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European Journal of Experimental Biology, 2012, 2 (4):1144-1150

ISSN: 2248 –9215
CODEN (USA): EJEBAU

The impact of elevated CO_2 on growth and competitiveness of C_3 and C_4 crops and weeds

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ABSTRACT

This experiment was conducted to evaluate the effects of normal CO_2 level (350ppm) and elevated concentration (700ppm) on growth and competitive ability of millet and soybean against pigweed and lambsquaters. The plants were planted as mono and multicultural to study inter- and intra-specific competition in the greenhouse. Root and shoot dry weights and chlorophyll value was measured at the end of vegetative growth. The results showed that plant chlorophyll content rose up by increasing CO_2 concentration, especially in C_3 plants when they were intercropped with C_4 plants. CO_2 elevation caused considerably higher root, stem and leaf weight in C_3 plants than in C_4 plants. In intercropping condition, C_4 plants shoot dry weights decreased under elevated CO_2 concentration. It indicated that competitive ability of those plants reduced in these situations. In all investigated plants, root shoot ratio reduced by increasing CO_2 concentration. Generally, PRY comparisons showed that competitive ability of soybean and lambsquarter increased and millet and pigweed decreased under elevated CO_2 concentration. Therefore weed – crop interactions would be highly affected by CO_2 concentration.

Key words: Climate change, competition, weed management, photosynthetic pathways

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INTRODUCTION

Weeds are usually known as plants that interfere in growth, yield and production of cropping systems. Weeds, due to their competition with crops for soil and water resources, cause reduction of yield quantity and quality and land value and farmers could not encountered the weed damages [1]. Nowadays, great portion of production expenditures belongs to weed control. For example it is reported that weeds caused 12 percent reduction in crop production and their control costs is 35 billion dollars [2]. Developing countries spend much more amounts [3]. Furthermore, weeds could be a pest and diseases host and these increase their control complexities. Recognition the characteristics which play role in weed competition ability are important in weed management. Environmental factors are important in alteration of weed competition ability. From the most recent attractive environmental topics is climatic change. CO_2 concentration have been risen up from 285 in 1950 to 370 (30 percent increase) [4]. CO_2 changes also caused the temperature to change. Therefore it is important to understand the effects of elevated CO_2 on plant growth and metabolism. It's reported that elevated CO_2 induced growth and development of more than 100 plant species [5,6,7].

One of the important agricultural aspects which influenced from CO_2 elevation is weed-crop competition [8]. The quality of crop and weed competition is shown to be affected by environmental condition and varied by increasing CO_2 concentration [9]. Different responses in C_3 and C_4 plants to crescent CO_2 and temperature might change their competition ability. This could be important because most of the world crops are C_3 and often the noxious weeds are C_4 [10].

It was showed that C_3 plant growth would be induced by CO_2 concentration [11]. However it was showed that there is a great interspecific variation in plants to respond to CO_2. Growth of C_4 plant also could be induced by CO_2 at lower rates [12,13,14). Porter, 1993 reported that by duplicating CO_2 concentration, the average growth of 156 species would be increased 37%. C_3 palnts growth (41%) was higher than C_4 (22%). CAM plants showed the lower responses. Ziska [13] examined the competitive ability of sorghum against *Xanthium strumariu*m under normal and higher CO_2 concentrations and concluded that by increasing CO_2 concentration, the competitive ability of sorghum decreased. It was observed that by increasing CO_2 concentration the photosynthesis, growth and competitive ability of C_3 plants would increase. Therefore time and dose of herbicides application like glyphosate would be changed for C_3 plants and had to be applied earlier or in higher concentrations. Such changes had not been observed in C4s [15]. Some researchers demonstrated that C_4 plants responded better to elevated CO_2. For example, Owensby *et al.* [16] observed the higher response to CO_2 in C_4 wheatgrass than C_3 plants. This variation in plant response can be related to different temperate, soil, water and nutrient ability [17].

The primary and transient response of plants to increasing ambient CO_2 is to increase photosynthesis rate and decrease in transpiration rates. Increasing CO_2 fixation is due to decrease in photorespiration; however decreased transpiration is related to stomata closure [18]. Nevertheless the permanent effects of CO_2 on growth and physiology of plants has been little detected. For example the advantageous of photosynthesis increase might be ruined by adverse effects of feedback [19].

With respect to increasing atmospheric CO_2 concentration and the necessity of understanding the interactions of crops and weeds in these circumstances, in order to improve managing methods, this experiment was conducted to examine the twin and separated responses of C_3 and C_4 crops and weeds to elevated CO_2 concentrations.

MATERIALS AND METHODS

This experiment was conducted in Lamerd region (52˚54'19"N , 28˚27'31" E , 500m above sea level, 250mm mean annual participation and4000 mm annual evaporation), Fars province, Iran in 2010. The experiment was carried out in the greenhouse. Soybean and millet as C_3 and C_4 crops respectively and lambsquaeter and pigweed as respective C_3 and C_4 weeds were selected. The experimental design was factorial based on completely randomized design with 20 treatments and four replications. The first factor included of two levels of CO_2 concentrations, 350ppm as normal and 700ppm as elevated concentration. The second factor consisted of monoculture and intercropping (50:50 ratio) of illustrated crops (millet, soybean, lambsquarter, pigweed, millet-soybean, millet-pigweed, millet-lambsquarter, soybean-pigweed and soybean-lambsquarter, pigweed-lambsquarter).

In order to elevating CO_2 concentration, the CO_2 container capsule was used from the 2-3 leaf stage. For measuring and controlling CO_2 concentration, the portable CO_2 meter (Model AZ77535, Thailand) was used. The greenhouse temperatures remained constant at 35˚C day and 25˚C night. The plants were cultivated in plastic pots (45cm diameter and 55cm height), which were filled by loamy soil and manure to avoid soil crusting. 50 % density of monoculture of each plant was considered as a mixed culture density. Appropriate phosphate and ammonium were applied according to soil chemical analysis.

The measured parameters were chlorophyll index during the growth season, root, stem and leaf dry weight of each plant at the beginning of flowering. Chlorophyll was measured from the three random points of ultimate fully expanded leaf by SPAD method using chlorophyll measuring probe (Model CI 200, Optiscience, USA). At the beginning of flowering the plants were cut from the soil surface and the stems and leaves were separated and oven dried at 70˚C for three days. The root also were washed up and after cleaning, were put in oven at 60˚C (50˚C for millet) for 3 days and then weighted. Root/shoot ratio were measured by dividing root dry weigh to shoot dry weight and plant relative yield (PRY) were measured as, shoot dry weight in monoculture to shoot dry weight in mixed culture. The data were analyzed using GENSAT 11 software. Means were compared by LSD examination. The graphs were drawn by Excel.

RESULTS AND DISCUSSION

Chlorophyll index- Chlorophyll indices of all examined species were increased by increasing CO_2 concentration but with different rates (Fig 1). The rate of chlorophyll increase in monoculture for millet, soybean, pigweed and lambsquarter were 7.8, 6.6, 6.5 and 7 percentages, respectively. It seems that C_3 plants responded better to CO_2 especially in mixed culture and in competition with C_4 plants. The highest chlorophyll enhancement (30.7%) was seen in lambsquarter when sown with millet (C(P)) followed by 25.4% increase which was seen in mixed cropping of lambsquarter and soybean (G(C)). The lowest chlorophyll increase (6.7%) was observed in competition of millet and pigweed (C_4). Higher chlorophyll increase in mix cropping may be related to higher competitive ability of C_3

plants under CO_2 elevation. There were contradictory cited results about the effect of CO_2 on chlorophyll. CO_2 enrichment, caused chlorophyll to increase in cotton [20] and clover [21]. Heagle *et al.* [22] also reported the 3% increase in wheat chlorophyll content due to CO_2 enrichment. However, decrease in chlorophyll content in *Brassica oleraceae* and lambsquarter was observed by Sage *et al*. [23] in elevated CO_2 condition. Different chlorophyll responses were might be related to different experimental conditions as well as soil nitrogen content variation. According to Hinmann *et al.* [24] the whole plant response to CO_2 would be altered due to biochemical limitations like lower rubisco activity, Ultrastructural limitations like chloroplast degradation and changes in canopy status like leaf area fluctuations.

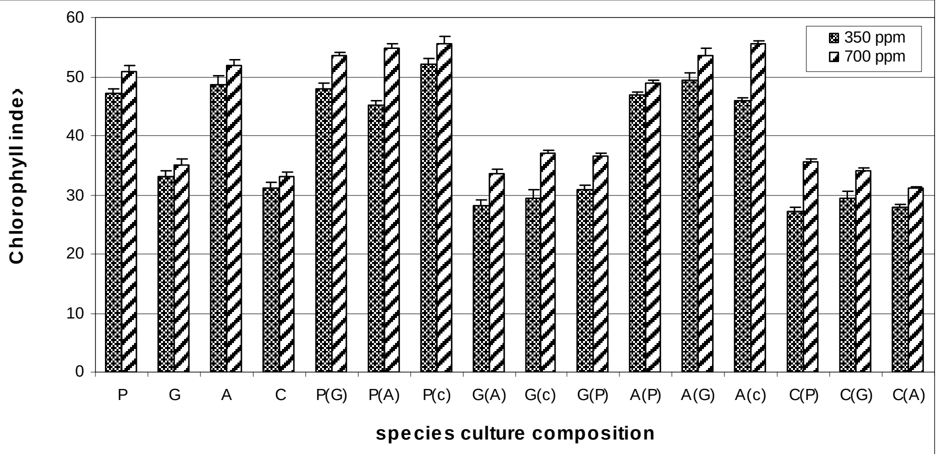

Fig.1 Effect of CO_2 elevation on species chlorophyll index
P, G, A and C showed Panicum, Glycine, Amaranthus and Chenopodium respectively.
The error bars represent standars error. LSD 5%= 1.45

Root dry weight- Effects of CO_2 increasing on root dry weight are shown in Fig. 2. The species showed different responses to elevated CO_2. In pure culture, root dry weight of soybean and lambsquarter increased but any obvious root dry weight increase was seen in millet and pigweed. This led us to conclude that C_3 plants respond better to CO_2 elevation then C_4. In competitive circumstances (mixed culture) the millet root weight remained constant when planted in mixture with soybean and pigweed, but decreased when planted with lambsquarter (Fig. 2). It shows that competitive ability would differ among C_3 plants and also under elevated CO_2 condition competitive ability of millet (C_4 plant) would decrease. The similar results were obtained from pigweed as in the vicinity of soybean and lambsquarter, its root dry weight decreased but when adjacent with pigweed its root dry weight remained constant. It could be concluded that millet and pigweed could compete better under normal CO_2 concentration. Golvi [25] reported that in normal situation pigweed competitive ability is higher than soybean but in higher CO_2 concentration soybean was stronger competitor.

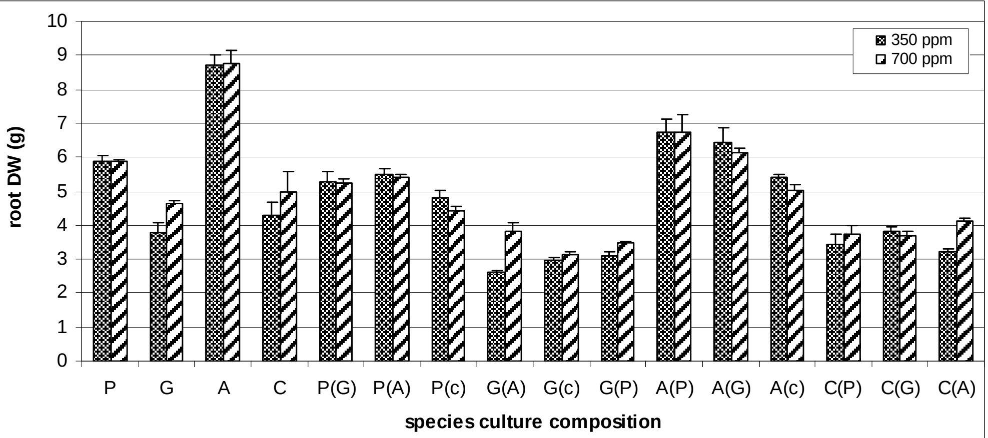

Fig.2 Effect of CO_2 elevation on species root dry weight
P, G, A and C showed Panicum, Glycine, Amaranthus and Chenopodium respectively.
The error bars represent standars error. LSD 5%= 0.239

It was seen that soybean root weight increased in the mix culture with millet and pigweed, but remain constant in the adjacent with lambsquarter. Also lambsquarter's root weigh increased in the vicinity of millet and pigweed. Pritchard *et al*. [26] demonstrated that root growth of C_4 plants like sorghum would decrease under elevated CO_2 condition. Derner *et al*. [14] perceived that root biomass response in cotton and sorghum depended to density and type of species competition. As in low density, root biomass of sorghum respond better to elevated CO_2, but in dense planting the cotton root weight increased (126% increasing) more than sorghum (13% increasing). Dippery *et al*. [27] observed that velvetleaf (*Abutilon theophrasti*) root weight respond better to CO_2 enhancement than pigweed. By increasing CO_2 concentration from 150 ppm to 700 ppm, root dry weight of velvetleaf increased from 0.38 to 11.7g. Such biomass and growth changes could cause plants to alter competition ability. Bazaz *et al*. [28] stated that pigweed competitive ability is high because of higher root growth and ability of absorbing nitrogen from subsoil. But such competitive ability decreased under increasing CO_2 concentration.

Leaf dry weight- Under elevated CO_2 condition, leaf weight of millet, lambsquarter and soybean increased when they were mono cultured (Fig. 3). The highest leaf weight increase was seen in soybean (47.9%) followed by lambsquarter (29.5%) and millet (21.2%). The lowest leaf weight increase was observed in pigweed (1.8%). Therefore the C_3 plants respond better to CO_2 increase. Ziska [13] observed that in elevated CO_2 concentrations, leaf weight and area increased 50 and 35 %, respectively in cocklebur (*Xanthium pensylvanicum*) but the increase of leaf weight and area was 0.5 and 2.4% in sorghum. The reaction rate was decreasing after a while. The same trend was seen in cotton and sorghum in response to elevated CO_2 [14]. Ghanoum *et al.* [29] believed that young leaves of C_4 plants react as similar as C_3 plants to elevated CO_2.

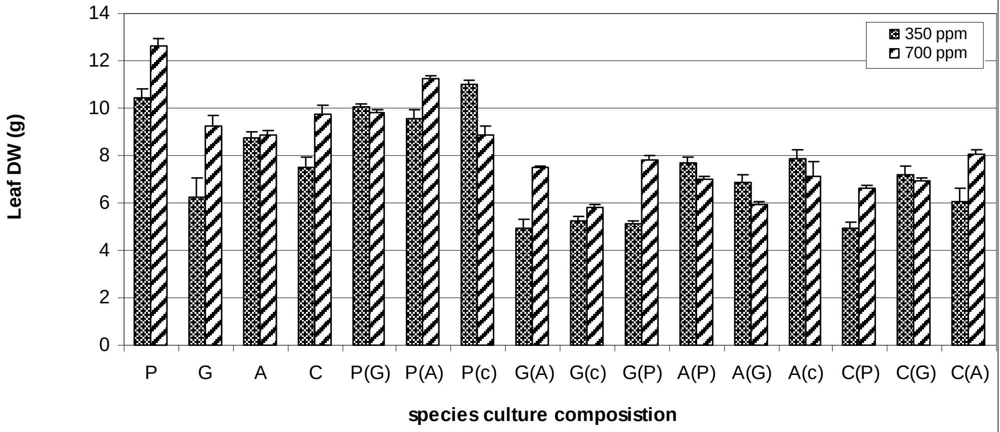

Fig. 3 Effect of CO_2 elevation on species leaf dry weight
P, G, A and C showed Panicum, Glycine, Amaranthus and Chenopodium respectively.
The error bars represent standars error. LSD 5%= 0.256

The different responses were seen in multiculture condition among the plants. In elevated CO_2 concentration, leaf weight of millet increased in the vicinity of pigweed and decreased in the vicinity of lambsquarter and soybean (Fig. 3). In pigweed, also the leaf weight decreased in the vicinity of all tested species especially lambsquarter and soybean. Contrary to C_4 species, the C_3 leaf weights increased in the vicinity of C4 species and remain constant in the vicinity of each other. So that by increasing CO_2 concentration, competitive ability of C_3 plants increased and this led to leaf higher growth.

Wand *et al*. [30] stated that by increasing CO_2 concentration, vegetative growth of both C_3 and C_4 plants increased. But in C_3 plants the response was much more visible. Also the species reaction was different under inter- and intra-specific competition situations. Ziska [13] observed that under interspecific competition (monoculture) the velvetleaf's leaf weight increased only 16% in response to elevated CO_2, but under intraspecific competition situation (multicultural) the leaf weight increased 42%. Ishizaki *et al*. [31] also reported that CO_2 concentration increase caused increasing in root shoot ratio and leaf weight ratio**.**

Stem dry weight- Fig. 4 shows the effect of CO_2 elevation on stem dry weight. The stem weights of millet, soybean, pigweed and lambsquarter increased 1.9, 42.2, 3.4 and 15.6%, respectively by increasing CO_2 in monoculture condition. In multicultural condition, stem weight of millet decreased (13%) in the adjacency of lambsquarter, increased (15%) in the adjacency of pigweed and remain constant in the adjacency of soybean. This indicates that competitive ability of millet increased against pigweed and decreased against lambsquarter. Soybean stem weight increased 76 and 69% in the vicinity of millet and pigweed, respectively but, in the adjacency of lambsquarter the soybean stem weight decreased slightly. Pigweed stem weight decreased 11, 12 and 15% in the vicinity of millet, soybean and lambsquarter, respectively. This indicated that although both millet and pigweed are C_4 plants but millet could enhance its growth ad photosynthesis under elevated CO_2 condition. By increasing CO_2 concentration lambsquarter's stem weight increased 19, 5 and 26% in the vicinity of millet, soybean and pigweed respectively. Mishra *et al*. [32] demonstrated that stem weights of *Brasica* species increased by increasing CO_2 concentration. The highest increase was seen in *B. juncea* (50%) followed by *B. compestris* (45%) and *B. nigra* (only 10%). Similar results were reported by Wand *et al*. [30], Porter [7], Collatz *et al*. [33] and Ghanom *et al*. [29].

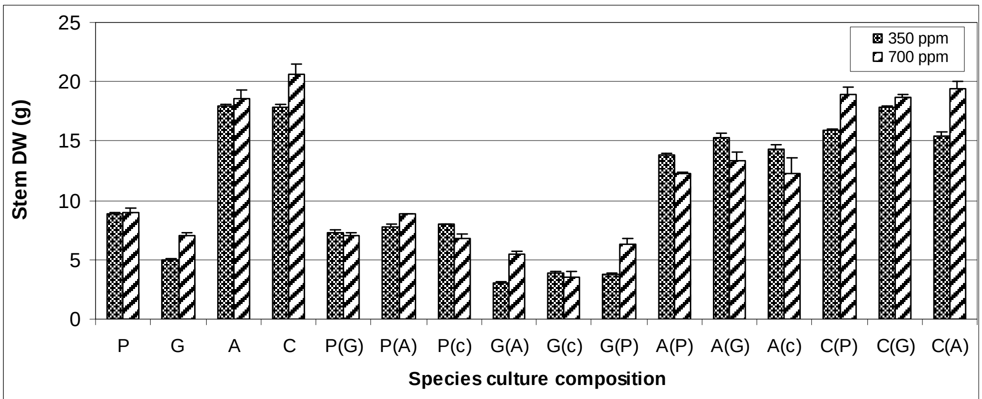

Fig. 4 Effect of CO_2 elevation on species stem dry weight
P, G, A and C showed Panicum, Glycine, Amaranthus and Chenopodium respectively.
The error bars represent standars error. LSD 5%= 0.610

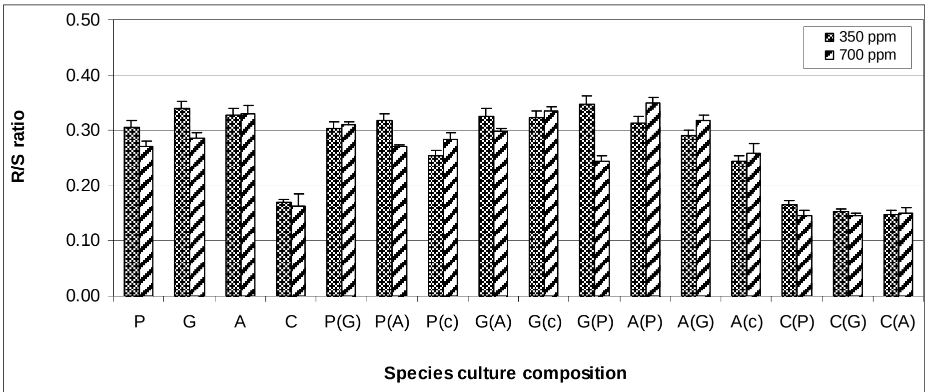

Fig. 5 Effect of CO_2 elevation on species root/shoot ratio
P, G, A and C showed Panicum, Glycine, Amaranthus and Chenopodium respectively.
The error bars represent standars error. LSD 5%= 0.012

Root shoot ratio- The root shoot ratio (R/S) often decreased by increasing CO_2 concentration (Fig. 5). In monoculture in pigweed remained constant and in soybean, millet and lambsquarter decreased 16, 11 and 3 percent respectively. R/S ratio also decreased in mixcropped plants except for millet and pigweed. R/S ratio increased 11% in millet mixcropped with lambsquarter. In mixcropping of pigweed with soybean, millet and lambsquarter, the R/S ratio increased 9, 12 and 6% respectively. It indicated that elevated CO_2 concentration altered translocation of assimilates and decreased the R/S ratio. Besides, R/S ratio increased in C_4 plants the under intraspecific competition (mixcropping). It indicated that by elevating CO_2 concentration, the competitive ability (for above ground resources like light and CO_2) and shoot growth of these species decreased. But in the case of underground resources, C_4 plants could be competitive under elevated CO_2 concentration.

Dippery *et al*. [27] also showed that by increasing CO_2 concentration, R/S ratio increased in pigweed. Polley *et al.* [34] reported that under duplicated CO_2 concentration, root and shoot biomass of *Prosopis glandulosa* increased 37 and 46%, respectively and consequently R/S decreased. R/S ratio and root growth depend exactly to soil fertility and mineral availability could alter the plant response. For example by increasing CO_2 concentration, root growth of C_4 plants like *Bouteloua gracilis* would decreased in unfertile and dry soils [35]. De Luis *et el*. [36 also demonstrated that drought stress altered plant response to elevated CO_2 as in normal concentration R/S ratio increased 108% under drought stress but in elevated CO_2 concentration, drought stress increased R/S ratio up to 269%.

Plant relative yield (PRY)- By increasing CO_2 concentration, PRY increased in soybean when intercropped with millet and pigweed but decreased when planted with lambsquarter (Table 1). The results also showed that PRY and consequently competitive ability of millet decreased facing with soybean and lamsquarter and increased when intercropped with pigweed under elevated CO_2 concentration. Competitive ability of pigweed decreased when intercropped with others. Competitive ability of lamsquarter increased against pigweed and millet and decreased in counter with soybean. Generally the results showed that CO_2 elevation increase competitive ability of C_3 plants versus C_4s. Among the C_4 species, millet responded better to CO_2 elevation therefore its competitive ability increased against pigweed. Similarly, soybean responded better to CO_2 than lambsquarter. The same results were cited about the competitive ability alteration by CO_2 enhancement. Ziska [13] showed that PRY of sorghum and cocklebur were similar in normal CO_2 concentration but in elevated CO_2 concentration the competitive ability of cocklebur increased against sorghum. Bazaz *et al*. [28] also showed that PRY of C_3 plants increased versus C_4s under elevated CO_2 concentration. Ziska [12] also demonstrated that competitive ability of pigweed and soybean yield loss decreased under elevated CO_2 concentration.

Table 1. Plant relative yield (PRY) for soybean, millet, pigweed and lambsquarter (base on shoot DW) in CO_2 concentration of 350 ppm and 700 ppm

Species	In competition with	PRY at 350 ppm	PRY at 700 ppm
Millet	Soybean	0.902	0.781
Millet	Pigweed	0.901	0.927
Millet	Lambsquarter	0.984	0.723
Soybean	Millet	0.794	0.872
Soybean	Pigweed	0.717	0.793
Soybean	Lambsquarter	0.819	0.573
Pigweed	Millet	0.807	0.723
Pigweed	Soybean	0.831	0.728
Pigweed	Lambsquarter	0.835	0.726
Lambsqurater	Millet	0.819	0.841
Lambsqurater	Soybean	0.987	0.844
Lambsqurater	Pigweed	0.849	0.904

CONCLUSION

Generally the results indicated that by CO_2 elevation vegetative growth of C_3 plants (soybean and lambsquarter) can increase. These inductions were much more visible in shoots than roots. Therefore root shoot ratio would be decreased in these pants. Although C_4 species responded to elevated CO_2 in lower degree, but millet responded higher than pigweed to elevated CO_2. Consequently the competitive ability (referred to PRY) increased in soybean and lambsquarter and decreased in C_4 species. It indicated that in future, the C_3 plants will be more competitive against weeds while competitive ability of C_4 plants will be decrease. With respect to the interactions between weeds and crops, it's necessary to evaluate the effect of CO_2 on seed bank and herbicides efficiency.

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