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**Influence of fertilization on growth and generative parameters of two short day strawberry cultivars grown in substrate, and evaluation of analysing tools for leaf nitrate and potassium**

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**Keywords: branch crowns, Electrical conductivity (EC), floral primordia, leaf, runner**

**Abstract**

**We examined influence of fertigation on vegetative and generative parameters of strawberry plants (*Fragaria x ananassa* Duch.) and evaluated rapid analysing tools for N and K in leaf tissue. Experiments were undertaken in open polytunnel on “table top” with ‘Sonata’ and ‘Korona’ grown in 2 l pots filled with a peat-based soil mixture. The experimental design was randomized plot with three replications. Plants were fertigated with EC levels of 0.5, 1.0, 1.5 and 2.0 mS cm-1, based on two stock solutions of 7.5 kg YaraLiva™ Calcinit and 7.5 kg Kristalon™ Indigo, both dissolved in 100 l of water. Percentage N and K in leaves differed between analysing methods, cultivars, EC and date. We found interactions between cultivar and EC level and between date and cultivar for N and K in leaf. Analysing NO3\_ by a photometric method (PM) in a lab, and by Laqua twin (LT), showed significant interaction with N% of leaf dry matter (DM) only for LT (r2=0.36). N% increased with higher EC level, and more for ‘Korona’than for ‘Sonata’. LT K+ did not correlate with K% (r2=0.014). Number of crowns and runners increased for both cultivars up to EC 1.5, while the number of leaves was unaffected. Petiols was shortest at lowest EC. Flower initiation was earlier at low EC in both cultivars. In the following spring, time to flowering and first harvest reduced with decreasing EC. Number of flowers per plant increased up to EC 1.5, but dropped strongly at EC 2.0 for ‘Korona’, while ‘Sonata’ had a gradually increase of flowers with increasing EC, but the number was only a third of ‘Korona’, except at EC 2.0, where the amount was equal for both cultivars. The conclusion can be drawn that LT correlated better than ChlDualex with N in strawberry leaves. However, r2 was only 0.36 indicating that LT NO3- is a coarse management tool. LT K+ was not a promising tool for rapid K+ test in these experiments. ‘Korona’ seemed to benefit of higher N levels for both vegetative growth and generative development than ‘Sonata’ up to EC 1.5, but ‘Sonata’ reached a higher floral primordia development stage in early October.**

**INTRODUCTION**

The growth and yield of strawberry are affected by fertilization. N and K are the macronutrients that the strawberry plant takes up most of, followed by calcium (Ca) and phosphorous (P) (Albregts and Howard, 1980; Albregts and Howard, 1986). To control growth and development of strawberry it is important to know the nutritional status of the plants, and to adjust fertilizer rates at any time during the season.

Traditionally, lab analyses of leaf dry matter (DM) after harvest are assessing the plant nutritional status, but the standard norm refers to a short time period. Also, these analyses take a week or more before the results are available. To reduce the time gap, rapid non-destructive analysing tools can be an alternative. Hand held tools for petiolar sap analyses and chlorophyll (CHL) meters, could be of vital importance in precision fertigation, since frequent monitoring is necessary. However, to quickly assess crop nitrogen status, tests and calibration could be better performed using the nutrient nitrogen index (NNI), ratio of N concentration of shoot biomass and critical N concentration as reference (Sadras et al., 2014). The SPAD-502 CHL meter (Minolta, Japan) related positively with nitrogen nutrient index (NNI, r2=0.72\*\*\*) (Guler et al., 2006; Yu et al., 2012). Another tool is the Dualex meter (DualexR Scientific, Force A, France), which calculate the NBI index [(ratio between fluorescence of chlorophyll and of flavonols (FLV)) giving r2 =0.93 in average of two turf grass species tested (Agati et al., 2013)]. Similar NBI and other CHL/FLV methods could be useful to assess the nitrogen status of potato crop (Abdallah and Goffart, 2014). The Dualex values gave strong linear correlation used in black currants and in sour cherries, and in strawberry (Pedersen, 2013; Nestby and Guéry, 2017). Another approach is to analyse plant sap of leaf stalks for ions like nitrate (NO3-) and potassium (K+). There are earlier work on this method for nitrate based on aqueous petiolar extracts (Hernando et al., 1971; Ulrich, 1978). Later the petiolar test demonstrated to be a practical tool for facilitating decision making, and a diagnostic tool that is well adapted to a rational management of nitrogen. Testing the petiolar method against a standard continuous colorimetry flow analyses gave r2=0.96 (Raynal Lacroix and Cousin, 1997; Raynal Lacroix and Abarza, 2002). A multi-tool that is using this principal is LT™ (Spectrum Technologies, INC, IL, USA). Their handheld meters analyse the content of NO3- and K+. LT K+ was compared with standard tests, and a linear relationship(r2=0.86) was found between K measured with a K+ meter in soil samples and standard analyses at several labs, similarly, a linear relationship was found between petiole K measured in the lab and petiole sap measured with the K+ meter (Stevens et al., 2016).

To get an insight in how to use rapid analysing tools and to evaluate their reliability in fertigated Norwegian strawberry substrate culture, we examined content of nitrate and potassium using the handheld LT™, the Pm NO3- (Yara) and the Dualex scientific (in this case only for chlophyll). We compared these measurements with standard lab analyses for N%, K% and P% of DM in strawberry leaves. Simultaneously, we studied the effect of fertigation with different levels of N and K on vegetative and generative parameters.

**MATERIAL AND METHODS**

The experiments were undertaken in four rows of “table top”, with strawberry grown in pots filled with substrate, in an open high polyethylene tunnel (polytunnel). The growth substrate was a peat-based soil mixture (Gartnerjord with Perlite, LOG, Norway). Overwintered plug plants of 3x3 cm2 were planted in 2 l pots on 21 May 2013 with one plant per pot in plots of 10 plants. The pots were kept outdoors before transferred to a polytunnel 27 May. The plants were tap watered until start of the fertilization treatments on 10 June. At the same date, leaves of ‘Korona’ and ‘Sonata’ were collected for analyses of K and N content of leaf sap (SAP) and of dry matter (DM). Plants were fertigated at each watering using two stock solutions, one with 7.5 kg YaraLiva™ Calcinit [Ca(NO3)2] and one with 7.5 kg Kristalon™ Indigo [NPK 9-5-25(Mg-S-mikro); YARA Norge AS, Norway], both dissolved in 100 l of water and dozed by an injector (DL16, Dosatron International, France). The experimental design was randomized block in three replications. Treatments: A. Fertigation (Table 1) B. Cultivar (‘Korona’, ‘Sonata’).

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| Table 1. Contet of N, P and K in mg l-1 of nutrient solutions for fertilization of strawberries, at four levels of Electrical conductivity (EC) in mS cm-1. | | | | |
| EC | N | P | K |
| 0.5 | 92.5 | 6.8 | 64.8 |
| 1.0 | 185.0 | 13.5 | 129,5 |
| 1.5 | 277.0 | 20.3 | 194.3 |
| 2.0 | 370.0 | 33.8 | 259.0 |

Fertigation was until 10% run off, every second time with either Calcinit or Kristalon. The fertigation pulses were equal for both fertilizers. For Laqua Twin (LT), analyses of young and fully developed leaves, four plants per cultivar were sampled at each time within plot and replication. For lab analyses (N% of DM), approximately 20 young and fully developed leaves from ten plants per cultivar were sampled within plot and replication. The Yara nitrate analyses were undertaken using a cold water extraction method, determining NO3- in the filtered sample by photometry (Pm, Yara analytical services, UK). Chlorophyll content was examined using Dualex Scientific (CleanGrow, UK). Registrations of growth parameters were on three extra plants per cultivar and fertilization treatment, in all replications. The registrations were number of runners and leaves, and length of petiols. First registration was 11 June and thereafter every 14 days terminating on 2 October. At termination, crowns were dissected to record the floral development stage of each treatment. The year after, number of days to anthesis and first harvest were recorded by monitoring of the plants three times a week, while number of crowns and flower parameters per plant were registered on 10 June, and 22 July, respectively. Fruit yield was not registered because of uneven fruit size between plant caused by freezing injury the winter 2013/2014. For data analyses and presentation, we used the procedures GLM, Corr, tabulate and Graph (SAS Institute INC., 1998).

**RESULTS AND DISCUSSION**

**Effect of EC on percentage N and K of leaf dry matter (DM)**

At start of fertilization treatments 10 June, N% in leaves of ‘Korona’ and ‘Sonata’ was higher than the Norwegian recommended value for ‘Korona’ in August (2.0-2.2%) of the harvest year (Yara Norway, 2015), which is more narrow than a general recommended international value of 1.9-2.8% (Haifa, 2014). First of July, N% was below optimum at lowest EC level, but above optimum at the highest level (Fig. 1). The differences between EC levels were larger in ‘Korona’ than in ‘Sonata’. ‘Korona’ had generally low values 22 July, 12 August and in late September. ‘Sonata’ did not have this drop during summer, but behaved similar with a drop on 23 September. The values were lower than recommended for growing strawberry in Norway when EC of the nutrient solution was 0.5. For ‘Korona’ also EC 1.0 was on the low side, while the highest level was too high. For ‘Sonata’, even the highest level seemed appropriate.

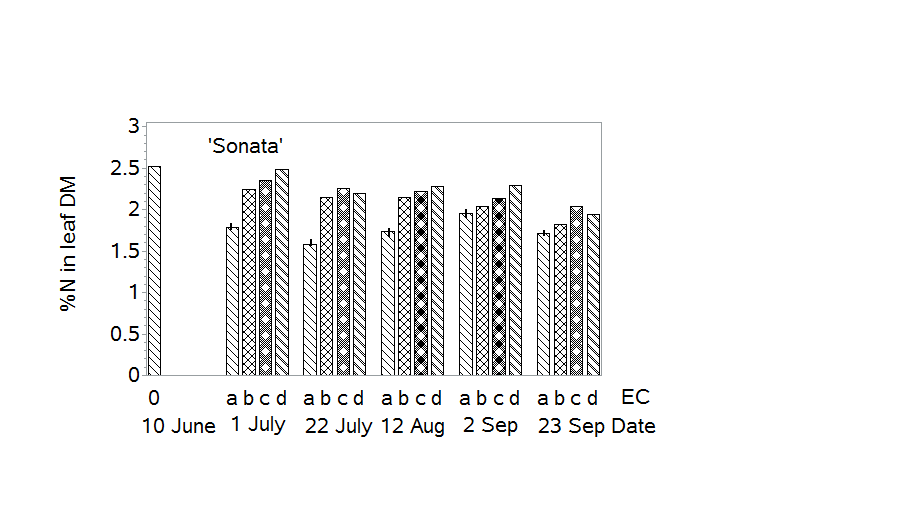


Figure 1. Influence of EC level on N% in leaf DM of two strawberry cultivars at intervals

of three weeks in the establishment year. Bars on left group column are standard errors within each date. EC values in mS cm-1: a=0.0, b=0.5, c=1.5, d=2.0.

For potassium the Norwegian recommended value is 1.2-1.8% in leaf DM in August of the harvest year (Yara Norway, 2015), which is partly lower and more narrow than a general recommended international value of 1.6-2.5% (Haifa, 2014). In our experiments, the values (not tabulated) were above lowest recommended value of 1.2% for all levels of EC in both cultivars. However, at 2 September the values were very high, and above the upper recommended level of 1.8% (not tabulated). This increase in September could partly be a reflection of entering a generative period and warm weather in August. There was no strong correlation between LT K+ and K% of leaf DM.

**Effect of EC level on NO3- in leaves analysed by the Pm method (Yara)**The pattern of nitrate level, as an exception from the other dates, had a downward trend 12 August- at increasing EC of the nutrient solution in ‘Korona’, except for the highest EC (not tabulated). The strong increase at EC 2.0 was also the case at all dates except 2 September. ‘Sonata’ showed a more even pattern, with almost no effect of varying fertilization before 2 September. However, NO3- was generally highest 2 September, and the level was negatively affected by increasing EC. The NO3-content was positively correlated with N% of leaf DM (Table 1). However, the coefficient was too low to make this method reliable as an alternative to a standard laboratory analyses.

**Effect of EC level on content of NO3- and K+ analysed by LT and by CHLDualex**

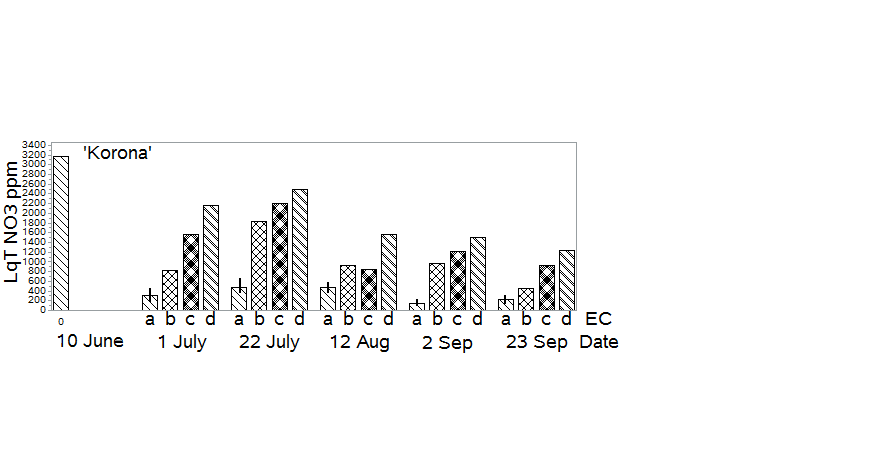
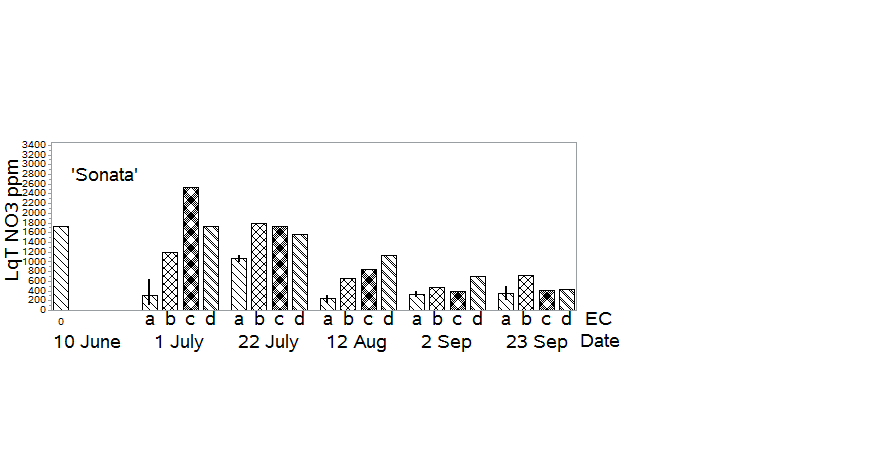
The pattern of nitrate analyses by LT is to some extent similar to N% in DM (Fig. 1) of both Cultivars before start of the fertilization experiments, with a lower level for ‘Sonata’ than for ‘Korona’. The July registrations show a strong increase in NO3- by fertilization, however with a reduced level at the highest concentration for ‘Sonata’ (Fig. 2). Later in the season, there was a strong drop in NO3- except at EC 0.5 where the content was relatively stable at a low level through the whole season, an effect not seen in the laboratory analyses of leaf DM.

Figure 2. Influence of EC level on content of LT NO3- in leaf stalk sap

registered at three weeks intervals in two strawberry cultivars in the

establishment year. The bar on each left group column is standard error

within each date. EC values in mS cm-1: a=0.0, b=0.5, c=1.5, d=2.0.

The correlation between LT NO3-and N% was significant (Table 2). However, suggested as valuable only as a tool for a coarse indication of nitrogen level. Also, LT and Pm nitrate (Yara) were positively, but not strongly correlated. Clorophyll (Chl) level measured using Dualex Scientific showed a low increase in ‘Korona’ in July and August with increased fertigation. For ‘Sonata’ the Chl level was a little lower than in ‘Korona’, and there were small differences between EC levels. Also, Chl did not correlate significantly with Pm or LT nitrate.

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| Table 2. Correlation between laboratory analyses (Lab) of N and K in % of leaf DM and rapid methods for analysing of NO3-, K+ and Chlorophyll (Chl), shown by Pearson’s correlation coefficients. Average of two cultivars. | | | | | | | |
| Analysing  method | | Rapid analyses of NO3, K+ and Chlorophyll | | | | |
| Pm Yara | LT\_NO3 | LT\_K | CHLDualex | | |
| N | Lab | 0.21\* | 0.68\*\*\* | 0.15ns | 0.11ns |
| K |  | -0.16ns | -0.29\*\*\* | 0.11ns | -0.22\*\* |
| Pm | Rapid |  | 0.38\*\*\* | -0.01ns | 0.11ns |
| Chl Dualex |  | 0.11ns | 0.13ns | 0.02ns |  |  | | |

ns,\*,\*\*,\*\*\* are not significant, significant on 5%, 1% and 0.1% levels, respectively.

**Effect of EC level on growth parameters**

Generally number of crowns and of runners and length of petiole increased for EC levels up to 1.5 in the planting season. EC level had no significant effect on number of leaves (table 3).

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| --- | --- | --- | --- | --- | --- |
| Table 3. Effect of EC level on number of crowns, leaves, accumulated runners and length of petiols (cm), for two strawberry cultivars grown in substrate on “table top” in polytunnel, recorded 2 October. | | | | | |
| Cultivar | EC | Growth parameters plant-1 | | | | |
|  | Crown | Leaf | Runner | Petiole | |
| Korona | 0.5 | 4.29 | 49.7 | 30.7 | 17.4 | |
|  | 1.0 | 5.60 | 57.2 | 45.3 | 22.8 | |
|  | 1.5 | 6.20 | 59.0 | 52.1 | 23.2 | |
|  | 2.0 | 6.50 | 64.0 | 55.4 | 23.5 | |
| Mean |  | 5.27 | 54.2 | 45.3 | 20.3 | |
| SE |  | 0.91\*\* | 7.8ns | 0.9\*\*\* | 4.2\* | |
|  |  |  |  |  |  | |
| Sonata | 0.5 | 2.80 | 26.3 | 20.1 | 12.2 | |
|  | 1.0 | 3.30 | 29.4 | 25.6 | 20.8 | |
|  | 1.5 | 4.00 | 32.6 | 32.2 | 21.8 | |
|  | 2.0 | 4.00 | 31.6 | 27.1 | 22.0 | |
| Mean |  | 3.53 | 29.1 | 26.5 | 19.2 | |
| SE |  | 0.71\*\* | 5.1ns | 0.9\*\* | 2.4\*\*\* | |
| AverageCv | 0.5 | 3.41 | 35.9 | 25.4 | 14.4 | |
|  | 1.0 | 4.07 | 38.7 | 35.5 | 21.5 | |
|  | 1.5 | 4.73 | 41.6 | 41.2 | 22.3 | |
|  | 2.0 | 4.71 | 41.5 | 41.3 | 22.4 | |
| Mean |  | 4.14 | 38.6 | 35.9 | 19.6 | |
| SE |  | 0.64\*\* | 8.2ns | 0.6\*\*\* | 3.0\* | | |

ns, \*,\*\*,\*\*\* are not significant, significant on 5%, 1% and 0.1% levels, respectively.

**Effect of EC level on primordial development stage and flowering**

Flower initiation was earlier at low EC in both cultivars 2 October 2013, and ‘Sonata’ had better developed flower primordia than ‘Korona’ at all EC levels except EC 2.0 when both had poor development (Fig. 3). The correlation between EC and development stage was significant for both cultivars. However, it was stronger for ‘Sonata’ (r2=0.47\*\*\*) than for ‘Korona’ (r2=0.22\*\*\*), probably because of more data available for ’Sonata’ than for ‘Korona’.

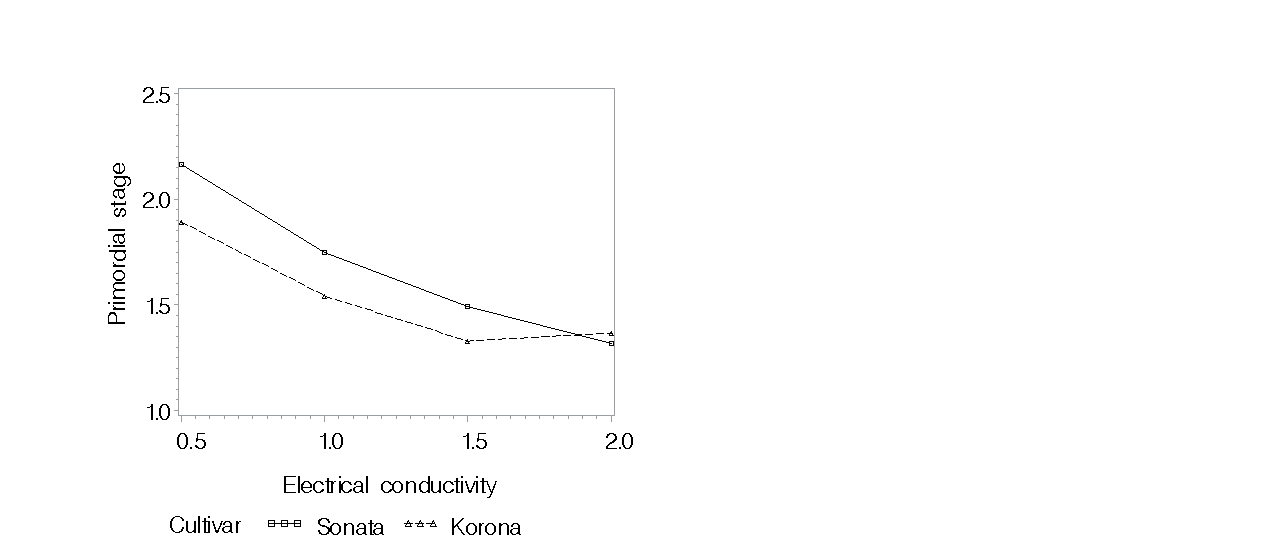


Figure 3. Effect of EC on primordial development stage

in the main crown of two cultivars 2 October 2013.

In spring 2014, number of crowns per plant increased as EC increased for ‘Sonata’, while ‘Korona’ tended to follow the same patter as for ‘Sonata’ up to EC of 1.5, but then the number dropped; there was no interaction of Cv vs EC (Table 4). The number of peduncles plant-1 went higher when EC increased up to 1.5 for ‘Korona’, and the mean of the cultivars, but not for ‘Sonata’. Total number of flowers per plant tended to increase for ‘Sonata’ with increasing EC, while ‘Korona’ and the average of the cultivars, had increasing numbers up to EC 1.5, but then dropped strongly at EC 2.0. The ratio of flowers peduncle-1 was in average of the two cultivars highest at lowest EC level. Number of days to anthesis and to first harvest, were less with decreasing EC for both cultivars, and in average of the two cultivars the effect was significant; there was no interaction between cultivar and EC. ‘Sonata’ seemed to respond better to high EC levels for most of the recorded parameters up to EC 2.0 than ‘Korona’. However, for the ratio peduncle plant-1, days to anthesis and days to first harvest, both cultivars reacted similar to increasing EC.

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| --- | --- | --- | --- | --- | --- | --- | --- |
| Table 4. Effect of cultivar and EC on number of crowns plant-1 June 10 , number of peduncles and flowers plant-1 and number of flowers peduncle-1 July 22, and number of days from May 1 to anthesis and first harvest in the year after planting | | | | | | | |
| Cv | EC | Crowns  plant-1 | Peduncles plant-1 | Flowers  plant-1 | Flowers  peduncle-1 | Days to  anthesis | Days  to harvest |
| Sonata | 0.5 | 4.2 | 7.0 | 42 | 6.1 | 45 | 81 |
|  | 1.0 | 3.6 | 7.0 | 41 | 5.9 | 47 | 84 |
|  | 1.5 | 5.0 | 9.5 | 47 | 4.9 | 51 | 84 |
|  | 2.0 | 5.4 | 8.8 | 51 | 5.7 | 50 | 85 |
|  | Mean | 4.5 | 8.0 | 45 | 5.7 | 48 | 84 |
|  | Se | 0.7\* | 1.5ns | 9.7ns | 0.9ns | 3.2ns | 1.9ns |
| Korona | 0.5 | 9.0 | 12.7 | 116 | 9.2 | 42 | 79 |
|  | 1.0 | 11.0 | 17.0 | 138 | 8.1 | 43 | 81 |
|  | 1.5 | 13.5 | 20.0 | 130 | 6.6 | 49 | 85 |
|  | 2.0 | 9.8 | 8.8 | 59 | 6.8 | 50 | 84 |
|  | Mean | 10.4 | 13.0 | 98 | 7.6 | 47 | 82 |
|  | Se | 2.4ns | 1.7\* | 6.7\*\* | 0.8ns | 2.8ns | 2.0ns |
| Average | 0.5 | 6.6 | 9.9 | 79 | 7.7 | 44 | 80 |
|  | 1.0 | 7.3 | 12.0 | 89 | 7.0 | 45 | 83 |
|  | 1.5 | 9.3 | 14.8 | 88 | 5.8 | 50 | 85 |
|  | 2.0 | 7.6 | 8.8 | 55 | 6.3 | 50 | 84 |
|  | Mean | 7.7 | 11.4 | 78 | 6.7 | 48 | 83 |
|  | Se | 0.8ns | 1.0\*\*\* | 5.4\*\*\* | 0.6\* | 1.8\* | 1.1\*\* |

**CONCLUSION**

LT nitrate correlated better with laboratory N% values in strawberry leaves than nitrate level analysed by PM (Yara). However, r2 was only 0.46 which indicate that LT NO3- only can be used as a coarse management tool. The correlation was a little higher for ‘Korona’ than for ‘Sonata’. Chlorophyll content from leaves alone, correlated poorly with fertilization level. LT K+ showed no promise as a tool for rapid K+ test in these experiments, though there was a positive but weak correlation, between K+ and LT K+ for ‘Sonata’, but not for ‘Korona’. It seems like ‘Korona’ take up more nitrate than ‘Sonata’, and that this reflect the stronger growth of ‘Korona’ than for ‘Sonata’. ‘Sonata’ seems to respond better to high EC levels for crowns plant-1, petiole length and flowers peduncle-1 up to EC 2.0 than ‘Korona’. However, for the ratio Flowers peduncle-1, days to anthesis and days to first harvest both cultivars reacted similarly (and negatively) to increasing EC, and increased fertilization delayed flower initiation in autumn the year before.

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