NITROGEN AND IRRIGATION WATER INTERACTIONS IN DROUGHT STRESSED KENTUCKY BLUEGRASS

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ABSTRACT

There is increasing pressure in arid regions to conserve water, especially during drought. Turfgrass is the irrigated crop of greatest acreage in the United States and water use for irrigating turf is coming under scrutiny in urban ecosystems. The purpose of this study was to evaluate water use and growth of Kentucky bluegrass (*Poa pratensis* L.) under various irrigation and nitrogen (N) regimes. A study was conducted in an environmentally controlled growth chamber with established Kentucky bluegrass. The turfgrass was grown in pots with a depth of 11 cm in calcined clay rooting media. The two moisture regimes were 60% or 100% evapotranspiration (ET) daily replacement values with three N regimes of deficient, optimal, and excessive. The N rates were 48.8, 146.5, and 439.6 kg ha^{-1} for the deficient, optimum, and excessive treatments, respectively. Nitrogen application was applied in the form of 50% urea and 50% polymer coated urea. Average daily ET was 7.1 mm for the fully irrigated treatment and 4.3 mm for the limited irrigation treatment. For the fully irrigated grass, the excessive N resulted in 14% greater water use and the deficient N had 12% less compared to the optimum N. For the drought stressed plants, excessive N resulted in 9.6% greater water use and deficient N 18% less water use. These results indicate that N management influences ET in Kentucky bluegrass. Reducing N can result in water conservation, but the effects on turf health and appearance must be considered. NDVI readings for the fully irrigated turfgrass increased linearly with increasing N rate with values 0.637, 0.694, and 0.725 for deficient, optimum, and excessive N, respectively. The same trend occurred with the drought stressed plants with values of 0.621, 0.662, and 0.698 for deficient, optimum, and excessive N, respectively. The results suggest that water conservation might be achieved by optimizing the interaction of N and water supply. In one case, limiting N may reduce ET of fully irrigated grass. In another case, high N may help maintain green grass when water supply is limited.

INTRODUCTION

Turfgrass is the irrigated crop of greatest acreage in the United States, occupying almost 2% of the total surface area (Milesi et al. 2005). As urban and suburban developments grow, turfgrass is quickly growing as the principle managed land cover (National Turfgrass Federation 2003; Walker 2007). Healthy urban ecosystems need care with regard to groundwater protection, erosion control, soil health, and cooling and cleaning of the air. Turfgrass can assist with all of these functions. Turfgrass improves air quality by acting as a filter, capturing smoke and dust, as well as absorbing sulfur and carbon dioxide, and reducing greenhouse gas concentrations (Haydu et al. 2006). Carbon cycle modeling has shown that turfgrass can sequester up to 127.1 g

C m^{-2} $year^{-1}$ (Zirkle et al. 2011). In addition, turfgrass is used for aesthetics in landscapes and for recreational purposes, including sports turfgrass (Beard 1993). Various applications provide utility to residential and public lands.

However, concerns of natural resource consumption and pollution issues have brought the use of turfgrass under scrutiny, particularly in the arid and semi-arid regions of the western US. Drawbacks of turfgrass include natural resource consumption, both in the mining of minerals for and production of fertilizers used on turfgrass. Proper management of turfgrass requires fossil fuels for mowing and water for irrigation. There is concern about pesticide use, and various problems result from pollution of the hydrosphere and atmosphere. Fragile ecosystems surrounding turfgrass can be permanently damaged by the nutrient pollution resulting from over fertilization and irrigation of turfgrass.

Plants require water and nitrogen (N) for survival. Nitrogen is the mineral nutrient required in highest concentrations and is vital in the plant's life cycle. Plant biogeochemical processes require N for the synthesis of chlorophyll, nucleotides for deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), and amino acids for protein and enzyme production (Ransom 2014; LeMonte 2011). Plant deficiencies of N lead to dramatic effects on the health of the plant. Plant vigor and verdure, visual landscape quality, recovery from damage, and overall plant health are maintained when sufficient N levels exist in the plant (Bowman 2002). Along with N, water is necessary for all plant functions. Turfgrass requires a significant amount of irrigation water, a resource that is scarce in the arid and semi-arid regions of the west. In many locales, there is not sufficient precipitation to meet water demand. Water scarcity is a pressing issue due to declining groundwater levels, increasing competition for water by municipal and industrial users, increasing frequency and severity of drought, rapid population growth, and declining water quality due to pollution and salinity (Gleeson et al. 2012). Unfortunately, turfgrass managers often over apply N fertilizers and do not properly manage irrigation, leading to many of the ecological and environmental problems mentioned above.

Over fertilization leads to an increase in water use, which leads to runoff resulting in pollution of the atmosphere and hydrosphere. Increased nutrients, especially N and phosphorus (P), in waterways leads to algal blooms and speeds up the natural eutrophication process. An increase in algal blooms often results in decreasing biodiversity, unsightly conditions, strong odors, economic losses, and a decrease in recreational use (Fangmeier et al. 1994; Mulvaney et al. 2009). Nitrate (NO_3^-) and ammonium (NH_4^+) are easily transported through soil erosion and surface runoff, and as they contaminate drinking water sources and nitrate can cause methemoglobinemia, commonly known as blue baby syndrome. In addition to water pollution, a percentage of N fertilizers are volatilized leading to air pollution, including: photochemical smog, particulate matter, and acid rain (Park et al. 2012). In addition, nitrous oxide (N_2O) is produced and contributes to greenhouse gas concentrations, with a higher warming potential than CO_2, furthering the warming effect of these gasses on the earth.

Environmental impacts caused by the production and use of N fertilizers has created the need to evaluate the use and management of turfgrass in urban ecosystems. It is imperative to apply N fertilizers at the appropriate rate and timing. As such, there have been a multitude of research studies that have been done to evaluate proper N management (Hopkins et al. 2008), including turfgrass studies. Candogan et al. (2015) found that irrigation requirements could be decreased by adjusting N fertilizer rates for a perennial ryegrass in a sub humid climate. Acceptable turfgrass color and quality can be maintained at 100% evapotranspiration (ET) replacement and 25 kg N ha^{-1}, and at 50 kg N ha^{-1} 75% of ET replacement is sufficient. St.

Augustine grass grown in Florida has a minimum N requirement of 196 kg N ha^{-1}. It has been shown that a rate of 98 kg N $^{ha-1}$ can sustain an acceptable turfgrass grass for two years, but long-term effects were not examined. It was suggested that a more appropriate rate could be found below the current requirement (Shaddox et al. 2016). In addition, studies have shown that the use of polymer coated urea (PCU) can be used with reduced N rates—resulting in significant reductions of N loss to the environment while maintaining functional and aesthetic landscapes (Ransom 2014; Buss 2016; LeMonte 2016).

Similarly, there have been many studies on water management. A study was conducted by Wherley et al. (2015) to determine if recommended irrigation rates were sufficient for warm season turfgrass. They found that recommended rates were insufficient during the peak of growing season, while being in excess during the fall when the turfgrass was slowing its growth and transitioning toward dormancy. However, there have not been many studies performed examining the interaction between N rate application and irrigation rate.

One such study was done to evaluate the drought stress effect on various rates of N (Carrol et al. 2015). In this study on corn (*Zea mays* L.), it was found that N deficiencies reduced chlorophyll concentration drastically, while irrigation deficiencies had a greater impact on canopy temperature. In an N deficient corn plant, the chlorophyll content was significantly lower than the sufficiently fertilized plant during growing season. However, 100 days after sowing, the chlorophyll content in the leaf for the deficient and sufficient N plants were equal. Similarly, the limited and sufficiently irrigated treatments did not produce a significantly different chlorophyll concentration, indicating that water conservation is possible without inhibiting the overall health of the plant and production potential.

Preliminary studies show a correlation between increased N use and irrigation requirement (Demirel 2014; Candogan et al. 2015; Shaddox et al. 2016). However, the threshold of N conservation and water conservation, before causing permanent damage to the crop, has not been determined. In a perennial ryegrass (*Lolium perenne* L.) study, Candogan et al. (2015) concluded that with proper N management in non-limited irrigation conditions, at least 25% of irrigation water could be conserved by reducing N use. In a study done by Demirel (2014), it was suggested that when managing perennial ryegrass in semi-arid conditions, 50% water deficit with excess N application can be used to achieve desired quality turfgrass. The interaction between N and irrigation has not been proven extensively and has not been done with Kentucky bluegrass (*Poa pratensis* L.).

Although there has been significant research conducted on water and N management in turfgrass, there is a need for investigation into the interactions of these important inputs. The objectives of this study are to evaluate the interactive effects of N rates on water stressed and non-water stressed Kentucky bluegrass for biomass, height, health, and verdure.

MATERIALS AND METHODS

This study was conducted from May 14 through June 20, 2015 at Brigham Young University in Provo, Utah 40.2518° N, 111.6493° W at 4,551 feet (1,387 m) above mean sea level in an environmentally controlled growth chamber. Established Kentucky bluegrass sod was transplanted and then grown in circular pots with a 14.5 cm diameter and an 11.5 cm height in a calcined clay growing media (Turface Athletics MVP). The turfgrass was irrigated with a pre-treatment solution for 60 d prior to beginning the study. The pre-treatment consisted of a dilute nutrient solution containing all essential plant macro- and micronutrients, except N (Geary et al. 2015). The growing media was leached to obtain consistent, low N levels and a biomass sample was collected on May 14 to determine beginning N tissue concentrations (2.9%). Turfgrass was trimmed to a height of 4.5cm each to begin the study and each week during the study. The growing media was saturated on May 14 and allowed to drain to approximately field capacity on May 15, at which time the N treatments were applied.

The study was a randomized complete block design with four replications of all combinations of two irrigation levels (sufficient at 100% and drought at 60% of ET), and three N levels (deficient at 49.0 kg ha^{-1}, optimum at 147 kg ha^{-1}, and excessive at 440 kg ha^{-1}). Nitrogen was applied with half from a traditional rapid release urea and the other half from a controlled release polymer coated urea (micro-prills SGN: 250; Duration, Koch Industries Inc., Wichita, KS US). Urea was dissolved in deionized water before being applied to the surface and the coated urea was applied in prill form to the surface. Irrigation treatment amounts were determined by calculating approximate field capacity gravimetrically 24 hours after saturation and then measuring and fully replacing daily water loss based on the average loss of all of the 100% ET replacement treatments. The turfgrass receiving the drought irrigation treatments received water based on 60% of the fully irrigated treatments. The irrigation water used was municipal water from the city of Provo.

Visual observations and NDVI readings, using a FieldScout TCM 500 NDVI Turfgrass Color Meter (Spectrum Technologies, Inc., Aurora, IL, USA), were taken weekly. The NDVI reader was placed on the turfgrass surface to prevent light infiltration. Thermal imagery was taken bi-weekly using an Ex-series E6 infrared camera (FLIR Systems, Inc., Wilsonville, OR, US). The pots containing the treated turfgrass were placed in a bucket and a lid was placed on top with a small hole for the camera. This was to prevent any temperature gradients interfering with the thermal imagery. Biomass was collected throughout the study on a bi weekly basis when turfgrass was trimmed to 4.5cm. After water uptake leveled off within the treatments, we took a final biomass and air-dried it to gravimetrically determine cumulative shoot biomass. Shoot biomass was analyzed for N and carbon (C) concentrations using a CN Determinator (TruSpec Micro, LECO, St. Joseph, MI, USA.

Statistical analysis was performed by Analysis of Variance with mean separation by the Tukey-Kramer method (SAS Inc., v. 9.0, Cary, NC, US).

RESULTS AND DISCUSSION

Both irrigation and N fertilization resulted in significant differences in this study (P<0.05 for main treatments; Figs. 1-5). The interactions between irrigation and N rate were not generally significant (Figs. 1-4) except for canopy temperature (Fig. 5).

Increasing N rates resulted in increased ET for both irrigation levels, although, not surprisingly, the magnitude of the ET was much greater when the turfgrass was fully irrigated as compared to deficit irrigation (Fig. 1).

The biomass results were nearly identical to the patterns observed with ET (Fig. 2). The correlation was highly significant (r^2=0.97). As with ET, turfgrass biomass generally increased with increasing N rates for both irrigation regimes. However, the difference between deficient and optimal N was only significant at the P=0.102 for the fully irrigated treatment. Not surprisingly, the magnitude of the biomass accumulation was much higher for the fully irrigated treatment as compared to deficit irrigation.

As expected, tissue N concentration increased with increasing N rate (Fig. 3). This effect was observed at both irrigation levels. The N concentration was lower for the deficit irrigated turfgrass at the optimum and excessive rates of N, but not at the deficit N rate.

At both irrigation levels, NDVI (a measure of plant health) increased with increasing N (Fig. 4). It is of interest to note that the NDVI for the highest rate of N at deficit irrigation was statistically equivalent the optimal N rate when fully irrigated. The same was true for the optimum N rate at deficit irrigation compared to deficient N when fully irrigated.

Reduced irrigation resulted in higher canopy temperatures and, presumably, greater plant stress for this cool-season turfgrass species (Figs. 5-6). The magnitude of the N impact on plant stress was much greater at deficit irrigation than it was with the adequately watered turfgrass. It is noteworthy that the lowest level of N at deficit irrigation had a tremendously higher temperature than any of the other treatments and is likely a formula for loss of the canopy. It is also noteworthy that the highest N rate at deficit irrigation produced a temperature statistically equivalent to the fully irrigated grass with a low rate of N.

These data suggest that combined management of water and N fertilizer can be used to manage drought. Although increasing N and water both increased water use, biomass, and plant health, it may be possible to conserve water when under drought caused water restrictions by applying a relatively higher amount of N when deficit irrigated. By doing so in this study, the ET was reduced by 24% instead of 36% for the high rate of N vs. the low rate at deficit irrigation (Fig. 1). Doing so resulted in improved biomass and plant health with only moderate canopy temperature increases. Adding a higher amount of N to deficit irrigated turfgrass may actually improve the likelihood of the turfgrass emerging from drought conditions compared to when low rates of N are applied. Further work needs to be done to verify these findings in the field and with other species.

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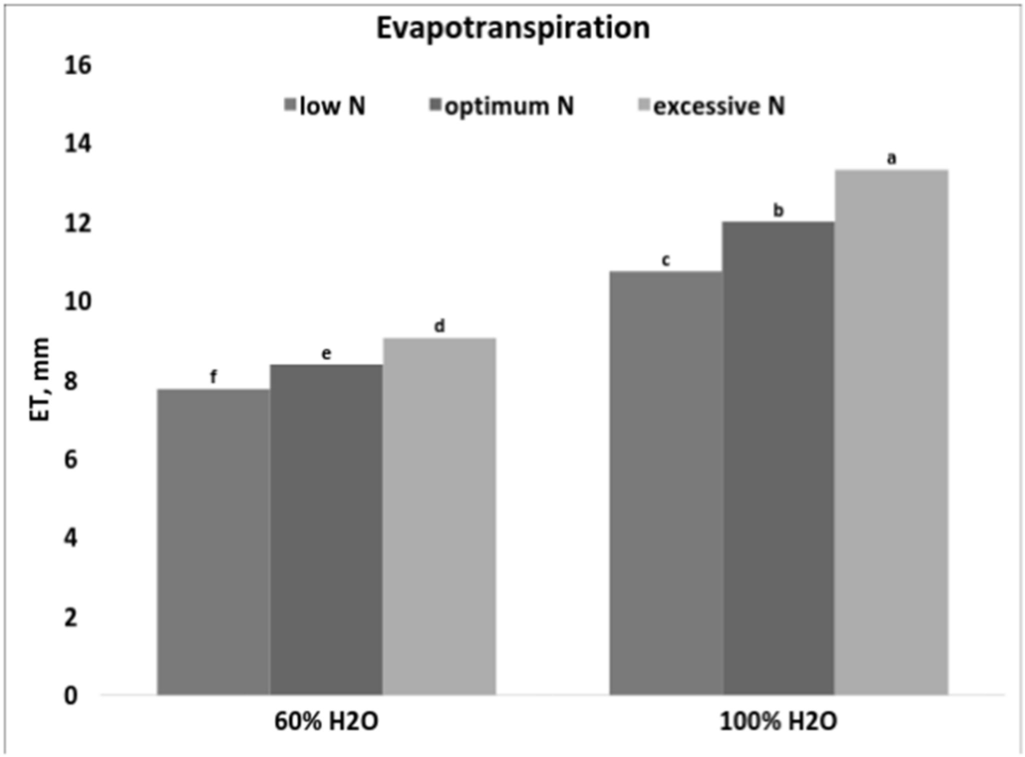

Fig. 1. Cumulative evapotranspiration (ET) over the course of nitrogen (N) by water management study with low, optimum, and excessive rates of N either fully or deficit irrigated. Data bars sharing the same letters (above) are not statistically different from one another.

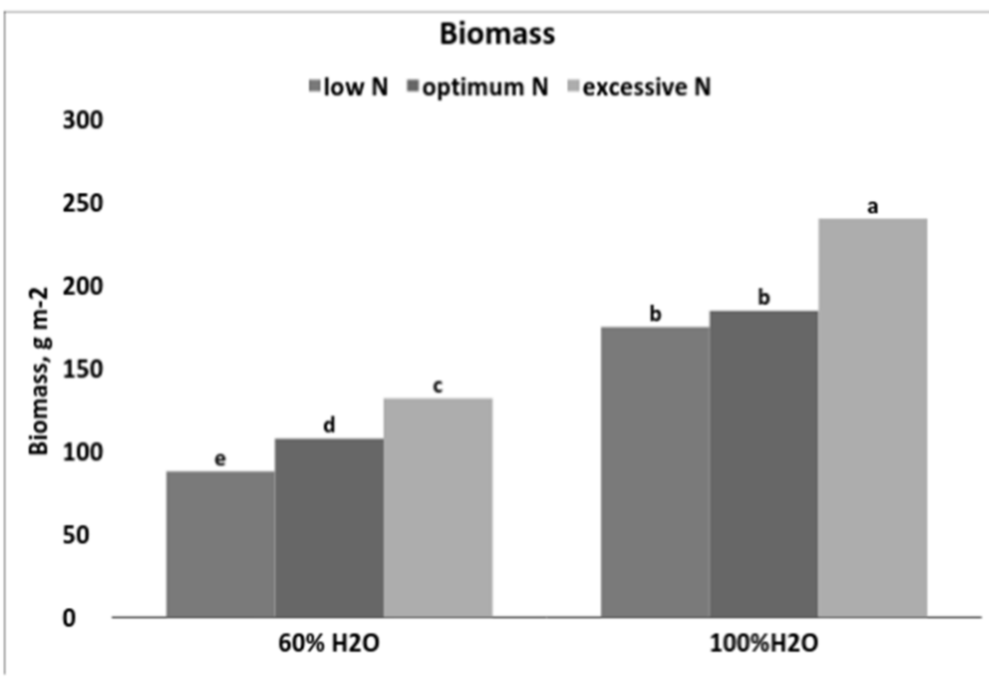

Fig. 2. Cumulative shoot biomass over the course of nitrogen (N) by water management study with low, optimum, and excessive rates of N either fully or deficit irrigated. Data bars sharing the same letters (above) are not statistically different from one another.

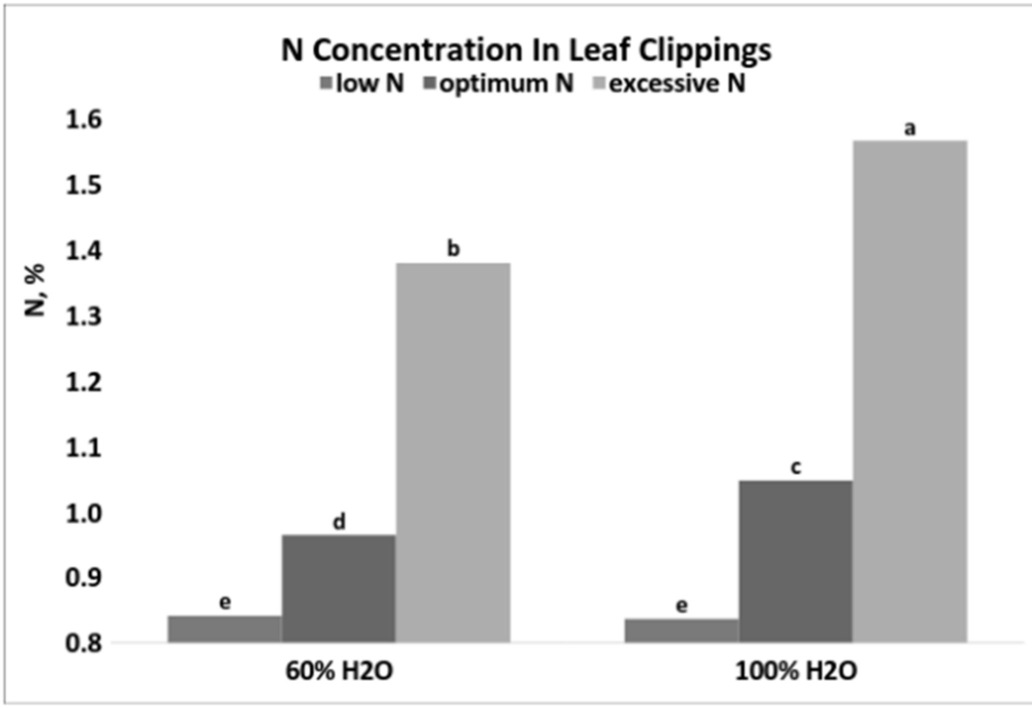

Fig. 3. Nitrogen (N) concentration in Kentucky bluegrass shoots at the end of a nitrogen (N) by water management study with low, optimum, and excessive rates of N either fully or deficit irrigated. Data bars sharing the same letters (above) are not statistically different from one another.

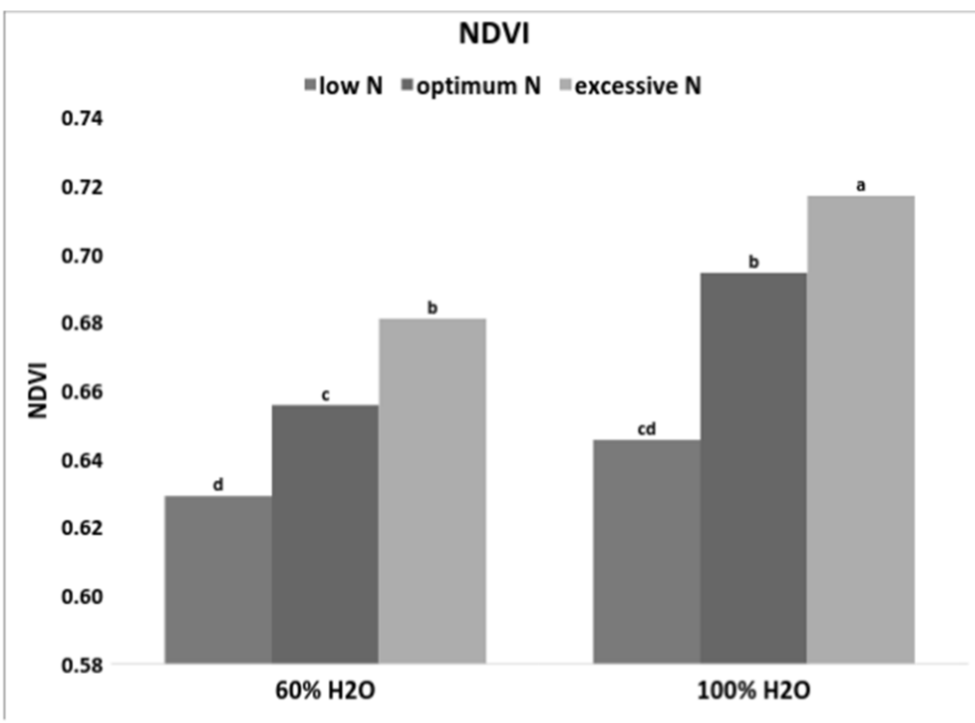

Fig. 4. Normalized Difference Vegetative Index (NDVI) at the end of a nitrogen (N) by water management study with low, optimum, and excessive rates of N either fully or deficit irrigated. Data bars sharing the same letters (above) are not statistically different from one another.

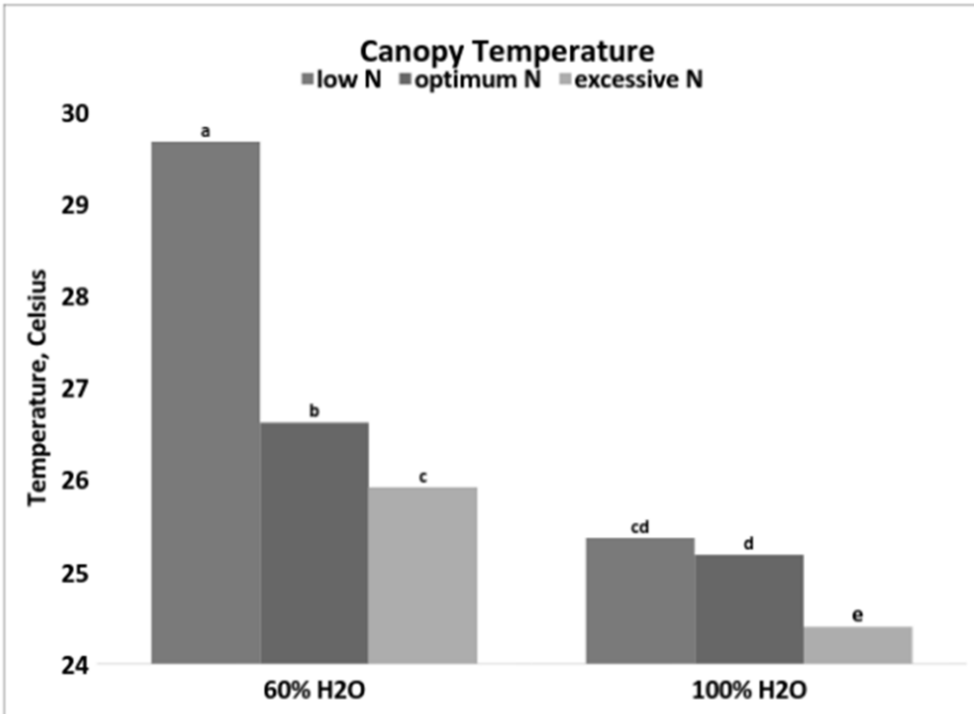

Fig. 5. Average canopy temperature for a nitrogen (N) by water management study with low, optimum, and excessive rates of N either fully or deficit irrigated. Data bars sharing the same letters (above) are not statistically different from one another.