Effects of Elevated CO₂ on Growth of the Industrial Sweetpotato Cultivar CX-1

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The rising concentration of atmospheric carbon dioxide (CO₂) is known to directly affect plants, increasing growth, yield, and resource use efficiency. Further, research has shown that sweetpotatoes (Ipomoea batatas) represent a potential source for bioethanol production, particularly industrial cultivars bred specifically for this purpose. However, the effects of elevated CO₂ on these new industrial cultivars of sweetpotato remain uninvestigated. We grew industrial cultivar CX-1 sweetpotato plants in open top field chambers exposed to either ambient or elevated (ambient + 200 μmol mol⁻¹) CO₂ for one growing season and examined growth and allocation responses. Growth in elevated CO₂ increased biomass production for cultivar CX-1. In particular, total storage root dry weight increased by 40.9% compared to plants grown in ambient CO₂. Fresh weight allocation to belowground plant organs (fine roots and storage roots) also increased under elevated CO₂, but dry weight partitioning was unaffected. Aboveground (vines plus leaves) dry weight: fresh weight ratio was increased by elevated CO₂, indicating possible alterations in tissue anatomy and/or chemistry. Our findings indicate that the industrial sweetpotato cultivar CX-1 has potential as a source for bioethanol production, and this potential could be enhanced as atmospheric CO₂ continues to rise.

Keywords: bioethanol, biomass, CO₂, Ipomoea batatas, sweetpotato

INTRODUCTION

Atmospheric CO₂ concentrations have been steadily rising each year, from approximately 315 ppm in 1958 to 385 ppm in 2009 (Keeling et al., 2009), and are continuing to rise, with some estimates showing an increase to ~700 ppm by the end of this century (Meehl et al., 2007). Generally, increases in CO₂ are largely attributed to anthropogenic causes, including fossil fuel combustion and land use changes such as deforestation and urbanization (Hegerl et al., 2007).

It is well established that elevated CO₂ increases growth and yield of most plant species (Kimball, 1983). This added growth and yield is primarily attributed to increased rates of photosynthesis and water use efficiency (Rogers and Dahlman, 1993; Amthor, 1995). Growth in elevated CO₂ induces a partial closure of leaf stomatal guard cells resulting in reduced transpiration and water loss (Jones and Mansfield, 1970) which increases water use efficiency for plants with both C₃ and C₄ photosynthetic pathways (Prior et al., 2011). However, research has shown that biomass response to atmospheric CO₂ enrichment is generally greater for plants with a C₃ (33-40% increase) vs. a C₄ (10-15% increase) photosynthetic pathway (Kimball, 1983; Poorter, 1993; Prior et al., 2003; 2005). Plants with a C₃ photosynthetic pathway show both increased water use efficiency and increased photosynthesis, while the CO₂-concentrating mechanism used by C₄ plants limits their photosynthetic response to CO₂ enrichment (Amthor and Loomis, 1996).

Sweetpotatoes [Ipomoea batatas (L.) Lam.] have a C₃ photosynthetic pathway and, like most plants, have a positive growth response to elevated CO₂ (Bhattacharya et al., 1985; Biswas et al., 1996). In fact, total storage root dry weight response to CO₂ enrichment can exceed the general range for C₃ plants. Bhattacharya et al. (1985) reported increases of 87% at 675 μmol mol⁻¹ and 172.6% at 1,000 μmol mol⁻¹ for dry weight of ‘Georgia Jet’ storage roots. Biswas et al. (1996) reported total storage root dry weight increases of 44% and 75% at 665 μmol mol⁻¹ for two growing seasons. These large increases are not surprising since it is known that plants with a strong sink for photosynthate, such as sweetpotato storage roots, can respond to a greater degree than plants with other growth habits (Idso et al., 1988).

In addition to use as a food crop, sweetpotato storage roots have been shown to be a good source material for bioethanol production (Qiu et al., 2010). In fact, Ziska et al. (2009) reported that sweetpotatoes (cv. Beauregard) have the ability to out-produce other sources of crop plant bioethanol (e.g., corn, potatoes, sugar cane, and sugar beets) in both Maryland and Alabama. Recently, several “industrial cultivars” of sweetpotatoes have been bred specifically for bioethanol production. For example, storage roots of the industrial sweetpotato cultivar CX-1 (Ryan-
Bohac, 2016) were shown to have a higher bioethanol production potential than table varieties (Mussoline and Wilkie, 2017). However, how these industrial sweetpotato cultivars might respond to increasing atmospheric CO2 has not been examined. Therefore, we conducted a study to evaluate the growth and yield of the industrial sweetpotato cultivar CX-1 to elevated levels of atmospheric CO2.

MATERIALS AND METHODS

Sweetpotato slips of cultivar CX-1 were cut and planted in black containers (37 × 38 × 37 cm) with 31.8 kg of a 2:1 mixture of mineral soil to sand on 12 April 2011. Since a previous study had raised concerns that soil temperatures were excessive when the black containers were exposed to direct sunlight, containers were wrapped with white polyethylene film to help maintain cooler soil temperatures. Each container was planted with two sweetpotato slips and were thinned to one per container per temperatures. Each container was planted with two sweetpotato slips and were thinned to one per container after slips were well established. Containers were placed into open top field chambers at the soil bin facilities of the USDA-ARS National Soil Dynamics Laboratory, Auburn, AL on 2 May 2011. The bin used for this study was 6 m wide and 76 m long and was modified for container studies; modifications consisted of installing a geomembrane liner (20 mL) and gravel drain system to ensure a good working surface and drainage for container studies. Open top chambers (Rogers et al., 1983a), encompassing 7.3 m² of ground surface area, were used to continuously (24 h d⁻¹) deliver target CO₂ concentrations of ~395 μmol mol⁻¹ (ambient) or ambient plus 200 μmol mol⁻¹ (elevated) using a delivery and monitoring system described by Mitchell et al. (1995). There were 4 replicate chambers of each CO2 level for a total of 8 experimental plots; each chamber held 2 contain- ers in the event that one failed. The experimental design was a randomized complete block design, with blocks occurring along the length of the soil bin. All plants survived until the end of the study so data were collected on both containers from each open top chamber separately. On 15 May and 15 June, all containers were fertilized with 2.8 g of 13-13-13 (N-P-K) fertilizer. Each fertilizer application was equivalent to 50.2 kg/ha. Containers were watered evenly twice weekly by laboratory personnel.

On 24 October 2011 sweetpotatoes were destructively harvested after 175 d of CO₂ exposure. Aboveground plant portions in each container were harvested by severing the plant at the groundline. After fresh weights were recorded, aboveground portions (vines and leaves) were stored in standard brown paper bags, placed in a forced air oven at 55°C, dried to a constant weight, and dry weights were recorded. Root systems were rinsed on a sieve to remove growth media, separated into fine roots and storage roots, and fresh weights recorded for each part separately. Fine roots were placed into paper bags and dried using the procedures described for aboveground biomass, with dry weight recorded. Core samples were taken from storage roots and placed in a food dehydrator for 48 h to determine dry matter content.

Prior to analysis, data from the two containers in each plot were averaged to yield one value per plot. Data analysis was conducted using the mixed model procedures (Proc Mixed) of the Statistical Analysis System (Littell et al., 1996). Error terms appropriate to the randomized block design were used to test the significance of CO₂ treatments. In all cases, differences were considered significant at α < 0.05 and trends were recognized at 0.05 < α ≤ 0.10.

RESULTS AND DISCUSSION

Growth in elevated CO₂ increased fresh weights of storage roots (28.7%), but not fine roots or aboveground biomass (Table 1). This increase in storage root fresh weight resulted in increased total belowground and total plant fresh weight. Similar results were observed for plant part dry weight, except that aboveground dry weight was also increased by growth in elevated, compared with ambient, CO₂ (Table 2).

As previously mentioned, research has shown that biomass response to atmospheric CO₂ enrichment varies between plants with a C₃ (33–40% increase) vs. a C₄ (10–15% increase) photosynthetic pathway (Kimball, 1983; Poorter, 1993; Prior et al., 2003; 2005). In fact, biomass of

| Table 1 | The response of sweetpotato fresh weights (g) to ambient and elevated (ambient ± 200 μmol mol⁻¹) CO₂. Means with associated separation statistics and percent change (ambient to elevated) are shown. |
|---------|----------------------------------------------------------------------------------|
| Plant Part | Ambient CO₂ | Elevated CO₂ | % Change | P-values |
|----------|--------------|---------------|-----------|----------|
| Aboveground | 922.5 | 1000.0 | 8.4 | 0.389 |
| Fine Roots | 168.5 | 234.4 | 39.1 | 0.193 |
| Storage Roots | 3001.2 | 3861.2 | 28.7 | 0.003 |
| Belowground | 3169.8 | 4095.6 | 29.2 | 0.001 |
| Total Plant | 4092.3 | 5095.6 | 24.5 | 0.003 |

| Table 2 | The response of sweetpotato dry weights (g) to ambient and elevated (ambient ± 200 μmol mol⁻¹) CO₂. Means with associated separation statistics and percent change (ambient to elevated) are shown. |
|---------|----------------------------------------------------------------------------------|
| Plant Part | Ambient CO₂ | Elevated CO₂ | % Change | P-values |
|----------|--------------|---------------|-----------|----------|
| Aboveground | 154.7 | 192.1 | 24.2 | 0.027 |
| Fine Roots | 24.6 | 33.7 | 37.0 | 0.319 |
| Storage Roots | 705.8 | 994.5 | 40.9 | 0.020 |
| Belowground | 730.4 | 1028.2 | 40.8 | 0.014 |
| Total Plant | 885.1 | 1220.4 | 37.9 | 0.011 |
sweetpotato table varieties has been shown to increase under elevated CO₂, with increases in storage root dry weight exceeding the range for C₃ plants (Bhattacharya et al., 1985; Biswas et al., 1996). In the present study, total storage root dry weight increase was also at the top of the CO₂ response range for C₃ plants.

It has been shown that, in the absence of a sufficiently strong sink (i.e., when plants are under water and/or nutrient stress), excess carbohydrate production from growth in elevated CO₂ can actually damage plant leaves (Pritchard et al., 1997). However, when photosynthate supply is not source-limited (such as under elevated CO₂), plants alter allocation to soil-resource acquisition (i.e., water and/or N) by investing in roots and mycorrhizas (Runion et al., 1997). Therefore, it is not unexpected that storage root biomass would increase substantially under elevated CO₂ as seen in this study, the others noted above, and with other root crops (Idso et al., 1988).

Growth in elevated CO₂ affected partitioning of fresh weight among plant organs, with more (P = 0.031) being allocated to belowground (80.3% vs. 77.6% for elevated and ambient CO₂, respectively). This increased belowground allocation resulted in a corresponding increase in root:shoot ratio on a fresh weight basis under elevated CO₂ (4.10 vs. 3.47 for elevated and ambient CO₂, respectively). Dry weight partitioning and root:shoot ratio on a dry weight basis were not significantly affected by atmospheric CO₂ concentration (data not shown), although data did show a pattern similar to fresh weight partitioning (i.e., slightly more belowground).

Dry weight to fresh weight ratios were significantly increased only in aboveground tissue (vines plus leaves; Table 3). The increase in aboveground dry weight: fresh weight ratio led to a trend for increased whole plant dry weight:fresh weight ratio (Table 3). This increase could be due to several anatomical changes resulting from growth in elevated CO₂. For example, Rogers et al. (1983b) found that high CO₂-grown plants had thicker leaves and that soybean plants also developed an extra layer of palisade cells. Further, growth in high CO₂ has also been shown to alter epi cuticular waxes in plant leaves (Graham and Nobel, 1996; Prior et al., 1997). In addition to anatomical changes, plants grown in elevated CO₂ can also exhibit changes in tissue chemistry, including increased carbohydrate content (Yelle et al., 1989; Tissue et al., 1995; Pritchard et al., 1997).

Ziska et al. (2009) reported that sweetpotatoes (cv. Beauregard) have the ability to out-produce other sources of crop plant bioethanol (e.g., corn, potatoes, sugar cane, and sugar beets) in both Maryland and Alabama. Roots of the industrial sweetpotato cultivar CX-1, examined in the current study, have been shown to have a higher bioethanol production potential than the table cultivars Hernandez (27.6%) or Beauregard (71.1%; Mussoline and Wilkie, 2017). Given that we observed a large (40.9%) increase in total storage root dry weight production under elevated CO₂, it is expected that ethanol yield would have a corresponding increase since 90% of the dry matter in the CX-1 cultivar is carbohydrate (Ryan-Bohac, unpublished data). Further, it has been shown that growth in elevated CO₂ often increases carbohydrate content in crop plants (e.g., Yelle et al., 1989; Tissue et al., 1995; Pritchard et al. 1997), including sweetpotatoes (Bhattacharya et al., 1989). Therefore, although carbohydrate analysis was not conducted in our study, it can be expected that as the concentration of atmospheric CO₂ continues to rise, the CX-1 sweetpotato cultivar will produce more net dry matter carbohydrate yield per hectare which will increase the quantity of bioethanol produced per hectare. The effects of elevated CO₂ on ethanol production and use of vines as a nutritional animal feed (Mussoline and Wilkie, 2017) from industrial sweetpotato cultivars, such as CX-1, deserves further investigation.

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