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EARLY GROWTH OF PARTHENIUM WEED (*Parthenium hysterophorus* L.) AND CLIMATE CHANGE

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ABSTRACT

Parthenium weed (Parthenium hysterophorus L.; Asteraceae), native to the tropical and subtropical Americas, is an aggressive herbaceous weed of tropical and subtropical environments. In Australia, parthenium weed occurs mainly in Queensland, where two distinct populations of the weed occur. This includes the more widespread 'Clermont' population and a less-aggressive 'Toogoolawah' population. Potential impacts of climate change on these two populations are not known. This study examined the early growth of the two Australian populations (Clermont or Toogoolawah) of parthenium weed in environmental chambers under two concentration of CO_2 (390 ppmv; ambient or 550 ppmv; elevated), two temperature (35/20°C; Warm or 30/15°C; Cool) and two soil moisture (field capacity; Wet or half of field capacity; Dry) regimes. The early growth (as measured by leaf production, the length of the longest leaf, the total leaf area and the plant dry weight) of both biotypes under the elevated CO_2, cool temperature, and wet or dry soil moisture conditions was higher from ca. 6% to ca. 305% (than the growth under ambient concentration of CO_2 and the same conditions of temperature and soil moisture. However, the growth rates were not significantly different when the young plants were grown under warm temperature and the same conditions of CO_2 concentration, soil moisture levels.

Keywords: CO_2 enhancement, climate change, *Parthenium hysterophorus*, seedling growth, soil moisture.

INTRODUCTION

Global atmospheric carbon dioxide (CO_2) concentrations are predicted to rise to 550 ppmv by the middle of this present Century (Prentice *et al.,* 2001 and CSIRO, 2007). The stimulative effects of atmospheric CO_2 enrichment upon plant growth and development are expected to enhance vegetative productivity, but this will depend upon the species (Kimball *et al.,* 2002; Ainsworth and Long, 2005). The variations in growth response, following photosynthetic enhancement by elevated CO_2 concentrations, will be associated with the differential

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responses of the species to other growth-limiting factors, such as temperature, soil moisture and their photosynthetic efficiency, that is whether they are C_3 or C_4 plants (Kimball *et al.,* 2002). In central Queensland, Australia, the average daytime summer temperature has been 30 to 32^{o}C for many years and has been suggested that there will be a significant increase in temperature of between 2.0 to 4.5^{o}C by 2070 (Australian Bureau of Meteorology website 2011, http://www.bom.gov.au). In addition, it is predicted that there will be a relatively small reduction in rainfall of between 10 to 20 % of the present rainfall by 2070 (Australian Bureau of Meteorology website 2011, http://www.bom.gov.au). Such a series of changes in climate will have significant impacts upon Queensland's agricultural systems. It is likely that there will be significant changes in the incidence (distribution) and abundance of certain kinds of weeds as a result of these changing climatic conditions (Houghton *et al.* 1990).

However, while there is a growing literature concerning the effects of CO_2 enrichment and other climate change variables upon the growth of other weed species, studies on how climate change may affect parthenium weed growth remain limited. Pandey *et al.* (2003) stated that an elevated CO_2 concentration (700 ppmv) would enhance the net leaf photosynthetic efficiency, the maximum photosynthetic rate, and the water use efficiency, while decreasing the light requirement for net photosynthesis, reducing stomatal conductance, and therefore the transpiration rate of *Parthenium* weed. Thus, *Parthenium* weed is likely to show an increasing growth rate in a climate enriched with CO_2 and with an increased temperature (Pandey *et al.,* 2003). Moore *et al.* (1987) and Tirumala Devi and Raghavendra (1993) have described the photosynthetic pathway used by *Parthenium* weed as being a C_3-C_4 intermediate. The upper leaves seem to use the C_3 photosynthetic pathway while the leaves in the middle and at the base of the plant have the typical Kranz leaf anatomy associated with C_4 photosynthesis. According to Navie *et al.* (2005), *Parthenium* weed plants show a typical C_3 plant response to elevated CO_2 (480 ppmv) becoming much taller with more biomass and a greater seed production than those grown under an ambient CO_2 concentration (360 ppmv), even when in competition with a C_4 pasture grass, buffel grass (*Cenchrus ciliaris* L.).

Parthenium weed had been introduced into Australia from North America on two separate occasions – the first was in the 1940s at Toogoolawah in south-eastern Queensland (referred to as the Toogoolawah population) and the second was in 1958 at Clermont, central Queensland (referred to as the Clermont population; Adkins and Navie 2006). It is interesting to note that plants from the Clermont population, when grown under one set of similar

environmental conditions, can become much taller and significantly more massive than those from the Toogoolawah population (Navie, 2002). Nevertheless, the effects of CO_2 enhancement, higher temperature and lower soil moisture level combination on the early growth of these two populations remain unknown.

Thus, the aims of this study are to measure the early growth (*viz.* the number of leaves, the leaf length, the leaf area and the dry biomass) of two populations of *Parthenium* weed (i.e. Clermont and Toogoolawah) when placed under ambient or elevated CO_2 conditions, and when growing under 'Warm' or 'Cool' temperature conditions, in a 'Wet soil' or a 'Dry soil' in a glasshouse, and assess the effect of an elevated atmospheric CO_2 concentration, temperature and soil moisture content (i.e. the main climate change variables) upon *Parthenium* weed early growth and development.

MATERIALS AND METHODS

Plant Material

Parthenium weed cypselas (hereafter referred to as seeds), obtained from the two Australian populations were collected from field-growing plants at Injune (S 25°46'18", E 148°21'06"; Clermont population) in central Queensland, and Toogoolawah (latitude 27S, longitude 152E; Toogoolawah population), in south-east Queensland. Seeds were germinated in plastic Petri dishes (9 cm diameter) on two layers of filter paper (Whatman No. 1) moistened with 7 mL of distilled water and placed in a germination incubator (12/12 hour day/night photoperiod with a 25/20 ± 1°C, day/night thermoperiod) for 4 days. At this time healthy seedlings of uniform size were transplanted into shallow trays (20 × 25 × 6 cm; w/l/h) containing *ca.* 2.5 to 3.0 kg of a heavy clay soil obtained from Gatton, Queensland (27º33'12'' S and 152º20'21'' E). The seedlings were planted at least 5 to 7 cm apart in these trays.

Growing Conditions

The trays with seedlings were distributed randomly on to the surface of a bench inside one of two temperature controlled growth chambers (internal dimensions 200 x 180 x 200 cm; l/b/h; Kirby Ltd., Sydney, New South Wales). Each chamber was positioned within one of two glasshouses (one chamber per glasshouse) at the University of Queensland, Brisbane allowing the plants to receive natural sun light of *ca.* 8 to 9 sunshine hours per day for the duration of the experiment (*ca.* 800 μmol m^{-2} s^{-1}). Within these chambers, a number of experiments were undertaken. In each experiment the transplanted seedlings were allowed to grow for 4 weeks before being harvested.

Experiment 1 and 2

Growth chamber (A) was set up with an elevated CO_2 concentration of 550 ppmv while growth chamber (B) was set up with an ambient CO_2 concentration of 390 ppmv for Experiment 1 and in inverse order for Experiment 2. Both chambers in two experiments were operated at a temperature regime of 30/15 ± 3°C, day/night. These experiments were conducted from 24th July to 25th September 2009.

Experiment 3 and 4

Growth chamber (A) was set up with an elevated CO_2 concentration of 550 ppmv and growth chamber (B) was set up with an ambient CO_2 concentration of 390 ppmv for Experiment 3 and in inverse order for Experiment 4. Both chambers in two were operated at a temperature regime of 35/20 ± 3°C, day/night. These experiments were conducted from 23rd March to 20th April 2010.

CO_2 Enrichment

To study the effect of CO_2 concentration on the growth of parthenium weed, the gaseous atmospheres within the two chambers were modified to create different concentrations of the gas. To do this 'Food' grade CO_2 gas was supplied from a 'G' size cylinder (Coregas Ltd., Brisbane, Queensland) and the concentration within the chamber monitored and modified using an ADC 2000 CO_2 monitor (ANRI Instruments and Controls Ltd., Melbourne, Victoria) in conjunction with a solenoid valve which when working together could modify the gas flow into the chamber.

Temperature

To study the effect of temperature on the growth of parthenium weed, seedlings in trays were placed in the growth chambers which were set at one of two temperature regimes (either 30/15 ± 3 °C; hereafter referred to as 'Cool' – used in Experiments 1 and 2 or 35/20 ± 3 °C, day/night; hereafter referred to as 'Warm' – used in Experiments 3 and 4).

Soil Moisture

To study the effect of soil moisture on the growth of parthenium weed, seedlings in trays within each chamber in each experiment were watered to create two soil moisture regimes, (i.e. field capacity, hereafter referred to as 'Wet' or half of field capacity, hereafter referred to as 'Dry') for these experiments. To determine field capacity for the soil, several kg of soil were placed into three pots and irrigated with tap water to the point of it becoming saturated. The pots were then covered at the top with section of black plastic sheet, and allowed to drain for 48 hours. The plastic sheet was then removed and three soil samples (*ca.* 300 g each) were taken from the mid position of each pot. These samples were weighed (referred to as the

wet weight of soil: A) before being dried in an oven at 90 °C for 72 hours. When no further change of soil sample weigh occurred, the samples were re-weighed (referred to as the dry weight of soil: B). Field capacity (FC) was then calculated by the formula (A – B) × 100/B and half of field capacity by the formula 0.5 × (A – B) × 100/B. However, for use in the experiment, the Gatton soil already contained some water. Therefore, only sufficient extra water was added to bring it up to the required level. To do this, three samples were removed from extra pots of soil, weighed (weight C), then the samples were dried in an oven at 90 °C for 72 hours. When no further change of soil weigh was observed, the samples were weighed again and recorded (weight D). Thus, the available water percentage in the starting soil was determined by E = (C – D) × 100. As a result of this calculation, the amount of additional water that was needed to be added to the pots was determined for both field capacity and half of field capacity soils. At one or two day intervals during the growing period of the plants, the pots and plants were weighed, and water readded until they reached their original moisture level.

Growth Determination

At the end of the 4 week growth period, the number of new leaves that appeared on each plant was recorded as was the length of the longest leaf. Measurements were also taken on the total leaf area and the above-ground dry biomass of each plant. For leaf area, all leaves were removed and their area measured using a leaf area scanner (Paton Electronic Planimeter developed in conjunction with CSIRO, South Australia). Then the leaves and other shoot parts were put into paper bags (12 × 7 cm) and the contents dried in an oven at 90 ± 2^{o}C until no further weight loss occurred. This weight of contents was then taken as the dry biomass of that plant.

Experimental Design and Statistics

A total of 480 parthenium weed seedlings coming from each of the two populations (Clermont or Toogoolawah) were studied in the four experiments. In each experiment, each treatment had three replicate trays and each tray had 10 seedlings. This meant that the growth parameters (number of leaf per plant, leaf length, leaf area and dry biomass) were measured from 30 replicate plants, in each of the experimental conditions. Because the experiments were repeated (by swapping the chambers over), and the data from the two experiments pooled, there were in fact 60 replicates seedlings per treatment, and a total of 960 seedlings used in all the experiments. All seedling growth parameter data sets (*viz.* leaf number, leaf length, leaf area and dry biomass) were analysed by an two-way Analysis of Variance method using a general linear model procedure in Minitab, version 16 (Minitab Inc., USA).

RESULTS

Leaf Production

The production of leaves followed a linear pattern with respect to time in all cases (Figures 1 and 2). The number of leaves produced per plant by the seedlings grown under the elevated CO_2 concentration was significant higher (F-value = 24.33, $P < 0.05$) than those of seedlings grown under the ambient CO_2 concentration from *ca.* 3% to *ca.* 30%. In addition, the number of new leaves produced per plant by the seedlings grown under the Warm condition was significant higher ($P < 0.05$) than those of seedlings grown under the Cool condition from *ca.* 25% to *ca.* 67%. There was a significant difference in leaf production between the two populations under the two temperature regimes (F-value = 13.00, $P < 0.05$) with Clermont producing the most (13 leaves/plant). At the Cool temperature, the number of leaves produced per plant under the elevated CO_2 concentration, were significantly higher (from *ca.* 6% to *ca.* 30%) than on seedlings grown under the ambient CO_2 concentration (F-value = 23.35, $P = 0.0002$; Figures 1 and 2). Under the Warm temperature, the number of leaves produced per plant was significantly higher (F-value = 367.73, $P < 0.05$) than under the Cool temperature condition (Figures 1 and 2). However, no significant differences were observed between seedlings grown under different CO_2 concentrations or in different soil moisture levels (Figures 1 and 2).

Leaf Length

The length of the longest leaf also followed a linear pattern with respect to time in all cases (Figures 1 and 2). The leaf length produced by the seedlings grown under the Warm condition was significant longer (F-value = 169.44, $P < 0.05$) from *ca.* 25% to *ca.* 140% than those of seedlings grown under the Cool condition. In addition, there was a significant difference (F-value = 6.70, $P < 0.05$) in leaf length between the two biotypes grown under both temperature regimes with Clermont population producing longer leaves (from *ca.* 6% to *ca.* 39%). Under the Cool temperature, the leaf length produced overtime by all seedlings grown under the elevated CO_2 concentration, were significantly longer (F-value = 19.23, $P < 0.05$) from *ca.* 14% to *ca.* 89% than those on seedlings grown at the ambient CO_2 concentration. Under the Warm temperature conditions, the leaf length produced by seedlings grown under the elevated CO_2 concentration was about the same as that seen in seedlings grown under the ambient CO_2 concentration (Figures 1 and 2).

Leaf Area

Seedlings grown under the elevated CO_2 concentration were significantly greater (F-value = 4.61, $P = 0.0464$) from *ca.* 4% to *ca.* 264% than seedlings grown under the ambient CO_2 concentration,

except for the Toogoolawah population (Figures 1 and 2). In addition, the leaf area per seedling grown under the Warm condition was significant greater (F-value = 73.62, $P < 0.0001$) from *ca.* 53% to *ca.* 570% than that of seedlings grown under the Cool condition.

Plant Biomass

The biomass of seedlings grown under the elevated CO_2 concentration was significantly higher (F-value = 38.40, $P < 0.0001$) from *ca.* 11% to *ca.* 305% than that of seedlings grown under the ambient CO_2 concentration, except for the Toogoolawah population grown under the Warm condition at field capacity (Figures 1 and 2). In addition, the biomass of seedlings grown under the Warm condition was significantly higher (F-value = 15.99, $P = 0.0009$) from *ca.* 60% to *ca.* 480% than that of seedlings grown under the Cool condition.

DISCUSSION

Growth and CO_2 Concentrations

Under the elevated CO_2 concentration (550 ppmv), leaf production, leaf length and the total leaf area were all promoted as well as the overall plant growth, especially for the Clermont population (Figures 1 and 2). The results of this study are similar to those reported by Navie *et al.* (2005) who showed parthenium weed (Clermont population), grown at an elevated CO_2 concentration (480 ppmv), are taller and heavier than those grown under an ambient CO_2 concentration (360 ppmv). However, the earlier study reported increases in plant height (*ca.* 500 %) and biomass (*ca.* 950 %; Navie *et al.,* 2005), much greater than those seen in the present study. One obvious difference between the studies is that the present one was only looking at early growth (young plant), whereas the earlier study was looking at the whole life of the plant. Another possibility to explain the difference in the biomass between the two studies might be the smaller variation in temperature between the day and the night used in the present study as compared to the earlier study (a 25 degree variation in the earlier study and a 15 degree variation in the present study). There is also the possibility that optimum CO_2 concentration for parthenium weed's growth might be closer to *ca.* 500 ppmv (earlier study) than to 550 ppmv, the concentration used in the present study.

Growth and Temperature

According to Entz and Fowler (1991), higher temperatures accelerate the rate of plant development and reduce the length of the growing period. In this present study, parthenium weed also appeared to behave in the same manner to that seen with other species. All of the growth parameters of the weed increased under the Warm condition (35/20^{o}C day/night; a temperature closer to what might be present under a changing climate by 2070 in central Queensland).

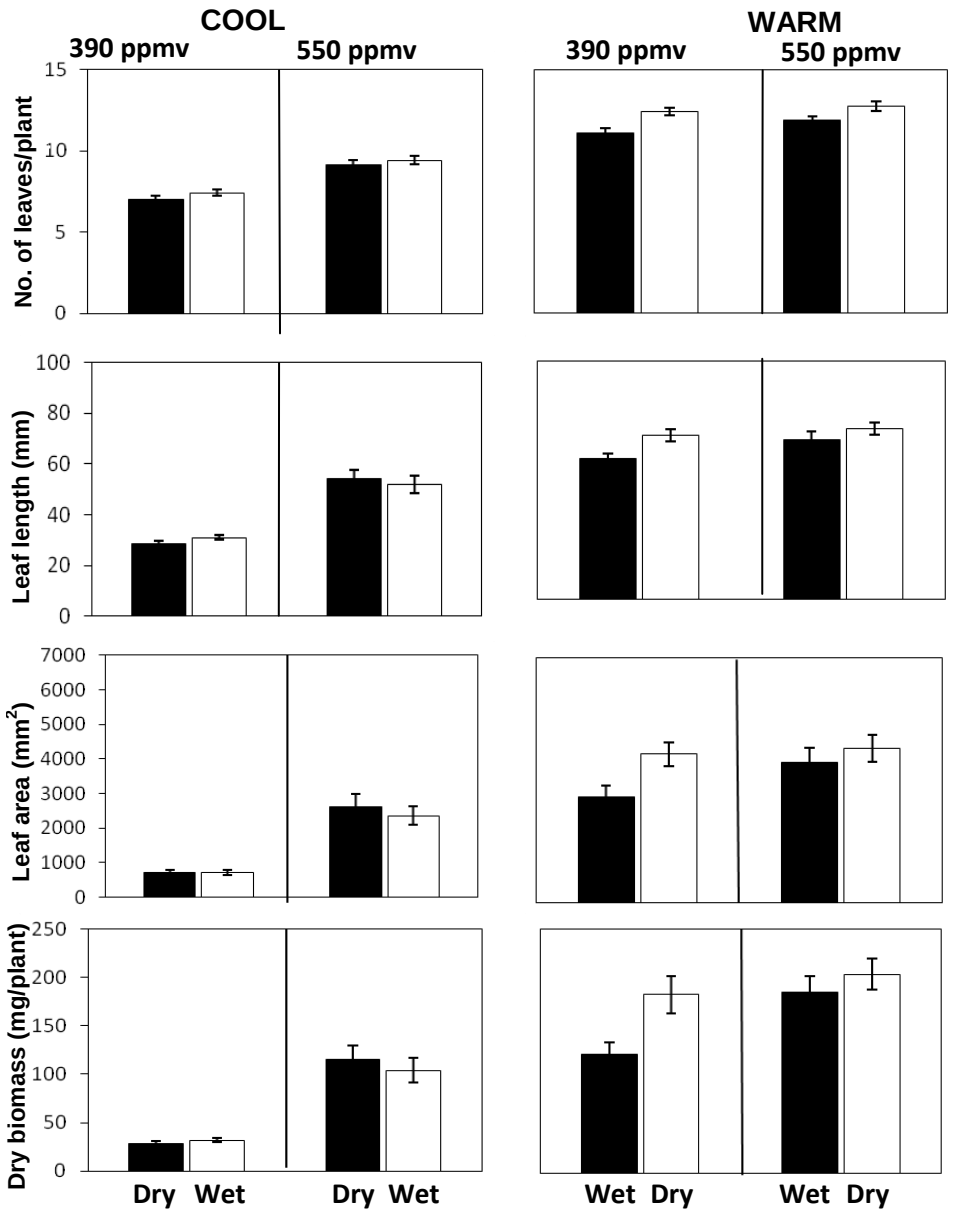

Figure 1. The number of leaves per plant, the length of the longest leaf, the leaf area and the dry biomass produced by seedlings of the Clermont population of parthenium weed grown under a Cool temperature regime (30/15°C; day/night) or under a Warm temperature regime (35/20°C; day/night) and under an ambient CO_2 concentration (390 ppmv) or under

an elevated CO_2 concentration (550 ppmv) at either of two soil moisture levels (i.e. field capacity: Wet or half of field capacity: Dry) and measured at the end of the 4 weeks study. Each treatment of the four variables had 60 replicate plants. Error bars represent two standard errors of the mean.

As compared to that seen under the Cool condition (30/15^{o}C day/night; a temperature closer to the present climate in central Queensland), under both the ambient and the elevated CO_2 concentrations (Figures 1 and 2).

This indicates that parthenium weed is likely to accelerate its growth and rate of plant development (reducing the length of its growing period) in a future, warmer environment. This means parthenium weed will become more aggressive, due to the warmer climatic conditions of the near future.

C_3 and C_4 species and changing climate: Parthenium weed is considered to be a C_3-C_4 intermediate species (Moore *et al*., 1987; Devi and Raghavendra, 1993), and therefore is most likely to increase its growth in an elevated atmosphere of CO_2. In the present study, parthenium weed responded in a similar manner to C_3 plants, with the plant dry weight increasing by 11 to 305 % (depending on the population and the environmental condition). Cure and Acock (1986) reviewed many prior experiments and reported an average 28 % increase in the growth of C_3 species when the CO_2 concentration was doubled, while in C_4 grass species the increase was only ca. 3 to 9 %, hence an increase in the atmospheric CO_2 is not as beneficial to C_4 grass species as it is for C_3 species. The findings of this present study have implications for the future threat that parthenium weed may pose to grazing industry under a changing climate. It is likely that parthenium weed will be more aggressive, especially at the early growth stage which is a stage that is critically important to most plants when invading the predominantly C_4 pasture lands of central Queensland. Of particular concern might be its ability to compete more at the early growth stage, produce more biomass which might elevate its allelopathic potential, produce more seed to retain its high seed bank capacity. It may also be to compete its life cycle more rapidly but this may or may not be an advantage.

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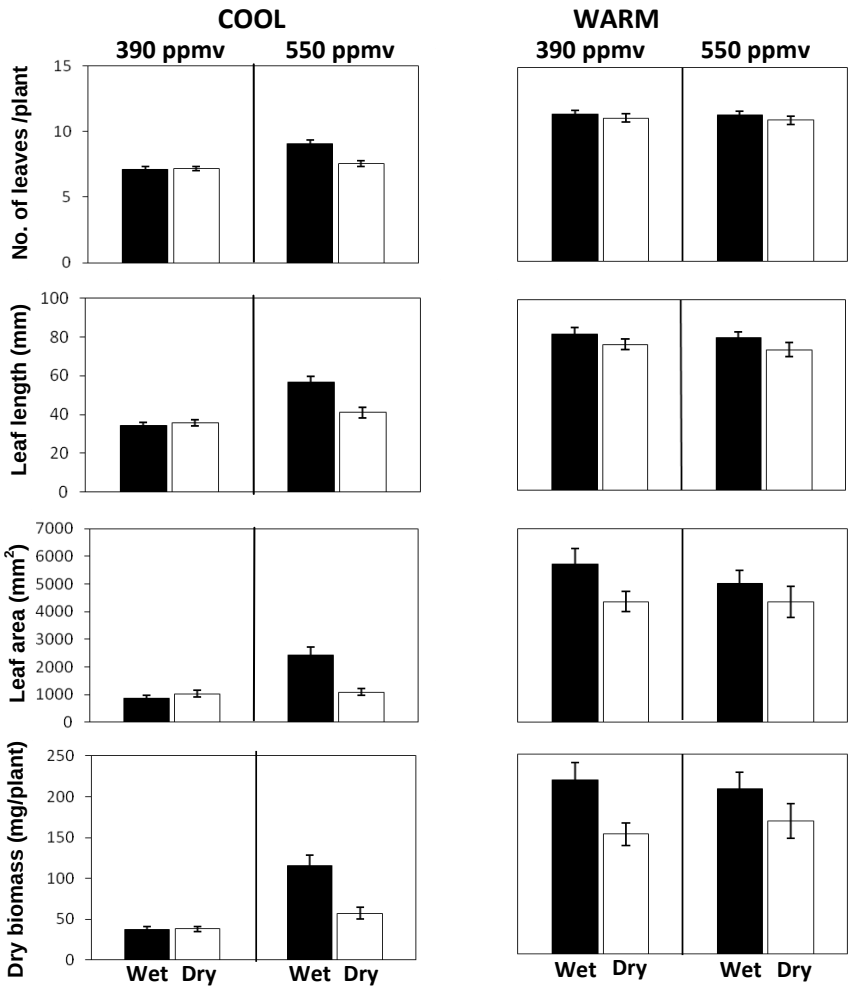

Figure 2. The number of leaves per plant, the length of the longest leaf, the leaf area and the dry biomass produced by seedlings of the Toogoolawah biotype of parthenium weed grown under a Cool temperature regime (30/15°C; day/night) or under a Warm temperature regime (35/20°C; day/night) and under an ambient CO_2 concentration (390 ppmv) or under an elevated CO_2 concentration (550 ppmv) at either of two soil moisture levels (i.e. field capacity: Wet or half of field capacity: Dry) and measured at the end of the 4 weeks study. Each treatment of the four variables had 60 replicate plants. Error bars represent two standard errors of the mean.

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