DETERMINING NITROGEN MOBILITY IN FOUR PRODUCTION CROPS GROWN IN HYDROPONICS

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ABSTRACT

Nitrogen is the most concentrated mineral essential element in higher plants. The amount of nitrogen in the plant influences the rate of photosynthesis. Nitrogen deficiency symptoms include lighter green plants and yellow lower leaves. This study investigated how plants react to the removal of nitrogen from the nutrient solution. Four plants, maize (Zea mays, monocot), wheat (Triticum, monocot), soybeans (Glycine max, dicot), and sunflower (Helianthus annuus, dicot), were grown in hydroponic conditions in the Utah State University Crop Science greenhouses in Logan, Utah, from 5 October to 21 November, 2012 (47 days). Nitrogen was removed from the nutrient solution of half of the treatments on day of 26. Plants with removed nitrogen had an average of 8% less chlorophyll concentration index values. Wheat, soybeans, and sunflower had an average 5% higher dry/fresh weight ratio with removed nitrogen. The removed nitrogen treatments had leaf ratio and root ratio of 11% less and 12% more, respectively. Plants showed multiple symptoms of stress after 21 days without nitrogen.

INTRODUCTION

Nitrogen is the most concentrated mineral essential element in higher plants (Salisbury and Ross, 1991). It is used for a variety of plant operations. Plants use nitrogen to maximize carbon fixation (Broadley et al., 2000). Nitrogen is part of necessary organic compounds in the plant (Resh, 1989).

The amount of nitrogen in the plant influences the rate of photosynthesis. Nitrogen is required the synthesis and transfer of energy in plant cells (North Carolina Department of Agriculture and Consumer Services). Increased photosynthesis promotes plant growth and crop yield.

Nitrogen mobility has been studied in a variety of plants. Salahas et al. (2012) investigated the effect of nitrogen deficiency on red beet plants. Plants under prolonged nitrogen deficiency allocate nitrogen to survival processes instead of growth processes. A study with hydroponic lettuce by Konstantopoulou et al, (2012) showed that increasing nitrogen application correlates with increased rates of photosynthesis and transpiration. Increased photosynthesis indicates healthier plants and is related to an increase in yield.

Broadley et al. (2000) found that limiting nitrogen reduced the number of photosynthetic enzymes and reduced lettuce growth. In a study where plants were grown for 61 days, nitrogen was removed from some plants after 47 days of growth. The nitrogen concentrations in plants without nitrogen and with nitrogen were 2.2% and 5.7%, respectively, after harvest.

Nitrogen deficiency is one of the most commonly diagnosed nutrient deficiencies due to its high mobility and high concentration in plants. It is one of the easiest to visually identify, though other element deficiencies are sometimes mistaken for a nitrogen deficiency. Nitrogen deficiency symptoms include lighter green plants, yellow lower leaves, and shorter stalks (Resh, 1989). Reduced chlorophyll causes the plant to be chlorotic and occurs in older leaves first. Younger leaves remain green longer.

Objective and hypotheses of study. The objective of this study is to determine how plants react to the removal of nitrogen from the nutrient solution. The research hypothesis is plants with nitrogen removed from the nutrient solution will have less chlorophyll and more roots.

MATERIALS AND METHODS

Four plants, maize (Zea mays, monocot), wheat (Triticum, monocot), soybeans (Glycine max, dicot), and sunflower (Helianthus annuus, dicot), were grown in hydroponic conditions in the Utah State University Crop Science greenhouses in Logan, Utah. Growth dates were from 5 October to 21 November, 2012 with a nutrient solution that either did or did not include nitrogen. These plants were chosen for their fast growth rate given the short timeframe of the project and seed availability.

Seeds were germinated in tap water-soaked paper towels and a 2-liter container watered by wicking through the paper towels (Figure 1a). The germination conditions were indoors at a temperature around 25°C. This study had eight treatments with three to five replicates. The seeds were started on October 5, 2012, and germinated for 10 days (Figure 1b and 1c). Maize, wheat, soybeans, and sunflowers had 4, 4, 3, and 5 replicates, respectively, based on the number of viable germinated seeds and hydroponic tub capacities.

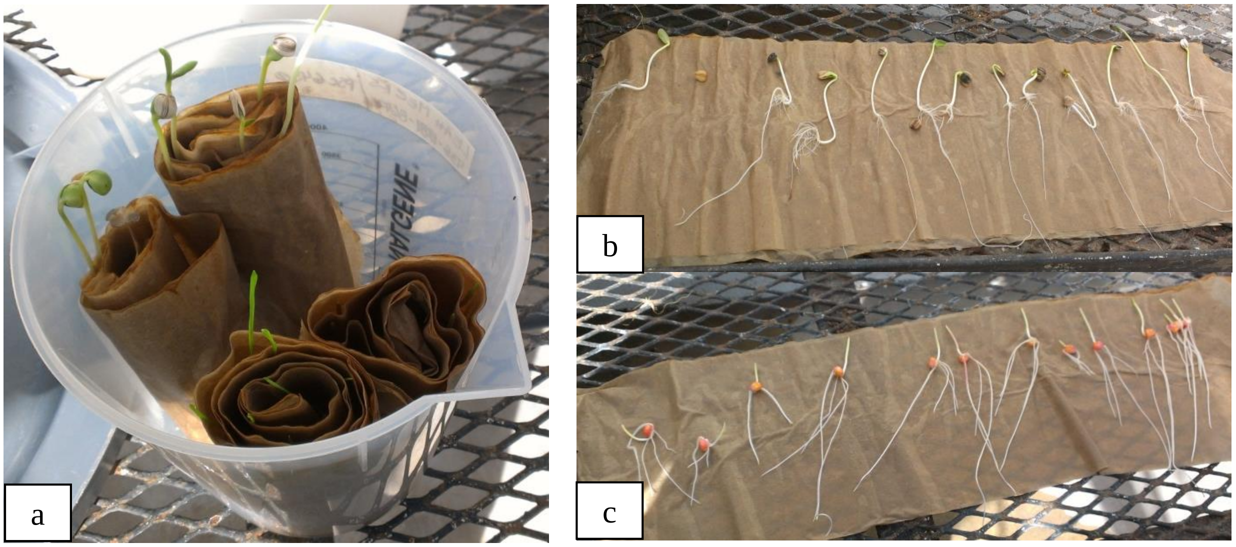

Figure 1. (a) Maize, wheat, soybeans, and sunflower after 10 days of seed germination. Germinated (b) sunflower and (c) corn before transplant into hydroponics.

Seeds were transplanted to hydroponic conditions on October 15th, 2012. The greenhouse maintained temperatures of 25°C and 20°C during the day and night, respectively. Each hydroponic tub (57x 44 x 24 cm) held 50 liters of solution with a bubbling unit and supported 8 plants. Initially, the four tubs were filled with a nutrient solution in deionized water that included nitrogen (NSol) to start the plants. The two monocot tubs each had four maize and four wheat plants. The two dicot tubs each had five sunflower and three soybeans. The iron chelates HEEDTA and EDDHA were added to the monocot and dicot tubs, respectively. The pH of the solution was brought to 5 by adding H^+ or OH^- as appropriate before adding the iron chelates. The nutrient solutions used in the study are the working solutions at the Utah State University Crop Physiology Laboratory in Logan, Utah and presented in Bugbee (2004).

On October 31st, 2012, (day 26 of growth and day 16 of hydroponic conditions) the nutrient solution in one monocot tub and one dicot tub were changed to the non-nitrogen solution (NoNSol). For the NoNSol, calcium was not added as a salt. Instead, Ca was supplied by using tap water for the nutrient solution. Table 1 details both nutrient solutions used in this study. Treatments with NSol during the entire study and those using NoNSol for last 21 days were named Ample N and Removed N, respectively.

Table 1. Nutrient solutions used for nitrogen mobility study based on Bugbee (2004).

Salt	Stock Conc	Nitrogen Solution (NSol)		Non-Nitrogen Solution (NoNSol)	
		ml/100L	Final Conc	ml/100L	Final Conc
$Ca(NO_3)_2$	1 M	200	2 mM	(supplied by using tap water)	
$K(NO_3)$	2 M	150	3 mM	-	-
KH_2PO_4	0.5 M	100	0.5 mM	100	0.5 mM
$MgSO_4$	1 M	100	1.0 mM	100	1.0 mM
K_2SiO_3	0.1 M	100	0.1 mM	100	0.1 mM
K_2SO_4	0.5 M	-	-	100	1 µM
$FeCl_3$	50 mM	20	10 µM	10	5 µM
EDDHA (red)	100 mM	25	25 µM	40	40 µM
HEEDTA (ylw)	100 mM	25	25 µM	25	25 µM
$MnCl_2$	60 mM	10	6 µM	10	6 µM
$ZnCl_2$	20 mM	50	10 µM	30	6 µM
H_3BO_3	40 mM	50	20 µM	100	40 µM
$CuCl_2$	20 mM	20	4 µM	40	8 µM
Na_2MoO_4	1 mM	10	0.1 µM	10	0.1 µM

The hydropoinc tubs were consistently bubbled and refilled with nutrient solution to minimize plant water, oxygen, or nutrient stress other than nitrogen. The nitrogen of each hydroponic tub was tested at the time of harvest using the Hach AquaChek nitrate solution strips (Hach, Loveland, Colorado, USA).

The leaf cholorphyll was recorded the day of harvest using the Opti-Sciences CCM-200 Chlorophyll Content Meter Serial #001876 (Opti-Sciences, New Hampshire, USA). The Opti-Sciences meter discharges 600 nm and 900 nm waveslengths through the leaf and reports the ratio as the chlorophyll concentration index. The same leaf was tested on each treatment with maize, wheat, soybeans, and sunflower test on the second youngest leaf, tallest stem leaf, second branch from top leaves, and fourth from bottom leaf, respectively.

The fresh and dry mass of the plants was recorded at harvest with the Ohaus Brainweigh B3000D (Ohaus, New Jersey, USA). All crops were harvested into brown paper bags for roots, stem, and leaves with wheat also having a bag for the head. The roots were dried using a diaper to remove excess water for the fresh mass measurement. Each bag was oven dried at 70°C for 48 hours before dry mass was taken.

RESULTS

The nitrogen level for Ample N and Removed N at the time of harvest was 50 ppm and 0 ppm, respectively. Figures 2-7 display the results of the study.

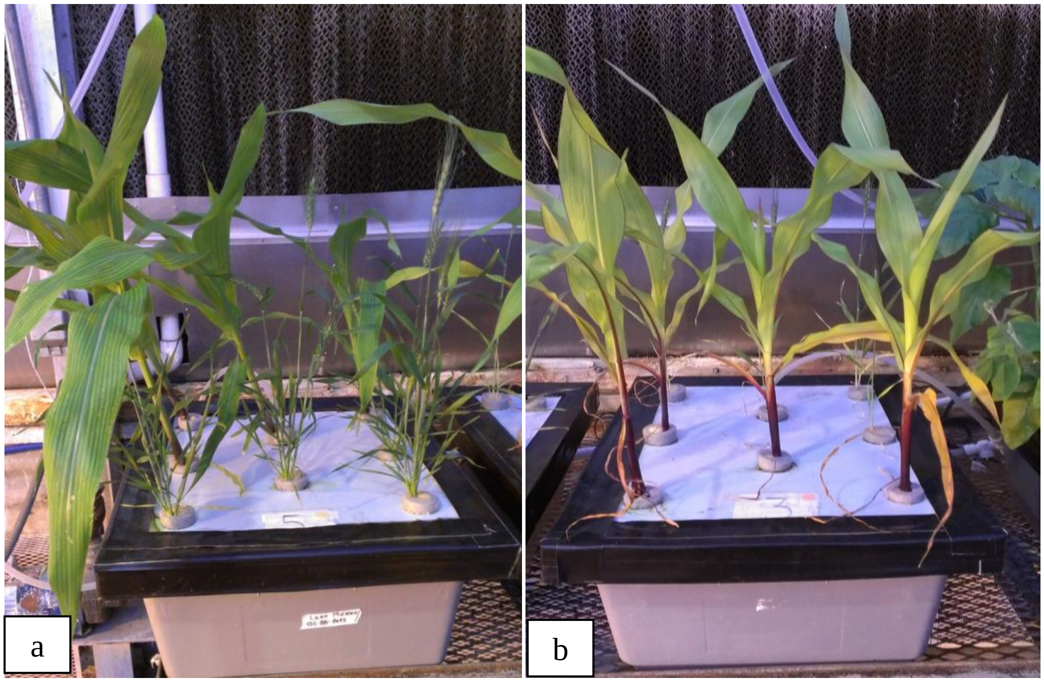

Figure 2. Maize and wheat grown in two nutrient solutions at 45-day harvest a) Ample N had nitrogen in solution during all growth and b) Removed N had nitrogen removed from nutrient solution after 21 days of growth.

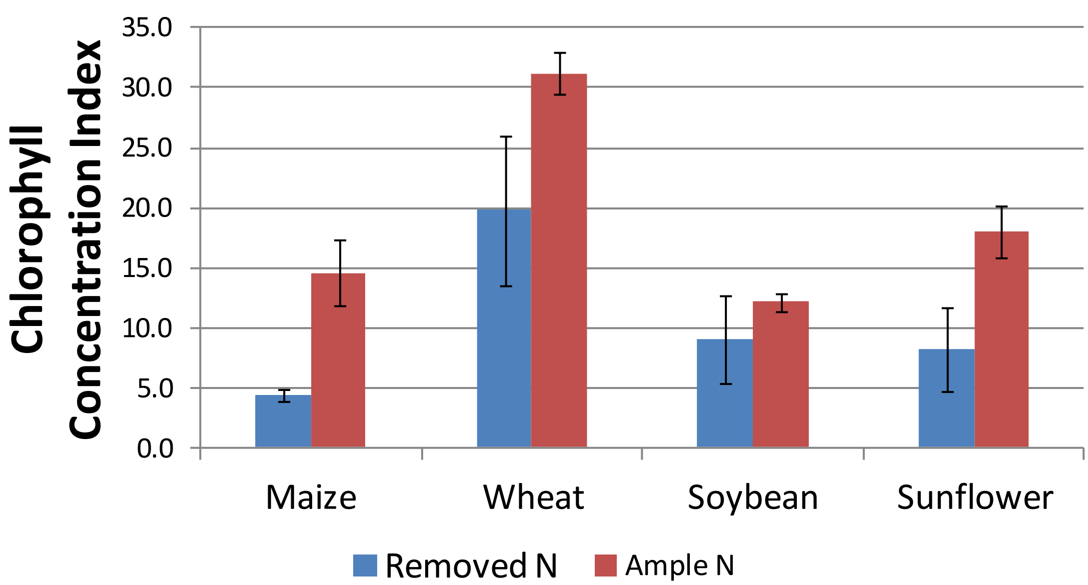

Figure 3. Chlorophyll concentration index of four crops with two nutrient solutions grown in hydroponic conditions at the time of harvest (47 days of growth and 21 days of Removed N solution being used).

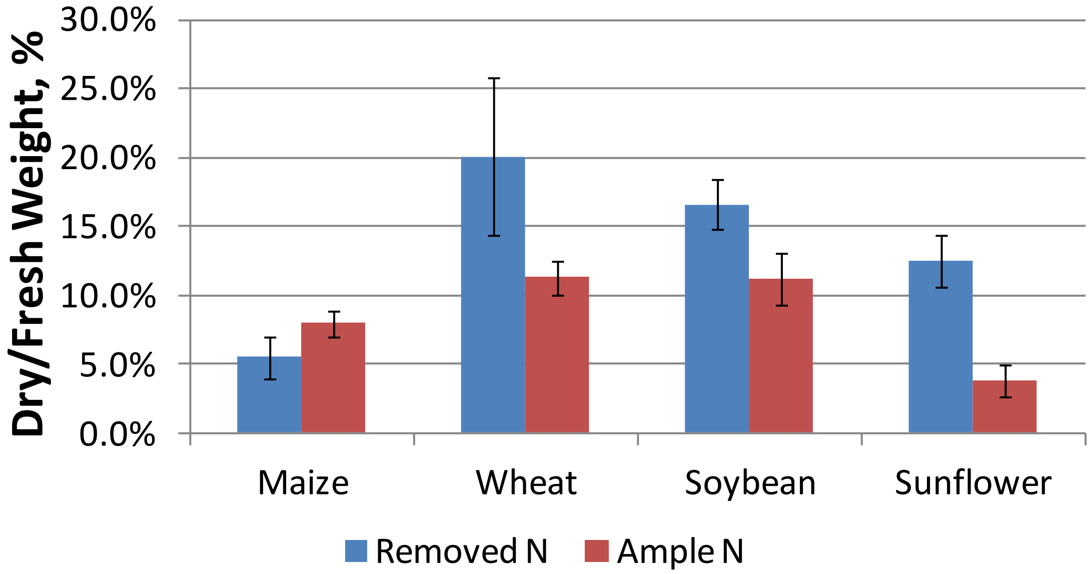

Figure 4. Dry/Fresh weight ratio of four crops with two nutrient solutions grown in hydroponic conditions at the time of harvest (47 days of growth and 21 days of Removed N solution being used).

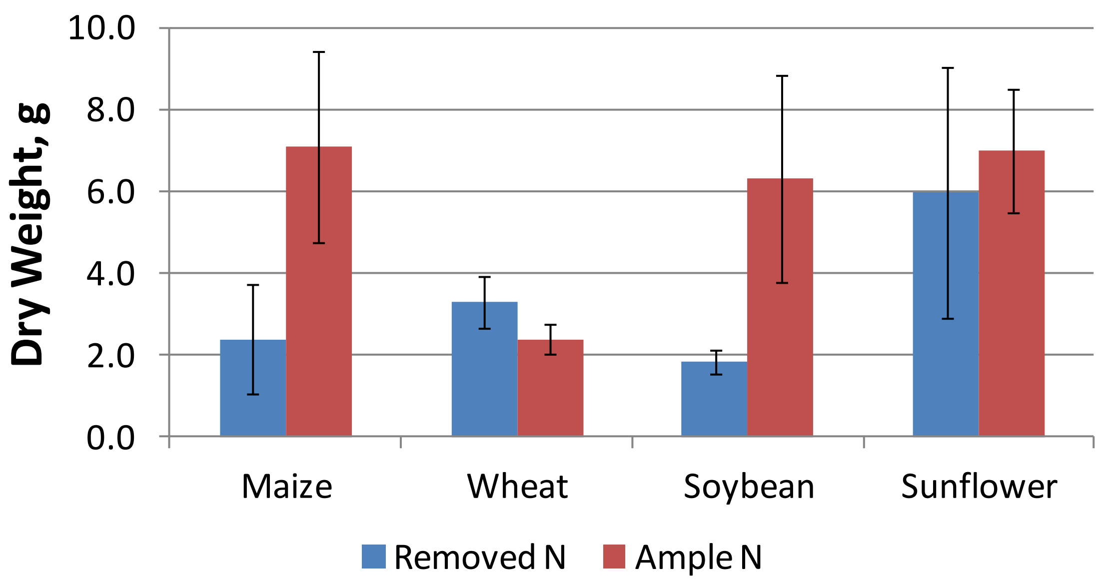

Figure 5. Dry/Fresh weight ratio of four crops with two nutrient solutions grown in hydroponic conditions at the time of harvest (47 days of growth and 21 days of Removed N solution being used).

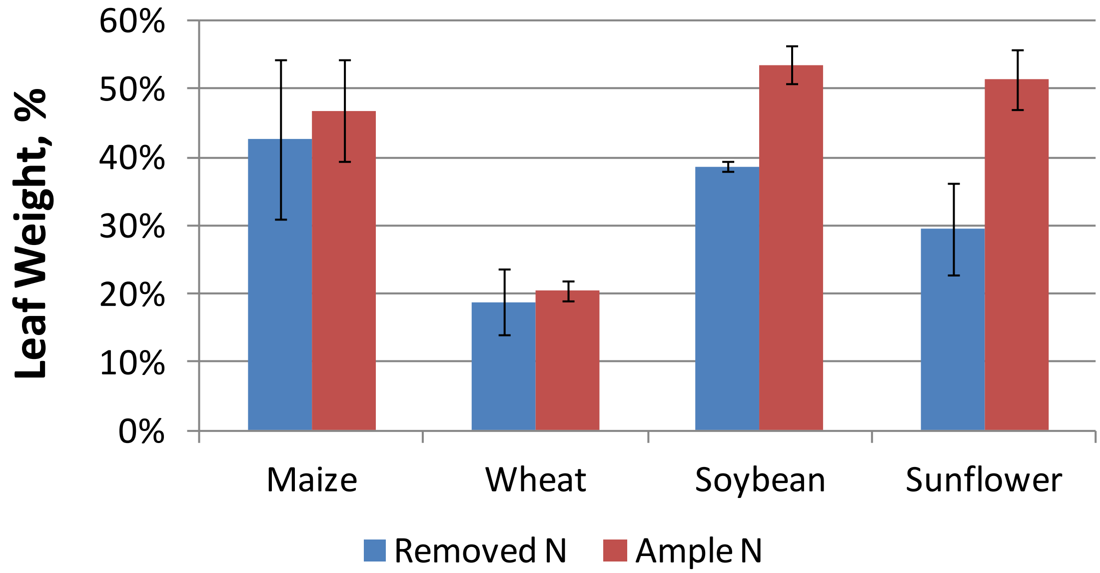

Figure 6. Leaf weight as a percent of the plant total weight of four crops with two nutrient solutions grown in hydroponic conditions at the time of harvest (47 days of growth and 21 days of Removed N solution being used).

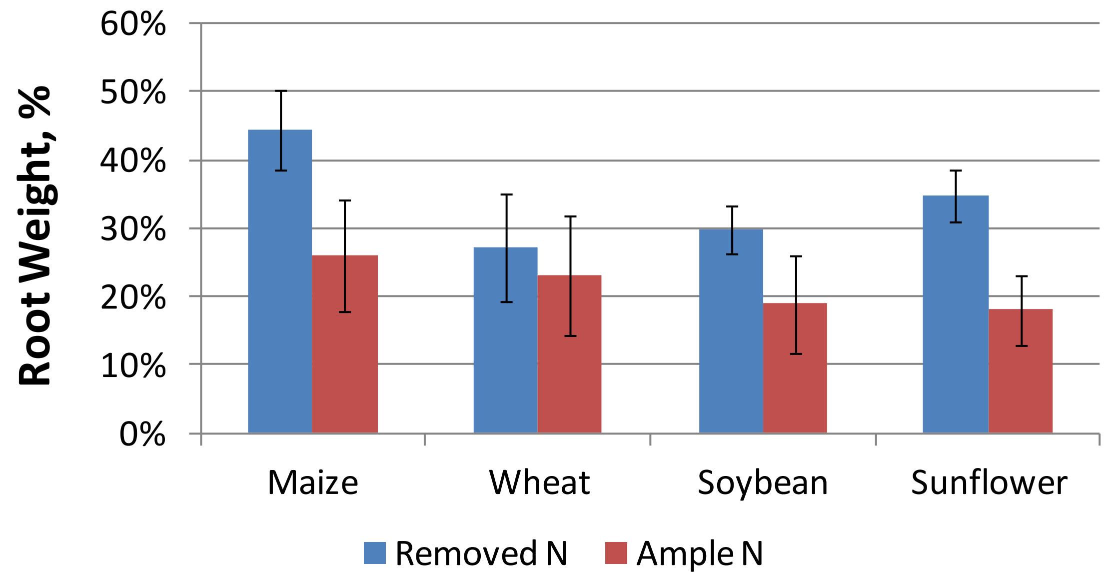

Figure 7. Root weight as a percent of the plant total weight of four crops with two nutrient solutions grown in hydroponic conditions at the time of harvest (47 days of growth and 21 days of Removed N solution being used).

DISCUSSION

The symptoms of nitrogen deficiency found in the literature review were seen in the study. The images in Figure 2 show lighter green plants, yellow lower leaves, and shorter stalks in the Reduced N treatment.

Plants in the Removed N treatments had an average of 8% less chlorophyll concentration index values (Figure 3). Soybeans were less influenced than the other crops, while other crops had at least one standard deviation of difference in the Removed N and Ample N readings. Wheat, soybeans, and sunflower had an average 5% higher dry/fresh weight ratio with Removed N (Figure 4). The absence of chlorophyll and decreased dry/fresh weight ratios indicate that the plants with Reduce N had stressed photosynthesis.

The Removed N treatments had leaf ratio and root ratio of 11% less (Figure 6) and 12% more (Figure 7), respectively than the Ample N treatments. Increased root mass is a sign that plants are trying to acquire more of a nutrient that they cannot uptake in their current root zone. By putting more energy into root production, those plants have less leaves.

FUTURE WORK

Taking chlorophyll measurements over the study would aid in the understanding the nitrogen mobility over time. Measuring plant height would also add to analysis. The dry/fresh weight ratio of maize is not as expected (Ample N had a higher ratio) nor is the higher dry weight of the Removed N wheat treatment.

It is also recommended that one hydroponic tub be used for each crop. Having two crops per tub may have introduced some issues (such as the maize shading the wheat) that influenced results.

Some of the treatments showed evidence of iron chlorosis and water stress, mostly the Ample N maize. These conditions need to be better controlled to isolate the effects of nitrogen removal from the nutrient solution.

This study confirmed that the removal of nitrogen from the nutrient solution during the early plant growth causes plant stress. The work here can be expanded to include more replicates, tracking leaf chlorophyll, and growing plants over a longer period of time.

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