EFFECTS OF COMMERCIAL ORGANIC AND CYANOBACTERIAL FERTILIZERS ON INSTANTANEOUS WATER USE EFFICIENCY IN DRIP IRRIGATED ORGANIC SWEET CORN

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ABSTRACT

Water and fertilizers are applied to maintain crop growth, yield, and quality. Nitrogen (N) fertilizer plays a crucial role in crop growth and yield development of sweet corn (*Zea mays*). Organic growers often use commercial organic animal-based fertilizers which vary in nutrient composition, forms of available N (NH_4^+-N and NO_3^--N), and have high transportation costs. Alternatively, cyanobacteria can be grown on-site as a source of N. Cyanobacteria haves unique dual properties because they can both fix N from the atmosphere and photosynthesize to produce N biofertilizer without fossil fuels. Forms of available N in organic fertilizers may influence photosynthetic enzymes, and therefore photosynthesis (Pn), stomatal conductance (g_s), transpiration rate (Tr), and instantaneous water use efficiency (iWUE) were measured to evaluate the effect of different organic fertilizers on sweet corn. A field experiment was conducted during the summer of 2014 at the Horticulture Field Research Center, Colorado State University, Fort Collins, CO. The treatments were solid organic fertilizers,; feather meal and blood meal and liquid organic fertilizers,; fish emulsion and cyanobacteria, applied at 56 and 112 kg N ha^{-1}. Liquid organic fertilizers were applied every two weeks after planting while the solid organic fertilizers were applied prior to planting. Leaf gas exchange measurements were conducted using a LI- 6400XT portable photosynthesis system at 66 days after planting and Pn, Tr, and g_s were automatically recorded. Instantaneous WUE was calculated as a ratio of Pn to Tr and expressed in $\mu mol\ CO_2 \cdot mol^{-1}\ H_2O$. The feather meal treatment recorded the significantly lowest Pn (19.5 $\mu mol\ m^{-2}\ s^{-1}$) at 112 kg N ha^{-1} compared to other fertilizer treatments at 56 and 112 kg N ha^{-1}. The cyanobacterial treatment recorded the significantly lowest Tr (0.6 mmol $H_2O\ m^{-2}\ s^{-1}$) and g_s (0.05 mol $H_2O\ m^{-2}\ s^{-1}$) at 56 kg N ha^{-1} compared with other fertilizer treatments at 56 and 112 kg N ha^{-1}. The cyanobacterial treatment also recorded the significantly highest iWUE (3 $\mu mol\ CO_2\ mmol^{-1}\ H_2O$) at 56 kg N ha^{-1} compared to other fertilizer treatments at 56 and 112 kg N ha^{-1}. In conclusion, feather meal fertilizer recorded significantly lower Pn at 112 kg N ha^{-1} and the cyanobacterial biofertilizer application resulted in significantly lower stomatal conductance and transpiration rate, thus recording a higher iWUE at both N rates in drip irrigated sweet corn.

INTRODUCTION

Nitrogen (N) is generally the most difficult nutrient to manage in organic crop production, and N uptake is dependent on the amount of plant-available N, such as NH_4^+-N and NO_3^--N. Nitrogen fertilizer plays a crucial role in crop growth and yield development of sweet corn (*Zea mays*). Nitrogen application affects crop physiological parameters. Therefore, Pn, Tr, g_s, and iWUE may be affected by the NH_4^+-N to NO_3^--N ratio in organic fertilizers. Organic growers often use commercial organic animal-based fertilizers which vary in nutrient composition, forms of available N (NH_4^+-N and NO_3^--N), and have high transportation costs to meet the N demand of crops. Alternatively, cyanobacteria can be grown on-site as a source of N. Cyanobacteria has unique dual properties because it can both fix N from the atmosphere and photosynthesize to produce N biofertilizer without fossil fuels.

Water deficiency is a major factor limiting crop yield in semi-arid areas, such as Colorado (Fuhrer, 2003). Colorado receives less than 50 cm of precipitation per year, and drip irrigation system is one of the practices to reduce water use and increase efficiency of water use by sweet corn. Drip irrigation interests vegetable growers because of this potential improvements in water use efficiency (Doerge et al., 1989). Water use efficiency (WUE) is a measure of carbon assimilated per unit of water transpired by the plant (Stanhill, 1986) and can be measured instantaneously using gas exchange approaches (Bunce, 2010). Methods of measuring instantaneous WUE (iWUE) are derived from direct measurements of photosynthesis/transpiration as long as plants have similar leaf to atmosphere water vapor concentration gradients under field conditions (Ehleringer et al., 1986).

The purpose of measuring iWUE is to estimate the total carbon accumulation as a function of the total amount of water used by the plant over a period of time. The overall aim of this study is to assess whether the forms of available N in organic fertilizers affect photosynthesis (Pn), stomatal conductance (g_s), transpiration rate (Tr), and instantaneous water-use efficiency (iWUE) of drip irrigated organic sweet corn under field conditions.

METHODS

A field experiment was conducted during the summer of 2014 at the Horticulture Field Research Center, Colorado State University, Fort Collins, CO. Previously, the field area was planted with winter cover crops such as rye and turnips. Soils were sampled one week before the fertilizer treatment, and the soil was classified as a fine, smectitic, mesic Aridic Argiustoll of the Nunn series (NRCS, 1980) (Table 1).

Table 1. Soil analysis results prior to planting.

	Soil texture	Soil pH	Soil OM	Soil inorganic N	
				NH_4^+-N	NO_3^--N
			-----%----	--------mg kg^{-1}--------	
Nunn series	Sandy clay loam	7.5	3.2	42.5	11.4

Luscious se+ sweet corn seeds were purchased from Johnny’s Seeds (Johnny’s Selected Seed, Waterville, ME). The sweet corn seeds were hand planted within a row spacing of 12 cm apart within rows spaced 75 cm apart on July 1st, 2014. The experimental units were arranged in a Randomized Complete Block design with four replications. The treatments were solid organic fertilizers,; feather meal and blood meal, and liquid organic fertilizers,; fish emulsion and cyanobacteria applied at 56 and 112 kg N ha $^{-1}$. Liquid organic fertilizers were applied every two weeks after planting while the solid organic fertilizers were applied prior to planting in a subsurface band 5 cm from the seed row. Water was applied daily at 8:00 to 8:30 using an automated drip irrigation system. Weather data were obtained from a nearby weather station (CoAgMet- http://www.coagmet.colostate.edu/). Inorganic N contents of the different types of organic fertilizers (blood meal, feather meal, fish emulsion, and liquid cyanobacteria) were analyzed using an auto analyzer (Technicon., Mequon, WI) (Table 2).

Table 2. Fertilizer analyses prior to application.

Fertilizer	NH_4^+-N	NO_3^--N	NH_4^+-N: NO_3^--N
	------------ppm------------		
Cyanobacteria	4.7	0.01	470
Fish emulsion	23.7	0.12	198
Blood meal	27.7	8.40	3.3
Feather meal	1232	2.30	536

The selected parameters reported in this study were Pn, Tr, g_s, iWUE, and total above-ground dry biomass. Leaf gas exchange measurements of the uppermost, fully expanded leaf from three plants in each plot were carried out 66 days after planting using a portable open photosynthesis system, LI- 6400XT (LI-COR Inc., Lincoln, NE). Measurements were taken between 10:00 and 15:00 at ambient CO_2 (380 µl L^{-1}), leaf temperature inside the cuvette was set to 26°C, and photon flux density was 2000 µmol m^{-2} s^{-1}. Relative humidity was monitored and ranged between 50 and 60% during the day. Each leaf was allowed to reach a steady state of CO_2 uptake in the LI-6400XT leaf chamber before measurements were taken. Instantaneous water use efficiency (iWUE) was calculated as the ratio of photosynthetic rate to transpiration rate and expressed in µmol CO_2 $mmol^{-1}$ H_2O. All above-ground plant parts from each treatment were hand harvested and separated into leaves, stems, and ears on September 19, 2014, at 79 days after planting. The separated plant parts were dried at 70°C for 72 hours and weighed to determine the total above-ground biomass.

Data were analyzed using SAS version 9.3 (SAS Institute Inc., Cary, NC). The Univariate and Boxplot procedures were used to evaluate the normality of data distribution. Analysis of variance (ANOVA) was performed on the data by using the GLM procedure. The Tukey value was calculated from the obtained mean square errors to determine whether main effects or interactions were significant ($P<0.05$).

RESULTS AND DISCUSSION

No significant difference was observed in sweet corn ear yield (data not shown). There were also no significant responses of photosynthetic rates (Pn) to N application rates among the fertilizer treatments except for feather meal (Table 3). The feather meal treatment recorded significantly lower Pn (19.5 µmol m^{-2} s^{-1}) at 112 kgN ha^{-1} compared to control and other fertilizer treatments at 56 and 112 kg N ha^{-1}. The forms of N available in fertilizers have significant effects on the growth and photosynthesis of plants. The preference for the forms of available N varies between plant species, and sweet corn prefers NO_3^--N over NH_4^+-N (Cramer and Lewis, 1993). Therefore, the high NH_4^+-N: NO_3^--N ratio of feather meal (Table 2) could explain the low Pn rate of sweet corn in the feather meal treatment applied at 112 kg N ha^{-1} (Table 3) because high NH_4^+-N could affect the Pn rate of sweet corn due to the influence of N forms on photosynthetic enzymes (Lips et al., 1991). Higher NH_4^+-N concentration in feather meal might also influence iWUE due to lower water use efficiency and increase susceptibility to water stress (Lips et al., 1991).

The total above-ground biomass in the feather meal treatment resulted in less dry biomass accumulation in leaves and total biomass compared to control and other fertilizer treatments at both N rates (Figure 1). Leaf photosynthetic rate has an important influence on biomass production. Higher leaf photosynthetic rate results in higher dry matter production (Li et al., 2008). In our study, reduced photosynthetic rates of sweet corn treated with feather meal (Table 3) resulted in reduced leaf biomass accumulation which leads to lower total biomass accumulation in the feather meal treatment (Figure 1), a similar results to Cramer and Lewis (1993).

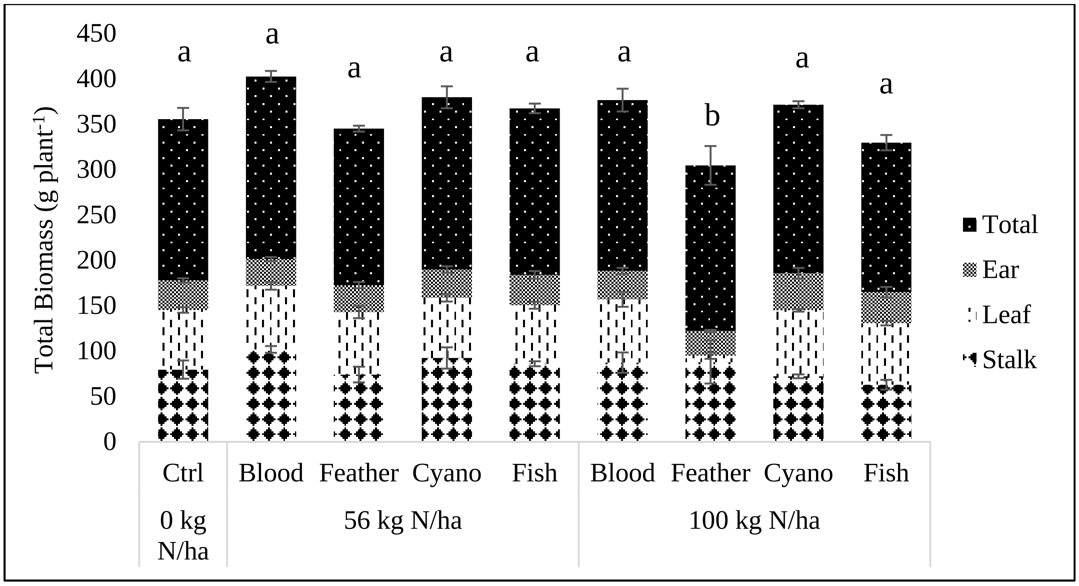

Figure 1. Effects of commercial organic and cyanobacterial fertilizers on total biomass of drip irrigated sweet corn 79 days after planting. The common letters among treatments and nitrogen rates are not significantly different from each other ($p < 0.05$) according to Tukey‘s test for mean separation.

The cyanobacteria, fish emulsion, and feather meal treatments significantly reduced Tr compared to the control and blood meal treatments (Table 3). Guo et al. (2008) reported that NH_4^+-N decreased stomatal conductance and transpiration in rice, and we predict that the high NH_4^+-N: NO_3^--N ratio of cyanobacterial fertilizer (Table 2) and high initial soil NH_4^+-N concentration (Table 1) might also contribute to the lower Tr and g_s in sweet corn. However, high NH_4^+-N: NO_3^--N ratio of cyanobacterial fertilizer had no significant effect on the photosynthetic rate in sweet corn at both N rates as compared to feather meal which has the highest NH_4^+-N: NO_3^--N ratio (Table 2).

The cyanobacterial treatment also recorded the significantly highest iWUE (60.2 µmol CO_2 mmol^{-1} H_2O) at 56 kg N ha^{-1} compared to control and other fertilizer treatments at 56 and 112 kg N ha^{-1} due to its lower g_s and Tr observed (Table 3). Based on the principal cluster analysis (data not shown), a very high correlation (r=0.986) was observed between the internal leaf carbon dioxide concentration (C_i) and iWUE, showing that cyanobacterial fertilizer had a higher carbon dioxide concentrating mechanism (CCM), which is a special adaptation to help maximize the efficiency of C_i uptake and fixation to elevate the CO_2 concentration around ribulose biphosphate carboxylase/oxygenase (Rubisco) (Price et al., 1998) which could explain the higher iWUE.

Table 3. Effects of commercial organic and cyanobacterial fertilizers on selected leaf gas exchange measurements of drip irrigated sweet corn 66 days after planting. The common letters among treatments and nitrogen rates are not significantly different from each other ($p < 0.05$) according to Tukey‘s test for mean separation.

Treatment	Nitrogen rate	Photosynthetic rate, Pn	Transpiration rate, Tr	Stomatal conductance, g_s	Instantaneous water use efficiency, iWUE
	kg N ha^{-1}	-µmol CO_2 m^{-2} s^{-1}-	----mmol H_2O ----	----mol H_2O m^{-2} s^{-1}----	--µmol CO_2 mmol^{-1} H_2O--
Control	0	38.1 a	8.5 a	0.24 a	4.5 b
Cyanobacteria	56	36.1 a	0.6 c	0.05 c	60.2 a
	112	39.9 a	2.7 b	0.15 b	14.8 b
Fish emulsion	56	38.9 a	4.3 b	0.21 ab	9.0 b
	112	36.9 a	3.4 b	0.17 b	10.9 b
Blood meal	56	41.2 a	9.2 a	0.26 a	4.5 b
	112	40.4 a	8.9 a	0.24 a	4.5 b
Feather meal	56	39.6 a	4.6 b	0.22 ab	8.6 b
	112	19.5 b	2.2 b	0.16 b	8.9 b

SUMMARY

In conclusion, feather meal fertilizer recorded significantly lower Pn at 112 kg N ha^{-1} and the cyanobacterial biofertilizer application resulted in significantly lower stomatal conductance and transpiration rate, thus recording higher iWUE at both N rates in drip irrigated sweet corn.

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