Biomass Accumulation and Partitioning of Eastern Gamagrass Grown Under Different Temperature and CO_2 Levels

Donald T. Krizek[1]
USDA, ARS,
Sustainable Agricultural
Systems Laboratory,
BARC-West, 10300
Baltimore Ave.,
Beltsville, MD,
USA, 20705-2350

Dennis C. Gitz, III
V.R. Reddy[2]
USDA, ARS,
Alternate Crops and
Systems Laboratory,
BARC-West, 10300
Baltimore Ave.,
Beltsville, MD,
USA, 20705-2350

Jerry C. Ritchie
USDA, ARS,
Hydrology and Remote
Sensing Laboratory,
BARC-West, 10300
Baltimore Ave.,
Beltsville, MD,
USA, 20705-2350

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Abstract

Eastern gamagrass has been reported to have one of the highest photosynthetic rates of any C_4 species but data on temperature x CO_2 interactions are lacking. This study was conducted to determine the potential effects of future increases of atmospheric carbon dioxide on growth, biomass accumulation and root/shoot carbon allocation under three day/night temperatures and two CO_2 levels. Eastern gamagrass (cv. Pete) plants were grown in 1 m^3 soil bins containing sand:vermiculite (1:1), fertilized weekly with a complete nutrient solution in closed, transparent SPAR (Soil, Plant, Atmospheric Research) chambers maintained at 370 or 740 μmol mol^{-1} CO_2 and 20/14°, 27.5/21.5° or 35/29°C day/night temperatures, and allowed to develop from mid-May to mid-October. Three harvests were taken during this period. Leaves were collected during the first two harvests. During the final harvest, leaves, crowns, and roots were collected from each individual plant. The optimum day/night temperature under our conditions for biomass accumulation in the leaves (35/29°C) was higher than that for the crowns and roots (27.5/21.5°C). Biomass accumulation in leaves increased two-fold over the entire temperature range. Temperature had a greater effect on vegetative growth than CO_2. CO_2 enhanced biomass accumulation was modest, restricted to leaves, and observed only at higher temperatures and later in development. Under optimum soil moisture conditions in the SPAR chambers, high amounts of carbon were captured in the above ground biomass for later incorporation into soil. This study demonstrates the potential of eastern gamagrass to capture carbon for sequestration under projected global climate change scenarios.

INTRODUCTION

Eastern gamagrass [*Tripsacum dactyloides* (L.) L.] is a robust, warm season, perennial bunch grass which is native to North America, Central America, and upper South America. It produces high yields of palatable and digestible forage with protein content comparable to alfalfa (Horner et al., 1985; Coblentz et al., 1998; Bidlack et al., 1999). It exhibits tolerance to a wide range of environmental stresses and soil conditions including drought, flooding, aluminum toxicity and acid soils (Foy et al., 1999; Gilker et al., 2002; Krizek et al. 2003). It is an attractive species for use in sustainable agriculture because of its ability to penetrate acid, compact soils (Clark et al. 1998; Krizek et al. 2003) and to reduce the runoff of nutrients and sediment to nearby streams, when planted as a buffer strip (Ritchie et al., 2000).

Increases in the Earth's atmospheric carbon dioxide (CO_2) concentration and associated changes in global climate have gained world-wide attention. There is keen interest among scientists as to how projected increases in CO_2 and the associated increase in atmospheric temperature will affect crop production of C_3 and C_4 species (Reddy et al.,

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1994; Kimball et al., 2002). Studies are needed to determine the response of eastern gamagrass to elevated CO_2 if this warm season grass is to be considered as a potential candidate for carbon sequestration. Eastern gamagrass has been reported to have one of the highest leaf photosynthetic rates of any C_4 species (Coyne and Bradford, 1985) but data on temperature x CO_2 interactions are lacking. This study was conducted to determine the potential effects of future increases of atmospheric carbon dioxide on growth, biomass accumulation and root/shoot carbon allocation at three temperatures and two levels of CO_2.

MATERIALS AND METHODS

Eastern gamagrass plants were grown in six naturally lit Soil-Plant-Atmosphere-Research (SPAR) plant growth chambers. These chambers are useful for studying canopy and ecosystem or small-plot responses to combinations of variables in controlled field-like environments (Tingey et al., 1996; Reddy et al., 2001). Each SPAR unit consists of a soil bin containing the rooting medium and a 1.27 cm thick acrylic (Plexiglas G) chamber that accommodates the aerial plant parts. Each chamber measures 2.5 m high x 2.0 m long x 0.5 m wide. A door in the bottom of each chamber is hinged for easy access to the plants. There are ducts on the northern face that connect to the cooling system. Conditioned air is introduced at the top of the chamber, flows down through the plant canopy, and is returned to the ducts just above the soil level. The soil bins containing the rooting medium measure 1.0 m high x 2.0 m long x 0.5 m wide and are not temperature controlled. The south face consists of tempered glass to allow root observations. Variable-density shade cloths, positioned around the edges of the canopy, are adjusted to simulate the presence of neighboring plants. Temperature, CO_2, and relative humidity are controlled and monitored by a computerized data acquisition and control system.

Germtec II^{TM} treated seed of eastern gamagrass (cv. Pete) were obtained from Gamagrass Seed Company (Falls City, NE) and sown in the greenhouse on a hot pad at 30^{o}C. On May 16, 2001, after 3 weeks in the greenhouse, seedlings were selected for uniformity and transplanted into six SPAR chambers. Seedlings were selected that had not developed lateral shoots. Two rows of eight plants each were transplanted into the 1 m^3 soil bins containing sand:vermiculite (1:1) mixture and fertilized weekly with a complete nutrient solution. Plants were grown at three day/night temperatures (20/14°, 27.5/21.5°, or 35/29°C) and two CO_2 levels (370 or 740 $\mu mol\ mol^{-1}$). Three SPAR chambers were maintained at each of these temperatures at 370 $\mu mol\ mol^{-1}$ CO_2 (ambient) and three were maintained at 740 $\mu mol\ mol^{-1}$ CO_2 (elevated). The thermoperiod was adjusted weekly. Water was supplied 2-3 times a day by a drip irrigation system. Analysis of variance was used to determine statistical significance at the 0.05 level of probability.

RESULTS

Growth and Flowering Responses

Temperature had a greater effect on vegetative growth of eastern gamagrass plants than CO_2 concentration (Fig. 1). Eastern gamagrass plants showed rapid increases in shoot elongation, leaf initiation and tiller development with increases in temperature. Plants grown at the warm temperatures (27.5/21.5^{o}C and 35/29^{o}C) were darker green than those grown at the cool temperature (20/14^{o}C), possibly reflecting a difference in leaf thickness and chlorophyll content. Plants grown at warm temperatures showed greater tiller development than those grown at a cool temperature (Fig. 1) but the number of leaves per tiller did not differ (data not shown). Reproductive shoots were observed within four months of transplanting the seedlings to the SPAR chambers. Within five months, a number of the plants had reached anthesis or had started to form seed heads. Reproductive development was most pronounced at 20/14°C and 27.5/21.5°C.

Biomass

Differences in biomass between any two, temperature treatments were always significant, but differences in CO_2 treatment were not always significant (data not shown). Biomass of leaves showed a progressive increase with increase in temperature, more than doubling from 20/14°C to 35/29°C; this was true at both ambient and elevated CO_2 (Fig. 2). Plants grown at 740 µmol mol^{-1} CO_2 generally had a greater biomass of leaves than those grown at 370 µmol mol^{-1} CO_2, although these differences were small at 20/14°C and 35/29°C. Biomass of crowns and roots increased rapidly from 20/14°C to 27.5/21.5°C, but then declined when the temperature was increased to 35/29°C; this was true at both CO_2 levels (Fig. 3, 4). There was little difference in biomass of crowns and roots between the two CO_2 levels at the warmer temperatures; however, at 20/14°C, there was a 20% increase in root biomass under elevated CO_2 (Fig. 4). CO_2 enrichment increased biomass per leaf by about 10% at warm temperatures, but had a slight inhibitory effect at cool temperature (Fig. 5).

Biomass Allocation

The percent of biomass allocated to the leaves was approximately 55 to 70%, while that allocated to the crowns was approximately 38% or less (Fig. 6). Only about 5 to 10% of the biomass was allocated to the roots. Overall, temperature had a much greater influence on amount of biomass allocated to the leaves, crowns and roots than did CO_2. There was a slight, but not significant, increase in biomass allocation to the roots at 20/14°C under elevated CO_2, but at warmer temperatures, the pattern was reversed (Fig. 6). In all cases, however, these differences in dry matter allocation to the roots with CO_2 were not significant. The root/shoot ratio was greatest in plants grown at 27.5/21.5°C, least at 20/14°C, and intermediate at 35/29°C; CO_2 enrichment increased root/shoot ratio at 27.5/21.5°C but otherwise had no appreciable effect (data not shown).

Leaf Expansion

Increasing the day/night temperature from 20/14°C to 27.5/21.5°C resulted in nearly a 10% increase in average leaf area at ambient CO_2 and nearly a 20% increase at elevated CO_2. A further increase in temperature from 27.5/21.5°C to 35/29°C resulted in only a slight increase in average leaf area at ambient CO_2 but a decrease in average leaf area at elevated CO_2 (Fig. 7).

Leaf Carbon and Nitrogen

Concentration of carbon and nitrogen in the leaf greatly increased with temperature (Figs. 8, 9). This was true at both ambient and elevated CO_2. There was approximately a two-fold increase in leaf nitrogen and a three-fold increase in leaf carbon between 20/14°C and 35/29°C.

DISCUSSION

The optimum day/night temperature in our experiments for biomass accumulation in the leaves of eastern gamagrass (35/29°C) was higher than that for the crowns and roots (27.5/21.5°C); this was true at both ambient and elevated CO_2. Biomass production in the SPAR chambers greatly exceeded that in the field (Krizek et al., 2003). The fact that only about 10% of the dry matter was allocated to the roots even at elevated CO_2 was surprising in view of the fact that CO_2 enrichment has frequently been found to stimulate root biomass (Reddy et al., 1994) and increase carbon allocation to the roots as reflected in an increase in root/shoot ratio (Rogers et al., 1996). Had the plants been grown in a different substrate and under conditions in which soil moisture was limiting, it is possible that the plants would have shown greater carbon allocation to the roots under both ambient and elevated CO_2. Baker et al. (1990) obtained a 50% increase in root/shoot ratio in rice (*Oryza sativa* L.) when plants were grown in SPAR chambers at 660 µmol mol^{-1} CO_2 vs 330 µmol mol^{-1} CO_2.

It is generally accepted that C_3 plants are more responsive to elevated CO_2 than C_4 plants (Krizek, 1986; Leonardos and Grodzinski, 2000; Kimball et al., 2002) and are expected to benefit more than C_4 plants from higher CO_2. However, recent reports suggest that at elevated temperatures and under moisture stress conditions, C_4 plants are capable of being more competitive than C_3 plants (Ward et al., 1997; Ziska et al., 1999; Seneweera et al., 2001).

Although there is anecdotal evidence (Dewald, personal communication, 1998) that warm temperatures are optimal for propagation of eastern gamagrass in the greenhouse, this is the first study in which elevated temperatures have been shown to be optimal for vegetative growth of eastern gamagrass plants at ambient and elevated CO_2 under controlled conditions. SPAR chambers have proved highly useful in studies on CO_2 x temperature interactions (Tingey et al., 1996; Reddy et al. 2001). Based on our results for a single growing season, it is clear that eastern gamagrass accumulates high levels of carbon in the above ground biomass at elevated temperature, which are projected to occur along with increasing CO_2. Much of this carbon is incorporated in the soil to increase the organic matter and contribute to carbon sequestration. Further studies are needed to assess the effects of CO_2 and temperature increases on carbon accumulation in this warm season grass and its contribution to soil carbon sequestration.

CONCLUSIONS

The optimum temperature in our study for biomass accumulation in the leaves (35/29°C) was higher than that for the crowns and roots (27.5/21.5°C). Plants grown at warm temperatures had twice the biomass as those grown at a cool temperature. Temperature had a greater effect on growth than CO_2 enrichment. Under optimum soil moisture conditions of our study, high amounts of carbon were captured in the above ground biomass for potential later incorporation into the soil. This study demonstrates the potential of eastern gamagrass to capture carbon for sequestration under projected global climate change scenarios.

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Figures

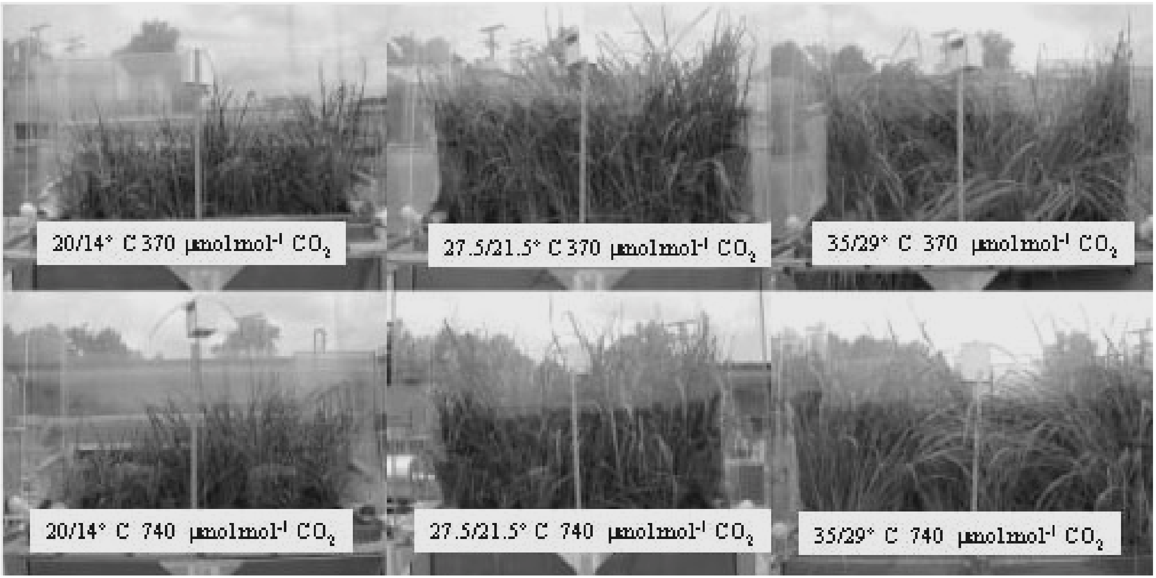

Fig. 1. Images taken on July 31, 2001 of 11 week-old eastern gamagrass grown in SPAR chambers at 3 day/night temperatures and 2 CO_2 levels.

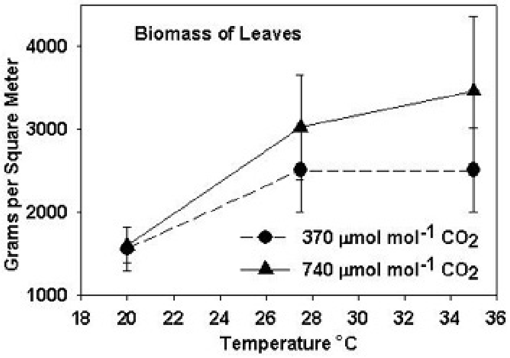

Fig. 2. Biomass of leaves of eastern gamagrass grown 5 months at 3 day/night temperatures and 2 CO_2 levels.

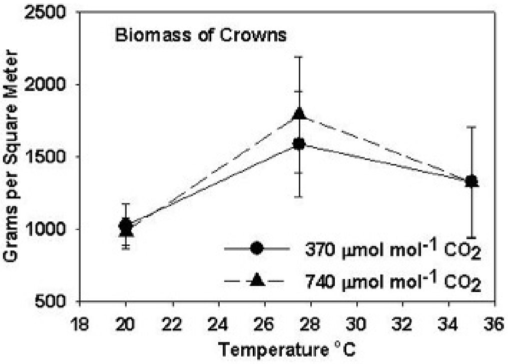

Fig. 3. Biomass of crowns of eastern gamagrass grown 5 months at 3 day/night temperatures and 2 CO_2 levels.

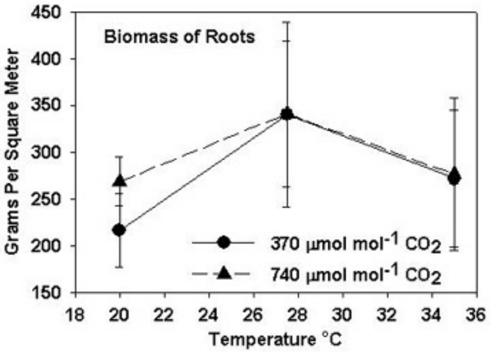

Fig 4. Biomass of roots of eastern gamagrass grown 5 months at 3 day/night temperatures and 2 CO_2 levels.

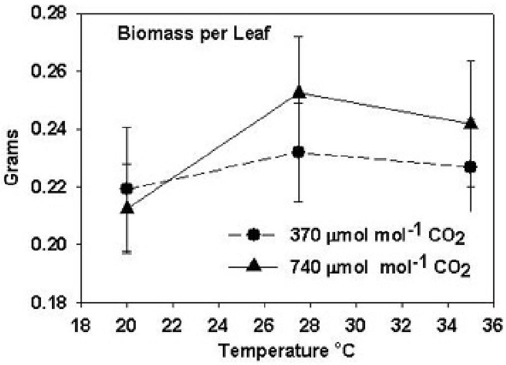

Fig. 5. Average biomass per leaf of eastern gamagrass grown 5 months at 3 day/night temperatures and 2 CO_2 levels.

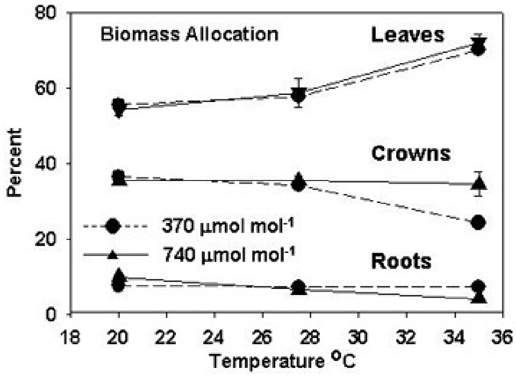

Fig. 6. Allocation of biomass of eastern gamagrass grown 5 months at 3 day/night temperatures and 2 CO_2 levels.

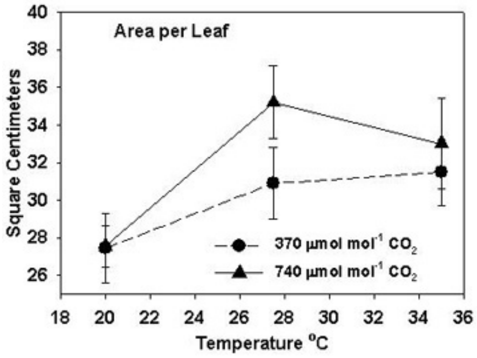

Fig. 7. Average leaf area of eastern gamagrass grown 5 months at 3 day/night temperatures and 2 CO_2 levels.

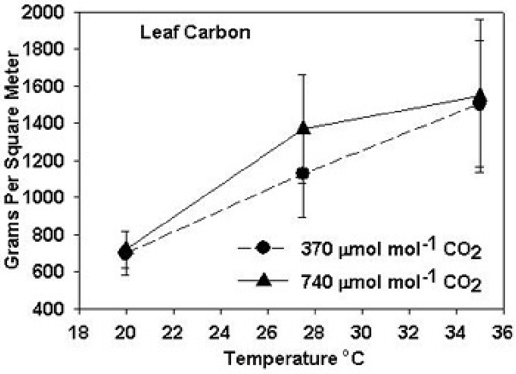

Fig. 8. Carbon content of leaves of eastern gamagrass grown 5 months at 3 day/night temperatures and 2 CO_2 levels.

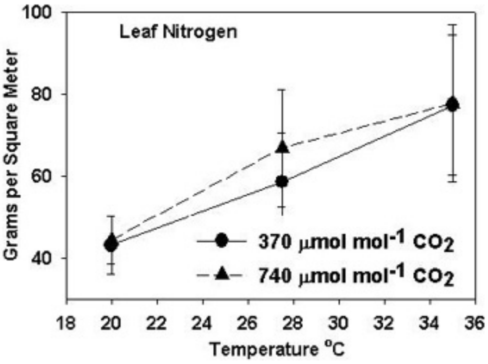

Fig. 9. Nitrogen content of leaves of eastern gamagrass grown 5 months at 3 day/night temperatures and 2 CO_2 levels.