NITROGEN DYNAMICS IN AN ORGANIC STRAWBERRY PRODUCTION SYSTEM

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ABSTRACT

Optimizing nitrogen (N) management in organic strawberries on the central coastal California is a challenge because of high N sensitivity and the long growth period of strawberries, transplanting immediately followed by the winter rainy season and unpredictability of N mineralization from organic fertilizers and soil organic matter. Moreover, research-based information on N fertility management in organic strawberries is lacking. In a replicated on-farm organic rotation trial in Moss Landing, California, N dynamics in an organic strawberry production system was monitored for two years. In the first year, we examined the grower's current N-management practice, and an improved N-management practice was demonstrated in the second year. Fertility management practices, soil inorganic N content (0-60cm deep), and fruit yield, plant biomass, and N content of strawberries (cv. Aromas) were monitored. Changes in cumulative daily N uptake of strawberries were calculated and N- loss from the root zone (0-30cm deep in the bed area) during the winter rainy season was estimated. We used a Monte Carlo simulation method to express statistical variability of the results. In the winter rainy season of the first year, we observed 214 kg-N ha^{-1} of inorganic N –loss from the root zone within 20 weeks after planting. Plastic mulch was applied 7 weeks after the planting. Marketable fruit yield was 38.7 tons ha^{-1} with a total N application rate of 255 kg ha^{-1}. Total N uptake of strawberries was ~120 kg ha^{-1} and about 80% of this occurred in the later half of the growth period. In the second year, we adopted pre-plant plastic mulch application and adjusted basal/supplemental organic fertilizer-N rates to better synchronize the N supply with the plant N demand. As a result, although the residual soil inorganic-N was much lower than the first year, the N-loss during the rainy season was decreased to 13 kg-N ha^{-1}, while maintaining fruit yield a similar to the first year.

INTRODUCTION

Organic strawberry production in California is on the rise. In 2001, 162 organic strawberry growers planted 757 acres of organic strawberries in California. The acreage increased to 1,279 acres in 2002 (Klonsky, 2003).

Strawberry is a nitrogen (N)-sensitive crop. The yield and quality of strawberry fruits is strongly affected by plant N status (May and Pritts, 1990). However, synchronizing N supply with the N demand of strawberries in organic systems is a challenge due to unpredictability of N mineralization from organic fertilizers and soil organic matter. In addition, under the winter-planting annual system, strawberry transplanting is immediately followed by the rainy season when N leaching potential is high. To meet the strawberry's N demand, growers intensify their use of commercial organic fertilizers that are relatively soluble. This practice has received criticism as "high-input organic agriculture", which may not convey environmental benefits commonly associated with organic farming (ATTRA, 2003). Impact of current N-management practices in organic strawberries on the environment is unknown in California. Thus, there is a critical need of research-based information on N fertility management in organic strawberry systems. The goals of this case study are to: 1) examine current N-management practice, and 2) demonstrate improved N-management practice, on an organic strawberry farm on the central coast of California.

MATERIALS AND METHODS

1. Study site and experimental design

The research takes place on the Elkhorn Ranch, located on the edge of the Elkhorn Slough Estuarine Reserve, Monterey County, California where non-point pollution from agricultural practices has been documented as a major problem (ABA Consultants et al., 1989). To demonstrate effects of diverse vegetable/strawberry rotations and multiple ecological practices on soil and agroecosystem health, an organic five-year rotation experiment was initiated in 2001 (Muramoto et al., 2003). Experimental design was a split plot arrangement of treatments in a randomized complete block with a break period between strawberries as the main plot and strawberry cultivar as a sub-plot with four replications. Each plot size was four 65 cm rows x 18.6 m long. The soil type is Santa Ynez fine sandy loam (Fine, montmorillonitic thermic, Ultic Palexerolls), 2 to 9 % slopes. The topsoil (0-15cm deep) showed organic matter content of 9.1 g kg^{-1}, and a pH of 6.2.

In the present paper, we discuss N-dynamics in an organic strawberry production system in this rotation experiment. We focus on cv. Aromas sub-plot and compare treatment A in the first year with the treatment C in the second year. These were the first strawberries in the five-year rotation of each treatment.

2. Cultural practices and fruit yield survey

Strawberry transplants were planted on Nov. 19, 2001 in the first year and on Nov. 26, 2002 in the second year. Plant population per ha was 52,340 in year 1 and 47,340 in year 2. To suppress *Verticillium dahliae* population in soils, we incorporated broccoli residues as a biofumigant (Koike and Subbarao, 2000). The application rate was 2.2 tons ha^{-1} and 3.9 tons ha^{-1} (dry matter each) in year 1 and 2, respectively. Total N application rate was 255 kg-N ha^{-1} in year 1 (compost 55*, pelletized organic fertilizer 82*, broccoli 86*, liquid organic fertilizer 33 kg-N ha^{-1}. * basal application) and 329 kg-N ha^{-1} in year 2 (compost 66*, pelletized organic fertilizer 37*, broccoli 151*, liquid organic fertilizer 75 kg-N ha^{-1}). See figure 1a (year 1) and 1b (year 2) for timing of each application. Fresh strawberry fruit yield was measured once to twice per week from 40 designated harvest plants in the middle two beds of each plot from May to September in both years. Marketable and cull fruit yields were weighed separately by experienced harvesters. Mortality of strawberry plants was examined from May to the end of the season.

3. N monitoring

Throughout the growth period, samplings were done 3 to 4 times for plants and once a month for soils from 0-60 cm deep. Biomass and T-N content in each part of the strawberry plant, including total fruit biomass and its N content, were determined. Cumulative daily N uptakes were calculated from regression curves of N content and biomass of plants and fruits (Hunt, 1982). Nitrate and ammonium was extracted from soil with 2M KCl and determined by the flow injection analysis method. Soil bulk density in all plots was determined using the soil core method at the end of season each year. Nitrate plus ammonium content was expressed volumetrically as inorganic N (= NO_3-N + NH_4-N kg ha^{-1}). We estimated N-Loss from the root zone during the rainy season (between 0 and 20 weeks after planting, which is approximately from mid November to early April) using the following formula:

$$\text{N-Loss}_{20wks}\ (\text{kg ha}^{-1}) = (\text{Soil inorg. N}_0 - \text{Soil inorg. N}_{20wks}) - (\text{Plant uptake N}_{20wks} - \text{Plant input N}_0)$$

where, Soil inorg. N_0; Inorganic N (kg ha^{-1}) in 0-30 cm deep soil on the planting day, Soil inorg. N_{20wks}; Inorganic N (kg ha^{-1}) in 0-30 cm deep soil at 20 weeks after planting, Plant uptake N_{20wks}; Plant uptake N (kg ha^{-1}) at 20 weeks after planting, and Plant input N_0; N input (kg ha^{-1}) from transplants. We defined a 0-30cm soil layer in the bed area as the strawberry root zone, based on literature (UC-IPM Program, 1994) and a preliminary strawberry root profile survey. N-Loss is considered to consist mainly of leached-N and denitrified-N with minor contributions from biological immobilized-N. To demonstrate statistical variability, we used the Monte-Carlo simulation method and expressed the results as a mean and 90% credible interval (5%, 95%) (Morgan and Henrion, 1990; Muramoto et al., 2001).

RESULTS

1. The first year (2001-2002)

Pre-plant soil inorganic N analysis revealed 150 kg-N ha^{-1} of residual inorganic N from the previous crop (fig. 1a). By adding 222 kg-N ha^{-1} of total basal N, inorganic N content at the time of planting rose to 260 kg-N ha^{-1}. After receiving 280 mm of precipitation, the grower applied plastic mulch in January 2002. In the meantime, a considerable amount of N was lost since planting. It was estimated that 214 (169, 262) kg ha^{-1} of inorganic N was lost from the root zone within 20 weeks from planting (fig. 1a).

Strawberries grew well and had no major disease problems. Marketable fruit yield and total fruit yield was 39.8 tons ha^{-1} and 63.1 tons ha^{-1}, respectively. Mortality of plants at the end of the season was 1.2 %. Cumulative daily N uptake of strawberry plants showed that ~80% of the total N uptake took place in the later half of the growth period (fig. 1a). It also indicated a negative accumulation in the late growth stage due probably to N removal from plants through fruits harvests. Total N uptake by strawberry was ~120 kg-N ha^{-1}.

2. The second year (2002-2003)

Based on the results of the first year, the grower modified his N fertility management for the following year. He adopted: 1) pre-planting plastic mulch application to reduce N-loss during the rainy season, and 2) adjusted the rates of basal/supplemental organic fertilizer applications to better meet the N demand of strawberries. He decreased the rate of pre-plant pelletized organic fertilizers to a half of the previous year and increased the rate of liquid fertilizers through fertigation in the late growth stage (fig. 1b).

As a result, the amount of N-loss during the rainy season (Nov. 2002-April 2003) was reduced to 13 (-16, 51) kg-N ha^{-1} (fig. 1b). It should be noted, however, that the residual N level at the time of planting in the second year was much lower than the first year and precipitation during 0 and 20 weeks after planting in the second year (318 mm) was 15% less than the first year.

The plant development in the second year was earlier than the first year due to warmer temperatures. Two-spotted spider mite (*Terranychus urticae*) reduced the plant vigor in May and June resulting in relatively smaller plant biomass. Marketable fruit yield was 38.7 tons ha^{-1}, a similar level with the first year, and total fruit yield was

58.4 tons ha^{-1}. Mortality of plants at the end of season was 0.3%. Unlike the first year, cumulative daily N uptake of strawberry plants in the second year did not show a negative accumulation in the late growth stage (fig. 1b). Total N uptake by strawberry was comparable with the first year.

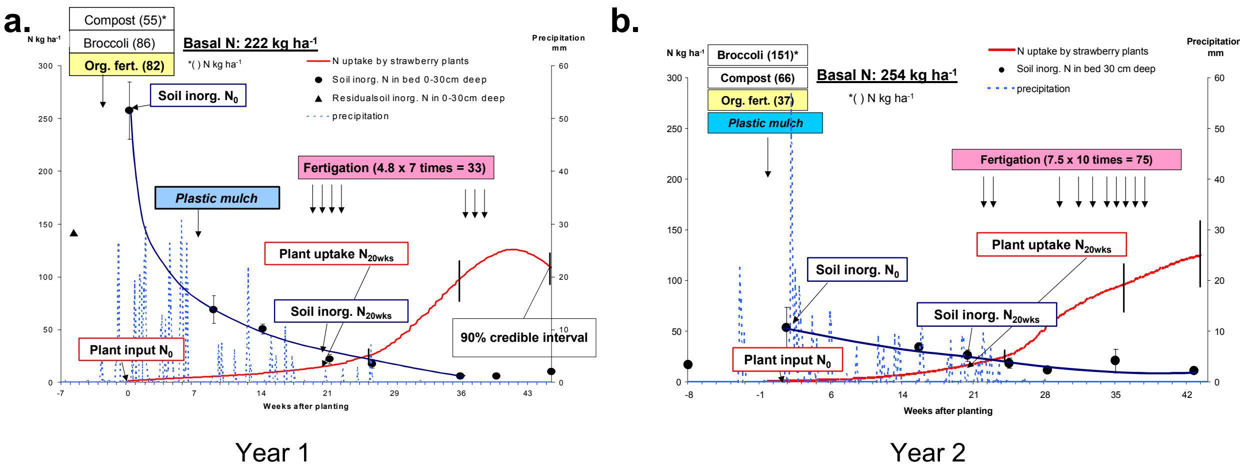

Fig. 1 N loss from an organic strawberry field in Moss landing, California. cv. Aromas. Estimated N-Loss during the rainy season was as follows: year 1; N-Loss$_{20wks}$ = 214 (169, 262)* kg ha^{-1}, and year 2; N-Loss$_{20wks}$ = 13 (-16, 51)* kg ha^{-1}.
* mean and 90% credible interval (5%, 95%).

DISCUSSION

The first year's results in this case study showed that organic strawberry production could have a considerable N-loss and a significant impact on the environment during the rainy season (ATTRA, 2003). On the other hand, the second year's results clearly demonstrate that relatively simple adjustments in N management can make a big difference in reducing N-loss while maintaining the fruit yield.

Use of plastic mulch is a common practice in California organic strawberry production (Gliessman et al., 1996), but time of mulch application varies among growers. Though the initial soil inorganic N level was low, our results from the second year indicate the potential of pre-planting plastic mulch application for minimizing N loss during the winter rainy season. Unlike conventional strawberry systems where use of control-release N fertilizers is widespread, no organic control-release N fertilizers that can synchronize the soil N release with the strawberry N demand are currently available. Therefore, a pre-plant plastic multi application might help reserve inorganic N that was mineralized in the soil during the early rainy season when the plant roots are not fully developed and hence the system is most susceptible to N leaching. Further studies are needed to figure out if interactions exist between timing of multi application and soil inorganic N level. The soil N monitoring in the first year also suggests the importance of examining residual inorganic N levels in organic systems. Some conventional practices such as this and irrigation management using soil water sensors should be used to enhance N use efficiency in organic systems.

Considering the 10-month growth period of strawberries, the total N uptake of 120 kg ha^{-1} appears not so high. Limited information is available on N application rates in organic strawberry production. Our N application rate was similar to an example given for sample costs to produce organic strawberries (Bolda et al., 2003), but we might be able to reduce it by furthering synchrony of N supply and N demand, which is the key to improve N use efficiency (Campbell et al., 1995; Woomer and Swift, 1994). Total fruit yield of the first year of the experiment was 83% of the average total yield of Monterey County in the same year (Monterey County Agricultural Commissioner, 2003).

The N uptake pattern of strawberry plants (fig. 1) suggests that the peak N demand exists in the mid to later growth stages, whereas less N is utilized in the early stage. N fertility studies for organic long-season vegetable production indicate cover crops or compost alone might be inadequate to fulfill the late N demand of these crops (Gaskell and Klauer, 2001; Gaskell et al., 2000). The same is likely to be true in organic strawberry production. Under the current system, fertigation and foliar N application are the only practical options as supplemental N application measures. In the second year of this case study, to meet the N demand of strawberries, the grower decreased the basal N rate of the organic fertilizer and increased the rate of liquid organic fertilizer for the late stage.

This appears to work fine in supplying sufficient N in the late stage, since, unlike the first year, we did not find a negative plant N accumulation in the late season. However, though we did not examine it in this case study, organic fertigation may have a high risk of N leaching under excess irrigation conditions (Pritts and Handley, 1998). Effectiveness of foliar N application in organic strawberry systems is not well studied.

Finally, in spite of a low uptake in this stage, a sufficient level of N in the early growth stage is necessary for bud formation (May and Pritts, 1990). A preliminary study showed a positive correlation between tissue T-N level in the early growth stage (March) and total fruit yield in organic strawberry systems with multiple cultivars (Muramoto, unpublished data). Further studies with different N rates and timings are required to determine the early N demand and appropriate rate and type of pre-plant N application in organic strawberry systems.

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