**) shoot dry weight and **c**) inflorescence dry weight of *A. retroflexus*. Error bars indicate SE of the means.

Table 3. Effect of Seedling Density (SD) and Water Stress on Model of Shoot Dry Weight (Y) and Leaf Area (LA) Per Plant of Cowpea and *A. retroflexus* at Different Growth Stages

Method	Time of water stress	Function	R^2	P	N
Cowpea					
Inverse	Vegetative to maturity	1/Y = 0.18+0.067*SD	0.91	0.000	24
Inverse		1/LA = 0.01*SD	0.99	0.000	24
Inverse	Flower to maturity	1/Y = 0.087+0.05*SD	0.94	0.000	24
Inverse		1/ LA = 0.0096*SD	0.99	0.000	24
Inverse	Optimum water	1/Y = 0.031+0.044*SD	0.96	0.000	24
Inverse		1/ LA = 0.0071*SD	0.99	0.000	24
A. retroflexus					
Inverse	Vegetative to maturity	1/Y = 0.41*SD	0.94	0.000	24
Inverse	Flower to maturity	1/Y = 0.38*SD	0.94	0.000	24
Inverse	Optimum water	1/Y = 0.29*SD	0.94	0.000	24

Table 4. Models Describing Growth of Different Organs of Cowpea and *A. retroflexus* Based on Days

Model	Plant part	Function	R^2	P	No.
Cowpea					
Growth	Leaf area (cm^2)	Ln (Y) = 2.3+0.05*day	0.98	0.000	12
Linear	LAR (cm^2/ g)	Y = 58.1-0.4*day	0.92	0.000	72
Linear	SLA (cm^2/g)	Y = 114-0.56*day	0.97	0.000	72
Growth	Leaf dry weight (g)	Ln (Y) = 4.4+0.06*day	0.98	0.000	12
Growth	Stem height (cm)	Ln (Y) = 1.67+0.017*day	0.98	0.000	12
Growth	Shoot dry weight (mg)	Ln(Y) = 4.6+0.06*day	0.98	0.000	12
Growth	Root dry weight (g/plant)	Ln (Y) = 4.3+0.05*day	0.99	0.000	12
Linear	Root to shoot ratio	Y = 0.71-0.005*day	0.62	0.002	12
Growth	Total dry weight (g)	Ln(Y) = 5.3+0.06*day	0.97	0.000	12
A. retroflexus					
Growth	Leaf area (cm^2)	Ln (Y) = 0.17*day	0.90	0.000	36
Exponential	LAR (cm^2/g)	$Y = 157.36*e^{(-0.0029*DD)}$	0.86	0.000	54
Growth	Leaf dry weight (g)	Ln (Y) = 0.21*day	0.98	0.000	54
Exponential	SLA (cm^2/g)	$Y = 235.16*e^{(-0.0036*DD)}$	0.91	0.000	54
Growth	Stem height (cm)	Ln (Y) = 0.07*day	0.95	0.000	72
Growth	Shoot dry weight (mg)	Ln (Y) = 2.45+0.14*day	0.87	0.000	72
Growth	Root dry weight (mg/plant)	Y = 0.12*day	0.86	0.000	72
Exponential	Root to shoot ratio	$Y = 1.16*e^{(-0.0018*DD)}$	0.93	0.000	72
Growth	Total dry weight (mg)	Ln (Y) = 3.65+0.12*day	0.86	0.000	72
Growth	Reproductive organ dry weight (g)	Ln (Y) = 0.02*day	0.96	0.000	72

Average relative shoot growth rate of *A. retroflexus* was 2.5 times greater than that of cowpea. Shoot dry weight of cowpea was strongly associated with leaf area (R^2 = 0.95, P<0.001) while that of *A. retroflexus* with plant height (R^2 = 0.94, P<0.001).

Average RGR of *A. retroflexus* roots was 2.4 times higher than that of cowpea, which enabled the weed to obtain maximum growth within a relatively short period (Table **5**).

Root/ shoot ratio of cowpea and *A. retroflexus* grew in quadratic and linear fashion, respectively (Table **4**). Cowpea root dry weight was strongly associated with leaf area (R^2 = 0.96, P<0.001) and *A. retroflexus* root dry weight with plant height (R^2 = 0.91, P<0.001).

Both species accumulated similar amount of dry matter up to 24 days after emergence, after which *A. retroflexus* accumulated substantially higher amount (Fig. **3b**). Relative growth rate of *A. retroflexus* was greater than that of cowpea

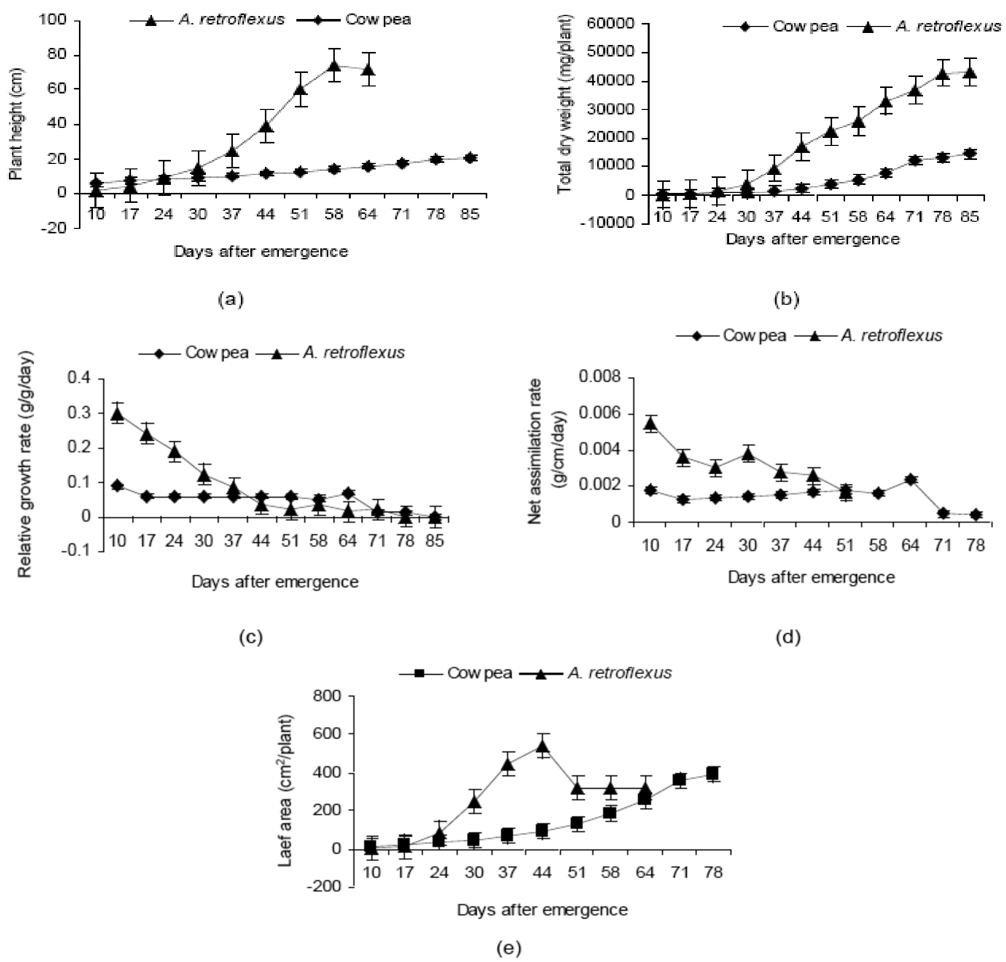

Fig. (3). Comparative **a**) plant height, **b**) total dry weight, **c**) relative growth rate, **d**) net assimilation rate and **e**) leaf area of cowpea and *A. retroflexus* grown in pure stands for different periods. Error bars indicate SE of the means.

Table 5. Growth Analysis of Roots, Inflorescence or Pod Dry Weights of Cowpea and *A. retroflexus* Grown in Pure Stands for Different Periods after Emergence

Days after emergence (DAE) (T ºC)	Root dry weight (mg/ plant)	Root dry weight (mg/ plant)	Inflorescence dry weight (mg/plant)	Pod dry weight (g/plant)
	Cowpea	*A. retroflexus*	*A. retroflexus*	Cowpea
10 (183.5)	80	6	-	-
17 (284.5)	187	56	-	-
24 (355)	266	445	-	-
30 (414)	359	1302	-	-
37 (511.5)	509	4658	148	-
44 (618)	722	5835	606	-
51 (726.5)	1025	6340	3097	-
58 (839)	1454	5970	5558	-
64 (928.5)	1963	6692	9568	-
71 (1009)	2785	-	13804	1050
78 (1089)	3452	-	19152	2125
85 (1175)	3608	-	19843	7284
LSD ($p \leq 0.05$)	150	914	1409	90

ºC = degree Celsius per DAE, T = temperature.

before 44 days after emergence (Fig. **3c**) and its net assimilation rate was higher until 51 days after emergence onward (Fig. **3d**).

Leaf of *A. retroflexus* started senescence earlier than that of cowpea and its leaf area declined at a faster rate (Fig. **3e**). On average, relative expansion rate of leaf area of *A.*

retroflexus was 3.4 times more than that of cowpea before 44 days after emergence (Table **4**). Both specific leaf area and leaf area ratio were linearly decreased for cowpea but exponentially decreased for *A. retroflexus* with time.

A. retroflexus started heading at 37 days after emergence and continued for seven weeks, while cowpea flowering started at 64 days after emergence and the crop matured within three weeks (Table **5**), thereafter, their absolute and RGRs were sharply increased. At the end of the growing season, inflorescence dry weight of *A. retroflexus* was 45 % and pod dry weight of cowpea was 51 % of their respective total dry weights.

Most stem dry weight of *A. retroflexus* was accumulated in the lower portion of its height and stem dry weight decreased with height (Fig. **4**). In contrast, most of the leaf dry weight and area of cowpea were located between 20 and 40 cm height and placed above the canopy (Fig. **3a**). More than 75 % and 65 % of the leaf area and inflorescence dry weight, respectively, of *A. retroflexus* were located in a better position in competition (Fig. **4**).

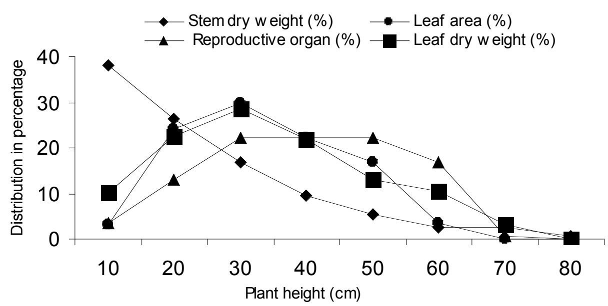

Fig. (4). Distribution percentages of stem dry weight, leaf area, leaf dry weight and reproductive organ of *A. retroflexus* in relation to its height.

3.3. Experiment 3. Growth of Cowpea and *A. retroflexus* Grown in Pure Stands and in Competition

In pure stand, cowpea plant produced the highest shoot and pod dry weight (Table **6**) but both decreased in competition and more at high density proportion of *A. retroflexus*. Pod dry weight in (1 cowpea: 5 *A. retroflexus*) and (5 cowpea: 1 *A retroflexus*) was about 4.2 and 2.7 times lower than that of the sole plant/pot, respectively. Similar pod dry weight was obtained when cowpea was grown with one or five plants of *A. retroflexus*.

Table 6. Growth of Cowpea (C) and *A. retroflexus* (A) Grown in Pure Stands and at Different Density Proportions in the Mixture

Density Proportions	Cowpea Pod Dry Weight (g /plant)	Shoot Dry Weight (g/ plant)	
		Cowpea	*A. retroflexus*
Pure stand (1plant/pot)	4.6	8.1	38.5
Mixture (5C:1A/pot)	1.7	3.2	49.3
Mixture (1C: 5A /pot)	1.1	1.8	8.5
LSD ($p \leq 0.05$)	1.3	1.2	5.2

A. retroflexus plant in competition with 5 plants of cowpea produced similar shoot dry weight to that produced by a single plant with no competition (Table **6**). However, the weed produced the lowest shoot dry weight per plant at density proportion of 1C: 5A. *A. retroflexus* in mixture (5C: 1A) produced 1.25 and 5.8 times higher shoot dry weight than that of a single plant and a mixture of 1C: 5A, respectively (Table **6**). Relative yields of *A. retroflexus* were 0.64 and 0.11 in (5C: 1A) and (1C: 5A), respectively while the yield of cowpea was 0.20 and 0.11 in the same treatments, respectively and their RYT was 0.93.

Results showed that intraspecific competition was more important for *A. retroflexus* than interspecific competition while the opposite was true for cowpea.

DISCUSSION

Shoot dry weight of cowpea was highly associated with its leaf area production at early growth stage (Cowpea shoot dry weight per plant (mg) = 90 + 24*LA, R^2 = 0.96, N= 72, SE = 3.34) which may aggravate its intra-shading effects and competition for light. Water stress during early vegetative growth reduced growth [14], shortened internodes and reduced rate of leaf appearance, number of expanding leaves and final leaf area per plant of wheat [15]. This indicates that stresses due to low water and high planting density decreased dry matter accumulation of both cowpea and *A. retroflexus* by reducing rates of leaf area expansion and growth (Tables **1** and **2**). Reduction in leaf area might reduce light interception and photosynthesis because both are strongly correlated [16]. Water deficit reduces the slope of such a relationship (i.e., radiation use efficiency) [14].

Low water and high density stresses reduced cowpea yield by decreasing pod size and number of seeds per plant. It has been reported that sensitivity of plants to water stress is particularly acute during the reproductive stage by accelerating leaf senescence, shortening seed filling period [17] and reducing final yield. Board and Harvile [18] reported that soybean yield was most affected by water stress that reduced crop growth rate, when occurred during the early reproductive period. Both seed number and photosynthesis during seed filling stage determined seed yield, but pods per plant and/or seed number per unit area and seeds per pod [19] under stress explain more of the variations in seed yield. Early stress during seed filling decreases the number of seeds per pod, whereas late stress decreases seed weight [20].

Intraspecific competition coefficients of cowpea were 6 and 8 times more when water stress started at flowering and vegetative growth stages, respectively than at optimum water, which indicates the severe intra-specific competition effect on pod growth under water stress. Competition for water greatly reduced growth and final yield of soybean under drought conditions**.**

Water and density stresses reduced inflorescence dry weight of *A. retroflexus* through reducing inflorescencebearing branches. Intra-specific competition coefficients for inflorescence of *A. retroflexus* under different water stress treatments ranged between 0.41 and 1.14, the highest was for water stress started at vegetative stage (Fig. **2c**). This indicates that competition for water during reproductive stage is very critical in reducing the reproductive organ (inflorescence) of the weed. However, drought stress reduced the potential shoot dry weight per plant and increased intensity of intra-specific competition. Density stress inversely reduced shoot dry weight per plant of cowpea (Table **3**) and plant height, shoot dry weight and inflorescence dry weight of *A. retroflexus* (Fig. **2a-c**). Other workers suggested that as *A. retroflexus* density increased, dry matter accumulation and seed production per plant were reduced [21].

Rapid leaf and root growth at early growth stage might help the weed to exploit more resources early in the season, which further enabled other organs development. Shurtleff and Coble [22] suggested that fast leaf biomass growth during early period could bring height differences between species and give a competitive edge of one species over the other.

Absolute growth rates of *A. retroflexus* shoots were slow when more resources were allocated to roots and leaves at early growth stage and when more leaves were senescence at later stages. Faster growth rate of the weed might enable it to effectively shade cowpea within 30 days after emergence and maintain its higher total dry weight for the rest of the growing season (Fig. **3b**). Other workers suggested that *A. retroflexus* has a faster growth rate than soybean [23, 24]. The rapid accumulation of total dry weight of *A. retroflexus* at earlier growth stage could be related to its faster leaf area expansion and root growth within the first few weeks after emergence to capture more resources and convert to dry matter accumulation. More leaf area of cowpea was required than that of *A. retroflexus* to produce the same total dry weight, which indicates less assimilation rate of cowpea, increased AGR of *A. retroflexus* than cowpea and expresses its faster occupation of available space to acquire water, nutrients and light [16].

Cowpea allocated more resources to expand leaf area while *A. retroflexus* increased dry matter accumulation per unit leaf area at a faster rate. Kropff [25] reported that leaf development and expansion rates were important factors in determining the outcome of crop-weed interference because the capacity to intercept photosynthetically active radiation and synthesize carbohydrates is a linear function of leaf area [16]. Therefore, morphological development (plant height and leaf area) appeared to be the most important factor determining competition effects.

Root weight of *A. retroflexus* was lower than that of cowpea at 17 days after emergence and was 9 times higher than that of the crop at 37 days after emergence. This indicates faster growth rate of the weed roots to occupy the soil and exploit resources within a short time. Early colonization of the soil is critically important for the outcome of weed-crop interaction [26]. Lynch [27] reported that *A. retroflexus* roots produced greater amount of lateral spread roots and contain several times as much root as bean. *A. retroflexus* produced double root length of any other species within 28 days after emergence [24] while root lengths and densities per unit volume of soil are characteristics associated with a superior competition for under ground resources.

Earlier flowering and heading of *A. retroflexus* enhance its rapid dissemination and invasion of new land and allow the weed escaping control measures before crop harvest. This equipped the weed with a survival and competitive edges over crop plants. However, *A. retroflexus* may increase its generations and range of infested area by producing large number of seeds over a long period of time within the season to tolerate unfavorable seasonal conditions.

The increase in shoot dry weight of *A. retroflexus* in response to increase in cowpea proportion in the mixture clearly demonstrated the importance of intraspeciefic competition of *A. retroflexus* and more than its interspecific competition. The opposite was true for cowpea. Cowpea produced similar pod dry weight whether grown with one or five plants of *A. retroflexus* and lower than that of the sole cowpea plant. This implies higher competition effect of *A. retroflexus* on cowpea even at low densities (Table **6**).

High leaf area produced at the upper portion of weed stem is an efficient strategy to trap light [28] by recruiting the majority of young leaves to increase photosynthesizing surface [29] and thus reducing the amount of light available to cowpea. The ability of a plant to place foliage in the upper, better light portions of, or above, the canopy is an important structural trait, which might be as important in determining competitive outcome as total leaf area. Mclachlan *et al.* [7] reported that competitive ability of *A. retroflexus* was associated with its overall leaf area, greater height, canopy structure and development.

CONCLUSIONS

Water stress reduced growth and performance of both cowpea and *A. retroflexus*, but had more negative effects on the former, especially on reproductive organ. The harmful effect of water stress increased with plant densities and cowpea suffered more than *A. retroflexus*. *A. retroflexus* exploited more resources and reproduced earlier than cowpea because of weed faster growth rate and early exploitation of resources.

REFERENCES

[1] Kropff MJ, Lotz LAP. Systems approach to quantify crop-weed interactions and their application to weed management. Agr Syst 1992; 40: 265-82.

[2] Harper JL. The population biology of plants: Academic press: London 1977: pp. 892.

[3] Pearcy RW, Tumosa NN, Williams K. Relationships between growth, photosynthesis and competitive interactions for C_3 and C_4 plant. Oecologia 1981; 48: 371-6.

[4] Summerfield R, Huxley PA, Steele W. Cowpea [*Vigna unguiculata* (L) Walp]. Field Crop Abs 1974; 27: 301-12.

[5] French RJ. Effects of early water deficit on growth and development of faba bean plant. Plant Physiol 1998; 116: 447-53.

[6] Weaver SE, Mcwilliams EL. The biology of Canadian weeds. 44. *Amaranthus retroflexus* L.: *A. powellii* S. Wats. and *A. hybridus* L. Can J Plant Sci 1980; 60: 1215-34.

[7] Mclachlan SM, Tollenlaar MS, Swanton CJ, Weise SF. Effect of corn induced shading on dry matter accumulation: distribution and architecture of redroot pigweed (*Amaranthus retroflexus* L.). Weed Sci 1993; 41: 568-73.

[8] Qasem JR. Pigweed (*Amaranthus* spp.) interference in transplanted tomato (*Lycopersicon esculentum*). J Hortic Sci 1992; 67(3): 421-7.

[9] Holt JS. Ecological and physiological characteristics of weeds. In: Altieri MA and Liebman M, Eds. Weed management in agroecosystems: ecological approaches: CRC Press: Inc. Boca Raton: Florida. 1988; 7-23.
[10] Lambers H, Dijkstra P. A physiological analysis of genotypic variation in relative growth rate: can growth rate confer ecological advantage? In: Andel J van, Bakker JP, Snaydon RW, Eds. Disturbance in grasslands: causes: Effects and processes: USA Kluwer Academic Publishers: 1987; 237-52.
[11] Dr. Dordrecht WJ. SAS. SAS user's guide: statistics. SAS institute: Cary: NC. 1996.
[12] Cousens R. Misinterpretation of results in weed research. through inappropriate use of statistics. Weed Res 1988; 28: 281-9.
[13] Dunan CM, Westra P, Moore F, Chapman P. Modeling the effects of duration of weed competition: weed density and weed competitiveness on seeded irrigated onion. Weed Res 1996; 36: 259-69.
[14] Nam NH, Subbarao GV, Chauhan YS, Johabsen C. Importance of canopy attributes in determining dry matter accumulation of pigeonpea under contrasting moisture regimes. Crop Sci 1998; 38: 955-61.
[15] Gutierrez- Boem FH, Thomas GW. Phosphorus nutrition affects wheat responses to water deficit. Agron J 1998; 90: 375-83.
[16] Spitters GJT. An alternative approach to the analysis of mixed cropping experiments. Neth J Agric Sci 1983; 31: 1-11.
[17] Desouza PI, Egli DB, Bruening WP. Water stress during seed filling and leaf senescence in soybean. Agron J 1997; 89: 807-12.
[18] Board JE, Harville BG. Late-planted soybean yield response to reproductive source/sink stress. Crop Sci 1998; 38: 907- 10.
[19] Ferris R, Wheeler TR, Ellis RH, Hadlley P. Seed yield after environmental stress in soybean grown under elevated CO_2. Crop Sci 1999; 39: 1065-9.
[20] Desclaux D, Tung–Thanh H, Roumet P. Identification of soybean plant characteristics that indicate the timing of drought stress. Crop Sci 2000; 40: 716-22.
[21] Knezevic SZ, Horak MJ. Influence of emergence time and density on redroot pigweed (*Amaranthus retroflexus*). Weed Sci 1998; 46: 665-72.
[22] Shurtleff JL, Coble HD. Interference of certain broadleaf weed species in soybeans (*Glycine max*). Weed Sci 1985; 33: 654-7.
[23] Vangessel MJ, Renner KA. Redroot pigweed (*Amaranthus retroflexus*) and barnyardgrass (*Echinochloa crus-galli*) interference in potatoes (*Solanum tuberosum*). Weed Sci 1990; 38: 338-43.
[24] Seiberi AC, Pearce RB. Growth analysis of weeds and crop species with reference to seed weight. Weed Sci 1993; 41: 52-6.
[25] Kropff MJ. Modeling the effects of weeds on crop production. Weed Res 1988; 28: 465-71.
[26] Perera KK, Ayres PG, Gunasena HPM. Root growth and the relative importance of root shoot competition in the interaction between rice (*Oryza sativa*) and *Echinolchloa crus-galli*. Weed Res 1992; 32: 67-76.
[27] Lynch J. Root architecture and plant productivity. Plant Physiol 1995; 109: 7-13.
[28] Shibles RM, Weber CR. Interception of solar radiation and dry matter production by various soybean planting patterns. Crop Sci 1966; 6: 55-9.
[29] Blomquist RJ, Kust CA. Translocation pattern of soybean as affected by growth substances and maturity. Crop Sci 1971; 11: 390-3.

Received: January 28, 2010 Revised: June 22, 2010 Accepted: June 28, 2010