The effect of global warming on dry bean and maize production on the highlands of Mexico.

A. Núñez[1*], E. Sánchez[1], J. L. Ibave[1], and S. NeSmith[2]

[1] *Facultad de Ciencias Agrotecnologicas, Universidad Autónoma de Chihuahua, Ciudad Universitaria s/n Campus 1. Teléfono (614) 4391844. Fax (614) 391845.* [2] *Horticulture Department, University of Georgia, Griffin, Georgia, USA*

Recibido 28 mayo 2007, revisado 09 septiembre 2007, aceptado 11 noviembre 2007

El efecto del calentamiento global en la producción de frijol y maíz en la sierra de México

Abstract

Global warming may affect growth and production of maize and beans. A study was conducted in the Georgia Environtron Laboratory of the University of Georgia. A factorial experiment with four temperatures (20, 25, 30 and 35°C) and two CO_2 levels (400 and 800 ppm) was established in chambers with control environment. Data were taken on dry matter production, plant height, stages of development and yield per plant. For maize, temperatures had a significant effect on plant height, flowering and dry matter accumulation but plant response to CO_2 concentrations was not significant. Dry beans responded to both, temperatures and CO_2 treatments. For 20 and 30°C, the increment of dry matter was 72 and 76% increasing CO_2 from 400 to 800ppm. Beyond 30°C, accumulation of dry matter in beans was drastically diminished. No reduction on maize yield was observed in the range of temperatures treatments, but for dry bean, seed production showed a significant decreased with temperatures above 25°C. A GIS system was used to estimate the risk of maize and bean production areas under a global warming scenario (+3°C). It was found that more than 100 000 ha planted with beans are under higher risk. Maize production seems not to be affected neither for increasing temperatures nor greater concentration of CO_2.

Key words: Global warming, carbon dioxide, temperature, maize, beans, highlands

Resumen

El calentamiento global puede afectar la producción de cultivos como el maíz y frijol. Este estudio se llevo a cabo en el laboratorio Environtron de la Universidad de Georgia. Un experimento factorial con cuatro temperaturas (20, 25,30 y 35°C) y dos niveles de CO_2 (400 y 800 ppm) fue establecido en cámaras de ambiente controlado. Se tomaron datos de materia seca, altura de planta, estados fonológicos y rendimiento por planta. El efecto temperaturas incrementó significativamente la altura de planta y acumulación de materia seca en maíz pero este cultivo no respondió a los tratamientos de CO_2. En cambio en frijol se observó respuesta tanto a temperaturas como a las concentraciones de bióxido de carbono. La materia seca se incrementó en un 76% al pasar de 400 a 800 ppm a una temperatura de 30°C. El rendimiento de frijol disminuyó drásticamente con temperaturas mayores a los 25°C reduciéndose en más de 50% su rendimiento. Con el Sistema de información Geográfica (SIG) se estimó que mas de 100 000 ha de frijol podrían estar en riesgo en el Altiplano Mexicano con un escenario de calentamiento global de +3°C. La producción de maíz parece tener un bajo impacto por los incrementos de temperatura y las altas concentraciones de CO_2.

Palabras clave: Calentamiento global, dióxido de carbono, temperatura, maíz, frijol, altiplano.

* Autor de correspondencia
E-mail: *anunez@uach.mx*

Introduction

Maize and dry beans are some of the most important crops growing in the highlands of Mexico where more than 1.5 million hectares are annually planted with these crops. The region covers the states of Chihuahua, Durango and Zacatecas, providing half of the beans consumed in the whole Country. Black and Pinto beans are the most important genotypes grown in the zone and they are well adapted to the mild temperatures of this region (Pajarito and Moncayo, 2000). Average yields of maize and beans are around 950 kg ha^{-1} and 595 kg ha^{-1} respectively (Acosta et al., 2002). However, global warming may be influencing the growth, development and yield of beans and corn decreasing the availability of the region to provide basic grains to the nation as well as diminishing the probabilities of better income for farmers. Projected changes in climate may reduce up to 50% farm production and profitability under dry land conditions as compared to the production obtained under regular historical climate (IPCC, 2001; Michele et al., 2005). Lower yields would likely affect the capacity of the farmers to adopt some practices that has been recommended to prevent land degradation and increasing CO_2 production. Areas well cultivated with maize and dry beans in Mexico highlands produced 4 times less CO_2 than areas with degraded soils and poor vegetation (Angoa Perez et al., 2004) nevertheless, the sustainability of these crops depends on our understanding of how the climate change may affect them. Maize and bean respond in a different way to increasing CO_2 and temperature. Bean is a C3 plant and it has been found that crops with this photosynthetic path system may increase dry matter production under enriched CO_2 environments (Owensby et al., 1989; Drake et al., 1997; Hungate et al., 1999), but they are susceptible to high temperatures, mainly during the flowering stages (Ahmed et al., 1992). Maize is a C4 better adapted to warmer environments (Sinclair and Rawlins, 1993). However it is not well understood how global warming may affect the growth and yield of maize and bean under the climatic conditions of

Mexico highlands in such a way that these crops will still be an economic and sustainable option for farmers. Hence, the objectives of this study were:
1.To understand the effect of increasing temperature and CO_2 concentration on the growth, development and yield of maize and dry beans.
2. To characterize regions with different production risks for maize and dry beans in Mexico's highlands.

Material and methods

This research was conducted during 2003 in the Georgia's Environtron Laboratory at Griffin Experimental Station of the University of Georgia. Six walk-in chambers with control environment were used for this investigation. Treatments (6) were set in a factorial experimental design with a combination of three day/night temperatures (25/20, 30/25 and 35/30°C) and two levels of CO_2 (400 and 800 ppm). Two smaller chambers set at 400 and 800 ppm were used to monitor crop response to cooler temperatures (20/15°C), completing 8 treatment total. Temperatures treatments were selected to simulate the range of temperatures observed during the growing season in the maize/beans producing region of México's highlands, this is from 20 to 30°C and the 35°C temperature was included to simulate the effect of global warming. A black bean raven variety and a maize short season hybrid, Pioneer 31G98, were used for this study. Plants were planted in plastic pots (25 kg weight) in a fine sandy soil and watered twice a week with a Hoaglan's solution using an automated irrigation system. Data were taken on dry matter production, plant height, stages of development and yield per plant. To estimate accumulated dry matter production per treatment, plants were harvested at the end of the experiment and placed in paper bags in an oven drier for 36 h at 60°C. For yield estimates, seed were collected at the end of the season and weights standardized at 12% seed humidity. Due to the homogeneity of the Environtron growing chambers, the collected data were analyzed in a Complete Randomized Design with three replicates per treatment.
The Environtron data were used to assess the possible risks of increasing temperatures at the maize/bean region of Mexico highlands. A Geographic Information System was applied as a tool to overlap the surface (hectares) planted with these crops and the temperature gradient

(isotherms) that cover the highlands of Mexico including Chihuahua, Durango and Zacatecas States. Isothermal lines were drawn in a range of 2°C (<18°C, 18-20°C, 20-22°C, 22-24°C and >25°C) taking into consideration the historical mean temperature of the growing season (June/October). Isotherms were overlapped to the maize/bean producing area (Acosta et al., 2002) and the number of hectares was counted in-between isotherms. Temperatures were then increased in 3°C trying to simulate the effect of global warming on the region to determine the qualitative risk (low, medium and high) of different zones using the response curves of maize and bean obtained in the Environtron. México's highlands may already be affected by global warming since higher than historical maximum temperatures have been observed in this area in the last five years.

Results and discussion

Temperatures gradient and concentrations of CO_2 set for this experiment affected in different ways the growth and development of the crops under study. Increasing temperatures had a positive effect on maize shoot extension. Plant height was increased by 12% with temperatures between 25 and 30°C. Flowering was 9 days earlier in the 30°C treatment as compared to the 25°C treatment under both concentration of CO_2. At higher temperature (35°C), maize plant height and development were not significantly different to the ones in the 30°C treatment. Increasing CO_2 levels had not a significant effect on maize plant height. Colleman and Bazzaz, (1992) found that C4 plants such as maize and sorghum were not affected by higher CO_2 concentration. On the other hand, plant height and flowering time on dry beans were influenced for both, temperature and CO_2 levels. Increasing CO_2 concentration from 400 to 800 ppm caused an augmentation of plant height of 24.5, 19.2, 17.1 and 3.6% for the 20, 25, 30 and 35°C treatment respectively. Higher temperatures seem to override the benefits that greater concentrations of CO_2 may have on a C3 plants. Bunce and Ziska, (1996) found that temperatures above 30°C significantly increase respiration and cell degradation on some C3 cultivars such as soybeans. In the current experiment, early flowering was observed at higher concentrations of CO_2 (800 ppm) as compared to the lower ones (400 ppm) mainly for temperatures treatments of 20 and 25°C. The CO_2 treatments had greater effects on the growth of bean than in maize. Accumulation of dry matter in plants is one of the main factors affected by global warming (Long and Woodward, 1988; Ewert et al., 2002) however the patterns of dry matter production of maize and dry beans in the current experiment were different as shown in Fig. 1 and 2.

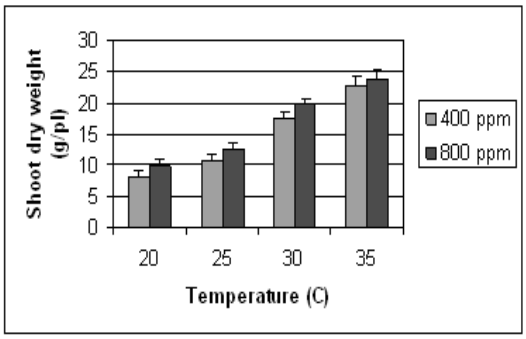

Figure 1. The dry matter production of maize under different temperaturees and CO_2 treatments.

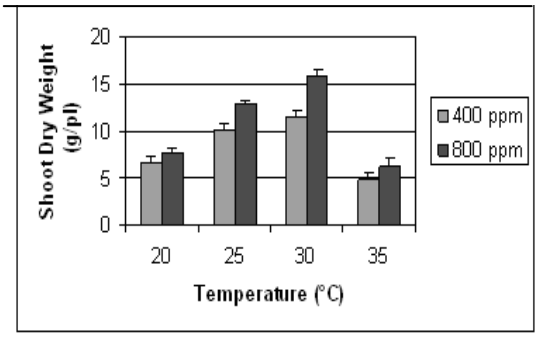

Figure 2. Beans dry matter profuction as affected by temperatures and Co_2 concentrations.

Maize has a significant increment of shoot dry weight (leaf and stems) in the temperature range between 20 and 35°C. The plant response to the different levels of CO_2 was not significant. On the other hand, the accumulation of dry matter on beans was affected by both, temperatures and CO_2 treatments. From 20 to 30°C the increment in dry matter was 72 and 76% for 400 and 800 ppm of CO_2 respectively. Beyond 30°C, accumulation of dry weight was drastically diminished. Temperatures of 35°C reduced the production of dry matter in more than 50% as compared to temperatures of 30°C. Flint and Patterson (1983) found that temperatures above 28°C began to affect the growth C3 species but C4 plants may stand

temperatures above 35°C without significantly reducing dry matter production. In the current experiment, greater concentration of CO_2 positively affected the growth of dry beans reaching the maximum difference at a temperature of 30°C where the treatment 800 ppm had 38.2% more dry weight (leaves and stems) than the 400 ppm treatment. This response of C3 plants to elevated CO_2 concentrations has been reported by different investigators (Coleman and Bazzaz, 1992; Poorter, 1993).

The yield of maize (Fig. 3) seems to follow the same pattern response than the one observed on dry matter accumulation. An increment of temperature from 20 to 35°C may double the seed weight under the conditions of this experiment. However, the yield response to temperatures in dry beans (Fig. 4) showed that at 30°C there is remarkable diminishing of more than 100% in seed weight as compared to the 25°C treatment. Flowering and pod set in dry beans and other C3 plants, have been found to be very sensitive to high temperatures frequently causing a detrimental decrease in final yield (Ahmed et al., 1992; Gross and Kiegel, 1994; Porch and Johns, 2000).

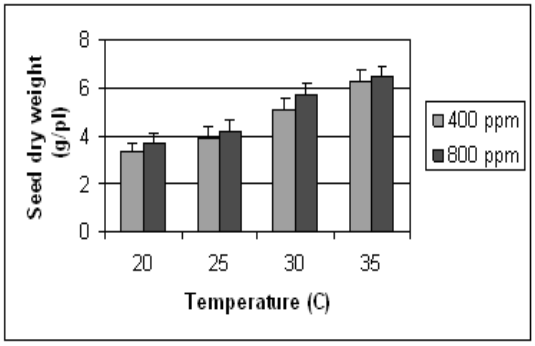

Figure 3. Yield of maize at different temperatures and CO_2 concentrations.

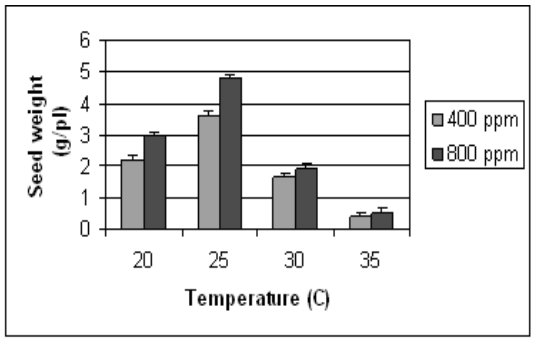

Figure 4. Yield of dry beans at different temeratures and CO_2 concentrations.

The simulation of global warming and the response curves obtained in the Georgia's Environtron laboratory were used to understand the risk of maize and bean producing regions of México's highlands at the foresight of increasing temperatures and concentrations of CO_2. Isotherms lines that cover the whole region were drawn based on historical mean temperature of the growing season with a gradient that goes from less than 18.0°C to more than 25.0°C. Utilizing the GIS tool, isothermal lines were overlap with the areas cultivated with maize and beans under both, actual and global warming (+3°C) scenarios. An increase of temperature and CO_2 seems not to affect the cultivation of maize on the highlands of Mexico. The Environtron data showed that this crop may withstand temperatures around 35°C which are much higher than the ones registered during the growing season in the area. Also, maize was not significantly affected by elevated concentration of carbon dioxide. However dry bean cropping and production may be much more sensitive to global warming especially to increasing temperature. The predicted risk of higher temperatures on dry bean and maize producing area is shown in Table 1.

We may observe in Table 1 that maize has a low risk in the whole area but the cropping region of dry beans actually located in zones with isotherms beyond 25°C may have the higher risk because the increment of temperature between 25 and 30°C could affect flowering, pod set and final bean yield as observed in the Environtron response curves. This region covers a surface about 110 000 ha and is located at the eastern part of Mexico highlands including important bean producing zones such as Cuencame and Guadalupe Victoria (Dgo.), Rio Grande (Zac.) and Cuauhtémoc (Chih.). A zone with medium impact level of the global warming is

found between 22 and 24°C. In this extended area some symptoms of climate change is already been noticed. Acosta et al. (2002) found that some varieties such as Pinto Villa and black beans began to show a decreasing yield due to an increasing fungal and bacterial diseases probably due to the unusual warmer years observed in the last five years. The risk on these areas may be reduced to some extent using the genetic improvement of beans base on heat tolerance. Tropical bean varieties have been found to be resistant to high temperatures and some programs have started a selection of heat tolerance bean genotypes (Hall, 1992; Porch and John, 2000).

Table 1. Isotherm range and the risk of bean and maize cropped surfaces (ha) in Mexico´s highlands under actual and global warming scenario.

Crop/surface	Isotherms				
	<18°C	18-20°C	20-22°C	22-24°C	>25°C
Bean/actual hectares Global warming risk (+3°C)	220 000 low	440 000 low	198 000 low	132 000 medium	110 000 high
Maize/actual hectares Global warming risk (+3°C)	120 000 low	160 000 low	150 000 low	140 000 low	130 000 low

Conclusions

Increasing temperatures affected more the growth in dry beans than in maize. Temperature above 25°C sharply diminished the yield of beans but increased the seed yield in maize. Higher concentrations of CO_2 (800 ppm) increased seed and dry matter production in beans, however this effect is overriding by temperatures beyond 30°C. Global warming may affect more the eastern part of México's highlands including more than 110 000 ha of the bean producing zone. A genetic improvement program of dry beans related to the development of heat tolerant varieties may help in the sustainability of this area as a source of food and production basic grains so needed for the Mexican population.

Bibliografia

Acosta G. J., Sánchez, I., Ochoa, R., Pajarito and Ibarra F., 2002. Impacto Económico de la variedad del frijol Pinto Villa en el Altiplano Semiárido de México. Campo Agrícola Experimental Valle del Guadiana. CIRNOC, INIFAP. Durango, México.

Ahmed, F.E., Hall, A.E. and Demason, D.A.,1992. Heat injury during floral development in cowpea (vigna uniguiculata, Fabaceae). American Journal of Botany, 79: 784-791.

Angoa Perez, J., Gonzalez Castañeda, J.T. and Frias Hernandez,A., 2004. Trace gas emissions from soils of the central highlands of Mexico. Biol. Fertility of Soils, 40: 252-259

Bunce, J.A. and Ziska, L.H., 1996. Responses of respiration to increase in carbon dioxide concentration and temperature in three soybean cultivars. Annals of Botany, 77: 507-514.

Coleman, J.S. and Bazzaz, F.A., 1992. Effects of CO_2 and temperature on growth and resource use of CO-occurring C3 and C4 annuals. Ecology, 73: 1244-1259.

Drake, M.A., Gonzalez, M. and Long, S.P., 1997. More efficient plants: a consequence of rising atmospheric CO_2. Ann. Rev. Plant Physiol., 48:987-995

Ewert, F., Rodríguez, D. and Jamieson, P., 2002. Agriculture, Ecosystems and Environment, 93: 249-266.

Flint, E.P.and Patterson, D.T. 1983. Influence and temperature effects on growth in soybean (Glycine max) and associated C3 ad C4 weeds. Weed Sci., 31: 193-199.

Gross, Y. and Kiegel J., 1994. Differential sensitivity to high temperature of stages in the reproductive development of common bean (Phaseolus vulgaris L.). Field Crops Research, 36(3): 201-212.

Hall A.E. 1992. Breeding for heat tolerance. Plant Breeding Reviews, 10: 129-168.

Hungate, B.A., Dijkstra, P., Johnson, D.W., Hinkle C.R. and Drake B.G., 1999. Elevated CO_2 increases nitrogen fixation and decreases soil nitrogen mineralization in Florida scrub oak. Global Change. Biol. 5: 1-9.

IPCC. 2001. Climate Change: Impact, adaptation and vulnerability. A report of working group II of the Intergovernmental Panel on Climate Change. 18 p.

Long, S.P. and Woodward, F.I.,1988. Plants and temperature. Symposia of the Society on Experimental Biology. 42: 53-71.

Michele, D., Pannell, J. and Kingwell, R., 2005. Climate change and the economics of farm management in the face of land degradation. Can. J. of Agric. Economics, 53:443-445

Owensby, C.E., Coyne, P.I. and Allen, L.M., 1989. Rangeland-plant response to elevated CO_2. II. Large Chamber system. Series 054. Response of vegetation to carbon dioxide. U.S. Dept. of Energy. Washington D.C. 42 pp.

Pajarito, A. and Moncayo, R.J., 2000. Transferencia de Tecnología del frijol en el estado de Durango: Análisis e impacto. Publicación Especial. Num. 15. CEVAG-CIRNOC-INIFAP-SAGAR. Durango, México.

Poorter, H. 1993. Interspecific variation in the growth response of plants to an elevated ambient CO_2 concentration. Vegetation, 104: 77-97.

Porch, T.G. and Johns, M., 2000. Effects of high temperature stress on microsporogenesis in heat sensitive and heat tolerant genotypes of Phaseolus vulgaris. Plant Cell Environ, 24: 723-731.

Sinclair, T.R. and Rawlins, S.L., 1993. Inter-seasonal variation in soybean and maize yield under global environmental change. Agron.J. 85:406-409.