Using Nitrogen Balance to Calculate Fertilization in Strawberries

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SUMMARY. In Santa Fe, Argentina, strawberries (*Fragaria × ananassa* Duch.) are cultivated in the area of Coronda where N fertilization usually exceeds crop requirements. The objective of this work was to test four types of fertilization methodology to optimize fertilizer use efficiency. Experiments were carried out at the horticultural center of the Facultad de Agronomía y Veterinaria, in Esperanza, Santa Fe, 31.15° S latitude, on a typical argiudol soil. 'Chandler' was planted 13 Mar. 1996. Nitrogen demand was related to the dry matter production with N content decreasing to increment of biomass (W), soil N mineralization was estimated according to the program EDAFO version 3. Using previous data, a monthly balance was calculated and four treatments were devised: control (T0) = without fertilization; treatment 1 (T1) = N fertilization covering the accumulated monthly deficit, 53 kg·ha⁻¹ (47 lb/acre); treatment 2 (T2) = N fertilization covering the monthly deficit 66 kg·ha⁻¹ (58 lb/acre); treatment 3 (T3) = N fertilization covering the total crop demand 117 kg·ha⁻¹ (104 lb/acre). All N treatments significantly increased yields over the control. Yield increased to increasing N rates from 0 to 53 kg·ha⁻¹. This response was due to an increase in fruit number but not in fruit weight. High N rates promoted

runner growth without increasing fruit yield. The use N balance method for strawberry fertilization showed satisfactory results. Accumulated N balance (T1), required the least amount of N fertilizer while producing good yield, thus it should be the method adopted to reduce costs and environmental risks of N fertilization.

In Santa Fe, Argentina, 4000 ha (1000 acres) of strawberries are cultivated in the area of Coronda, along the river of the same name. Fertilization is used to minimize percolation losses, optimize nutrient applications and to satisfy crop water demand.

Preplant fertilizers generally exceed the N necessary, as reported in Spain (Guimera et al., 1995) and Florida (Albregts et al., 1991), where recommended rates were >220 kg·ha⁻¹ (196 lb/acre). In recent works, rates decreased to 100 to 150 kg·ha⁻¹ (89 to 134 lb/acre) (Albregts et al., 1996; Hochmuth et al., 1996) due to split applications based on the requirements of the different phenological phases. Some experiments have demonstrated further reductions in N applications are possible. Human and Kotze (1990) obtained maximum yields with fractionated, autumn and spring applications, of 70 kg·ha⁻¹ (62 lb/acre).

In Coronda, traditional base applications are made with 10 to 15 t·ha⁻¹ (4 to 6 tons/acre) of chicken manure followed by balanced chemical N-P-K fertilizers applied in spring (Scaglia et al., 1985). This convention probably exceeds crop demands greatly. The soils of this area show very high base levels of nutrients. In the case of phosphorus, it is common to find values ranging from 60 to 500 mg·L⁻¹ (ppm), while in uncultivated soils, the levels are around 8 mg·L⁻¹ N, due to its mobility, doesn't remain in the soil but rather percolates toward the aquifers (Guimera et al., 1995). In some areas of Israel with a long agricultural history, it was found that the heavy use of N fertilizers caused an increase in the nitrates of aquifers, from 40 to 105 mg·L⁻¹ in a 30-year period (Hagin and Lowengart, 1996).

These considerations establish the necessity to modify the traditional fertilization based on requirements at the different phenological crop phases. The objective of this work is to test four types of N fertilization practices to optimize fertilizer use efficiency.

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Table 1. Yield, dry matter, plant N content and accumulated N demand of 30 t·ha⁻¹ fresh strawberries (1.0 t·ha⁻¹ = 0.45 tons/acre, 1 kg·ha⁻¹ = 0.89 lb/acre).

Parameter	Month								
	March	April	May	June	July	August	September	October	November
Fruit/ha (t·ha ⁻¹)						3.0	7.5	16.5	30.0
Dry matter (kg·ha ⁻¹)	20	100	200	400	800	1200	2500	4714	6857
N (%)	4.2	4.2	4.2	4.2	4.2	3.7	2.3	1.7	1.7
N demanded (kg·ha ⁻¹)	0.8	4.2	8.4	16.8	33.6	44.6	56.9	80.1	116.6

Table 2. Soil N mineralization, accumulated N demand by crops, monthly and accumulated N balance. Nitrogen balance is the difference between N demand by crops and available soil N [°F = 1.8 (°C) + 32].

Parameter ^z	Month									Total
	March	April	May	June	July	August	September	October	November	
Soil temperature (°C)	17	16	14	13	13	14	16	18	20	
Soil N mineralization (kg·ha ⁻¹)	8	7	6	6	6	6	7	8	10	64
Demanded N (kg·ha ⁻¹)	0.84	3	4	8	17	11	12	23	36	117
Monthly N balance (kg·ha ⁻¹)	7	4	2	-3	-11	-5	-5	-15	-27	-66
Total N balance (kg·ha ⁻¹)	7	11	13	10	-1	-6	-11	-26	-53	-53

^zN-NO₃ offered by soil = (TF/7) × HF × 30, where TF = temperature factor = $e^{(17.75 - 6343.4/(273 + ST))}$; ST = soil temperature; and HF = humidity factor = $-0.08 + [0.88 \times (q/qcc)]$, where q/qcc is the relative soil water content.

Materials and methods

The research was carried out at the horticultural experimental center of the Facultad de Agronomía y Veterinaria, in Esperanza, (31.15 lat. S, 60 long.) on a typical argiudol soil with 0.128% total N; 0.010 % stabilized organic N; 35 mg·L⁻¹ (ppm) soluble P and 1.1 meq % of interchangeable K.

The outplanting was done 13 March 1996 with cold stored plants of 'Chandler', a short day cultivar. Plants were established in the field on double rows 60 cm (24 inches) apart with a path of 40 cm (16 inches) within plant spacing was 25 cm (10 inches), with a density of 80,000 plants/ha (32,000 plants/acre). The rows were covered with black plastic mulch. Drip tape with emitters every 20 cm (8 inches) positioned between rows was used. Watering was done when the tension of the soil reached -30 kPa.

Mature fruit were harvested twice a week to touch total production and fruit weight average. Five plants were sampled monthly for weight of root, crown, leaves, inflorescence and runners as fresh and dry matter.

A randomized complete block design with four replications and four treatments was used; the experimental

met was a double row 4.25 m (14 ft) long.

N demand for the crop was calculated from a fitted curve of dry matter increased over time (Gariglio et al., 1995), for a prospective production of 30 t·ha⁻¹ (12 tons/acre) of fresh fruit (Table 1). The N content in the biomass was estimated from N decline with increment of biomass (W). (Greenwood et al., 1990).

The N-NO₃⁻ soil mineralization per month (Table 2) was calculated according to the program EDAFO version 3 (Pilatti and Grenón, 1996) from total N content corrected by an N mineralization factor as a fraction of on soil temperature and humidity.

Treatments defined by N balance (difference between N demand and soil availability), were as follows:

T0 = Control.

T1 = Daily N fertigation covering the accumulated monthly deficit [Table 2, 53 kg·ha⁻¹ (47 lb/acre)].

T2 = Daily N fertigation covering the monthly deficit. [Table 2, 66 kg·ha⁻¹ (59 lb/acre)]. It is assumed that in the month, the excess N is lost.

T3 = Daily N fertigation covering the total crop demand [Table 2, 117 kg·ha⁻¹ (104 lb/acre)].

Before planting, plots were fertilized to reach nutrient levels of 50 mg·L⁻¹ soluble P and 30 mg·L⁻¹ nitrates, using phosphoric and nitric acid. In addition, to maintain a relationship N:K = 1:1.4 (Sarooshi and Cresswell, 1994), ammonium nitrate was used until flowering and a mixture of ammonium nitrate and potassium nitrate after flowering.

Table 3. Strawberry yields components to different N-NO₃ fertilization rates (1 kg·ha⁻¹ = 0.89 lb/acre, 305 g·m⁻² = 1 oz/ft², 10.8 fruit/m² = 1 fruit/ft², 28.35 g = 1.0 oz).

N-NO ₃ (kg·ha ⁻¹)	Yield (g·m ⁻²)	Yield (fruit/m ²)	Fruit wt (g)	Total biomass (g·m ⁻² dry matter)
0	286.4 a ^z	279 a	10.26 a	693 a
53	305.5 b	294 b	10.40 a	737 b
66	312.5 b	299 b	10.45 a	792 b
117	318.4 b	298 b	10.68 a	1018 c

^zValues followed by the different letter, represent significant differences, according to Tukey test for $\alpha = 0.05$.

Fig. 1. Effects of four different N treatments on accumulated strawberry production during the harvest period. T0 = control, without N fertigation; T1 = N fertigation covering the accumulated monthly deficit, 53 kg·ha⁻¹ (47 lb/acre); T2 = N fertigation covering the monthly deficit, 66 kg·ha⁻¹ (59 lb/acre); T3 = N fertigation covering the total crop demand, 117 kg·ha⁻¹ (104 lb/acre).

Results and discussion

All N treatments significantly increased yields over the control (Table 3). Yield increased to increasing N rates from 0 to 53 kg·ha⁻¹ (47 lb/acre). This response was an increase in fruit number but not in fruit weight. This type of response was observed in previous research (Hochmuth, et al., 1996), stronger in soilless media, where only N concentration in the nutrient solution was varied (Rindom and Hansen, 1995).

Early fruit yield did not respond to the treatments (Fig. 1), but increased greatly in October and November. During these months the great fruit and the total biomass was produced (Table 4) and the soil was deficient in N (Table 2). Hochmuth et al. (1996), found the best responses to N fertilization at peak fruit production.

The weight of the fruit is influenced by factors other than N fertilization. Aging of the plant and fruit position in the inflorescence (Hortynski et al., 1991) reduces fruits size; a second fruit is 70% of a first fruit, thirds, and

Table 4. Accumulated total biomass (dry matter) (1 kg·ha⁻¹ = 0.89 lb/acre) and partition of assimilates in strawberry.

Nitrogen (kg·ha ⁻¹)	Dry matter (kg·ha ⁻¹)	Month						
		May	June	July	August	September	October	November
0	Leaves	108	632	808	1340	1884	2536	2412 a
	Root	28	68	96	172	436	112	292 a
	Crown	20	80	124	324	548	348	616 a
	Flowers	40	8	0	0	0	1032	748 a
	Fruit	47	53	55	55	100	2 234	2 864a
	Total	243	1001	1083	1891	2968	6262	6932 a
	Harvest index = 41%							
53	Leaves	100	892	1184	1576	1112	2172	2776 ab
	Root	12	64	72	268	284	104	132 a
	Crown	4	124	104	304	464	692	544 a
53	Flowers	0	20	0	0	0	2360	864 a
	Fruit	72	79	81	81	126	2 478	3055b
	Total	208	1567	1441	2229	1986	7806	7371 b
	Harvest index = 41%							
66	Leaves	108	580	972	872	1392	2008	2380 a
	Root	16	25.2	116	108	208	676	268 a
	Crown	16	80	92	160	356	504	512 a
66	Flowers	32	8	0	0	0	1072	1636 b
	Fruit	51	56	56	56	113	2571	3125b
	Total	223	1009	1236	1196	2069	6831	7921 b
	Harvest index = 39%							
117	Leaves	108	816	1928	1560	1408	2756	3064 b
	Root	60	64	184	292	428	376	900 b
	Crown	40	100	244	344	388	500	828 b
	Flowers	40	8	0	0	0	976	2208 c
	Fruit	38	48	51	51	96	2411	3184b
	Total	286	1744	2407	2247	2320	7019	10184 c
	Harvest index = 31%							

^aThe values followed by the different letter, represent significant differences, according to Tukey test for $\alpha = 0.05$. Harvest index = dry matter fruit/dry matter total $\times 100$.

Fig. 2. Evolution of average daily temperature and mean strawberry weight along harvest period in Santa Fe, Argentina, 31.15° S latitude.

fourths fruits 37% and 21% respectively (Miura et al., 1994).

Temperature is the main environmental factor that affects the fruit size, because warmth decreases the growth period and the daily growth rate (Miura et al., 1994). This could explain, the reduction of fruit size during the growth season (Fig. 2) and the low fruit weight in the Coronda area, over the harvest period (Table 3).

Total biomass, showed significant differences among N treatments (Tables 3 and 4), but was not correlated with fruit production. Nitrogen fertilization increased total biomass and decreased the harvest index (dry matter fruit/dry matter total $\times 100$) due to a bigger partition toward leaves and runners (Table 4).

Strawberries have increased photosynthesis rates and dry matter is partitioned to leaves and runners when the environmental conditions are unfavorable to flowering, (Schaffer et al., 1986). High temperature affects flowering and favor runner development in strawberry (Durner et al., 1987), which is enhanced by N fertilization and long days (Tafazoli and Shaybany, 1978).

In our climatic conditions $\geq 50\%$ of the total biomass (Table 4) was produced in 2 months (October and November) and optimal availability of nu-

trient in the soil was necessary, but a supply of N that exceeds crop demand, in combination with temperature and photoperiod of those months, promotes runner production.

In conclusion, N fertilization in Santa Fe, Argentina, can improve fruit yield, but high N rates applied under long day and high temperature conditions, promotes runner growth without increasing fruit production. The use of the N balance method for strawberry fertilization showed satisfactory results. Accumulated N balance (T1), required the least amount of N fertilizer while producing good yield, thus it should be the method adopted to reduce costs and environmental risks of N fertilization.

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