Influence of Fall Nitrogen and Spring Nitrogen–Potassium Applications on Yield and Fruit Quality of ‘Chandler’ Strawberry

G.S. Miner¹, E.B. Poling², D.E. Carroll³, and L.A. Nelson⁴

North Carolina State University, Raleigh, NC 27695

C.R. Campbell⁵

Plant/Waste/Solution Advisory Section, Agronomic Division, North Carolina Department of Agriculture, Raleigh, NC 27695-6465

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ABSTRACT. Annual-hill strawberry (*Fragaria ×ananassa* Duch.) production with black plastic mulch and drip irrigation is gaining popularity in North Carolina. Two experiments (E1 and E2) were conducted on a Wagram loamy sand (Arenic Kandiudult) in 1992 and on a Norfolk sandy loam (Typic Kandiudult) in 1993 to investigate the effects of fall-applied N and spring-applied N and K on ‘Chandler’ strawberry yield and fruit quality. E1 treatments included factorial combinations of banded fall-applied N (0, 34, and 67 kg·ha⁻¹) and drip spring-applied N (0, 0.19, 0.37, 0.56, and 0.75 kg·ha⁻¹·d⁻¹ and 0, 0.37, 0.75, and 1.12 kg·ha⁻¹·d⁻¹ in 1992 and 1993, respectively). E2 treatments included combinations of drip spring-applied N (0.56, 1.12, 1.68, and 2.24 kg·ha⁻¹·d⁻¹) and K (0.46, 1.39, and 2.32 kg·ha⁻¹·d⁻¹ and 0, 0.75, 1.49, and 2.24 kg·ha⁻¹·d⁻¹ in 1992 and 1993, respectively). There were no significant interactions among main effects for any of the measured variables. Market yield maximized with total N at ≈120 kg·ha⁻¹ with one-half banded in the fall and the remainder drip-applied in the spring. Fruit firmness decreased with increasing N rate. Fruit pH and concentrations of total acids and soluble solids were not affected by N treatments, but soluble solids increased as the harvest season progressed. Plant crown number was not affected by N treatment but crown yield increased with N rate similar to market yield. There was no response to drip-applied K for any variable in either year. Based on soil test, fall-applied K (broadcast-soil incorporated) met the K requirements both years.

Strawberry production has evolved rapidly from the matted-row to the annual-hill, plastic mulch system in North Carolina and other southeastern states (Poling, 1993). The plasticulture system is management intensive and requires significant monetary investment but provides 2- to 3-fold higher yield, earlier harvest, higher fruit quality, and higher customer appeal. Cultural factors including soil moisture and weed control also are optimized.

Nutrient management for strawberry plasticulture has been intensively investigated in California (Cannell et al., 1961; Voth et al., 1961) and Florida (Albregts and Howard, 1987; Albregts et al., 1991), but similar information for the southeastern United States, where the environment, harvest duration, and yield potential differ markedly (Poling, 1993), is lacking. Many growers in North Carolina use high rates of N with a large proportion applied in the fall as S-coated urea. While N rates used by North Carolina growers for the plasticulture system vary from 110 to 450 kg·ha⁻¹, excessive rates have been reported to reduce yields, delay ripening, and produce soft fruit (Albregts et al., 1991; May and Pritts, 1990; Voth et al., 1967). Additionally, a high rate of N often results in production of excessive foliage (Voth et al., 1967) leading to

increased disease susceptibility (Stadelbacher, 1963) and interference with harvest.

A high-yielding strawberry crop can remove K at 40 to 70 kg·ha⁻¹ in fruit and calyx tissue (Albregts and Howard, 1978). Potassium concentration in leaves should be 15 to 25 g·kg⁻¹ (May and Pritts, 1990), and levels <10 g·kg⁻¹ may reduce yield and fruit quality (Bould, 1964). Low leaf K concentrations have been associated with low levels of soluble solids and titratable acidity (Ricketson and Hill, 1966). A decrease in fruit firmness has been reported with increasing K rate (Locascio and Saxena, 1967), but Albregts et al. (1996) reported that K rates ranging from 50 to 250 kg·ha⁻¹ had no effect on fruit firmness.

The plasticulture system provides several options for nutrient management. In addition to preplant soil-incorporation of nutrients, a drip tube can be used for applying irrigation and nutrients. Our purpose was to investigate the effects of preplant (fall) N and drip (late winter and spring) N and K applications on strawberry yield and quality. Specific objectives were to determine optimum N rates for each time period and to evaluate the response to supplemental K (spring-applied) beyond soil test K recommendations.

Materials and Methods

GENERAL. Two strawberry experiments (E1 and E2) were conducted at the Central Crops Research Station, Clayton, N.C. (lat. 35° 40' N, long. 78° 30' W, elevation 106 m) in 1992 and 1993 using the plasticulture management system and drip irrigation. E1 was designed to evaluate rates of fall- and spring-applied N. E2 investigated spring-applied N and K. Both experiments were located on Wagram loamy sand (loamy, siliceous, thermic Arenic Kandiudult) in 1992 and Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Kandiudult) in 1993. Initial pre-experiment

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¹Professor, Dept. of Soil Science.

²Professor, Dept. of Horticultural Science.

³Professor, Dept. of Food Science and Statistics.

⁴Professor emeritus, Dept. of Statistics.

⁵Chief.

soil tests for the Wagram, with P and K determined by means of the Mehlich-III extractant (Mehlich, 1984), were pH, 5.4; CEC, 1.7 $\text{cmol}_c\cdot\text{L}^{-1}$; base saturation, 52%; P, 98 $\text{mg}\cdot\text{L}^{-1}$; and K, 0.09 $\text{cmol}_c\cdot\text{L}^{-1}$. Dolomitic lime was applied to the Wagram in Sept. 1991, and soil pH and base saturation were 6.5 and 79%, respectively, at the end of harvest in June 1992. Initial soil tests for the Norfolk soil were pH, 6.2; CEC, 2.8 $\text{cmol}_c\cdot\text{L}^{-1}$; base saturation, 79%; P, 122 $\text{mg}\cdot\text{L}^{-1}$; and K, 0.10 $\text{cmol}_c\cdot\text{L}^{-1}$, and lime was not required.

The North Carolina soil test K recommendation for both soils was 111 $\text{kg}\cdot\text{ha}^{-1}$. This K was broadcast before fall bed preparation both years as K_2SO_4 and was incorporated by disking before planting. Phosphorus was not applied as both sites tested high to very high in P. Beds ($0.25 \times 0.91 \times 6.1$ m) were formed on 1.5-m centers by means of a bedshaper, and fall-applied N was banded 15 cm deep in the center of each plot with the application rate varying with experiment. The bedshaper was passed over the beds a second time and a single drip-irrigation line was buried 10 cm deep in the center of each bed. Methyl bromide was injected at 250 $\text{kg}\cdot\text{ha}^{-1}$, and 0.025-mm-thick, embossed, black polyethylene mulch was sealed over the beds.

Green, nondormant 'Chandler' strawberry plugs (Poling and Parker, 1990) were transplanted in two rows through the plastic on 8 Oct. in both years. Plant spacing was 30.5 cm between and within rows. A plot was one bed with 40 plants. Immediately after transplanting, 2 cm water was applied via overhead irrigation and an equivalent amount was applied 2 d later. Standard cultural practices were followed throughout the winter until March when vegetative growth began. Irrigation for frost/freeze protection followed recommendations of the North Carolina Cooperative Extension Service for commercial strawberry production (Poling and Monks, 1994).

Spring-applied drip treatments were injected using a continuous dilution injector (D.C. Sanders, personal communication) consisting of a polyvinyl chloride pipe (15 cm in diameter) 90 cm long with each end connected to the feed line. Valves were located so water could bypass or be diverted through the reservoir. There was one injector per treatment, and plots of the same treatment among replications were interconnected in series and fertilized simultaneously. Red food dye was used to determine time requirements for fertilizer delivery. Fertilizers were dissolved in ≈ 3.5 L water and placed in the reservoir through an access valve. After the system was fully pressurized (≈ 15 min), water was diverted through the injector. About 40 min were required for nutrient delivery to the end of the drip tube. The system was operated for an additional 20 min to ensure complete nutrient delivery and clearing of the drip tube.

Composite soil samples were collected from the 0- to 20-cm depth before planting and were analyzed by the Agronomic Division of the North Carolina Dept. of Agriculture. At the end of harvest, crown number was determined on 10 randomly selected plants per plot.

E1 EXPERIMENT. Treatments consisted of a factorial combination of N at 0, 34, and 67 $\text{kg}\cdot\text{ha}^{-1}$ from NH_4NO_3 banded the previous fall and 0, 0.19, 0.37, 0.56, and 0.75 $\text{kg}\cdot\text{ha}^{-1}\cdot\text{d}^{-1}$ in 1992 and 0, 0.37, 0.75, and 1.12 $\text{kg}\cdot\text{ha}^{-1}\cdot\text{d}^{-1}$ in 1993 applied via drip irrigation in the spring. Treatments were arranged in a split-plot design with the whole-plots arranged in a randomized complete-block design with three blocks. Drip N treatments were whole plots and fall N subplots. Spring N was applied two times weekly commencing 2 and 9 Mar. 1992 and 1993, respectively, and continued for 12 weeks. Based on the area under plastic mulch, 0.6 cm water was required to deliver each drip fertilizer application (1.2 cm weekly or 14.4 cm season total). Additional water was applied using the

drip-irrigation system when tensiometers at 20-cm depth reached 30 and 50 kPa in 1992 and 1993, respectively. Irrigation above that required to apply nutrients commenced 1 week before first harvest and totaled 6.6 and 4.0 cm for 1992 and 1993, respectively. Total water applied was 21.0 and 18.4 cm for 1992 and 1993, respectively. Since the total area was twice the plastic-mulched area, water values for the total area would be one-half those previously cited.

Blanket applications of MgSO_4 with S at 0.37 $\text{kg}\cdot\text{ha}^{-1}$ weekly and Solubor with B at 0.09 $\text{kg}\cdot\text{ha}^{-1}$ weekly were drip-applied once a week during the 12-week drip fertilization period in 1992. In 1993, S was increased to 1.12 $\text{kg}\cdot\text{ha}^{-1}$ weekly and B and Mn (MnSO_4) were drip-applied once (26 Apr.) just before harvest at 0.28 and 1.12 $\text{kg}\cdot\text{ha}^{-1}$, respectively, because tissue levels of these two nutrients approached deficiency levels.

E2 EXPERIMENT. The previous fall, N at 56 $\text{kg}\cdot\text{ha}^{-1}$ from NH_4NO_3 was banded as previously described. Spring drip treatments in 1992 consisted of factorial combinations of N (0.56, 1.12, 1.68, and 2.24 $\text{kg}\cdot\text{ha}^{-1}\cdot\text{d}^{-1}$) and K (0.46, 1.39, and 2.32 $\text{kg}\cdot\text{ha}^{-1}\cdot\text{d}^{-1}$). In 1993, the K rates were changed to 0, 0.75, 1.49, and 2.24 $\text{kg}\cdot\text{ha}^{-1}\cdot\text{d}^{-1}$ and N remained the same. Treatments were arranged according to a randomized complete-block design with three blocks. Drip-fertilizer treatment application and water requirements were as described for E1. Blanket applications of MgSO_4 , Solubor, and MnSO_4 were drip-applied with MgSO_4 supplying S at 1.12 $\text{kg}\cdot\text{ha}^{-1}$ weekly both years. Boron was applied at 0.28 $\text{kg}\cdot\text{ha}^{-1}$ weekly for only 6 weeks in 1992 because B in trifoliate leaves approached toxicity levels. In 1993, B and Mn were applied as described in E1 for 1993.

Ripe fruit were harvested biweekly for a total of 13 harvests in 1992 and 11 harvests in 1993. The culls, market fruit, and 25 random market fruit (for mean fruit mass) were weighed. Additionally, ≈ 600 g of randomly selected market fruit per plot from harvest 3, 5, and 7 in 1992 and harvest 4, 6, and 8 in 1993 were placed in cold storage within 1 h of picking and were analyzed for pH, soluble solids (Brix no.), and total acidity as citric acid. The procedure involved removing caps, and pureeing the fruit in a blender for 10 s. Soluble solids were determined by table refractometer, and pH was determined by means of a glass electrode and pH meter. Total acidity was determined by titration of a 10-g aliquot of puree plus 90 mL distilled water with 0.1 N NaOH to a pH 8.2 endpoint. Fruit firmness was measured using an Instron universal testing machine (model 112; Instron, Canton, Mass.). A punch-and-die assembly was adapted to the Instron to determine tissue firmness by penetration force (Thompson et al., 1982). A cylindrical punch (0.315 cm in diameter) and a 2-kg compression load cell with a 0.5-kg full scale setting were used. Both crosshead and the chart drive speed was 200 $\text{mm}\cdot\text{min}^{-1}$. Three random berries from each plot were sliced in half lengthwise. The thickness of the slice at the point of penetration was measured in millimeters with a caliper. Halves were presented slice side down. Peak height is expressed in grams of force. The first peak represents the force necessary to penetrate the skin. The second peak represents the force necessary to penetrate the interior flesh. There was a third peak if the berry was hollow with a fibrous filament in the center.

Statistical analysis of the data was performed using analysis of variance (SAS Institute, 1982) and linear-plateau regression analyses (Anderson and Nelson, 1987). There were no interactions in either year of either study so linear-plateau models were fitted to main effect treatment means using vectors specific for each model that represented equally spaced treatment rates of application. Models used are described in Table 1. Slopes of the best-fit linear-plateau yield models were compared with the cost : price ratio (r),

assuming N at \$0.66 per kilogram and fruit value at \$1870 per megagram. If the slope exceeded r , the return from increased fruit production would more than pay for the N, and the N rate coinciding with the beginning of the plateau was selected as the optimum N rate of application (Anderson and Nelson, 1987). An average then was taken of the optimum N recommendations across both years to arrive at final recommended rates of fall- and spring-applied N. Best-fit linear-plateau models for all other horticultural variables were determined based solely on minimizing mean square error. The NLIN procedure in SAS (SAS Institute, 1982), as modified by Cox (1992), was used to calculate linear-plateau functions relating relative yield to N application rates for combined data from the four experiments.

Results and Discussion

E1 EXPERIMENT. There were no interactions between rates of fall-applied and spring-applied N on market yield, cull yield, and fruit mass in either year (Table 2). Market yield increased both years with increasing rate of fall N with a model IV₁ providing the best fit in 1992. The optimal fall N level was calculated to be 34 kg·ha⁻¹ [$1 + (1.29 \div 3.42)$] = 47 kg·ha⁻¹. The regression coefficient, $b_2 = 1.29$, exceeded $r = 34(\$0.66 \div \$1870) = 0.012$, so we concluded that it pays to fertilize to the point where the plateau begins (N at 47 kg·ha⁻¹). A model II was appropriate in 1993, with $b_1 = 2.24$ exceeding $r = .012$. Thus, it paid to apply N up to 67 kg·ha⁻¹, which was the highest N rate evaluated. Cull yield increased linearly with fall N rate in 1993, but it was unaffected in 1992. Average fruit mass significantly increased by fall N in 1992 but not in 1993.

Drip-applied N increased market yield and fruit mass in both years but had no effect on cull yield (Table 2). For market yield, model III₂ (optimum rate of N at 0.37 kg·ha⁻¹·d⁻¹) was appropriate in 1992, and model III₄ (optimum rate of N at 0.75 kg·ha⁻¹·d⁻¹) was appropriate in 1993. In both cases, the b_1 slopes exceeded the r values, meaning that it would pay to fertilize to the point where the plateau begins. Compared to no N, the mean yield increase averaged over both years from the mean optimum fall N rate (N at 57 kg·ha⁻¹) was 4.6 Mg·ha⁻¹. The mean yield increase averaged over both years from the mean optimum drip N rate applied in the spring (0.56 kg·ha⁻¹·d⁻¹; total = 47 kg·ha⁻¹) compared to no N was 9.2 kg·ha⁻¹. Thus, the spring-applied N was 2.4-times more effective than that applied in the fall on a per-kilogram basis. Fruit mass was maximized with N at 0.28 and 0.37 kg·ha⁻¹·d⁻¹ in 1992 and 1993, respectively (Table 2).

The rate of harvest was slightly higher in 1993 compared to 1992 and is illustrated in Fig. 1 for the treatment combination of N at 67 kg·ha⁻¹ (fall) and 0.75 kg·ha⁻¹·d⁻¹ (spring). Although total yields were similar both years, the fruit matured earlier in 1993 resulting in a shorter harvest season compared to 1992. The rate of harvest was 4763 kg·ha⁻¹ weekly in 1993

compared to 3800 kg·ha⁻¹ weekly in 1992.

Crown numbers were not affected by either fall- or spring-applied N, but they were slightly higher in 1993 compared to 1992 (Table 3). Fall planting date and subsequent climatic conditions have the greatest influence on crown development (Poling, 1992). Mean crown yields were 148 and 145 g per crown in 1992 and 1993, respectively. Crown yield tended to increase for N at 34 kg·ha⁻¹ compared to no N ($P > F = 0.10$) in 1992 but was not affected by fall N rates in 1993. Significant increases in crown yields by spring N rates up to 0.37 and 0.75 kg·ha⁻¹·d⁻¹ occurred in 1992 and 1993, respectively. Plant yield increased with fall- and spring-applied N (Table 3) in the manner previously described for market yield (Table 2).

There were no significant differences in fruit chemistry among any of the fall and spring treatments for the three harvests evaluated (data not presented). Mean fruit pH across treatments and harvests were 3.43 and 3.40, and mean total acid concentrations were 8.3 and 8.8 g·kg⁻¹ in 1992 and 1993, respectively. Soluble solids concentrations were not affected by treatment, but they increased with later harvest dates. Mean soluble solids were 66.3, 84.9, and 90.4 g·kg⁻¹ for harvest 3, 5, and 7, respectively, in 1992 and 68.4, 82.9, and 95.6 g·kg⁻¹ for harvest 4, 6, and 8, respectively, in 1993.

Table 1. Description of models from Anderson and Nelson, 1987.

Model no.	Nature of model
I	Plateau—no response
II	Linear response
III _j	Linear-plateau response with join point between segments located on a treatment level (j)
IV _j	Linear-plateau response with join point between segments located between treatment levels j and j + 1
V	Two linear response segments with slope of first greater than slope of the second ($b_1 > b_2$).

Table 2. Effect of fall- (banded) and spring- (drip) applied N on market and cull yield and fruit size (Expt. 1).

Main effect	Yield (Mg·ha ⁻¹)				Avg. fruit mass (g/fruit)	
	Market		Cull			
	1992	1993	1992	1993	1992	1993
treatment						
Fall N (kg·ha ⁻¹)						
0	17.1	18.2	1.2	0.6	18.4	18.3
34	20.6	19.9	1.3	0.7	20.1	18.3
67	21.9	22.7	1.3	0.9	20.5	18.0
$P > F$	<0.01	<0.01	0.67	0.01	<0.01	0.60
Model	IV ₁	II	I	II	III ₁	I
Optimum N (kg·ha ⁻¹)	47	67	0	67.0	34.0	0
Average	57		33.5		17.0	
Drip N (kg·ha ⁻¹ ·d ⁻¹)						
0.00	14.0	13.7	1.5	0.6	17.4	16.8
0.19	18.2	---	1.4	---	19.5	---
0.37	21.5	20.2	1.3	0.7	20.0	19.0
0.56	21.9	---	1.4	---	20.7	---
0.75	23.7	24.7	1.0	0.8	20.9	19.0
1.12	---	22.6	---	0.8	---	18.1
$P > F$	<0.01	<0.01	0.46	0.52	<0.01	0.05
Model	III ₂	III ₄	I	I	IV ₁	III ₂
Optimum N (kg·ha ⁻¹ ·d ⁻¹)	0.37	0.75	0	0	0.28	0.37
Average	0.56		0		0.33	
CV ² (%)	13.9	10.6	21.8	23.7	4.7	4.0

E2 EXPERIMENT. There were no interactions between rates of drip-applied N and K for any measured horticultural variable either year. The estimated optimal drip-applied N rates for market yield were 1.12 and 0.56 kg·ha⁻¹·d⁻¹ in 1992 and 1993, respectively (Table 4). The mean optimal drip-N rate averaged over years (0.84 kg·ha⁻¹·d⁻¹) was higher than that obtained in E1 (0.56 kg·ha⁻¹·d⁻¹). This higher N requirement may be due to the higher yields obtained in E2 compared to E1. The rate of fall N selected for this experiment (56 kg·ha⁻¹) is comparable to the mean optimal fall N (57 kg·ha⁻¹) obtained in the E1 experiment and should have been adequate for fall N fertilization.

The reason for higher yields in the E2 experiment in 1993 compared to 1992 are not apparent since similar yield differences between years were not obtained in the E1 experiment. The Norfolk soil used in 1993 generally is considered to have greater productive potential than the Wagram because of a shallower argillic horizon. Increasing rate of drip N increased fruit mass in 1993 and cull yield in 1992 (Table 4). It had no significant effect

on crown number, crown yield, or plant yield in either year (data not presented).

Drip-applied K had no significant effect on market or cull yield or fruit size (Table 4). Albregts et al. (1996) obtained a decrease in 'Oso Grande' fruit size with increasing K rate with no differences among K sources. Crown and plant yields did not respond to K (data not presented), but crown count was increased ≈0.5 crown per plant by additional K in 1992. The K at 111 kg·ha⁻¹ applied according to soil test in the fall apparently was sufficient to meet strawberry K requirements both years. This finding agrees with Albregts et al. (1996), who did not obtain a yield response on low- to medium-K soils to drip-applied K ranging from 50 to 250 kg·ha⁻¹. The highest drip rates of K in this study (2.32 and 2.24 kg·ha⁻¹·d⁻¹ in 1992 and 1993, respectively) supplied an additional mean value of 191 kg·ha⁻¹ of drip-applied K with no apparent benefit.

As in the E1 experiment, there were no significant differences in fruit chemistry among N and K treatments for the three harvests evaluated (data not presented). Mean fruit pH across treatments and three harvests was 3.5 both years. Mean total acid concentrations were 8.2 and 8.9 g·kg⁻¹ in 1992 and 1993, respectively. As in the E1 experiment, soluble solids concentrations increased with time after first harvest. Mean values were 68.3, 87.9, and 92.2 g·kg⁻¹ for harvests 3, 5, and 7, respectively, in 1992 and 68.9, 78.7, and 89.5 g·kg⁻¹ for harvests 4, 6, and 8, respectively, in 1993.

MEAN YIELD RESPONSE TO DRIP AND TOTAL N. Market yields from the four experiments were converted to relative yield (based on the highest yield for each experiment) to determine the relationship between yield and rate of drip N across all experiments (Fig. 2). The relationship was best described by a linear-plateau model IV, and the intercept indicates yield without drip N was only two-thirds maximum yield. The optimum rate of drip N required to reach the join point of the linear response with the plateau was 0.71 kg·ha⁻¹·d⁻¹ and confirms the mean value (0.70 kg·ha⁻¹·d⁻¹) derived from E1 (Table 2; N at 0.56 kg·ha⁻¹·d⁻¹) and E2 (Table 4; N at 0.84 kg·ha⁻¹·d⁻¹) from individual experiments discussed previously. The total drip N applied at this rate would be 59.6 kg·ha⁻¹ (applied 12 weeks).

Relative yields for the various combinations of fall and drip N, expressed as total N applied, also were combined across all experiments to determine the relationship between yield and rate of total N (Fig. 3). The intercept of the linear-plateau model indicates yield without N was one-half that obtained with an optimum total N rate. The optimum rate of total N required to reach the join point was 111 kg·ha⁻¹. This value is slightly less than the mean N value (116.6 kg·ha⁻¹) derived from individual experiments (fall, 57 kg·ha⁻¹; drip, 59.6 kg·ha⁻¹).

Hochmuth et al. (1996) maximized total strawberry production with N at 100 kg·ha⁻¹ applied at 0.56 kg·ha⁻¹·d⁻¹ throughout the growing season in Florida. Winter temperatures prevent full season drip irrigation in North Carolina. Thus, banding N at 55 to 65 kg·ha⁻¹ as NH₄NO₃ in the fall and applying the remaining N by drip irrigation in the spring

Fig. 1. Weekly and cumulative yields of strawberries receiving N at 67 kg·ha⁻¹ (fall-applied) and 0.75 kg·ha⁻¹·d⁻¹ (spring drip).

Table 3. Effect of fall (banded) and spring (drip) applied N on crown number, crown yield, and plant yield (Expt. 1).

Main effect	Crown				Plant yield	
	No./plant		Yield (g/crown)		(g/plant)	
treatment	1992	1993	1992	1993	1992	1993
Fall N (kg·ha ⁻¹)						
0	3.1	3.2	133	146	403	439
34	3.2	3.5	157	140	483	478
67	3.4	3.8	154	149	514	548
P > F	0.47	0.15	0.10	0.79	<0.01	<0.01
Model	I	I	III ₁	I	V ₁	II
Optimum N (kg·ha ⁻¹)	0	0	34	0	67	67
Average	0	17	67			
Drip N (kg·ha ⁻¹ ·d ⁻¹)						
0.00	3.1	3.4	109	101	329	334
0.19	3.3	---	132	---	428	---
0.37	3.1	3.8	167	131	504	488
0.56	3.3	---	163	---	515	---
0.75	3.4	3.4	169	183	555	592
1.12	---	3.4	---	165	---	541
P > F	0.96	0.72	0.01	<0.01	<0.01	<0.01
Model	I	I	III ₂	III ₄	V ₂	III ₄
Optimum N (kg·ha ⁻¹ ·d ⁻¹)	0	0	0.37	0.75	0.75	0.75
Average	0	0.56	0.75			
CV ^z (%)	18.3	19.2	21.5	22.6	13.9	10.3

($\approx 0.75 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{d}^{-1}$) is a reasonable alternative. The drip N is applied over 12 weeks, beginning in early spring when plants initiate vegetative growth and the danger of freezing weather is minimized.

FRUIT FIRMNESS. Potassium treatments (E2) had no effect on interior flesh firmness of fruit in the six harvest dates evaluated (data not presented). Potassium significantly increased the force required for skin penetration in the 5th harvest in 1992 from 11.9 to 14.9 Newtons but had no effect on skin firmness in the five other harvests evaluated. This finding is in contrast to a decrease in fruit firmness obtained by Locasio and Saxena (1967) with increasing K rate.

Skin firmness decreased with increasing rate of total N in all three E2 harvests evaluated in 1992. The mean force required to penetrate the skin for the total N rates (103, 150, 197, and $244 \text{ kg} \cdot \text{ha}^{-1}$) applied in this experiment were 15.4, 13.2, 12.7, and 12.9 Newtons, respectively. The effect was similar for one harvest in 1993, but it was not significant for the other two harvests. Interior flesh firmness was not affected by total N in E2 in either year.

In E1, fall-applied N decreased skin firmness in one harvest in 1992. Skin penetration force required decreased from 15.7 Newtons for N at $0 \text{ kg} \cdot \text{ha}^{-1}$ to 13.9 Newtons for N at $67 \text{ kg} \cdot \text{ha}^{-1}$ applied in the fall. Fall-applied N had no effect on interior flesh firmness either year. Increasing rates of drip N decreased skin firmness in two harvests in 1992 but did not affect skin firmness in the remaining four harvests that were evaluated. Similarly, increasing drip-N rates decreased interior flesh firmness in two harvests in 1992 and had no effect on the other four harvests evaluated.

While increasing N rates did not decrease strawberry fruit firmness in all samples evaluated, it did so in $\approx 25\%$ of the harvests evaluated, which implies that applying N at rates higher than optimum may further reduce fruit quality. The effect was greater on the skin than on interior flesh, and high N may enhance bruising and reduce the holding quality of strawberry fruit. These results agree with those of others (Voth et al., 1967), but Saxena and Locasio (1968) obtained increased fruit firmness with increasing N rate.

Conclusions

High N rates used by many growers for strawberries in the annual-hill plastic mulch system are not necessary to maximize yields in North Carolina and the surrounding region. Excessive N may reduce fruit quality by reducing fruit firmness and producing excessive foliage, which complicates harvest. Maximum N requirements on the sandy soils used in these studies were $\approx 120 \text{ kg} \cdot \text{ha}^{-1}$ with one-half applied in the fall and the remainder ($\approx 0.7 \text{ kg} \cdot \text{ha}^{-1} \cdot \text{d}^{-1}$ for 12 weeks) drip-applied in the spring. On heavier textured soils with less leaching potential, the total N requirement may be $< 120 \text{ kg} \cdot \text{ha}^{-1}$.

Table 4. Effect of spring (drip) applied N and K on market and cull yield and fruit size. (Experiment 2).

Main effect treatment	Yield ($\text{Mg} \cdot \text{ha}^{-1}$)				Avg. fruit mass (g/fruit)	
	Market		Cull			
	1992	1993	1992	1993	1992	1993
Drip N ($\text{kg} \cdot \text{ha}^{-1} \cdot \text{d}^{-1}$)						
0	---	24.1	---	0.6	---	18.2
0.56	17.9	28.6	0.4	0.7	19.8	19.6
1.12	22.7	30.0	0.5	0.7	19.8	19.4
1.68	23.8	27.1	0.6	0.7	20.1	19.4
2.24	22.2	28.3	0.5	0.7	19.8	18.1
P > F	<0.01	0.02	0.05	0.99	0.87	0.04
Model	III ₂	III ₁	III ₂	I	I	III ₁
Optimum N ($\text{kg} \cdot \text{ha}^{-1} \cdot \text{d}^{-1}$)	1.12	0.56	1.12	0	0	0.56
Average	0.84		0.56		0.28	
Drip K ₂ O ($\text{kg} \cdot \text{ha}^{-1} \cdot \text{d}^{-1}$)						
0	---	27.9	---	0.7	---	19.2
0.6	21.8	---	0.5	---	20.3	---
0.9	---	26.3	---	0.6	---	19.1
1.7	21.0	---	0.5	---	19.6	---
1.8	---	28.5	---	0.7	---	18.9
2.7	---	27.9	---	0.7	---	18.5
2.8	22.2	---	0.5	---	19.7	---
P > F	0.51	0.54	0.29	0.31	0.15	0.53
Model	I	I	I	I	I	I
Optimum K ₂ O ($\text{kg} \cdot \text{ha}^{-1} \cdot \text{d}^{-1}$)	0	0	0	0	0	0
Average	0		0		0	
CV ² (%)	11.8	15.2	25.2	42.8	11.4	21.9

²CV = coefficient of variation.

Fig. 2. Relationship between the relative yield of strawberries and rate of drip N (data from Expts. 1 and 2 in 1992 and 1993).

The K requirements of a strawberry crop can be met by applying K in fall at rates suggested by soil tests. Additional drip-applied K did not enhance yield, fruit firmness, or fruit chemistry. Soil samples must be representative of the area to be planted so that K recommendations are reliable.

Crown number, which directly affects flower and fruit production, was not enhanced by either N or K fertilization. Attention must be given to planting at the proper time to maximize flower production potential.

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Fig. 3. Relationship between the relative yield of strawberries and rate of total N (data from Expts. 1 and 2 in 1992 and 1993).

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