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Preplant Fertilization and Fertigation in Strawberry (*Fragaria* x *ananassa* Duch. cv. 'Korona') in an Open Field Experiment

N. Opstad[1)], A. Nes[1)] and F. Måge[2)]
([1)] Norwegian Institute for Agricultural and Environmental Research (Bioforsk), Arable Crops Division, Section Kise, Nes H., and [2)]Norwegian University of Life Sciences, Department of Plant and Environmental Sciences, Ås, Norway)

Summary

Effects of preplant fertilization and fertigation in strawberry were studied in a field experiment established August 2003 in South-Eastern Norway. Half the field was fertilized at planting and fertigated with a low nutrient rate from spring 2004 (T1), while the second half was unfertilized at planting and instead fertigated with excessive nutrient solution from spring 2004 (T2). In 2005, both treatments were fertigated with an equal fertilizer rate. None of the treatments caused any deficiency symptoms during the trial, but, of all parameters recorded, only the number of leaves and leaf area compensated for the early limitation in nutrients. Yield and berry size in T1 were significantly higher compared to T2 in the first harvest year, despite the low fertigation rate in T1. The following year, no significant effects of treatments were found. Leaves and petioles for chemical analyses were sampled several times during the trial for sap and dry matter analysis. Few significant differences between treatments were found, but it appeared that sap analysis provides most information on the present uptake in leaves. However, neither leaf dry mass analyses nor sap analyses reflect yield potential when conditions during plant establishment are suboptimal.

Key words. dry matter – fertilizer timing – plant analyses – sap – shelf life – yield

Introduction

Fresh rooted plug plants for commercial strawberry production are cheap and available in late summer, when labour for planting is also accessible. In Norway, late autumn planting restricts the time for plant establishment before frost, but as waiting bed plants are rarely used in Norway, late transplanting is recommended despite low yield expectations for the next year (Nestby 1985). Optimising plant growth and yield potential by ensuring the best possible growing conditions during establishment is therefore essential.

Several trials have compared preplant fertilization with fertigation (Locascio et al. 1977; Locascio and Martin 1985; Tosi 1986; Albregts et al. 1991; Cadahia et al. 1993; Miner et al. 1997). The conclusions have been contradictory, and none of these trials have been related to temperate regions and Nordic production systems. Preplant fertilization might be excessive if fertigation starts immediately after planting (Tosi 1986; Albregts et al. 1991), but an increase in fruit crop after preplant application with N and K has also been reported (Locascio et al. 1977). Bradfield et al. (1975) found that K fertilization from planting to dormancy had no significant effects on yield components in cv. 'Cambridge Favourite', while K application during flowering and fruiting significantly increased flower production. N fertilization of mother plants in nurseries has been found to be more important than later field application (Rodgers et al. 1985), and Webb and White (1971) concluded that nutritional and other cultural conditions in the period between rooting and flower initiation are critical for number of inflorescences and initiated flowers.

The nutritional status of the plants may be measured by chemical analyses. The traditional time for dry matter analyses has been after harvest when foliar levels are relatively stable, but in recent years sap analyses have proved to be a quick method to assess nitrate concentration in strawberry petioles (Lacroix and Cousin 1997). The response time following changes in N supply was only a few days, compared to weeks when analysing leaf dry mass.

The aim of the study was to document (1) how nutrient supply in autumn influence yield potential and plant development the following seasons, (2) how plants with limited nutrient supply in autumn and early spring are able to compensate for early nutrient limitations when fertilized with ample fertilizer rates the following year, and (3) how nutrient supply is reflected in leaf dry matter and sap analyses at different times in the season.

Materials and Methods

The trial was conducted from 2003 to 2005 at Apelsvoll Research Centre division Kise, Norway (60 °40 'N,

Table 1. Soil contents of mineral N, and ammonium-lactate (AL) extractable P and K (EGNÉR et al. 1960) (mg 100 g^{-1}) in 0–25 cm depth during the trial.

Time of sampling	Treatment	N_{min} total	NO_3	NH_4	P-AL	K-AL
Before planting	T1 + T2	1326	1173	153	–	–
Autumn 2004	T1	216	31	184	9.1	14.3
	T2	209	40	169	8.6	13.7
Spring 2005	T1	204	57	147	10.4	17.9
	T2	316	142	173	9.1	14.7
Autumn 2005	T1	244	91	153	9.5	19.5
	T2	228	92	136	8.7	17.6
Mean		236	76	160	9.2	16.3

Treatments are presented in Table 2

10 °11 'E), on a morainic loam soil with 6–8 % humus. Soil samples were taken from all plots before planting in August 2003, on October 4th 2004 and May 2nd and August 18th 2005. Mineralised nitrogen (NO_3-N + NH_4-N) in 0–25 cm depth prior to planting was 1326 mg g^{-1}, corresponding to 41.4 kg N ha^{-1} (Table 1). Temperature and precipitation were recorded continually and are presented in Fig. 1. The experimental design was a randomised complete block with three replicates, each replicate counting 200 plants. The field was planted on August 22nd 2003 using certified rooted plug plants. Plants of the cultivar 'Korona' were planted in double rows, on low ridges covered with black polyethylene mulch. Plant spacing was 25 cm within the row, 40 cm between the double rows and 160 cm between ridges. After planting, the field was covered with 17 g m^{-2} polyethylene filt mulch (P17) for improved winter survival. The whole field was equipped with a pressure compensated drip irrigation system connected to a fertilizer injector. The drip irrigation tubes had a 40 cm emitter spacing and 2.3 l h^{-1} per emitter discharge rate. The tubes were placed under the polyethylene mulch in the centre of the ridges. Before planting, compound fertilizer equivalent to 500 kg ha^{-1} of 6-5-20 NPK with micronutrients (Fullgjødsel® NPK 6-5-20-Mikro) from Yara was applied to half of the rows (treatment 1; T1) (Table 2). The rows in the latter half were not fertilized prior to planting (treatment 2; T2). Fertigation was carried out twice a week from May to August both harvesting years, using Calcinit™ (15.5 % N, 19.0 % Ca) and Superba™ Rød (7-4-22 NPK + micronutrients) (both from Yara). In the first cropping year, T1 and T2 were fertigated with different amounts of nutrients in the same volume water. In T2, the EC was kept constant at 2.4 mS cm^{-1} and the ratio between Calcinit™ and Superba™ was 5:7, to get a total nutrient composition similar to T1. T1 was fertigated concurrently, but EC was kept on 1.6 mS cm^{-1}. At the end of the first cropping season, the total amount of water and N that had been applied was similar for both treatments for the first two years. The amount of N added during 2003 and 2004 was 80 kg ha^{-1} in total, which is the recommended fertilizer rate per year for 'Korona' in Norway. In the second harvesting year, the after-effects of the initial treatments were studied, and the whole field was then fertigated twice a week, keeping EC at approximately 1.6 mS cm^{-1}. The total amount of N added during 2005 was also 80 kg ha^{-1}. Plant protection was performed according to a minimum of the local recommended spraying program,

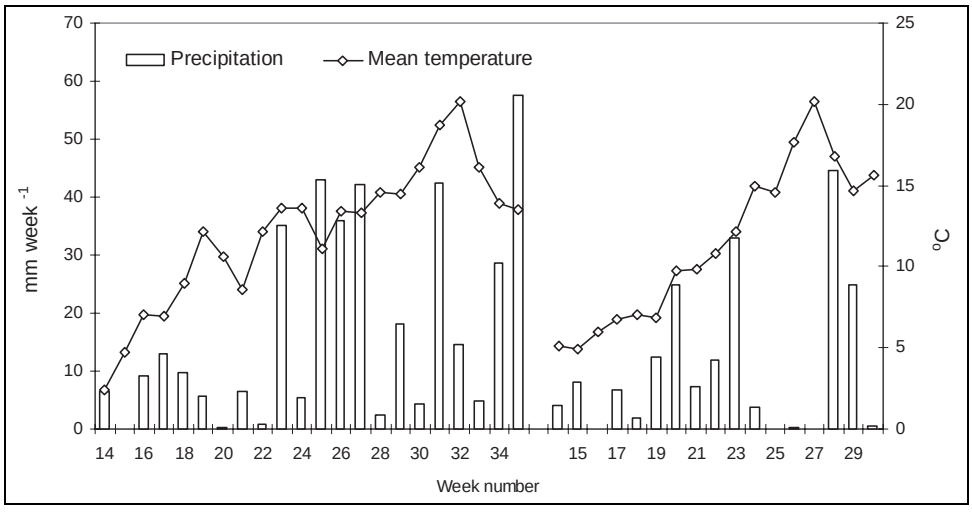


Fig. 1. Mean weekly temperature (°C) and sum weekly precipitation (mm) at the experimental site in the period April to August 2004 and April to July 2005.

Table 2. Fertilizer treatments in the trial, presented as applied N (kg ha^{-1}). A compound fertilizer was applied prior to planting in August 2003 in T1 only, while in 2004 and 2005, all fertilizer in T1 and T2 were applied as fertigation from May–August. The amount of water was the same for both treatments.

Treatment	2003	2004	2005
T1	30	50	80
T2	0	80	80

including three fungicide applications in May and early June and one insecticide spraying in late May. The number of crowns and leaves were recorded in subplots of ten randomly selected plants per plot six times during the 2004 season and twice in 2005. Leaf area was measured on two random plants from each plot at the beginning of the 2004 season and at every sampling throughout 2004, using a LI-3100 Area meter (LI-COR Inc. Lincoln, Nebraska, USA). Runners and runner plants were counted five times in 2004 and once in 2005 in the subplots. 50 plants per plot were picked three times a week. The number and weight of all berries, including berries with grey mould (*Botrytis cinerea* Pers.), were recorded. Leaves were sampled from the entire plot of 100 plants. Plant parts for analyses were sampled five times during the 2004 season and twice in 2005 (Table 2). For sap analyses both leaves and petioles were sampled, as recommended by AB Lennart Månsson International (LMI, SE-251 07 Helsingborg), while for dry matter analyses only the leaf lamina were used. The youngest fully developed leaves were sampled and analysed. Samples for sap analyses were stored at –18 °C and sent to LMI. At LMI the sap was mechanically separated from the solids in the samples according to their procedures. The raw sap was then purified, to remove water-soluble organic components, and the resulting liquid was analysed by ICP-OES (metals + P, S and B) and segmented flow analysis (NO_3 and NH_4). Leaves for dry matter analyses were dried at 70 °C and ground. Plant macronutrient contents were analysed after sulphuric/hypochloric acid digestion (Allen et al. 1974), using a Skalar autoanalyser for N and P, flame photometry for K and atomic absorption spectrophotometry for Ca and Mg. The dry matter analysis from the sampling after harvest was made for comparisons with recommended values. Shelf-life tests were completed twice during both seasons with berries from the 3rd and 6th harvest: 30 berries from each plot were carefully put in humid egg-cartons and placed in a plastic bag to keep a constant RH of 100 %. The berries were stored at 4 °C for 72 h before being placed in room temperature at 20 °C. The number of berries with grey mould was recorded every 24 h until 50 % of the berries were damaged by *Botrytis*.

All data were subjected to analysis of variance (ANOVA) using MiniTab® Release 14 Statistical Software. Percentage data from shelf life tests were arcsine square transformed prior to statistical analyses. Significant differences between treatments were identified at the 5 % probability level. For correlations, the Pearson correlation coefficient (r) was calculated. To illustrate the variation in sampling methods, coefficients of variance (CV%) were calculated using MS_{Error} from the analysis of variance for each sampling time.

Results

The N_{min} resources in the soil prior to planting were abundant (Table 1). There were no significant differences in nitrogen content in the soil at any of the sampling

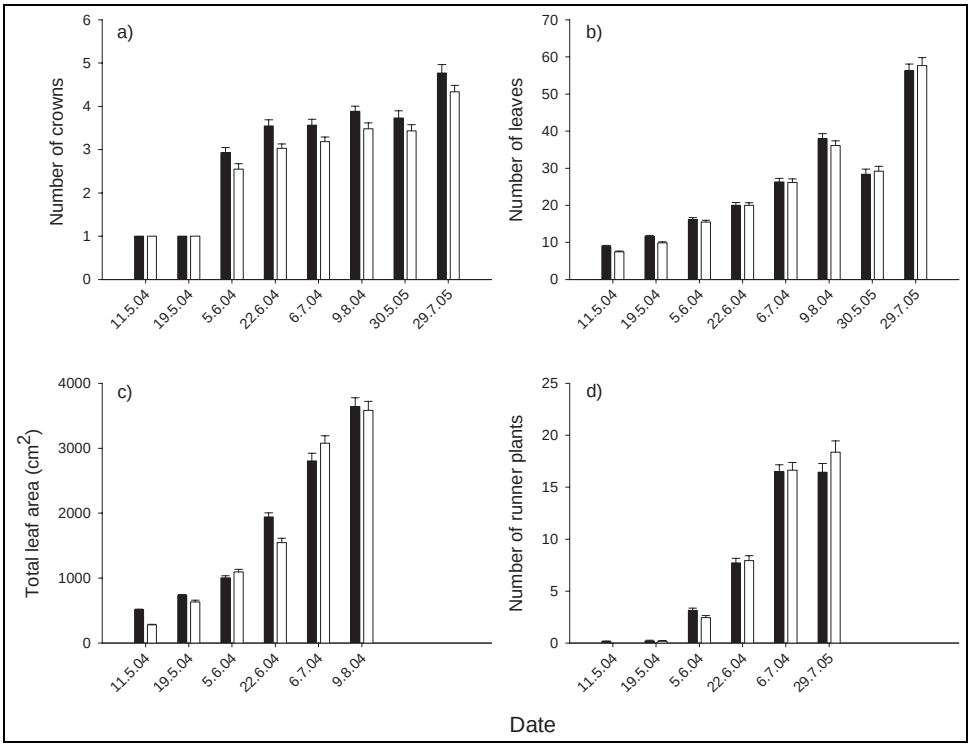


Fig. 2. Effects of preplant fertilization and fertigation (T1: filled bars) and fertigation only (T2: open bars) on number of crowns (a) and leaves (b), leaf area (c) and number of runner plants (d) at 8 times in 2004 and 2005. Dates are connected to developmental stage in Table 3. Vertical bars indicating standard error (SE).

times, most likely because of high variation between plots (SD=52). NO_3-N content increased from autumn 2004 to next autumn (r=0.62, P=0.007) while content of NH_4 tended to decrease during the same period (r=−0,45, P=0.06). Contents of P and K were in the upper part of the recommended range in all samples. There were significant differences between treatments only for P in autumn 2004 (P=0.029).

Vegetative growth

Plants not fertilized at planting showed no deficiency symptoms in 2004, but, compared to the fertilized plants, the growth and plant size in 2004 was significantly lower. The number of leaves developed during establishment in autumn 2003 was higher in plots with preplant fertilization (P<0.001), and the size of these leaves was also significantly affected by fertilization (P<0.001) (data not presented). Preplant fertilization affected the number of crowns (Fig. 2a), and the fertigated plants did not make up for this during the two years of the trial. The number of leaves was not affected by treatment either in 2004 nor 2005 (Fig. 2b). From mid season 2004 the leaf area in both treatments was also the same (Fig. 2c); from May 11th to August 9th, total leaf area per plant had increased from approximately 200 cm^2 (T1) and 110 cm^2 (T2) to an average of 3500 cm^2.

Generative development

Due to late planting the plants had only one crown and one inflorescence in spring 2004 (Fig. 2). The first opened flower was on May 16th in 2004, and on May 27th the next year.

The number of runner plants increased considerably during the cropping period in both treatments in 2004 (Fig. 2d). They were similar for both years and both treatments when counted at the 6th harvest: the preplant fertilized plants had on average 16.3 runner plants on 16.5 runners, and the fertigated plants 16.0 runner plants on 16.6 runners. In 2005, the fertigated treatment (T2) produced on average 18.4 runner plants on 16.6 runners, compared to 16.4 runner plants on 16.1 runners in the preplant treatment (T1).

Yield components

As a consequence of the late planting, yield was generally low in 2004 (Fig. 3c). The strawberry weevil also affected yield level, as low temperatures before flowering made spraying ineffective. Still, significant differences between treatments were found (P<0.002). Mean number of berries and yield per plant in registration plots in T1 was 9.3 and 171 g, respectively, compared to 6.9 berries and 92 g per plant in T2. The most productive plants in T1 and T2 yielded 306 and 180 g per plant, respectively. Very few berries were damaged by grey mould, despite frequent rainfall during the 2004 season (Fig. 1), and no significant differences between treatments were found. No significant differences between treatments were found in yield in 2005 (P=0.222)(Fig. 3d).

Preplant fertilization (T1) had a significantly positive effect on berry size in 2004 (P=0.003) (Fig. 3a), while number of berries was the same for both treatments (P=0.091)(data not presented). Primary berries were larger in both treatments in 2004 compared to 2005 (Fig. 2). Significant effects of treatment on berry weight were not established in 2005.

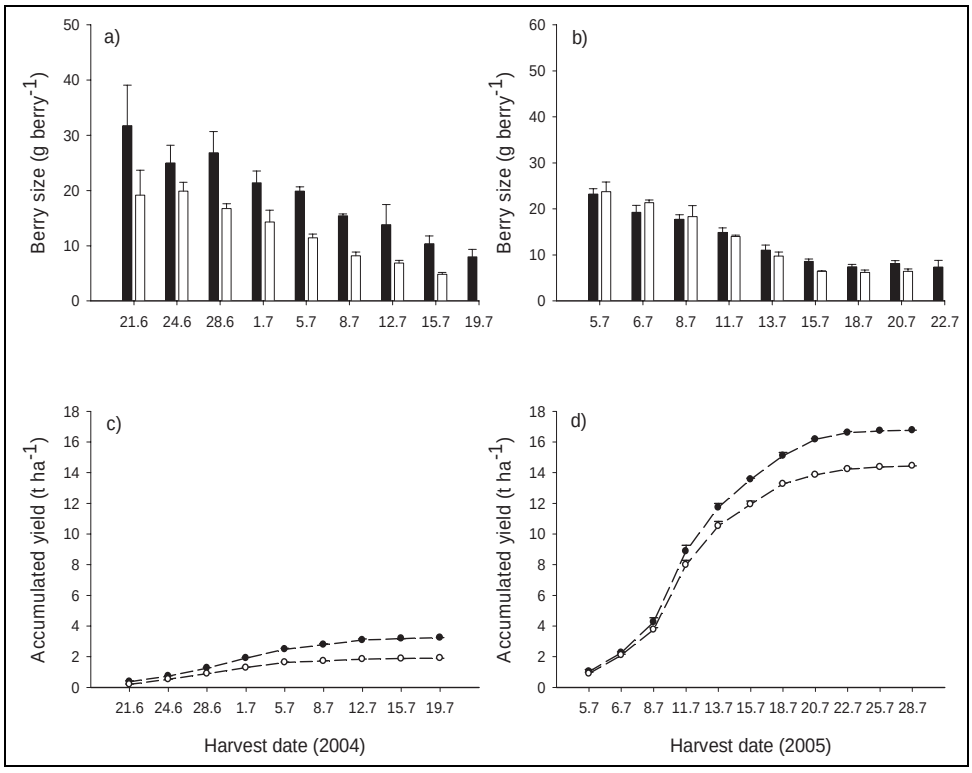


Fig. 3. Effects of preplant fertilization and fertigation (T1: filled) and fertigation only (T2: open) on berry size and yield in 2004 (a, c) and 2005 (b, d). Vertical bars indicating SE (standard error) at each harvest date.

Table 3. Concentration of N, P, K, Ca and Mg (mg g^{-1}) in leaf dry matter and leaf and petiole sap (mg L^{-1}) after two fertilizer treatments (T1 and T2) at defined developmental stages during first and second cropping year (2004 and 2005). Coefficients of variation (CV%) are calculated as mean of CV for each sampling time. Recommended values in leaf dry matter in parenthesis.

	Sampling time	Treatment	Leaf dry matter					Leaf and petiole sap					
			Total-N	P	K	Ca	Mg	NO_3-N	NH_4-N	P	K	Ca	Mg
2004													
11.05.	Flower bud	T1	28.4	3.2	12.6	5.8	2.4	129	11.7	323	3542	464	361
		T2	27.5	2.9	11.1	7.6	2.7	142	17.0	397	3472	589	489
19.05.	Anthesis	T1	25.3	3.3	15.5	5.5	2.2	81	5.7	330	3348	310	262
		T2	26.4	3.9	16.2	6.0	2.4	75	6.0	435	3554	409	329
05.06.	1st harvest	T1	24.6	2.9	13.7	6.8	2.4	108	5.3	238	2774	371	237
		T2	25.1	3.3	14.1	6.5	2.3	114	7.3	309	3003	424	279
22.06.	Mid season	T1	19.8	2.8	13.0	6.5	2.3	82	4.7	356	3699	456	291
		T2	20.5	2.8	12.3	5.4	2.1	154	7.3	428	3952	517	329
06.07.	Last harvest	T1	16.7	2.8	14.4	6.1	2.4	21	3.0	609	4419	490	336
		T2	19.1	3.1	15.0	4.6	2.1	45	5.0	601	4638	522	356
09.08.	3 weeks after harvest	T1	18.3	3.2	16.8	4.8	2.2	-	-	-	-	-	-
		T2	21.3	3.5	18.0	4.3	2.3	-	-	-	-	-	-
2005													
30.05.	Anthesis	T1	32.4	3.2	14.1	7.1	2.3	137	12.1	330	3911	835	449
		T2	22.2	3.2	14.2	8.3	2.6	162	13.3	294	3687	567	335
05.07.	1st harvest	T1	24.6	2.7	16.6	5.7	2.1	108	6.0	316	3743	467	303
		T2	26.6	2.7	15.5	5.6	2.1	160	4.7	311	3705	396	247
16.08.	3 weeks after harvest	T1	17.2	1.9	10.3	11	2.3	-	-	-	-	-	-
		T2	17.9	2.0	11.0	8.1	2.2	-	-	-	-	-	-
Mean of 2004 and 2005		T1	23.0	2.9	14.1	6.6	2.3	95	6.9	357	3634	485	320
		T2	23.0	3.0	14.2	6.3	2.3	122	8.7	396	3716	489	338
Analysis of variance (P-value)													
Source	Fertilization		0.304	0.071	0.766	0.041	0.566	0.067	0.039	0.016	0.03	0.043	0.033
	Sampling time		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
		CV%	6.3	6.1	7.4	8.9	3.9	14.9	17.2	8	6.2	9.2	9.5

Shelf life

Shelf life was significantly longer early in the 2004 season in both treatments (P<0.001), with a tendency for best post harvest quality in T1 (p=0.062)(data not presented). At the third harvest, 50 % of the berries were attacked by grey mould ten days after harvest, while 50 % rot was registered after only eight days later in the season. No significant differences in shelf life between treatments or harvesting time was found in 2005 (data not presented), but shelf life was not as good as in the previous year, with only 50 % of the berries being saleable seven and six days after harvest.

Plant analyses

Nutrient concentration in both sap and dry matter varied between sampling time for all nutrients presented (P<0.001) and the effects of treatments were variable (Table 3). Variation between blocks was large even with defined methods of sampling, and significant fertilizer effects in leaf dry matter and sap were found on only a few of the sampling dates. N concentration of leaf dry matter decreased from anthesis to the end of harvest both years, and the highest concentration was found in spring 2005. N concentration in sap showed no distinct seasonal pattern, and only sampling at the last harvest in 2004 and at anthesis in 2005 showed significantly higher concentrations of nitrogen in T2. Concentrations of P, K and Mg in dry matter were within recommended ranges in most samples (Table 3), while Zn was below at all sampling times (data not presented). Mean values for all minerals except Zn had a tendency to be higher in sap in T2 than in T1 at most of the sampling times. P, K, Ca and Mg in sap all increased during harvest, and showed very similar uptake patterns (Table 3).

Discussion

The period between rooting and flower initiation has been found to have a critical influence on fruit yield the

following season (Webb and White 1971), and Long (1939) observed that the period immediately preceding visible flower bud differentiation was critical for flower production and thus yield potential. In the South Eastern Norway, first visible flower bud initiation is about September 1st (Døving 2006), a few days after planting of the present experiment. Miner et al. (1997) got an increase in market yield with an increasing rate of fall N. Crown number was not affected, indicating that the increased yield was a result of improved flower production.

A high fertilizer level in autumn may delay the onset of dormancy and extend the period of inflorescence development, and by that allow more flowers to form (Breen and Martin 1981). Due to the late planting date in this trial, there was only one inflorescence per plant, and number of berries did not differ significantly between treatments in 2004. Still, T1 tended to produce more berries, and the superior berry size in T1 resulted in a significantly higher yield with preplant fertilization.

Late rooting date is known to give few but large berries (Webb and White 1971; Webb et al. 1973; Nestby 1985; Yoshida et al. 1991), and berry size was indeed largest in the beginning of the first harvesting year of the trial. Berry size is determined by two factors; achene number and surface expansion (Abbott et al. 1970). Surface expansion is determined during berry development in the fruiting season, while achene number and potential berry size is determined during flower formation the previous autumn and is fixed by the time the flowers emerge (Webb and White 1971). In this study, the nutritional conditions during flower initiation in 2003 were limited in T2, and optimal conditions for berry expansion did not compensate for the earlier inadequacy. The need for nitrogen is reported to be highest in the flowering and fruiting period (Ulrich et al. 1992; Nestby 1998; Tagliavini et al. 2005), and most of the plants elemental accumulation occurs during the fruit harvest (Albregts and Howard 1980). Our results show, however, that nutrient availability during flower differentiation in autumn should not be neglected. Excessive fertigation in early spring compensated for limited vegetative development in respect to leaf number, leaf size and leaf area. The number of crowns and yield potential was not possible to compensate, and these stayed lower in the fertigated plots (T2) throughout the period of the trial. This was also reported by Ulrich et al. (1992), who found that plants on unfertilized soil ran out of nitrogen soon after planting. High nitrogen absorption the following spring was insufficient for optimum fruit production.

In late fall, crowns and roots accumulate significant amounts of N, which become remobilised the following spring (Archbold and MacKown 1995; Strik et al. 2004; Tagliavini et al. 2005). An allocation of biomass from leaves to the root system in the autumn, followed by an increase in the number of crowns has been documented by Fernandez et al. (2001). This internal distribution may partly explain the strong effect of preplant fertilization found in this work. However, according to Miner et al. (1997) crown yields (g crown^{-1}) increased with spring N, and we cannot ignore the possibility that high fertilization from early spring (April) can modify some of the long term negative effects of T2 found in this trial.

Shelf life was only slightly affected by fertilizer treatment early in the season the first cropping year, and restricted nutrient availability during fruiting (T1) was positive. Applying nitrogen at rates higher than optimum may reduce shelf life (Miner et al. 1997), and decreased fruit firmness from early to late in the season has also been documented (Hochmuth et al. 1996). The effect of fertilizer strategy on shelf life was generally small compared to the differences found between harvesting times.

Leaf mineral content in the dry matter of strawberry leaves has been the subject of numerous studies, and in later years also other methods such as petiole sap analysis have been of interest. The goal with sap analyses is to measure the concentrations of inorganic nutrients together with nutrients in active enzymes in the plant. Nutrient concentration in sap reflects the actual uptake at the time of sampling rather than the amounts of accumulated nutrients over time, and may become a useful tool to fully make use of the advantages of fertigation.

Many publications have described the decrease in N concentration in dry matter of leaves at the end of the fruiting season (Bould 1964; John et al. 1976; Cutcliffe and Blatt 1984; Locascio and Martin 1985; Stanisavljevic et al. 1997; Nestby 1998), and it was also recorded in both treatments in the present experiment. Ulrich et al. (1992) suggested this decrease to be caused by physiologically dormant roots, and Cutcliffe and Blatt (1984) found no effect of applied N on the N concentration in leaves collected soon after the second harvest. Kongsrud (1986) and Sønsteby et al. (2004) suggested this decrease in leaf N to be caused by translocation of N to branch crowns due to flower induction and growth of inflorescences . This is supported by resent research, describing significant effects of N supply on autumn plant growth, with high N applications increasing crown dry weight (Tagliavini et al. 2005). The plants allocate resources to the crowns in fall and spring (Fernandez et al. 2001), and may be a reason for the lack of fertilizer response on N concentration in leaf samples. Nitrate N in sap increased during harvest. A significant increase in leaf dry weight and leaf area at the time of fruiting has been documented (Fernandez et al. 2001). Consequently, N uptake in leaves seems to be best reflected in sap analysis. Concentrations of P, K, Ca and Mg in sap all increased during the harvesting season in 2004. Although there were few significant differences between treatments, the tendency for higher uptake of macronutrients in T2 was very clear in sap compared to dry matter. Daugaard and Todsen (1999) suggested leaf sap analyses as an indicator of the actual nutrient uptake, and found significant correlations for all macronutrients except nitrate at the beginning of flowering.

Reliable sampling practice in sap was difficult, and caused few significant differences between treatments. Inaccuracy in sampling, expressed by the coefficient of variation (CV) was 6.3 % for total N in leaf dry matter, and 14.9 and 17.2 % for NO_3^- and NH_4^+ respectively, in sap (Table 3). Variation in N concentration was largest in sap at all sampling times. This may partly be due to differences in plant parts analysed, as petioles have a different chemical composition than leaflets (Kwong and Boynton 1959; John et al. 1975; Archbold and MacKown 1997; He et al. 1998). The relative proportion between leaf lamina and petiole will change during the season (Kwong and Boynton 1959; May et al. 1994; Archbold and MacKown 1995), as well as the elemental composition of leaves and petioles (Stanisavljevic et al. 1997). According to Kwong and Boynton (1959), leaflets were the

best plant organs for analysis, while ULRICH et al. (1992) recommended analyses of petioles for monitoring nitrate concentration in strawberry. The optimal plant part for sampling will probably depend on developmental stage as well as element analysed.

Recommended values of 1.0–1.5 % Ca in leaf dry matter have been suspected to be too high for 'Korona' in Norway. Our results showed a mean Ca concentration three weeks after harvest between 0.43 and 1.10 percent, suggesting a lowering in recommended values for leaf Ca in 'Korona'.

It seems that concentrations in leaves and/or petioles do not reflect plant requirements or nutrient uptake at all developmental stages, as elements at certain times mainly accumulate in reproductive organs, roots or crowns (TAGLIAVINI et al. 2005). Still, in periods with active growth, foliar tissue contains the greatest amount and concentration of N (ARCHBOLD and MACKOWN 1997; STANISAVLJEVIC et al. 1997), and should in general be an important indicator of plant N status.

In conclusion, to maximise yield and berry size the first harvesting year, fertilization at planting is essential when planting in late autumn. Our results demonstrate that fertilizer utilization in relation to productivity is highest when fertilizer is available at the time for flower differentiation, since supply of an equal total amount of fertilizer next spring caused significant reductions in yield and berry size. We also demonstrated that leaf analyses do not reflect yield potential in plants established under suboptimal conditions.

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Addresses of authors: Nina Opstad (corresponding author) and Arnfinn Nes, Norwegian Institute for Agricultural and Environmental Research (Bioforsk), Arable Crops Division, Section Kise, Kisevegen 337, N-2350 Nes H, Norway, and Finn Måge, Norwegian University of Life Sciences, Department of Plant and Environmental Sciences, Pb. 5003, N-1432 Ås, Norway, e-mail: nina.opstad@bioforsk.no.