Effects of Increasing Fertilization Rates on Onion Growth and Nitrogen Losses

Abstract

Current fertilization practices call for a constant rate of application of fertilizer over the entire growing season. To optimize crop fertilization by reducing pollution via two pathways, NO_3 and N_2O gas losses, a variable fertilization schedule has been proposed. The onion received fertilizer in increasing amounts to optimize nutrient absorption. Three groups of onions were grown and three different fertilization schedules were applied to them: constant rate, increasing rate, and no fertilizer. Plant yields (mass) for the two treated groups was similar. The group without fertilizer was five times smaller. NO_3 and N_2O losses were not significantly different for the two groups.

Introduction

Just in the year 2008 alone, the price of nitrogen phosphorus potassium fertilizers (NPK) has increased almost 78% (NSCB 2008). For vegetable crops, the cost of fertilizers can be up to 30-40% of the total cost of production. While it is hard to keep production targets by using less fertilizer, fertilizer use efficiency may be increased by using different methods of fertilization. The main pathway of efficiency of is to loss as less nutrients as possible.

To hit a target yield, farmers use a maximum yield amount (MYA) - an amount of fertilizer per area. And how the MYA is applied determines efficiency and productivity.

Different combinations of nutrients have different MYAs. A MYA for an onion for nitrogen and sulfur: 120kg/ha N and 40 kg/ha S respectively (Nasreen 2007). But using both nitrogen and sulfur gives a different MYA because they have a synergistic effect on yield- the yield was greater than what the individual nutrients could produce. Likewise, the right combination of nitrogen and water can increase yield while using less than the recommended amount of nitrogen (Paolo and Rinaldi 2008). The recommended amount is calculated by considering existing soil nutrient content, nutrient loss rates, and expected yield. This amount is then split equally into several doses and applied in equal intervals across the growing season. Despite this application of equal doses, the fact that nutrient uptake rates and growth of an onion varies with time (Horneck 2004) puts into question whether the fertilizer should be distributed unevenly with time.

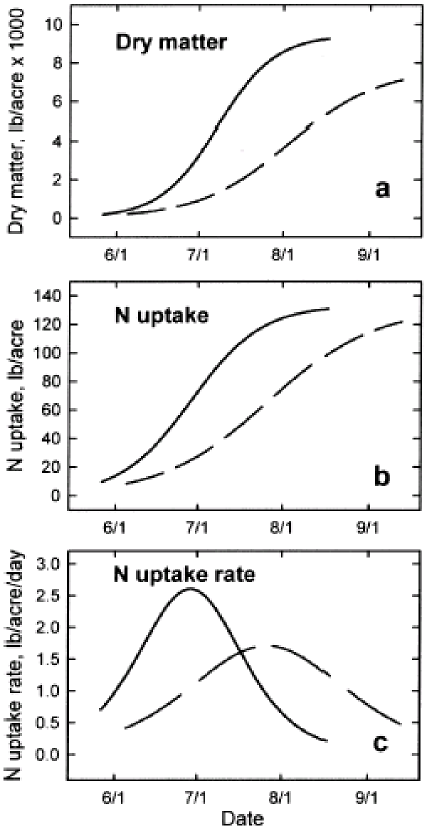

Figure 1: Onion mass increase rate, nitrogen uptake rate, and change in uptake rate of nitrogen in two different sites, distinguished by solid and dashed lines. Horneck, 2004.

Based on the uptake rate, an MYA that is applied in equal doses does not seem to take advantage of an onion's change in uptake rate.

One area that is not addressed adequately in fertilizer use efficiency research is the discrepancy between how plants absorb nutrients- at a variable rate- and how farmers fertilize them- at a constant rate. At least in a couple of cases variable rate studies have been shown to have additional benefits. Koch et al (2004) by distributing fertilizer differently across both time and area managed to decrease total nitrogen use by 6-46%. Another study (Timmer 1996) used a variable rate of fertilization in the context of reforestation: tree seedlings in a greenhouse were fed fertilizer in an increasing (exponential) rate to ensure that they grow with no nutrient stress and therefore will be more competitive when planted in a forest. The exponentially fertilized seedlings were more competitive when planted outside at competitive sites. The success of Timmer's (1996) study raises doubt if a constant rate optimizes nutrient absorption and if low amounts of fertilizer can be used in the beginning stages of growth without growth loss. Pire's (2001) record of the nutrient uptake levels of onions throughout its growth supports this idea. He concluded that nitrogen uptake at early stages, during root development, is low compared to when the bulb is growing later on in the growing season.

I investigated the following question: can fertilizer be distributed differently with time in an increasing manner so that nutrient losses are minimized while onion yield (dry weight) is the same as constantly fertilized onions?

For my research I chose the onion for two reasons. One, the onion is widespread and has a sigmoid nutrient absorption curve just like other vegetable crops (Tei et al 1996). So using the onion makes the results applicable to other crop plants. Two, having looked at several food crops including beans, lettuce, and tomatoes, the growing and harvesting time frame of an onion fits the time frame available to me.

My hypothesis is that nutrient loss due to increasing rate fertilization will be lower than that of constant rate fertilization provided that the variable schedule approximates the nutrient absorption rate of the onion with time. And also they will have similar masses at harvest since the same amount of fertilizer is used. The idea is that the onion gets the right amount of nutrients it needs at the right time. The null hypothesis is the case where the losses are similar. This means that the variable rate had no effect. Nitrous oxide (N_2O) in the form of gas and nitrate (NO_3) in the leach water – two important Nitrogen loss pathways- will be used as indicators of all nutrient loss in the plants. The graph below demonstrates a lot of the concepts- it is not based on onions and it does not represent my project schedule (modified figure from Timmer 1996):

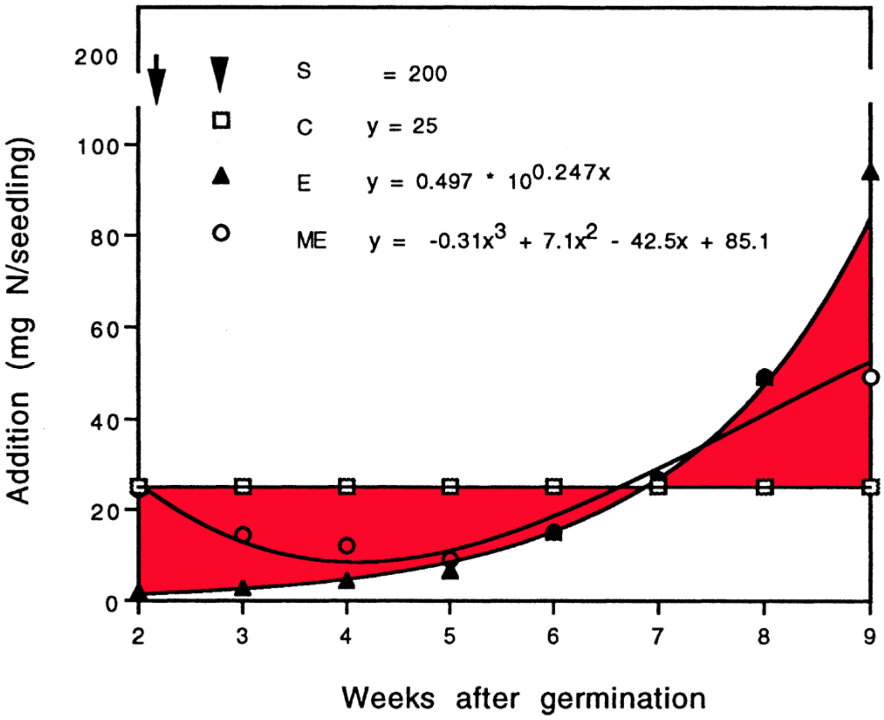

Figure 2: The square dotted line represents constant fertilization. The triangle dotted line represents exponential. The red areas represent excess nutrients (left side) because the amount given is above the amount absorbed and nutrient stress (right) due to constant rate fertilization because the amount applied is lower than the amount absorbed. For my project, I start fertilization a couple of weeks after germination and this graph reflects that.

A constant rate has excess nutrients at the beginning of the cycle because there is no root development to support it; the unabsorbed excess is lost to the plant. And there is nutrient stress at the end of the cycle because the maturing plant absorbs the majority of the necessary nutrients at this point. Initially a low amount of fertilizer will be used on the seeds while the roots are growing and the amount will be gradually increased to the maximum yield rate, this will coincide with the growth of the bulb of the onion. In contrast, standard practice averages the fertilizer across the growing season. The same amount of fertilizer is used for both methods but in one there could be less fertilizer loss, which means less weed competition and environmental pollution.

To answer my question, I will conduct an experimental study examining growth of onions and nitrogen losses under two different fertilizer regimes (a constant rate and an increasing rate) relative to *Allium cepa* (USDA plant profile) grown without fertilizer.

Methods

Allium cepa onions were studied in a controlled fertilizer experiment. Three groups of onion seeds were planted in the UC Jean Grey research greenhouse starting December 13, 2008. They were harvested late February 2009. Different schedules of NPK fertilizer with a ratio of 18-6-18 (the percentages of NPK in the fertilizer) in composition were used on two of the groups. The third group received no fertilizer and acted as the control group.

The two groups that received fertilizer were given the same total amount of fertilizer, but the distribution of that amount over the course of the growth season was different. The group labeled ‘Constant’ received the same amount of fertilizer each time it was fertilized. The group ‘Increasing’ received a variable rate of fertilizer that closely followed the nutrient absorption curve of the onion. The rate application of the Constant group simulates the current practice of fertilization used by farmers (Koch et al 2004). The amount of fertilizer added increases over time in the Increasing group. It is modeled after a modified exponential curve that initially uses less fertilizer when the plant is young and applies the majority of the fertilizer later in the season when the onion has the capacity to absorb as much as it needs (Figure 1). The Constant and ‘Increasing’ groups should indicate whether timing is important for nutrient absorption and therefore nutrient loss of the crop plant. The control should confirm that fertilizer is important for growth. I used the size (dry weight) of the onion at harvest time, leaf height, the nitrous oxide flux from the plants after fertilization, and nitrate loss via water as indicators of nutrient absorption and loss. Greater loss of nutrients should result in smaller bulbs and shorter leaves.

Allium cepa seeds were planted in pots (18cm in height, 15 cm in diameter) filled with Metro Mix 700 sterilized soil (manufacturer: SunGro). Onion seeds need high organic content soil to sprout (Sullivan 2001) so the top inch was mixed with store bought chicken manure by the recommendations of a gardener at Adachi’s Flower Nursery (Richmond, CA). Five seeds were planted in each pot to ensure sprouting. They were thinned to one onion per pot once they grew to two to three inches in height. In the end, the sample size was about ten plants (in individual pots) per group. It took about two weeks for the seeds to sprout. Once the seeds were thinned they were fertilized. Total fertilizer needed across entire growing season was calculated based on the expected yield of medium sized onions, which are 150 grams. The equation is (Sullivan 2001): $\frac{150g}{pot} x\ unit\ crop\ uptake\ x\ N\ uptake\ efficiency$ =

$$\frac{150g}{pot} x\ 0.0019gN\ x \frac{1}{.50} = \frac{0.57gN}{pot}$$

The total fertilizer amount was divided in three parts and then applied in equal intervals of three weeks after the first fertilization. For the Constant rate group, the fertilizer was divided equally, while the Increasing group's fertilizer was scaled according to onion growth curve (Tei et al. 1996). Phosphorus and Potassium uptake efficiencies are similar to that of Nitrogen (Sullivan 2001) so 50% efficiency was used. The NPK amount necessary for growing my expected yield of 150g/pot had a ratio of 10:3:10. A fertilizer with the same ratio was used: Palm Food (brand name) 18:6:18. Therefore .57g/0.18 = 3.17g Palm Food is need for each pot. Each application was 3.17g/3= 1.06g Palm Food/pot for the Constant group. The split ratio for Increasing group was 1:3:6. The fertilizer is water soluble and was added to a constant amount of water each time and then sprayed over the pots.

Table 1: The amount of fertilizer used on each fertilization time for the three groups of onions is summarized.

	1st Fertilization	**2nd Fertilization**	**3rd Fertilization**
Constant	1.06g NPK/pot	1.06gNPK/pot	1.06gNPK/pot
Increasing	.32g NPK/pot	.95g NPK/pot	1.90g NPK/pot
Control	0	0	0

The height of the leaf was measured from the soil to the top of the highest leaf. At the end of February, the onions were uprooted and cleaned then the leaves and roots were cut off around the bulge of the onion bulb. Leaf height was measured periodically and recorded once every month. The bulbs were then put into oven at 70 C and dried to 10-15 minutes.

To quantify N loss as an estimate of fertilizer use, the N_2O gas samples were collected by enveloping each plant with a gas bag 30 minutes after application of the fertilizer. This would give the plant plenty of time to cycle the nutrients. N_2O content was measured using a gas chromatographer. Also after each application a sample of the leaching water that comes out from the bottom of the pot was captured in a test tube and then the nitrate content was measured with a Lachatt. For the first fertilization, the bags were left on for one hour which may have contributed to plant death. The time was reduced to thirty minutes for the second fertilization. To ensure equal exposure to sunlight the pots were rotated after each application of the fertilizer.

NO_3 samples were collected by capturing the water draining out of the pot in tubes after each fertilization time.

An independent two sample t-test and a one way ANOVA was used with Matlab 7 to see if the average weights of the three groups are significantly different. My hypothesis will be confirmed if the Increasing rate group has both an equal yield of onions and a lower average N_2O and NO_3 loss than the Constant group.

Results

Plant mortality due to pests was observed in the Increasing group. The average height for Increasing group was only 0.3cm and 2.1cm taller than that of the Constant group (Table 2). The Control grew less than four centimeters in one month. At the time of harvest, the presence of treatments on Constant and Variable groups had a significant effect (Table 2).

Table 2: Three group ANOVA results show average leaf height at the time of harvest. The Control group had a significantly smaller mean. F-value detected significant factor between the Control group and the other two groups.

Groups	**Sample size**	**Mean (cm) 1 month**	**Mean 2 month**	**Degrees of Freedom**	**F value**	**P- value**
Constant	10	20.5±5.2	52.3±10.2	2 between groups	31.53	0.0001
Increasing	8	20.8±3.1	54.4±5.6	20 due to error		
Control	5	16.1±4.4	20±5.3			

Plant mass did not differ between plants grown in the constant and variable fertilizer treatments (Table 3). The mean of the Control group was more than four times smaller than the other two groups. An F-value greater than one (much greater in this case) signifies that the treatment (presence of fertilizer) had a significant effect (Table 4).

Table 3: Three group ANOVA results show average dry mass. The Control group had significantly smaller mean. The Constant and Increasing group means were not significantly different. F-value detected significant factor between the Control group and the other two groups.

Groups	**Sample size**	**Mean (grams)**	**Degrees of Freedom**	**F value**	**P- value**
Constant	10	9.33±4.02	2 between groups	7.579	0.0009
Increasing	8	8.90±3.72	21 due to error		
Control	5	1.98±1.27			

The mean N_2O emissions did not vary between fertilizer treatments and decreased through time for both groups ranging from 2.0 to 0.75 (Figure 3). Also of note is that the two first measurements have the greatest range in N_2O concentrations. The N_2O concentration differences between the Increasing and Constant groups were not significant (Table 4).

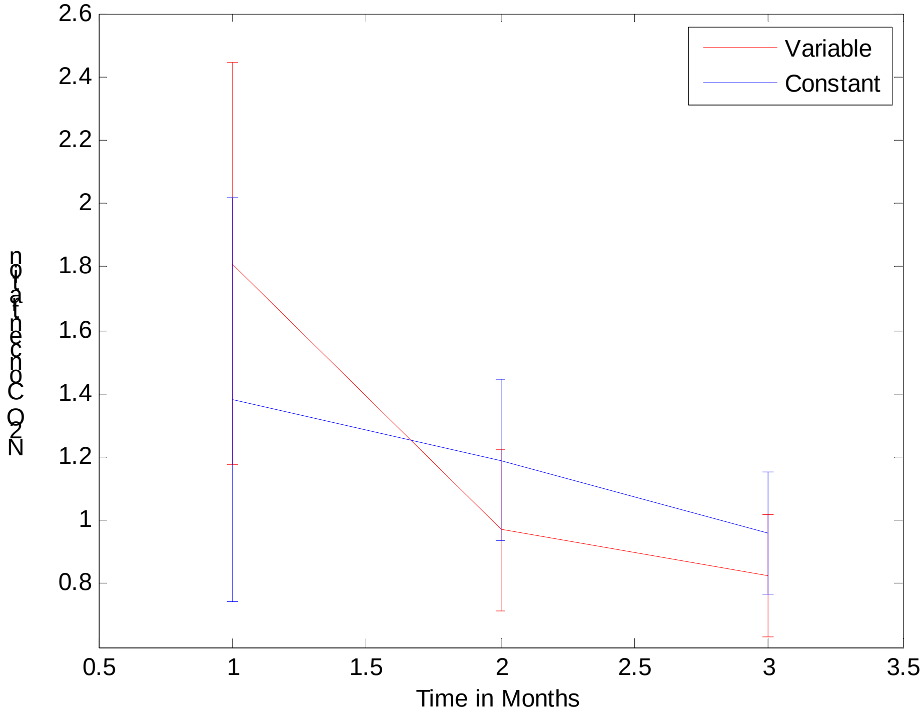

Figure 3: Average N_2O concentrations (ppm) of the Variable and Constant groups as collected after each fertilization (*n*=10). Months one, two, and three were the times of fertilization. Vertical bars show variability (± 1 s.d.). The middle points are average N2O concentrations. Sample size was ten.

Table 4: The results of the two sample independent t-test between the Increasing and Constant groups are summarized. The Control group was not sampled. The two groups had no significant differences (with alpha=0.05).

	1st fertilization	**2nd fertilization**	**3rd fertilization**
p-value	0.09	0.18	0.17
t-stat	-1.7	1.3	1.4
df	18	18	18

The nitrate emission measurements for the Constant group did not have a decreasing trend. The emissions for the Increasing group decreased over time (Figure 4). The variance of both groups generally increased with time (Figure 4). The Increasing group had a significantly higher NO_3 emission after the first month (Table 5), the following measurements showed no significant difference in NO_3 emissions.

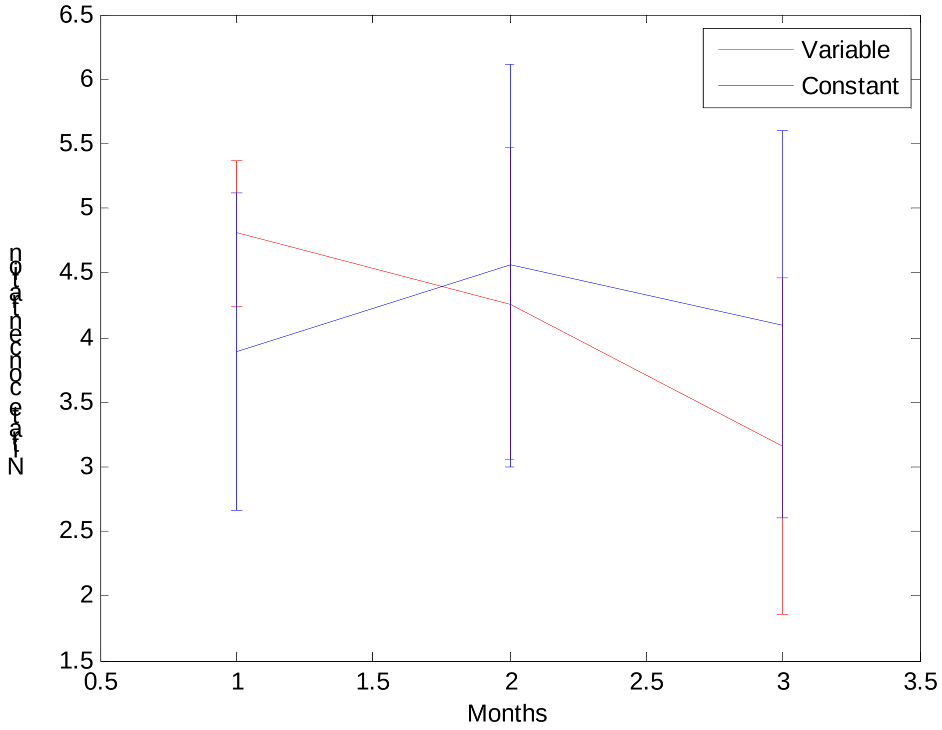

Figure 4: NO_3 concentrations of the Variable and Constant groups as collected after each fertilization. Months one, two, and three were the times of fertilization. Vertical bars show variability. The middle points are average NO_3 concentrations. Sample size was ten.

Table 5: The results of the two sample independent t-tests between the Variable and Constant groups of nitrate samples are summarized. The Control group was not sampled. Only the result of the first nitrate sampling had significant differences (with alpha=0.05).

	1st fertilization	**2nd fertilization**	**3rd fertilization**
p-value	0.04	0.64	0.14
t-stat	-2.1	.47	1.5
df	18	18	18

In summary, the Variable group showed decreasing emissions of both N_2O and NO_3 as well as growth comparable to that of the Constant group (Table 2).

Discussion

There was no significant difference in plant mass, leaf height, N2O emissions and NO3- leaching between the fertilizer treatments. For the Increasing group leaf height was taller and N_2O and NO_3 losses were similar. Now the question is how much of the results can be attributed to the differences in treatments.

Nitrogen directly affects both leaf growth and bulb growth (Henrikson, 1987). Too much nitrogen will lead to more leaf growth than to bulb growth (Pire et al. 2001). This may have been a factor in the Constant group leaf growth, which was almost as tall as the Increasing group. The averages of the Increasing group were greater by insignificant amounts. The leaf heights of the Control group stopped growing substantially after a month (Table 2). An exponential fertilizing pattern leads to onions of comparable size as those grown with the constant fertilization. The dry masses of the Constant and Increasing groups were not significantly different (Table 3). The Control group's mean mass was significantly smaller than the other two groups (Table 3) therefore the presence of fertilizer did increase yield. The Increasing group lost two plant samples, but they were lost before fertilization actually began. The smaller sample size may have contributed to its smaller mean and larger standard deviation. The constant group with its full sample of 10 had both a larger variance and mean onion weight. Unexpected factors such as pests and damage from taking the gas sample hurt the plants. Unfortunately these factors hurt the Variable more by chance, hence the smaller sample size, therefore a concrete relationship between bulb size and nutrient loss cannot be drawn even though the Increasing group's N_2O losses decreased faster than the Constant group's as the bulb got bigger (Figure 3).

The N_2O emissions decreased over time. The wide distribution of those first samples (Figure 3) suggests that the soil and gas trapped in unabsorbed water- due to lack of sizable roots- were probably bigger factors than the plants. While the differences between the Increasing and Constant groups were not significant, the similar masses indicate that variable fertilization does not harm the plants.

The NO_3 results were not consistent with the gas samples. The distribution gets wider as time progresses but still the range of values get lower (Figure 4). The average concentrations decreased for the Increasing group. There is no pattern for the Constant group. The NO_3 loss was expected to decrease for both groups. This may be due to the nature of the shallow onion root: small roots mainly affect their local area so uneven watering is a problem (Spek, *et al*. 1988).

The leaf heights were taller than expected and the bulb size smaller than expected. These results were consistent with findings by other studies that application of excess nitrogen leads to increased leaf growth rather than bulb growth (Pire *et al.* 2001). There was also another discrepancy between my calculated NPK ratio and research suggested ratio. For my experiment, the necessary N, P, K values were calculated individually according to my expected and desired yield. Synergetic effects and their timing were not considered. Pire *et al*. (2001) stress that onions have “low nutrient removal” at the beginning of the cycle, and the N_2O gas trend seems to confirm this because of high emissions at first fertilization (Figure 3). Timmer (1996) makes several exponential growth curves and applies fertilizer according to those curves. The idea was that the plants would also grow exponentially. This was true in my case as well; the plant leaves at least grew from zero to twenty to fifty centimeters in the end (Table 2). The idea that exponential nutrient loading would make plants more resilient when transplanted in a outside (Timmer 1996) seem to apply because the procedures used to measure gas and water samples were invasive and damaging to the plant and still my plants survived.

While the variable rate fertilization has been recommended by others, it has not reached the mass market of crop production yet. My project seeks to start research at a small scale and spread the idea of varying fertilization with time. With lots of replicates, a consistent trend might be possible. This study has given support that a variable schedule certainly doesn’t detract from the growth. As more successful studies are conducted the benefits of this method will become clear. There may be other benefits to losing fewer nutrients. This sort of fertilization method might be more environmentally friendly in terms of pollution. And a whole another area of study of what the nutrient content of crops under different fertilization methods might be needs more research.

Besides a ‘significant’ result, an experiment can also educate those who read it. Whether the reader becomes more literate in the specific topic or decides to try the experiment on their own, the design is simple enough for anyone to replicate on a small scale. And that is what I think this experiment aims to show: people can cut back on excessive use of fertilizers at early stages of growth yet have productive yields.

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