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Precision-regulation of tree growth and crop loads in apple

Results from the project 2016-2020

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TITTEL/TITLE

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Keywords

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Horticulture

SAMMENDRAG/SUMMARY:

Denne rapporten omhandlar resultat frå feltforsøk med epletre i vekstsesongane 2016 - 2020 ved NLR Viken i Lier og NIBIO Ullensvang. Føremålet med dette prosjektet var å stimulera til auka produksjon av norske eple med god fruktkvalitet dyrka på ein effektiv måte. Det vart gjennomført feltforsøk med kjemisk tynning under blomstringa og på karten med bruk av ulike bioregulatorar, mekanisk tynning med maskin under blomstringa, rotskjering med kniv påmontert traktor, utprøving av vekstregulatoren Regalis og gjødselvatning til to eplesortar. Kontrollert gjødseltilføring med epletre i potter i plasthus vart gjennomført ved Nibio Særheim. Målsetjinga heile tida var å gjera forsøk med miljøvennlege teknikkar til å gjødsla epletre optimalt for å auka den generelle fruktkvaliteten og heva andelen av årleg klasse 1 kvalitet. Dessutan var det viktig å nytta bærekraftige metodar for å redusere skotveksten og regulera avlinga i trea for å oppnå rett fruktsetjing under norske vilkår.

This report is summarizing results from field trials with apple trees conducted during the seasons 2016-2020 at growers orchards in the Lier region, Eastern Norway and NIBIO Ullensvang, western Norway. The aim of this project was to stimulate and to increase the production of Norwegian grown apples of high fruit quality focusing on efficient production methods. The field trials were related to mechanical thinning during flowering, chemical thinning during flowering and early fruitlet development using different bioregulators, root pruning with a vertical knife mounted on the back side of a tractor, testing of the bioregulator Regalis for shoot growth reduction and fertigation experiments giving minerals through the drip water system. A fertigation trial with apple trees in

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pots in polyhouse was done at NIBIO Særheim. The trees were grown in containers in a homogeneous substrate and the amounts of water and nutrients applied to the trees were controlled for studing the demands for nutrients and water of an apple tree.

LAND/COUNTRY:	Norway
FYLKE/COUNTY:	Vestland
KOMMUNE/MUNICIPALITY:	Ullensvang
STED/LOKALITET:	Lofthus

GODKJENT /APPROVED	**PROSJEKTLEDER /PROJECT LEADER**
Inger Martinussen	Mekjell Meland
NAVN/NAME	**NAVN/NAME**

Preface

This project aims to stimulate an increased production of Norwegian grown apples of high fruit quality focusing on efficient production methods. The total consumption of apples in Norway is increasing, but it is mainly as a result of imported fruit. The total Norwegian apple production has declined the last 10 years, as well as in the Norwegian production season from September to November. Production statistics are showing a pattern of alternate bearing, high yields one year followed by a low yield the year after. This irregular production pattern is creating problems for both growers and the market. To achieve regular yields of large apple crops of premium quality, the crop loads and the tree growth must be better synchronized and controlled. The field trials in 2016, 2017, 2018, 2019 and 2020 were related to chemical fruit thinning using different bioregulators, root pruning, testing of the bioregulator Regalis for reduced shoot growth, and fertigation experiments giving minerals through the drip water system. The bioregulator Regalis reduces the annual shoot growth without having any negative effect on yields and fruit quality. Uptake and distribution of minerals in apple trees in pots are studied in a greenhouse. Different management techniques are improved which are environmentally friendly and lowering the production cost for the growers. NIBIO Ullensvang in cooperation with Viken Fruit Advising Team and Norwegian fruit growers is conducting these experiments and implementing the results to the fruit industry and elsewhere. Results from the seasons were disseminated to growers as newsletter, field meeting at growers sites, at the biannual meeting Fruit and Berry seminar in March 2017 and 2019, Norwegian fruit seminar in Voss February 2018 and at international meetings. This report gives a summary of all the field trials conducted.

Project owner were Viken Agricultural Advising, project leader Gaute Myren, Viken and project industry partners were Hardanger Fjordfrukt, Ullensvang Fruktlager, Nå Fruktlager, Sognefrukt, Fellespakkeriet og Rogaland Fruktdyrkarlag

NIBIO Ullensvang was R&D responsible by Mekjell Meland

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Lofthus, 24.03.21

Mekjell Meland

Content

1 Introduction

Regular annual production of high quality apples in modern high density orchards requires timely and accurate cultivation practices to maintain the delicate balance between vegetative growth, flowering, fruit set, fruit growth, final fruit yield and fruit quality at harvest. Too low numbers of flower buds or conditions that lead to very low fruit set will generally cause excessive shoot growth shading the apples and preventing optimal fruit skin colour development. In addition low numbers of fruits will result in high numbers of flower buds the next growing season with the risk of a too high fruit set and crop yield. Too many apples per tree will reduce fruit size and fruit sugar content. To prevent these negative effects on fruit quality timely thinning of fruits is needed.

In addition, fruit trees require adequate fertilization and irrigation during the growing season to maintain the shoot and fruit growth. Controlling the amount, the time during the season and the method of application of fertilizers is needed to obtain a regular annual level of growth and yield of fruit trees in an orchard.

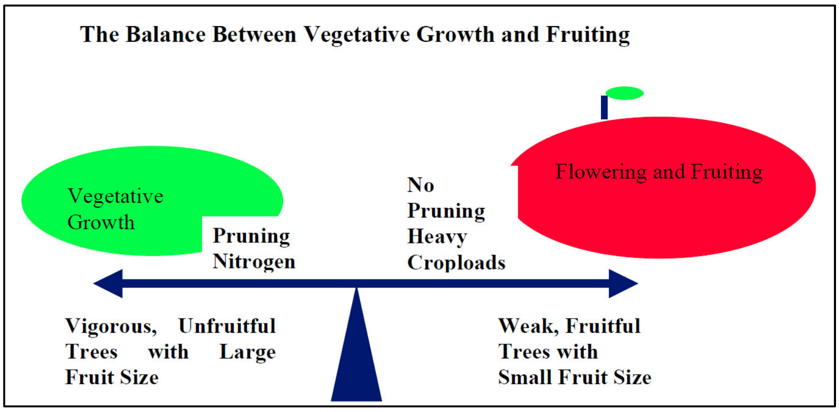

Figure 1. The balance between vegetative growth and cropping is heavily influenced by pruning, nitrogen fertilization (tree vigor), and crop load (source: T.. Robinson, Department of Horticultural Sciences, New York State Agricultural Experiment Station, Cornell University, Geneva, USA*).*

Achieving and maintaining the right balance between vegetative growth, flowering and fruiting, as presented schematically in fig. 1, is the day to day challenge for fruit growers. Factors seriously disturbing the delicate balance, e.g. due to low fruit set due to bad pollination conditions or frost damage to the flowers, require a lot of measures that growers have to take to restore it.

Fruit set depends on pollination and fertilization of the flower followed by the partitioning of sufficient assimilates to the young fruitlets to sustain their growth. Consequently, cultivation techniques aimed to regulate fruit load of ample blooming apple trees have been focused on the prevention of fertilization of a proportion of the flowers or limiting the partitioning of assimilates to the weaker fruitlets in a cluster to trigger a fruit abortion response (Wertheim & Webster, 2005). Shoot development competes with fruit set and fruit growth for the available assimilates, especially during the first weeks from flowering. During the beginning of the growing season the vast majority of the assimilates is used for the development of new bourse shoots and fruit growth mainly depends on assimilates produced by the spur leaves (Wünsche and Lakso, 2000). Manipulation of the fruit load of apple tree has shown to be possible by measures that:

- affect the pollination and fertilization of flowers
- assimilate partitioning to young fruitlets

- assimilate availability within the trees

As the efficacy of these measures varies between cultivars, geographical position and weather conditions, potentially useful measures have to be evaluated for local conditions and cultivars in order to develop tailor-made advices to the growers in a particular area.

To maintain or restore the proper balance between shoot development and yield of high-quality apples, a number of cultivation practices have been studied which can be readily applied by fruit growers:

1. Reduction of shoot growth using Regalis containing the active ingredient prohexadione-calcium, an inhibitor of the shoot elongation promoting plant growth regulator gibberellin.
2. The use of a root pruning knife to inhibit shoot growth by a regular reduction of the root volume.
3. Chemical thinning of flowers and fruits to avoid excess fruit set or to reduce the crop load of trees with a too high fruit set.
4. Mechanical fruit thinning.
5. Optimizing fertilization and irrigation using drip line fertigation.

To examine which of these cultivation practices might be useful to optimize the growth and yield of high-quality apples in Norway a number of trials were carried out in the fruit growing regions Ullensvang and Lier.

2 Trials 'PresiEple' project

2.1 Regalis

Regalis, containing 100 g/kg prohexadione-calcium as the active ingredient, is an inhibitor of the synthesis of gibberellins, a naturally occuring growth regulator in plants. One of the roles of gibberellins in plant development is the stimulation of cell elongation. In shoots gibberellins increase their final length by increasing the length of the internodes.

The aim of the trial was to study the effect of different concentrations and time of application of Regalis on shoot extension growth in apple trees. The hypothesis is that by reducing shoot extension growth more of the sugars produced in photosynthesis become available for fruit set and fruit growth. In addition, shorter shoots will give a better light penetration into the canopy of the trees and is expected to improve current year fruit quality and flower bud development for the next season. To study the possible carry-over effects of a Regalis treatment, the number of flowers buds, number and length of shoots and trunk diameter were also determined in the year after the application of Regalis.

2.2 Design and implementation of trials with Regalis

The trials with Regalis were carried out in orchards at two locations in Norway. At NIBIO Ullensvang Regalis was applied on 7-year old 'Summerred'/M.9 trees in 2018. In the fruit growing area at Lier Regalis was applied on 15-year old on 'Aroma'/M.9 trees and on 10-year old 'Summerred'/M.9 trees.

Treatments:

1. Control, untreated
2. 0.62 kg/ha Regalis when new terminal shoots are about 2.5 cm (about 10 days after full bloom).
3. 1.25 kg/ha Regalis when new terminal shoots are about 2.5 cm (about 10 days after full bloom).
4. 2.5 kg/ha Regalis when new terminal shoots are about 2.5 cm (about 10 days after full bloom).
5. 2x 1,25 kg/ha Regalis , 1st application when new terminal shoots are about 2.5 cm (about 10 days after full bloom), 2nd application about one month later.

Statistical layout of the trial

Randomized block design of four replicated plots of six trees per treatment of which the middle three trees were used as observation trees.

Trials Lier area

Year:	2016-2017	2019-2020
Cultivar/rootstock:	'Red Aroma' /M.9	'Summerred' / M.9
Planting distance:	3.5 x 1.0 m (2857 trees/ha)	4.5 x 2.0 m (1111 trees/ha)
Year of planting:	2003	2009
Soil type:	Silty medium sand	Silty light clay
Harvest date:	September 21, 2016	September 6, 2019

Trial Ullensvang

Year:	2019-2020
Farm:	NIBIO, Kvitavoll
Cultivar/rootstock:	'Summerred'/M.9
Planting distance:	4.0 x 1.0 m (2500 trees/ha)

Planting date:	May-2012
Soil type:	Sandy soil
Harvest dates:	Oct 10, 2016; Oct 16, 2017

2.3 Results and discussion

Shoot growth in 'Red Aroma' apple trees in the orchard in Lier was significantly reduced by a single application of 2.5 kg/ha Regalis (Figure 2). At 1.25 kg/ha a trend in reduction of shoot growth was already visible. However, due to the large variation in shoot growth this reduction was not statistically significant. Two successive applications of 1.25 kg/ha with an interval of 33 days resulted in a similar significant reduction in shoot growth as the single application of 2.5 kg/ha.

Despite the strong reduction in shoot growth by the two highest doses of Regalis no statistically significant effects were observed on the number of fruits and yield per tree and the average fruit weight (Table 1). Fruit skin colour, firmness, contents of sugars, acids and starch were also not affected by any of the Regalis treatments (Table 2).

No carry-over effects of the Regalis treatments in 2016 were observed on the flowering and shoot growth of the trees in 2017. Shoot growth in 2017 was similar for all the trees, independent of the Regalis treatment in 2016 and was equal to that of the untreated control trees in 2016 (Figure 3). Bloom in 2017 was similar for all trees, independent of the amount of Regalis applied in 2016 and was on average 66% less than the previous year (Figure 4).

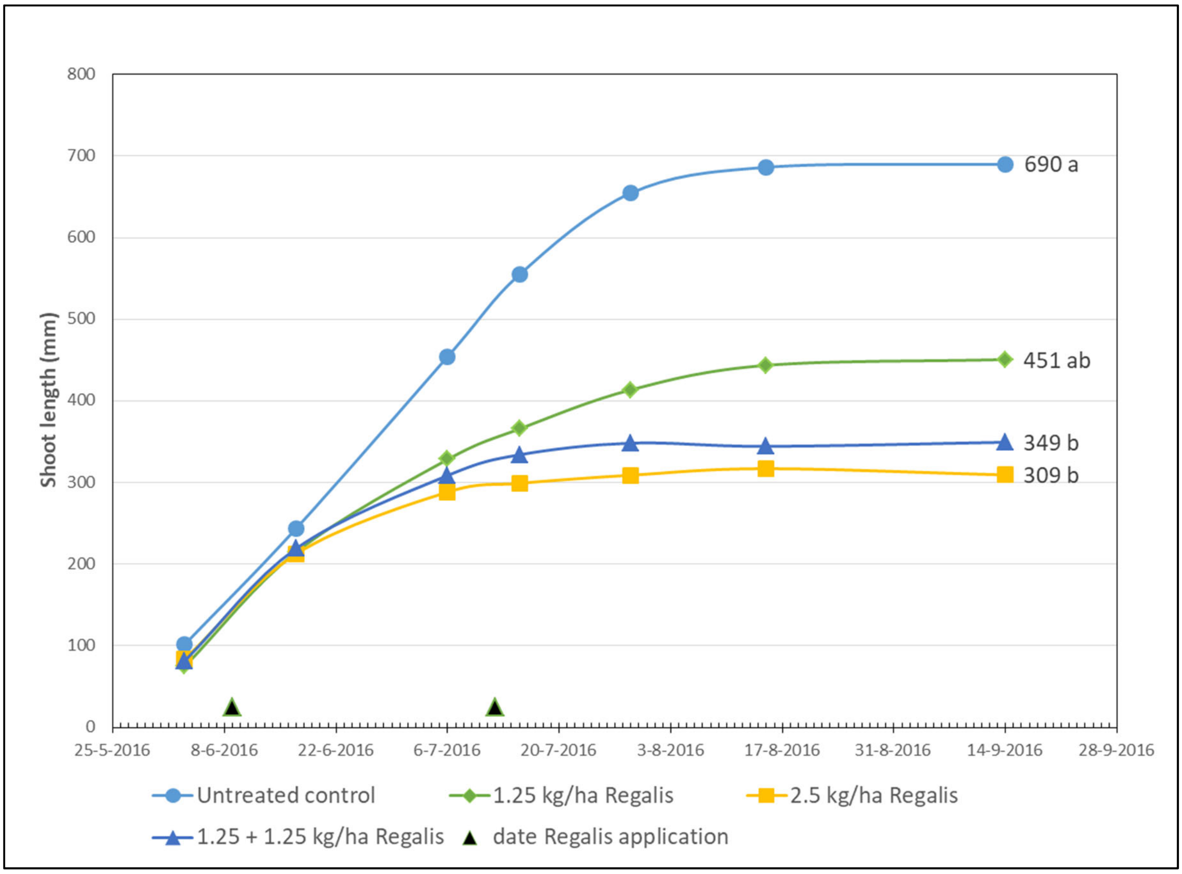

Figure 2. Shoot length development in 'Red Aroma' apple trees in Lier in 2016 after a single or twofold application of Regalis. The data represent the means of 5 marked shoots per tree on three trees per treatments.

Table 1. Harvest data 'Red Aroma' trees treated with Regalis in Lier in 2016

Treatment	Fruits/tree	Kg/tree	g/fruit	Kg < 60 mm	%kg < 60 mm
Untreated	249	44.2	183	0.6	1.4
1.25 kg/ha	161	32.6	202	0.2	0.5
2.5 kg/ha	177	31.1	179	0.7	2.4
2x 1.25 kg/ha	206	37.0	187	0.1	0.3
F-test	NS	NS	NS	NS	NS

Table 2. Fruit quality data 'Red Aroma' apples of trees treated with Regalis in Lier in 2016.

Treatment	Ground colour	Blush colour	Firmness (kg)	Sugars (°Brix)	Acids (%)	Starch index
Untreated	5.3	7.5	5.9	10.4	0.74	8.6
1.25 kg/ha	5.2	7.3	5.9	10.6	0.77	9.1
2.5 kg/ha	5.2	7.5	6.0	10.7	0.75	8.8
2x 1.25 kg/ha	5.0	6.6	5.6	10.9	0.76	9.6
F-test	NS	NS	NS	NS	NS	NS

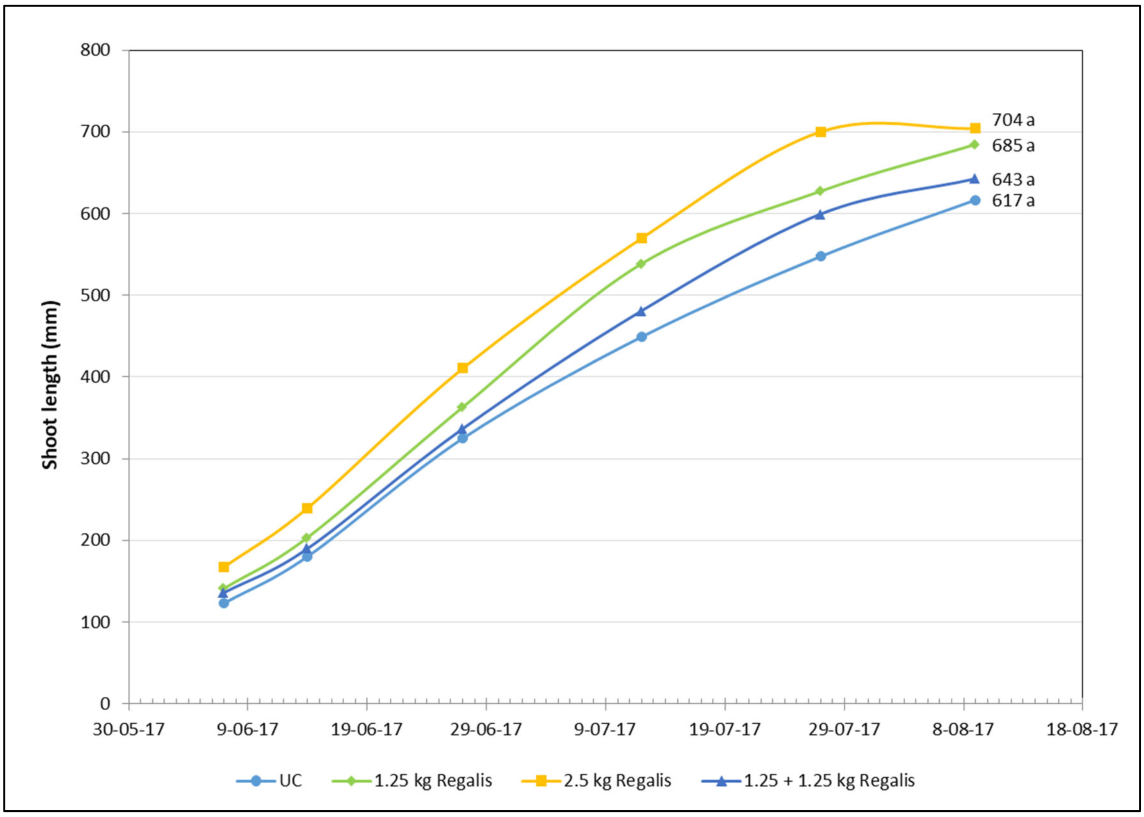

Figure 3. Shoot growth of 'Red Aroma' trees in 2017, the year following year of the application of Regalis. The data represent the means of 5 marked shoots per tree on three trees per treatments.

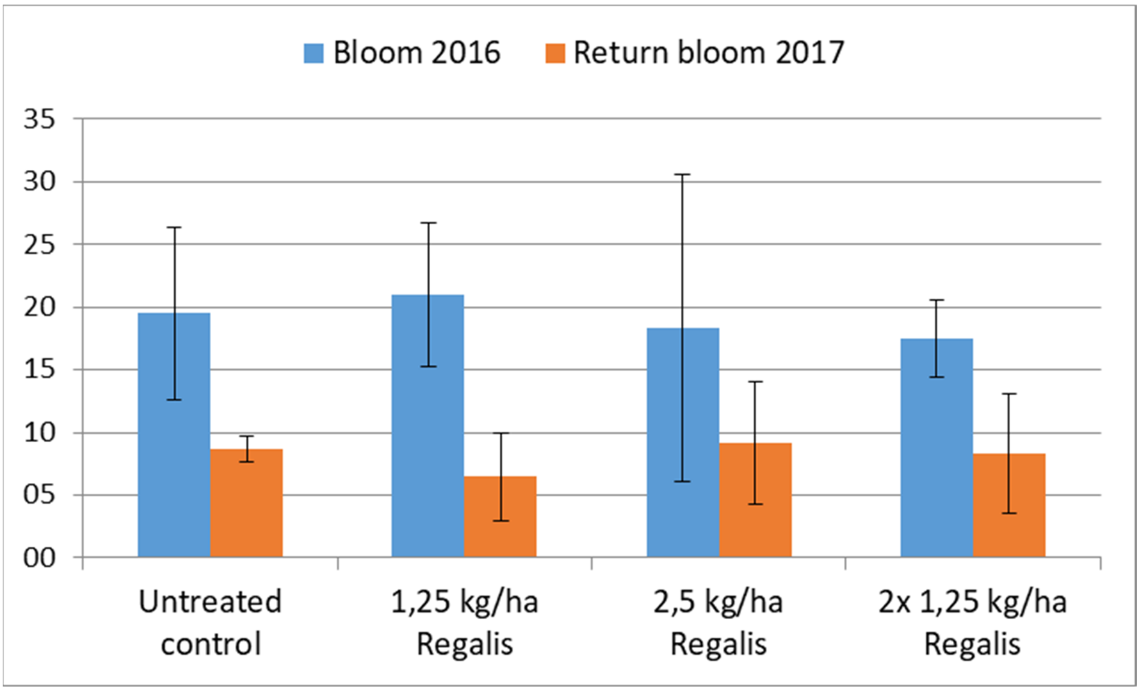

Figure 4. Bloom of 'Red Aroma' trees treated with Regalis in 2016 and return bloom in 2017. Data represent the means and standard deviation of flowers clusters counted on two marked branches per tree and three replicates per treatment ± standard deviation.

Table 3. Carry-over effect of Regalis application in 2016 on fruit production of Red Aroma in 2017.

Treatment	kg/tree	fruits/tree	g/fruit	%kg >60 mm
Untreated	29.8	232	138	94.2
1.25 kg/ha	15.1	97	157	98.3
2.5 kg/ha	16.7	110	153	97.9
2x 1.25 kg/ha	20.5	141	152	95.8
F-test	NS	NS	NS	NS

Table 4. Carry-over effect of Regalis application in 2016 on fruit quality of Red Aroma in 2017.

Treatment	Ground colour	Blush colour	g/fruit	Soluble solids (°Brix)	Fruit firmness (kg/0,5 cm²)	Starch index
Untreated	6.0	5.9	166	11.4	6.4	9.4
1.25 kg/ha	5.1	3.8	174	11.7	6.5	8.6
2.5 kg/ha	5.7	5.0	174	12.0	6.7	8.2
2x 1.25 kg/ha	5.1	4.7	176	12.5	6.6	9.1
F-test	NS	NS	NS	NS	NS	NS

A second trial with Regalis was carried out in Lier in a 'Summerred'/M.9 orchard in 2019. Shoot extension growth decreased progressively with the amount of Regalis applied (Figure 5). At the lowest dosage of 0.62 kg/ha Regalis a clear trend of reduction in shoot extension growth was already noted but at the end of the growing season it did not result in statistically significant shorter shoots than those of the untreated control trees. A single application of 1.25 kg/ha and 2.5 kg/ha resulted in a similar significant reduction in shoot length compared to untreated controls. The strongest reduction in shoot length was observed in trees that received two applications of 1.25 kg/ha Regalis (Figure 5). The final average shoot lengths at the end of the growing season in 2019 were reduced by about 20%, 40% and 60% for trees treated with respectively 0.62, 1.25 or 2.5, and two times 1.25 kg/ha Regalis.

Fuits set, yield and fruit weight of Summerred was not affected by any of the Regalis treatments (Table 5). On avereage the trees produced 270 fruits per tree with an average fruit weight of 120 g and a total yield of 31.2 kg per tree. The percentage of the yield per tree consisting of fruits with a diameter above 60 mm was also not significantly different between the treatments and was 85.5%.

The measured fruit quality parameters skin colour, firmness, contents of sugars, acids, starch and number of seeds were not significantly affected by any of the Regalis treatments (Table 6).

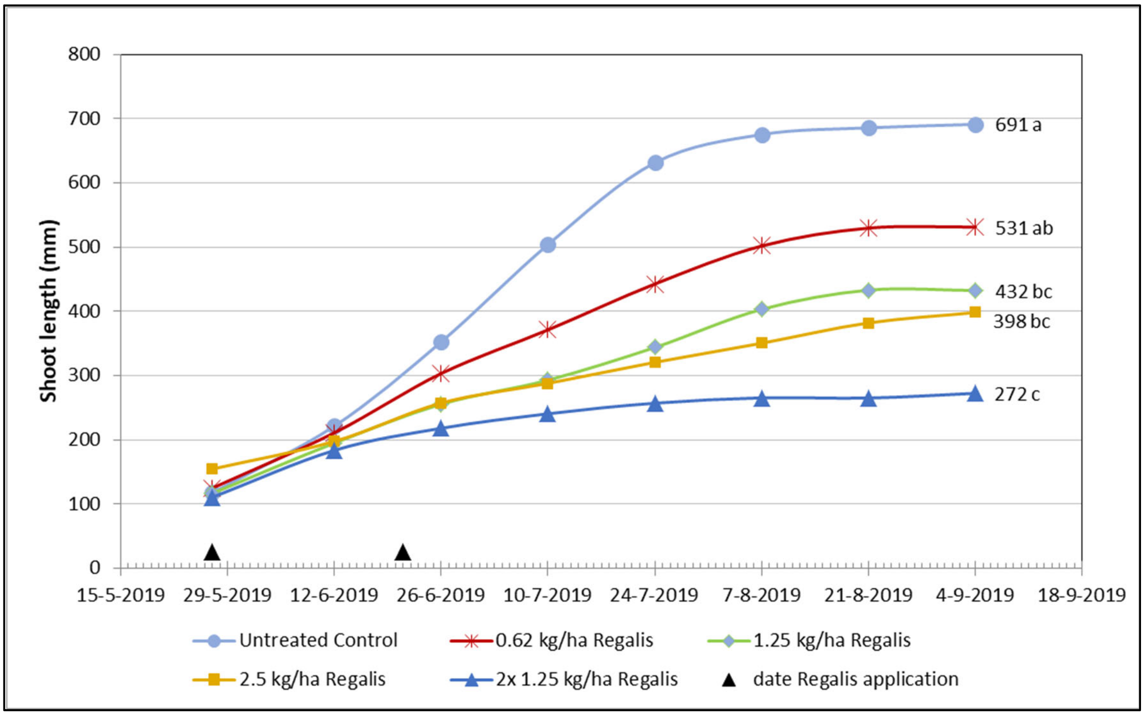

Figure 5. Shoot length development in 'Summerred' apple trees in Lier in 2019 a single or twofold application of Regalis.

Table 5. Harvest data 'Summerred' trees treated with Regalis in Lier in 2019.

Treatment	Flower clusters/ tree 2019	Fruit set[1] (%)	Fruits/ tree	g/fruit	Yield (kg/tree)	%kg >60 mm	Return bloom 2020 (%)
Untreated	79	368	268	121	31.2	88	420
0.62 kg/ha	79	234	234	127	28.0	93	424
1.25 kg/ha	80	290	290	122	34.7	87	483
2.5 kg/ha	79	279	279	115	30.8	79	548
2x 1.25 kg/ha	81	279	279	116	31.1	82	345
F-test	NS	NS	NS	NS	NS	NS	NS

[1]number of fruits per 100 flower clusters

Table 6. Fruit quality data 'Red Aroma' apples of trees treated with Regalis in Lier in 2019.

Treatment	Ground colour	Blush colour	Firmness (kg)	Sugars (°Brix)	Acids (%)	Starch index
Untreated	4.9	5.6	5.8	10.2	0.75	9.0
0.62 kg/ha	5.4	6.0	6.1	10.4	0.72	8.5
1.25 kg/ha	5.3	5.8	5.6	10.0	0.69	9.4
2.5 kg/ha	4.7	5.8	5.9	10.2	0.72	9.2
2x 1.25 kg/ha	5.2	5.8	5.4	9.9	0.69	9.5
F-test	NS	NS	NS	NS	NS	NS

In the year Regalis was applied evenly flowering trees were selected for the trial. On average the trees had 80 flower clusters each in spring 2019. In the year after the Regalis treatment return bloom in the trees used in the experiments was about 3.8 times higher. Return bloom in 2020 varied between 240 and 370 flower clusters per tree for the different Regalis treatments. However, these differences in mean numbers return bloom were not statistically significant due to the large variation of about 80 flower clusters per tree between the five observation trees in each treatment (Figure 6).

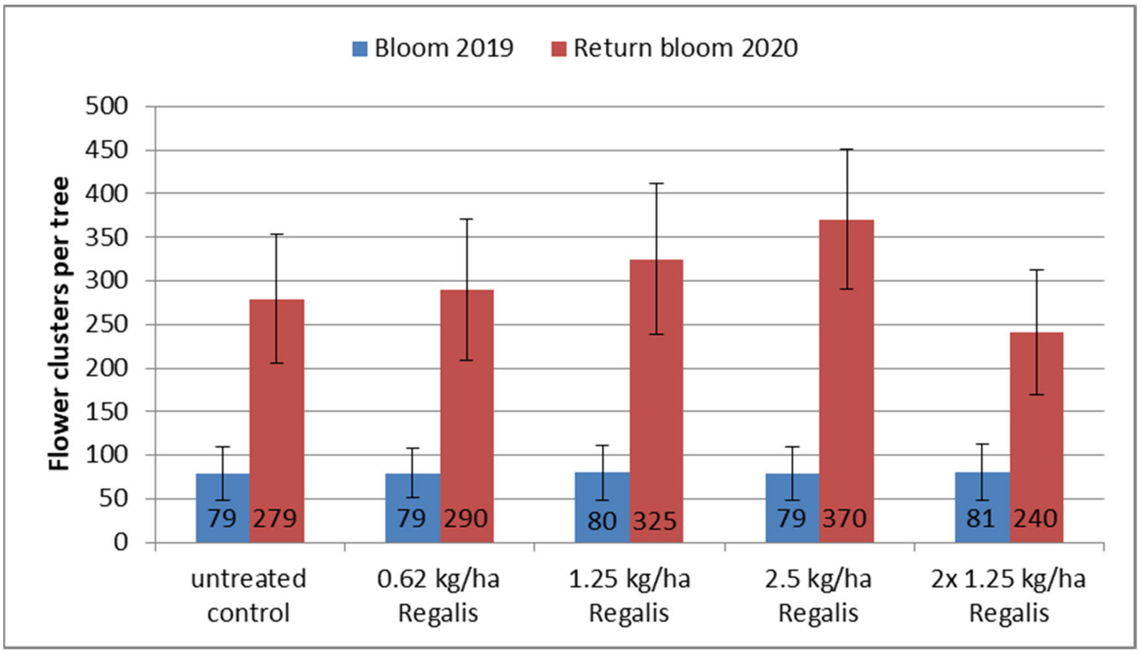

Figure 6. Bloom and return bloom of 'Summerred' trees in Lier treated with Regalis in 2019.

In Ullensvang the use of Regalis to control shoot growth in 'Summerred'/M.9 trees was studied in a 7-year old orchard at a research field of NIBIO-Ullensvang. Tree rows were planted on a 20-degree slope from the lower side of the fjord upward in the direction of the mountains. Shoot length development of the 'Summerred' trees is shown in figure 7. Compared to the growth of the shoots of the 'Summerred' trees in Lier, the elongation of the shoots in Ullensvang was very limited. In Lier the average length of the shoots at the end of the growing season was almost 70 cm (Figure 5), whereas in Ullensvang it only reached 17 cm (Figure 7). Although the shoot length development in 2019 shows a distinct trend of being reduced by the highest dosages of Regalis (Figure 7), the variation in shoot length was too high to obtain a statistically significant difference in shoot length at the end of the growing season. Given that shoot growth was already very low in the untreated control trees, inhibition of shoot growth of the trees in this orchard had also not been necessary. The low fertility of the sandy rocky soil of this field in combination with the crop level on the weak growing and still very slender trees in this orchard (Figure 8) already prevented excessive shoot growth in the trees, even in a year with a low crop due to a very low number of flower clusters per tree in spring 2019 (Table 7.)

The harvest data presented in table 7 show a trend of higher numbers of fruits and yield per tree with increasing dosages of Regalis with a statistically significant higher yield for trees treated with a 1.25, 2.5 and two times 1.25 kg/ha Regalis. As the fruit set was not affected by any of these Regalis treatment, these higher yields are most likely the result of the higher number of flower clusters in trees used for these Regalis treatments.

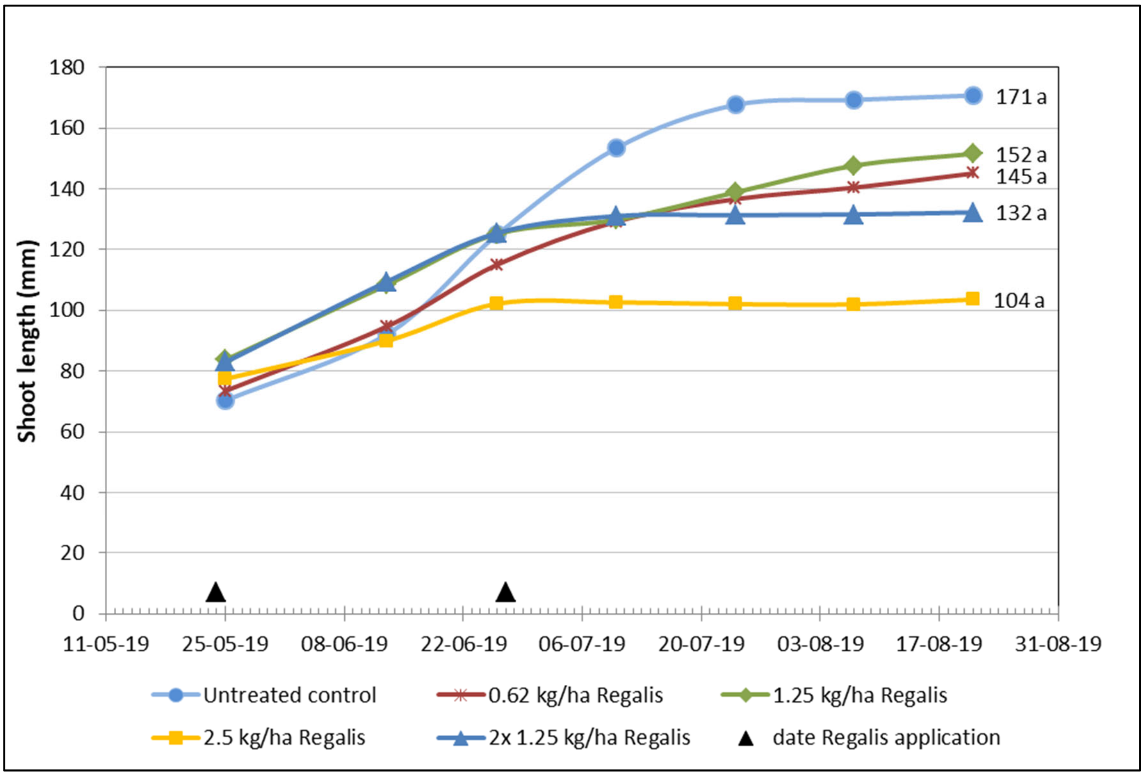

Figure 7. Shoot growth in 'Summerred' trees in treated with Regalis in Ullensvang in 2019.

Figure 8. 'Summerred'/M.9 orchard planted in 2012 in Lofthus, Ullensvang during bloom in 2018 and 2019. (photos: Frank Maas).

Table 7. Results Regalis treatments on shoot growth and yield of 'Summerred' in Ullensvang in 2019.

Treatment	Flower clusters/tree	Fruit set (%)	Fruits/tree	Kg/tree	g/fruit	%kg > 60 mm
Untreated	22.6 e	110	24.8 b	4.5 c	181	99.7
0.62 kg/ha	26.8 d	107	28.8 ab	5.0 bc	174	97.4
1.25 kg/ha	30.0 c	111	33.4 ab	6.6 ab	200	98.7
2.5 kg/ha	33.8 b	106	35.8 ab	5.4 ab	154	97.0
2x 1.25 kg/ha	38.2 a	105	40.2 a	7.0 a	174	98.9
F-test	P<0.001	NS	p=0.010	p=0.003	NS	NS

Table 8. Fruit quality data 'Summerred' apples of trees treated with Regalis in Ullensvang in 2019.

Treatment	Ground colour	Blush colour	Firmness (kg)	Soluble solids (°Brix)	Acids (%)	Starch index	# seeds per fruit	seed weight (g)
Untreated	4.8	6.2	8.8	13.4	1.2	5.2	3.2	0.23
0.62 kg/ha	4.3	6.5	8.6	12.7	1.2	5.2	3.4	0.24
1.25 kg/ha	4.5	6.3	8.7	13.1	1.2	5.0	3.3	0.22
2.5 kg/ha	4.8	6.9	8.1	12.6	1.1	7.2	3.1	0.17
2x 1.25 kg/ha	4.3	6.2	8.7	12.9	1.2	5.7	3.0	0.22
F-test	NS	NS	NS	NS	NS	P<0.05	NS	NS

Several studies have shown an increase in the final number of fruits per tree at harvest in trees treated with Regalis (Costa et al. 2004; Rademacher et al. 2004; Vercammen et al. 2016; Zadravec et al. 2008). This increase was not caused by a higher initial fruit set but by the reduction in the number of fruits lost during the June drop. In some cases such an increase in crop load reduced average fruit weight. Effects on yield and fruit quality were absent or only very small in most of the trials carried out in other countries.

Rademacher et al. (2004) observed a reduction in return bloom in pear trees treated with a dosage above 4 kg/ha. However, at the maximum dosage of 2,5 kg/ha used in this study no effect of Regalis on return bloom was observed in any of the apple cultivars used in the trials in Lier and Ullensvang.

The main advantage of the use of Regalis reported in literature is reduced need for summer pruning and the amount of pruning needed in winter. Multi-year use of Regalis in a vigorous 'Elstar'/M.9 orchards resulted in a more stable fruit production (Lafer, 2003; Lafer and Schröder, 2003).

2.4 Root pruning

Root pruning is a non-chemical cultivation technique to reduce shoot growth in fruit trees. At the end of the 20th century fruit growers were no longer allowed to use the chemical growth regulators Alar and Chloromequat (CCC) to control shoot growth in apple and pear trees in most European countries. As the currently registered chemical regulator Regalis was not yet registered as an alternative chemical growth retardant, growers had to find other methods to reduce shoot growth and increase fruit production of too vigorously growing fruit trees. Root pruning and making incisions in the trunk of the trees were examined as alternative methods to control shoot growth in vigorous orchards (Maas, 2008). Excessive shoot growth usually occurs in orchards in fertile soils in years with a very low crop load. A very low number of fruits per tree may be the result of too low number of flower clusters or by a very low fruit set, often caused by adverse weather conditions during bloom. In The Netherlands and many other fruit growing countries where orchards are planted in fertile soils without too many large stones or rocks, root pruning has become a standard cultivation practice to control shoot growth when excessive shoot growth is expected to occur.

At first, root pruning was done with a fixed vertical knife mounted on a tractor (Figure 9). This knife had to be pushed into the soil at the start of driving into a row of trees. To get better control on which trees to root prune and also to be able to not only cut roots next to the tree rows but also partially under the trees, a root pruning device was developed which can be pushed into the soil hydraulically at a variable angle and lifted during driving (Figure 9). This makes it possible to selectively prune the roots of only those trees in a row that need it and to lift the knife to avoid root pruning of the weaker trees while driving. All together these options give a fruit grower the choice to adjust the level of root pruning by selecting the distance of pruning from the tree trunk, pruning the roots at one or two sides of the tree, partially undercutting the root system and avoiding root pruning of weaker growing trees within a tree row. Another critical factor that needs to be taken into account is the time of year to apply the root pruning to get the best results.

In the project 'PresiEple' root pruning has been studied as a non-chemical method for the control of shoot growth in apple trees.

2.4.1 Design and implementation of root pruning trials

The root pruning trials were carried out in orchards at two locations in Norway. Root pruning was carried out with a vertical 40 cm long knife.

Treatments

1. Untreated control
2. One-sided early root pruning 3-4 weeks before bloom, vertical knife, 30 cm from trunk
3. One-sided late root pruning middle of June, vertical knife, 30 cm from trunk
4. Two-sided root pruning, one side 3-4 weeks before bloom, vertical knife, 30 cm from trunk, other side middle of June, vertical knife, 30 cm from trunk

Figure 9. Root pruning devices with vertical knife (left) and hydrolic slant knife (right) mounted on back side of tractor (photos: F. Maas and M. Meland).

2.4.2 Results and discussion root pruning trials

The first root pruning trial in Lier was carried out in a 6-year old 'Summerred'/M.9 orchard. The dates of the treatments were April 29 for the early root pruning and July 5 for the late root pruning. For the two-sided root pruning one side of the tree row was pruned early and the other side of the tree row late. The orchard was covered by a crystal-coloured anti-hail net after flowering.

The trees of the orchard used for this trial showed a large variation in the number of flower clusters per tree, as it was the expectation that this would also give a large variation in the number of fruits per tree. Generally, crop load normally has a strong effect on shoot growth. Therefore, two groups of trees were selected for each root pruning trial, trees with a low number of flower clusters and trees with a normal number of flower clusters.

In 2016 the longest shoots developed on the untreated control trees with the low crop load. They reached an average length of about 40 cm at the end of the growing season (Figure 10C). With a normal crop the final length of shoots of the untreated control trees was 31 cm (Figure 10A). One-sided root pruning significantly reduced the elongation growth of the shoots and resulted in significantly shorter shoots at the end of the growing season at both crop levels. Although the final shoot lengths were not statistically different between the two one-sided root pruning treatments, the shoot elongation curves in figure 10 show a clear trend of a stronger reduction by the early root pruning on April 29 than the late root pruning on July 5. This was most evident in the trees with the low crop in 2016 (Figure 10C), giving circa 60% and 40% reduction in shoot length, respectively, compared to the untreated control trees. Surprisingly, root pruning in April reduced shoot growth more in trees with a low crop load than in trees with a normal crop load. A possible explanation might be that at the low crop load the trees invested a larger proportion of their assimilates into the development of new roots at the expense of shoot growth. The two-sided root pruning resulted in the strongest reduction of shoot growth and resulted in final shoot length to about 10 cm at both crop load levels (Figure 10AC).

In 2017, the year after the root pruning treatments, shoot growth of the untreated trees was less than in 2016 (Figure 9BD). Although the trees with a normal crop level in 2016 had a low crop level in 2017 (Tabel 9), they still developed shorter shoots at all root pruning treatments than the trees that had a low crop in 2016 and a normal crop in 2017, as is shown in figures 10AB and 10CD, respectively. Possibly, trees with a low crop level developed a stronger root system and stored more reserves in their trunks than trees with a normal crop load resulting in a stronger vigour of the trees in the next season.

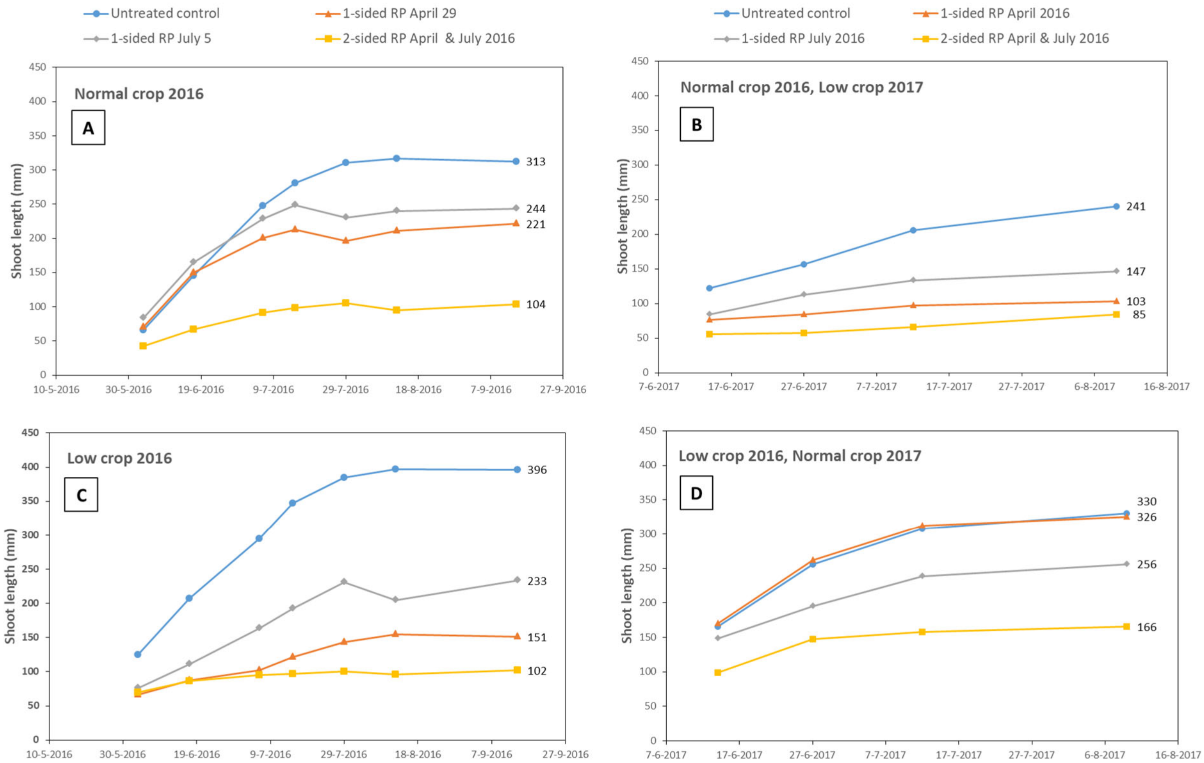

Figure 10. Effect of root pruning of Summerred trees in Lier with a normal crop and low crop load in 2016 on shoot growth in 2016 (A, C) and 2017 (B, D). RP = root pruning.

The harvest data of the trees are presented in table 9 and illustrate a clear alternate bearing pattern of the 'Summerred' trees. The trees with few flower clusters in 2016, the so called 'off-year' trees, produced the lowest crop with the higest fruit weight in 2016. In the following year 2017 the same trees were in an 'on year' and had the highest number of flower clusters and the largest yield. Due to the higher number of fruits per tree the average fruit weight in the on-year was less than in the off -year. The opposite results were observed for the on-year trees at the beginning of the trial in 2016. No significant effects of the root pruning treatments were observed on the number of fruits, yield, average fruit weight and the percentage of the yield made up of fruits larger than 60 mm (Table 9).

In summary, root pruning is a useful practical method to reduce shoot growth and to prevent vigorous growth in apple trees. It can be applied in years with expected excessive shoot growth in trees with low fruit numbers, either resulting from poor flower bud development in the previous year or by a low fruit set due to poor weather conditions during bloom. Root pruning can be used as an alternative to chemical growth control by Regalis. However, root pruning requires a soil without rocksand the possibility to irrigate the orchard in dry periods following the root pruning to avoid a reduction in fruit size and yield due to a diminished water uptake capacity by the reduced root volume of the root-pruned trees.

Table 9. Results root pruning treatments 2016 on yield of 'Summary' trees in Lier in 2016 and 2017.

Treatment	Flc/tree		Fruits/tree		Kg/tree		g/fruit		%kg >60 mm	
Off-year 2016	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Untreated	10 b	341 a	16 bc	240	3.1 b	27.1 a	201 a	116 abc	98	89 a
RP 1 side April 29	20 b	411 a	42 abc	277	7.4 ab	28.7 a	156 abc	105 bc	94	83 ab
RP 1 side July 5	11 b	358 a	11 c	265	2.7 b	27.0 a	200 a	102 bc	100	85 ab
RP 2 sides[2]	7 b	365 a	6 c	263	1.0 b	24.1 ab	165 ab	92 c	96	69 b
On-year 2016										
Untreated	237 a	42 b	134 a	78 c	17.3 a	10.7 c	131 bc	143	95	98 a
RP 1 side April 29	266 a	23 b	137 a	63 c	16.3 a	8.6 c	119 bc	138	89	96 a
RP 1 side July 5	199 a	88 b	124 a	103 bc	15.6 a	12.3 bc	139 bc	135	94	93 a
RP 2 sides[2]	209 a	92 b	112 ab	93 c	12.3 ab	9.7 c	111 c	122	87	89 a
F-test	***	***	***	***	***	***	***	***	NS	***

[1]RP 1 side = root pruning 1 side tree row on April 29, 2016. RP 2 sides = 1 side tree row on April 29, 2016 and the other side of tree row on July 5, 2016. Values within each column that do not share a letter are significantly different at P<0.001.

2.5 Chemical thinning

Crop load regulation in high-density apple orchards is a prerequisite to obtain regular large yields of good quality apples that meet retailer and consumer demands. Excess fruit set often results in large crops but at the expenses of reduced fruit size, sugar content and blush colour development. Also, too many fruits will strongly inhibit flower bud development, thus inducing an alternate bearing cycle with a large crop one year and a small crop the year after. A limited number of flowers on the other hand may cause fruits to become larger than the commercial standard and result in excessive shoot growth.

Inhibition of fruit set and stimulation of fruit drop by chemical products, so-called flower and fruitlet thinning compounds, are widely used in integrated fruit production. The most commonly used products for flower thinning are ATS (Costa et al., 2004; Maas, 2016) and ethephon (Meland and Kaiser, 2011). Their mode of action is to prevent fertilization of the flower by desiccation and accelerating ovule degeneration, respectively. In both cases the pollen tube will not reach the ovule during the period it is receptive to fertilization. Once fruit set has occurred, ethephon, naphthalene acetic acid (NAA) and 6-benzyladenine (6-BA) are the main thinning agents being used by growers wordwide to reduce the number of fruits on the tree (Fallahi et al., 2014). All these products are plant bio-regulators that each, in their own way, induces the abortion of the weakest growing fruitlets in the flower clusters. Most growers prefer the use of the fruitlet thinning compounds to avoid the risk of a too low fruit set. Unfortunately, the efficacy of the ethephon, NAA and 6-BA strongly depends on environmental factors like temperature, solar radiation and biological factors like vigour and available carbon reserves in the tree. E.g. it has been shown that temperatures of at least 18°C and enough shoot growth on the tree are required to obtain a good thinning efficacy of 6-BA. Weak growing trees or drooping branches often do not show any thinning response to a 6-BA treatment (Maas, 2006). This makes 6-BA an unreliable thinning compound in countries with lower temperatures and less solar radiation.

During the last few years, fruit thinning research has been focused on the use of the photosynthetic inhibitor metamitron. Köpcke (2005) showed the good thinning efficacy of metamitron in 'Elstar' apples grown in northern Germany. In cooperation with the chemical company Makhteshim-Agan (now ADAMA), the compound Brevis®, with metamitron as the active ingredient, was tested in many European countries by researchers of the EUFRIN Thinning Working Group. Generally the thinning efficacy of Brevis® was good in most apple and pear cultivars tested (Basak, 2011; Brunner, 2015; Clever, 2007; Köpcke, 2005; Kuster and Schweizer, 2015; Maas and Meland, 2016; Maas and van der Steeg, 2011; Stern, 2014, 2015; Widmer et al., 2013). Brevis® also seemed to thin more reliable than 6-BA at temperatures below 18°C. The aim of this study was to quantify the effect of metamitron as a fruit thinning agent by testing it at two rates and two application times on apple tree cultivars grown in the cool, nordic climate in the fruit growing regions of Ullensvang and Lier in Norway.

2.5.1 Design and implemenation of chemical thinning trials

Chemical thinning trials were carried out in orchards in the fruit growing regions Ullensvang and Lier. Trees with equal numbers of flower clusters per tree were selected at the start of each trial. The general trial layout was a randomized block design of 4 replicated treatments with 2 to 4 trees per plot.

Treatments:

1. Untreated control
2. Hand thinning after June drop
3. 1.1 kg/ha Brevis (165 mg/L metamitron) at 8-10 mm
4. 2.2 kg/ha Brevis Brevis (330 mg/L metamitron) at 8-10 mm
5. 1.1 kg/ha Brevis Brevis (165 mg/L metamitron) at 8-10 mm and 12-14 mm
6. 2.2 kg/ha Brevis Brevis (330 mg/L metamitron) at 8-10 mm and 12-14 mm
7. 0.5 L/ha Cerone (240 mg/L ethephon) at full bloom (May 12, 2016)
8. 15 kg/ha ATS (ammonium thiosulphate) at full bloom (May 12, 2016)

THINNING TRIAL 'SUMMERRED' ULLENSVANG 2016

In 2016 a thinning trial was carried out in a 'Summerred'/M.9 orchard planted in 2012 in a field of NIBIO-Ullensvang. The crab apple cultivars 'Dolgo' and 'Red Everest' were planted as pollenizers alternately 10 m apart in the rows and cross wise between rows. The trees selected for the trial had on average 94 flower clusters in spring 2016 (Table 10). The average production of the untreated control trees produced was 90 fruits and 13.6 kg per tree of apples with a mean fruit weight of 151 g. About 68 of the yield consisted of marketable fruits with a diameter of more than 60 mm. The need for thinning in 2016 proved to be quite low. In the hand-thinning treatment only a few fruits per tree were manually removed to obtain a crop load of 85 apples per tree. This resulted in a yield of 12.9 kg per tree and a slightly higher mean fruit weight of 170 g. None of the applications of the chemical thinning agents resulted in a significant decrease in fruit set and yield of the trees. The strongest response to the thinning treatments was observed on the percentage return bloom in spring 2017. Compared to 35% return bloom in the untreated control trees, hand thinning and the application of ATS at bloom were the only treatments resulting in a higher level of return bloom of 65%. Thus, in all treatments the number of flower clusters per tree was less in the year the thinning agents were applied. However, this does not imply that a more thinning was required in 2016. If the target crop load of the 'Summerred' trees is 90 fruits per tree it is possible to obtain this number of fruits in trees having only 33 flower clusters per tree (35% of 94 flower clusters in 2016), but only if fruit set is excellent and all flower clusters produce 3 fruits per cluster. At a return bloom of 65% (ca. 58 flower clusters per tree) it will be more realistic to achieve the crop load of 90 fruits per tree as it requires a lower fruit set of about 1.5 fruits per flower cluster. A good thinning strategy aims to obtain a regular flowering and fruit set from year to year and to avoid the start of an alternate bearing cycle due to either a much too low or too high crop load on the trees.

Fruit skin colour and sugar content are fruit quality parameters that are strongly affected by crop load level in most apple cultivars. Apart from a reduction in fruit size a too high crop load may result in poor blush colour development and lower sugar content. None of the fruit quality parameters determined for the fruits of the different thinning treatments showed a significant difference to those of the untreated control trees (Table 10). This is in line with expectations given the lack of a difference in crop load between all treatments.

Table 10. Results thinning treatments on fruit set, yield and return bloom of 'Summerred' trees in Ullensvang, Norway.

Treatment	Flower clusters 2016	Fruit set[1,2]	Fruits/ tree	Yield (kg/tree)	Fruit weight (g)	%kg >60 mm	Return bloom 2017 (%)[3]
1. Untreated control	94	108	90	13.6	151	68.6	35 ab
2. Hand thinning	88	97	85	12.9	170	63.0	64 a
3. 1.1 kg/ha Brevis	104	110	113	15.5	138	60.3	24 ab
4. 2.2 kg/ha Brevis	93	124	118	15.1	127	56.7	17 b
5. 2x 1.1 kg/ha Brevis	100	101	100	14.3	145	61.5	9 b
6. 2x 2.2 kg/ha Brevis	99	100	95	13.0	137	63.2	35 ab
7. 0.5 L/ha Cerone	89	110	97	14.3	156	51.1	16 b
8. 15 kg/ha ATS	94	121	109	14.2	137	60.5	65 a
F-test	NS	NS	NS	NS	NS	NS	P<0.001

[1]No. of harvested fruits per 100 flower clusters; [2]NS = not significant. Values within a column that do no share a letter are significantly different; [3] No. of flower clusters per tree in 2016 in percentage of previous year.

Table 11. Results thinning treatments on fruit fruit quality parameters of 'Summerred' trees in Ullensvang, Norway in 2016.

Treatment	Ground colour	Blush colour	Firmness (kg)	No. seeds	Sugar	Acids (%)	Starch index
1. Untreated control	4.5	6.6	5.9	3.9	9.7	0.68	9.8
2. Hand thinning	5.0	7.6	6.4	4.2	10.8	0.81	9.4
3. 1.1 kg/ha Brevis	4.7	7.5	5.8	4.5	9.5	0.69	10.0
4. 2.2 kg/ha Brevis	4.7	7.4	5.9	4.4	10.4	0.72	9.8
5. 2x 1.1 kg/ha Brevis	4.7	7.4	5.9	4.8	10.0	0.67	10.0
6. 2x 2.2 kg/ha Brevis	4.7	7.1	5.7	5.0	10.0	0.70	10.0
7. 0.5 L/ha Cerone	4.6	7.6	6.0	4.0	10.2	0.74	9.7
8. 15 kg/ha ATS	4.9	7.4	6.1	4.1	11.0	0.78	9.6
F-test	NS	NS	NS	NS	NS	NS	NS

THINNING TRIAL 'SUMMERRED' LIER 2016

Without any thinning treatment the 'Summerred' trees in the orchard in Lier produced almost 200 fruits and 26 kg per tree. The mean fruit weight of the apples was 137 g and 98% of the yield had a marketable size of more than 60 mm (Table 12). In the hand thinning treatment crop load was reduced to about 100 fruits per tree after June drop. This reduced the yield to 16.8 kg per tree, increased average fruit weight to 158 g and all fruits reached a diameter of more than 60 mm. The chemical thinning treatments that gave a very good thinning equivalent or closely similar to the target crop load achieved by hand thinning were a single application of 15 kg/ha ATS during bloom or a single application of 1.1 or 2.2 kg/ha Brevis when the fruitlets had reached a size of 8-10 mm. A too strong thinning was observed in trees treated with Cerone at full bloom or after two applications of 1.1 or 2.2 kg/ha Brevis. Return bloom in 2017 showed very erratic results which were not in agreement with those normally observed in thinning trials. Generally, too high crop loads inhibit flower bud development and strongly reduces flowering the following season. Hand thinning carried out after June drop normally has a positive effect on fruit size but is done too late to stimulate flower bud development. The earlier the target number of fruits per tree is achieved, the stronger the stimulation of flower bud development and bloom in the next season. Thus, preventing fruit set during bloom normally gives both larger fruits and a higher return bloom than chemical fruitlet thinning of fruitlets four to five weeks after full bloom.

Table 12. Results thinning treatments in 2016 on fruit set, yield and return bloom of 'Summerred' trees in Lier, Norway.

Treatment	Flower clusters 2016	Fruit set[1,2]	No. Fruits	Yield (kg)	Fruit weight (g)	%kg >60 mm	Flower clusters 2017
1. Untreated control	135	153 a	194 a	25.8 a	137	98	108
2. Hand thinning	159	71 ab	107 ab	16.8 ab	158	100	89
3. 1.1 kg/ha Brevis	114	106 ab	110 ab	14.8 ab	144	96	225
4. 2.2 kg/ha Brevis	180	67 b	112 ab	17.9 ab	166	99	72
5. 2x 1.1 kg/ha Brevis	98	81 ab	40 b	6.5 b	175	100	142
6. 2x 2.2 kg/ha Brevis	146	46 b	63 b	9.2 b	150	99	160
7. 0.5 L/ha Cerone	92	44 b	47 b	8.1 b	199	100	267
8. 15 kg/ha ATS	124	114 ab	113 ab	17.3 ab	152	99	154
F-test	NS	P<0.01	P<0.05	P<0.05	NS	NS	NS

[1]No. of harvested fruits per 100 flower clusters; [2]NS = not significant. Values within a column that do no share a letter are significantly different; [3] No. of flower clusters per tree in 2016 in percentage of previous year.

Despite the differences in crop load and fruit size observed between the thinning treatments no significant effects were noted in any of the fruit quality parameters determined after harvest. The very high starch index values indicate that the fruits did almost not contain starch anymore and were harvested at a very mature stage.

Table 13. Results thinning treatments in 2016 on fruit fruit quality parameter ‘Summerred’ trees in Lier, Norway.

Treatment	Ground colour	Blush colour	Firmness (kg)	No. seeds	Sugars (°Brix)	Acids (%)	Starch index
1. Untreated control	5.3	6.4	4.2	3.7	10.7	0.72	9.7
2. Hand thinning	5.3	7.2	4.5	2.5	11.7	0.74	9.7
3. 1.1 kg/ha Brevis	5.3	7.0	4.4	2.5	11.5	0.76	9.6
4. 2.2 kg/ha Brevis	5.2	7.2	4.5	4.4	11.5	0.75	9.4
5. 2x 1.1 kg/ha Brevis	4.9	5.8	4.5	3.1	11.8	0.78	9.9
6. 2x 2.2 kg/ha Brevis	5.4	8.0	4.6	4.4	12.1	0.84	9.2
7. 0.5 L/ha Cerone	5.4	7.3	4.2	2.9	11.8	0.88	9.5
8. 15 kg/ha ATS	5.0	7.1	4.3	2.8	11.0	0.71	9.4
F-test	NS	NS	NS	NS	NS	NS	NS

THINNING TRIAL ‘SUMMERRED’ ULLENSVANG 2017

Thinning of the ‘Summerred’ trees in the orchard in Ullensvang was necessary in 2017. Without thinning the slender trees produced on average 146 fruits and 13.4 kg per tree, about 90 fruits more and twice the target levels of the hand thinning treatment (Figure 11, Table 14). Mean fruit weight at harvest was as low as 88 g and only 46% of the yield had a marketable size of more than 60 mm. Both thinning treatments applied during bloom with Cerone or ATS significantly reduced crop load by 45% to about 80 fruits per tree. However, this degree of thinning was not sufficient to bring about a large increase in average fruit weight and percentage of fruits larger than 60 mm. Both thinning treatment did have a positive effect on return bloom. Compared to the untreated control trees return bloom was about 1.8 and 2.4 times higher in trees treated with ATS and Cerone, respectively. A single application of Brevis around the time the fruitlets had reached a diameter of around 10 mm resulted in a small reduction in the number of fruits and an increase in fruit weight, with the 2.2 kg/ha having a bit stronger effect than 1.1 kg/ha. However, the variation between the replicates in the trial was too high to make these differences statistically significant. A further visible trend is that the thinning efficacy of both these Brevis applications was slightly increased after a second application when fruitlets were about 12 mm in size. Fruit weight did not show any further increase after the two-fold applications of Brevis. Return bloom was increased after a single application of Brevis but reduced after a twofold application. In both cases the dosage of 2.2 kg/ha resulted in a lower return bloom than the 1.1 kg/ha.

Table 14. Results thinning treatments in 2017 on fruit set, yield and return bloom of 'Summerred' trees in Ullensvang, Norway.

Treatment	Flower clusters/tree 2017	Fruit set[1,2]	Fruits/ tree	Yield (kg/tree)	Fruit weight (g)	%kg >60 mm	Return bloom 2018 (%)[3]
1. Untreated control	92	179 a	154 a	13.4	88	46	39
2. Hand thinning	92	69 b	60 b	6.7	114	79	48
3. 1.1 kg/ha Brevis	92	147 ab	128 ab	11.7	93	47	78
4. 2.2 kg/ha Brevis	91	105 ab	98 ab	9.9	105	57	60
5. 2x 1.1 kg/ha Brevis	91	128 ab	110 ab	9.3	88	50	30
6. 2x 2.2 kg/ha Brevis	91	88 b	73 b	9.1	106	64	22
7. 0.5 L/ha Cerone	90	100 ab	88 ab	8.2	92	44	92
8. 15 kg/ha ATS	90	94 b	83 b	8.5	100	59	69
F-test	NS	P<0.05	P<0.01	NS	NS	NS	NS

[1]No. of harvested fruits per 100 flower clusters; [2]NS = not significant. Values within a column that do no share a letter are significantly different; [3] No. of flower clusters per tree in 2018 in percentage of previous year.

Figure 11. Crop loads of control 'Summerred' trees in thinning trial at Ullensvang in 2017. (photos: Frank Maas 18-09-2017).

Similar to the thinning trials with the same treatments carried out in 2016, no significant effects of the thinning treatments were observed on any of the fruit quality parameters determined in the harvested fruits (Table 15). From the high starch index values it can be concluded the fruits were harvested at an advanced ripening stage.

Table 15. Results thinning treatments in 2017 on fruit fruit quality parameter 'Summerred' trees in Ullensvang, Norway.

Treatment	Ground colour	Blush colour	Firmness (kg)	No. seeds	Sugars (°Brix)	Acids (%)	Starch index
1. Untreated control	5.4	6.6	8.1	2.8	10.1	0.74	9.3
2. Hand thinning	5.5	6.9	8.7	3.4	11.0	0.79	7.8
3. 1.1 kg/ha Brevis	5.5	7.1	8.1	3.1	10.4	0.77	9.3
4. 2.2 kg/ha Brevis	5.2	6.8	8.4	3.5	10.7	0.79	8.9
5. 2x 1.1 kg/ha Brevis	5.0	6.8	8.2	3.8	10.6	0.76	9.0
6. 2x 2.2 kg/ha Brevis	4.9	7.1	8.3	3.8	10.8	0.78	9.7
7. 0.5 L/ha Cerone	5.3	7.2	8.0	2.7	10.3	0.84	9.6
8. 15 kg/ha ATS	5.8	7.1	7.9	2.6	10.8	0.79	8.8
F-test	NS	NS	NS	NS	NS	NS	NS

THINNING TRIAL RUBINSTEP' ULLENSVANG 2018

Just like 'Summerred' trees 'Rubinstep' apple trees also require a regulation of crop load to avoid overcropping resulting in too small fruits and to obtain a regular annual production and prevent the start of an alternate bearing cycle. In 2018 the 'Rubinstep' trees selected for the trial had on average 134 flower clusters per tree (Table 18). Without any thinning treatment the trees produced 221 fruits and a yield of 19.1 kg per tree, about 70 fruits per tree more than the target fruit load of the hand thinned trees. As a consequence of this far too high crop load the fruit weight of untreated control trees was as low as 86 g and only 49% of the yield consisted of fruits with a diameter over 60 mm. In the hand thinned trees average fruit weight was 145 g and 97% of the yield were fruits having a diameter over 60 mm. Two applications of 2.2 kg/ha Brevis was the only chemical treatment that resulted in a significant reduction in fruit set. None of the thinning treatments significantly affected the yield of the trees. ATS applied at bloom was the only thinnning agent that significantly increase average fruit weight. Average values for return bloom were highest for flower thinning treatments ATS and Cerone and lowest for fruitlet thinner Brevis. However, the variation in return bloom treatments varied so widely between replicates that the average values in return did not statistically differ between treatments. Fruit quality parameters determined after harvest were very similar for all treatments, None of the thinning treatment caused a statistically significant change in any of the measured fruit quality parameters (Table 19).

Table 18. Results thinning treatments in 2018 on fruit set, yield and return bloom of 'Rubinstep' trees in Ullensvang, Norway.

Treatment	Flower clusters/tree 2018	Fruit set[1,2]	Fruits/ tree	Yield (kg/tree)	Fruit weight (g)	%kg >60 mm	Return bloom 2019 (%)[3]
1. Untreated control	134	164 a	221 a	19.1	86 c	49 c	50
2. Hand thinning	134	89 c	120 b	17.1	145 a	97 a	73
3. 1.1 kg/ha Brevis	133	187 a	253 a	22.5	86 c	53 bc	25
4. 2.2 kg/ha Brevis	133	178 ab	237 a	23.2	97 bc	71 abc	14
5. 2x 1.1 kg/ha Brevis	133	158 ab	210 ab	18.5	89 bc	55 bc	35
6. 2x 2.2 kg/ha Brevis	133	141 b	185 ab	17.3	93 bc	70 abc	18
7. 0.5 L/ha Cerone	134	192 a	258 a	26.3	101 bc	79 abc	105
8. 15 kg/ha ATS	135	157 ab	212 a	23.8	113 b	87 ab	122
F-test	NS	P=0.001	P=0.001	NS	P<0.001	P=0.002	NS

[1]No. of harvested fruits per 100 flower clusters; [2]NS = not significant. Values within a column that do no share a letter are significantly different. [3] No. of flower clusters per tree in 2019 in percentage of previous year.

Table 19. Effect thinning treatments in 2018 on fruit fruit quality parameter 'Rubinstep' trees in Ullensvang, Norway.

Treatment	Ground colour	Blush colour	Firmness (kg)	No. seeds	Sugars (°Brix)	Acids (%)	Starch index
1. Untreated control	4.3	4.2	9.3	12.96	10.4	0.94	7.3
2. Hand thinning	4.1	4.0	10.1	12.81	11.5	0.76	5.9
3. 1.1 kg/ha Brevis	4.0	3.6	9.3	13.98	10.4	0.48	7.0
4. 2.2 kg/ha Brevis	4.3	4.3	9.5	12.69	10.5	0.56	7.1
5. 2x 1.1 kg/ha Brevis	4.3	4.3	9.6	13.29	10.9	0.68	6.9
6. 2x 2.2 kg/ha Brevis	4.2	4.3	9.7	13.28	10.7	0.68	6.9
7. 0.5 L/ha Cerone	5.0	3.9	9.3	12.50	10.7	0.61	7.2
8. 15 kg/ha ATS	4.3	3.8	9.4	11.98	10.9	0.55	6.6
F-test	NS	NS	NS	NS	NS	NS	NS

THINNING TRIAL ‘RUBINSTEP’ ULLENSVANG 2019

In 2019 a second thinning trial with the same treatments as in 2018 was carried out on ‘Rubinstep’ apple but in another orchard. Without thinning the trees in this orchard produced 144 fruits and 12.3 kg per tree and the mean fruit weight at harvest was 95 g (Table 20). The target fruit load set by hand thinning was 74 fruits per tree which resulted in a yield of 8.3 kg per tree and a mean fruit weight of 111 g. Because of the large variation between the trees in the replicated plots none of the harvest parameters was statistically different from the untreated control trees. However, like in the other thinning trials in this report a number of similar trends was noted. The strongest reduction in fruit set and crop load was observed in trees treated with Cerone during bloom, with a resulting increase in mean fruit weight and percentage of fruits larger than 60 mm. Contrary to earlier trials none of the Brevis treatments even resulted in a trend of reduction in fruit set. Noteworthy is the trend of a reduction in mean fruit weight after the single and double application of 2.2 kg/ha Brevis. Another trend noted before is the reduction in return bloom compared with trees that had the same crop load with the lowest return bloom observed in the trees treated with 2.2 kg/ha. Fruit quality parameters of ‘Rubinstep’ were not affected by any of the thinning treatments. A remarkable observation is the high number of 11 seeds per fruit indicating a very good pollination in this orchard in 2019 (Table 21).

Table 20. Results thinning treatments in 2019 on fruit set, yield and return bloom of ‘Rubinstep’ trees in Ullensvang, Norway.

Treatment	Flower clusters/tree 2019	Fruit set[1,2]	Fruits/ tree	Yield (kg/tree)	Fruit weight (g)	%kg >60 mm	Return bloom 2020 (%)[3]
1. Untreated control	107	130 abc	144 abc	12.3 ab	95 abc	68.4 abc	50
2. Hand thinning	108	69 bc	74 bc	8.2 ab	111 ab	97.1 ab	73
3. 1.1 kg/ha Brevis	108	173 a	188 a	16.4 a	91 abc	63.5 bc	25
4. 2.2 kg/ha Brevis	110	183 a	202 a	15.2 a	73 c	40.9 c	14
5. 2x 1.1 kg/ha Brevis	110	152 ab	164 ab	16.0 a	101 abc	78.6 ab	35
6. 2x 2.2 kg/ha Brevis	108	95 abc	104 abc	9.4 ab	89 bc	80.4 ab	18
7. 0.5 L/ha Cerone	107	47 c	49 c	6.1 b	121 a	99.2 a	105
8. 15 kg/ha ATS	107	94 abc	104 abc	10.2 ab	103 abc	85.1 ab	122
F-test	NS	P=0.001	P<0.001	P=0.004	P=0.001	P=0.001	

[1]No. of harvested fruits per 100 flower clusters; [2]NS = not significant. Values within a column that do no share a letter are significantly different; [3] No. of flower clusters per tree in 2019 in percentage of previous year.

Table 21. Results thinning treatments in 2019 on fruit fruit quality parameter 'Rubinstep' trees in Ullensvang, Norway.

Treatment	Ground colour	Blush colour	Firmness (kg)	No. seeds	Sugars (°Brix)	Acids (%)	Starch index
1. Untreated control	5.2	5.7	11.1	11.2	0.61	8.6	8.0
2. Hand thinning	7.0	6.6	11.5	11.6	0.64	6.5	8.8
3. 1.1 kg/ha Brevis	4.6	5.5	10.8	11.1	0.59	8.8	9.6
4. 2.2 kg/ha Brevis	4.6	5.3	10.7	11.2	0.61	8.2	10.3
5. 2x 1.1 kg/ha Brevis	4.8	5.9	10.8	11.4	0.61	8.3	8.2
6. 2x 2.2 kg/ha Brevis	4.7	5.4	10.8	11.3	0.64	6.9	9.0
7. 0.5 L/ha Cerone	7.1	5.4	11.5	11.9	0.70	5.0	9.0
8. 15 kg/ha ATS	5.9	6.0	10.9	11.4	0.62	8.1	9.9
F-test	NS	NS	NS	NS	NS	NS	NS

2.5.2 Conclusion thinning trials

The thinning trials carried out on 'Summerred' and 'Rubinstep' apple trees in the fruit growing regions Ullensvang and Lier resulted in variable results from year to year and between orchards. In most of the trials the variability in response between the replicates of each treatment was too large to obtain statistically significant effects on any of the assessed harvest and fruit quality parameters even though homogenously flowering trees were selected for the trial. This variability in reponse between trees makes it difficult to make any final conclusion about the usefulness of any of the tested thinning agents for thinning apple trees in Norway. As some of the trials showed a clear trend of thinning efficacy of Brevis and an earlier trial done in 2014 (Maas and Meland, 2016) showed a strong thinning response of 'Summerred' to Brevis in Ullensvang, additional testing is needed to gain a better understanding of the conditions at which Brevis will be effective. To obtain less variability in the reponse to the thinning treatments the new trials need to be done in orchards in years with high bloom density on trees with equal vigour and similar amounts of flowers. Especially the observed trend of a reduction in return bloom by Brevis should be examined more closely because an effective chemical thinning agent should never decrease return bloom below a reasonable level to obtain an optimal crop the following year. Although further research is needed to more precisely define the conditions that will give a reliable thinning by Brevis there should also be the prospect of registration of Brevis for use as thinning agent in fruit orchards in Norway before new research is started.

2.6 Mechanical thinning

The results of chemical thinning trials described in the previous chapter and the results of earlier trials with several chemical thinning agents (Maas and Meland, 2016; Maas et al. 2019; Meland 1998; Meland and Birken, 2009; Meland and Kaiser, 2011) clearly show that no reliable thinning strategy with these chemical thinners has been developed so far for the tested apple cultivars under Norwegian growing conditions. For organic as well as traditional fruit growers, that do not have the possiblity to use a chemical thinning product, the use of a mechanical thinning device may reduce the amount of manual thinning needed to limit the fruit load on their trees. Initial trials to demonstrate the mechanic al thinning device developed by the University of Bonn in Germany have been carried out and described in NIBIO report no. 163 (Meland, 2016).

2.6.1 Design and implemenation of mechanical thinning trial

In 2018 a mechanical thinning strategy was tested using the 'Baum' thinning machine manufactured by Bonn University (Figure 11A) to thin flowers and reduce fruit set in apple trees. The objective of this trial is to manage tree fruit production by achieving consistent yields with high fruit quality and overcome alternate bearing in the long term. In addition to mechanical thinning, we included the application of Cerone to some of the treatments to study if Cerone would stimulate the thinning effect of the mechanical thinning. The hypothesis is that the small wounds cause by the wires of the mechanical thinning machine will initiate ethylene production by the tree. In ripening fruits ethylene production is autocatalytic, meaning it is stimulating its own rate of production. Ethephon, the active ingredient in Cerone, is converted into ethylene after it is absorbed into the cells of the plant. Combining mechanical thinning with the application of Cerone might therefore result in higher ethylene levels in the shoots and followed by in a stronger reduction in fruit numbers than by each treatment separately.

Treatments:

1. Unthinned control (UC)
2. Hand thinning (HT)
3. Mechanical Thinning 440 rpm x 4 km/h
4. Mechanical Thinning 440 rpm x 4 km/h + Cerone
5. Mechanical Thinning 550 rpm x 4 km/h
6. Mechanical Thinning 550 rpm x 4 km/h + Cerone
7. Cerone

Trial layout was a split plot design. The experimental field was divided into a block for the treatments without and another block for treatments with the mechanical thinning machine. All treatments were carried out in 6 replicated plots of a single tree.

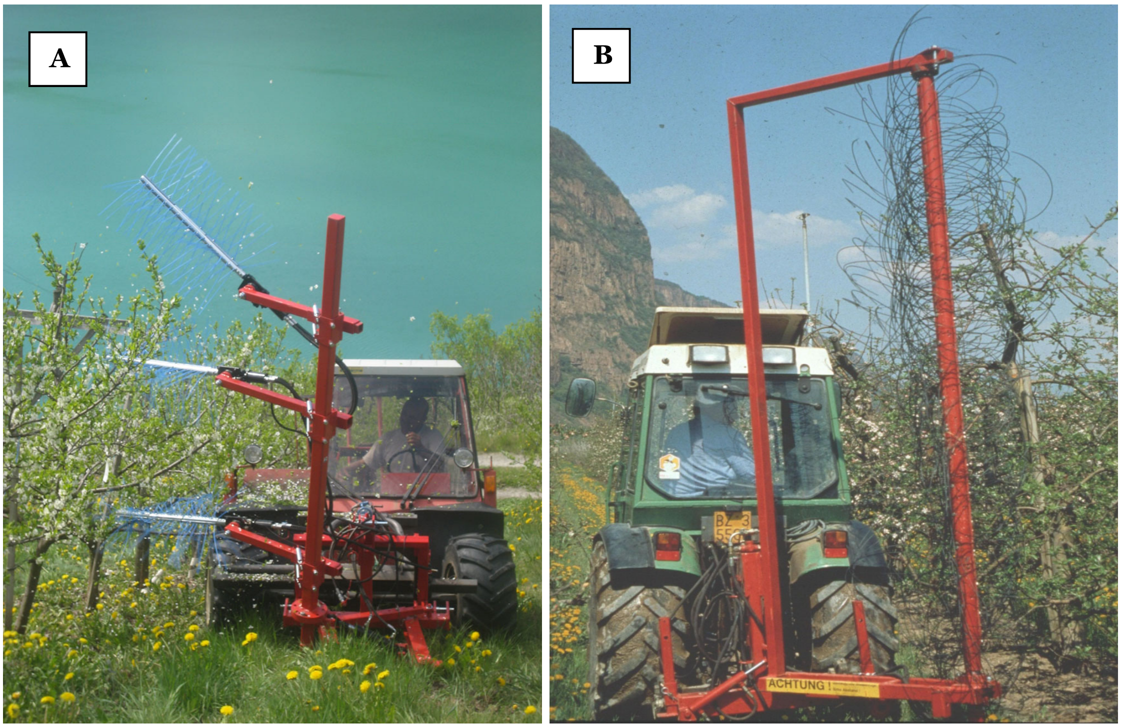

Figure 12. Univerisity Bonn Mechinal thinning device (A) and the Darwin 250 Blossom thinner (B). Photos: M. Meland (Fig. 12A) and M. Kelderer (Fig. 12B)

2.6.2 Results and discussion mechanical thinning trial

The 'Summerred' trees selected for the trial had a roughly similar numbers of flower buds per tree. On average the trees had 234 ± 46 flower clusters. Without any thinning treatment trees produced 385 fruits weighing about 44 kg per tree and a mean fruit weight of 117 g (Table 22). The target crop load in the hand thinned trees was set to 215 fruits per tree, yielding 29 kg per tree and a mean fruit weight of 139 g. None of the mechanical thinning treatments with or without Cerone resulted in a significant difference in fruit set, yield, fruit weight or return bloom with the untreated control. The variation in return bloom between the 6 trees of each treatment varied between 50 and 160% of the average value. Therefore, no statistically significant difference could be determined in return bloom in 2019 despite the large differences in their average values shown in Table 22. Fruit quality parameters were also not significantly affected by any of the thinning treatments (Table 23).

Table 22. Results mechanical thinning (MT) treatments with or without additional application of Cerone in 2018 on fruit set, yield and return bloom of 'Summerred' trees in Lier, Norway.

Treatment	Flower clusters/tree 2018	Fruit set[1,2]	Fruits/ tree	Yield (kg/tree)	Fruit weight (g)	%kg >60 mm	Return bloom 2019 (%)[3]
1. Untreated	177 b	224	385 a	43.9 ab	117 ab	93	164
2. Hand thinned	185 ab	126	215 b	29.2 b	139 a	99	105
3. MT 440	266 ab	194	453 a	49.0 a	109 b	90	38
4. MT 550	244 ab	164	320 ab	33.2 b	107 b	90	176
5. MT 440 + Cerone	267 ab	125	327 ab	42.1 ab	134 ab	95	47
6. MT 550 + Cerone	296 a	150	444 a	48.6 a	112 ab	91	20
7. Cerone	205 ab	234	443 a	49.9 a	114 ab	92	44
F-test	P<0.05	NS	P<0.001	P<0.001	P<0.01	NS	NS

[1]No. of harvested fruits per 100 flower clusters; [2]NS = not significant. Values within a column that do no share a letter are significantly different; [3] No. of flower clusters per tree in 2020 in percentage of previous year.

Table 23. Results thinning treatments in 2019 on fruit fruit quality parameter 'Rubinstep' trees in Ullensvang, Norway.

Treatment	Ground colour	Blush colour	Firmness (kg)	Sugars (°Brix)	Acids (%)	Starch index
1. Untreated	6.2	7.6	5.1	12.7	0.74	5.5
2. Hand thinned	6.5	7.7	5.6	13.1	0.79	4.6
3. MT 440 rpm	6.1	7.6	4.6	11.8	0.66	7.1
4. MT 550 rpm	6.3	7.9	5.0	12.9	0.75	6.0
5. MT 440 + Cerone	6.0	7.3	4.8	12.6	0.75	6.3
6. MT 550 + Cerone	5.8	7.8	4.8	12.9	0.74	6.6
7. Cerone	6.1	7.4	4.6	11.9	0.67	6.5
F-test	NS	NS	NS	NS	NS	NS

In conclusion, the use of the mechanical thinning device has not been successful in the spindle trees of the orchards in Lier. The thinning machine manufactured by Bonn University was developed for use in orchards with standard spindle trees with large side branches at different positions along the main trunk. In practice it is very difficult to adjust the arms with rotating wires in such a way to achieve a good average level of thinning in the trees. Differences in the height and angle of the side branches on the trunk have a large effect on the degree of thinning, varying between the extreems of no thinning to the removal of all flower clusters on a part of the branch. Therefore, mechanical thinning is considered to be a practical method only for trees in narrow fruit walls and using the Darwin type thinning machine (Figure 12B). Ideally, the mechanical thinning device should remove only a few flowers from a cluster without much damage to the leaves. The machine used in Lier removed too many complete flower clusters including their surrounding leaves on some of the branches (Figure 12)

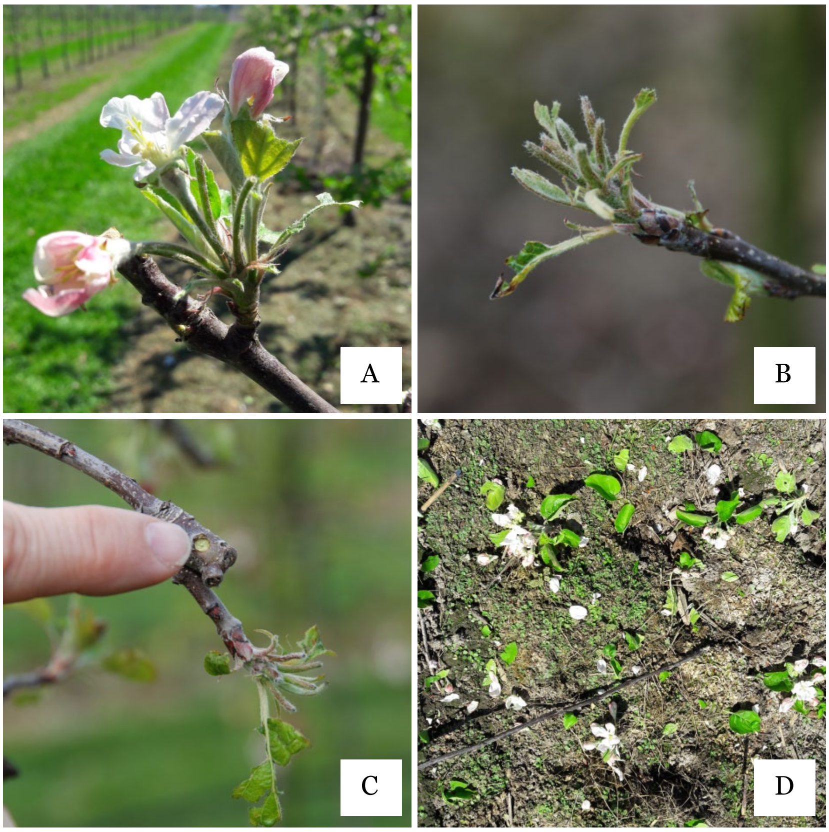

Figure 13. Partial removal (A), removal of all flowers (B) and complete removal of a flower clusters with surrounding leaves (C, D) caused by mechical thinning machine. Photos: F. Maas

2.7 Fertilization

The challenge for the fruit grower is to establish and maintain the optimal balance between tree shoot growth and crop load to get regular yields annually with the maximum proportion of high quality fruits desired by the market. To achieve regular annual yields and a high pack-out of premium quality fruit, the number of fruits must be in balance with the tree volume and the vigour of the tree. Different management techniques are available to growers. Apart from managing crop load levels, balancing plant nutrient concentrations and regulating water supply are important tools for influencing annual growth and fruit quality. The rate of uptake and usage of different nutrients vary throughout the season in apple trees (Neilsen and Neilsen, 2003; Neilsen et al., 2009). Different nutrients may be relocated within the trees. Nitrogen storage in fall is used to support new growth the following spring (Malaguti et al., 2001). High-density apple orchards laid out with trees on dwarfing rootstock with a shallow root system require regular fertilization and irrigation during the growing season to sustain an optimal development of shoot growth and to obtain a good crop of high-quality apples at harvest. The traditional way of supplying the trees with nutrients is through ground fertilization while foliar sprays typically correct visual nutrient imbalances. Modern technology allows a continuous supply of nutrients throughout the season by fertigation, where nutrients are dissolved in water and applied through the drip system. Small trees have a limited capacity to store nutrients in the roots and the trunk and a more precise application of nutrients is critical. Previous studies have shown that timing and quantity of nutrients affect yield, fruit weight, firmness and colour of apples grown at high density

(Neilsen et al., 2001, 2009; Xia et al., 2009). The aim of this study was to stimulate the growth of young apple trees without affecting precocity, increase yield without stimulating alternate bearing and enhance fruit quality. In the PresiEple project several trials with different methods of fertilization were carried out in an orchard of NIBIO in Ullensvang, with trees in pots in a polyhouse of NIBIO in Særheim and at a number of commercial farms in and around Lier in cooperation with Norsk Landbruksrådgiving Viken.

2.7.1 Fertigation trial Rubinstep in Lier 2016-2018

Year:	2016-2019
Cultivar/rootstock:	'Rubinstep'/M.9
Planting distance:	3.5 x 1.0 m (2857 trees/ha)
Year of planting:	2012
Soil type:	light clay

Treatments in addition to a general broadcast spring fertilization

1. Only water (drip-line irrigation)
2. Solid soil applied fertilizer + water (drip-line irrigation)
3. Drip-line fertigation

In 2016, the first year these fertilization treatments were applied, the crop load and yield were not significantly affected by any of the fertilization treatments compared to water only. However, average fruit weight had significantly increased by 10% in trees of the fertigation treatment (Table 24). Fruit skin colour at harvest was also significantly affected by the fertigation treatment. The apples from these treatment had a darker green background colour and a stronger blush colour than those from trees that had been given water only (Table 25). No effect of fertilization was noted on fruit firmness and the levels of sugars, acids and starch in the fruits. Shoot growth and final shoot length were similar for trees in all three fertilization treatments (Figure 13).

Table 24. Yield parameters of 'Rubinstep' grown at 3 different fertilization treatments in Lier in 2016

Fertilizer treatment	Flower clusters/tree	Fruits/tree	Yield (kg/tree)	g/fruit	%kg >60 mm
Water	48	67	10.8	162 b	100
Water + Fertilizer	51	54	8.9	165 ab	100
Fertigation	45	64	11.4	179 a	100
F-test	NS	NS	NS	P<0.05	NS

Table 25. Fruit quality parameters of Rubinstep grown at to 3 fertilization treatments in Lier in 2016

Fertilizer treatment	Ground colour	Blush colour	Firmness (kg)	Sugars (°Brix)	Acids (%)	Starch index
Water	8.0 b	5.7 b	9.6	12.6	0.73	7.0
Water + Fertilizer	8.2 b	5.9 ab	9.8	13.2	0.74	6.4
Fertigation	8.7 a	6.3 a	9.5	12.4	0.74	6.5
F-test	P<0.001	P<0.01	NS	NS	NS	NS

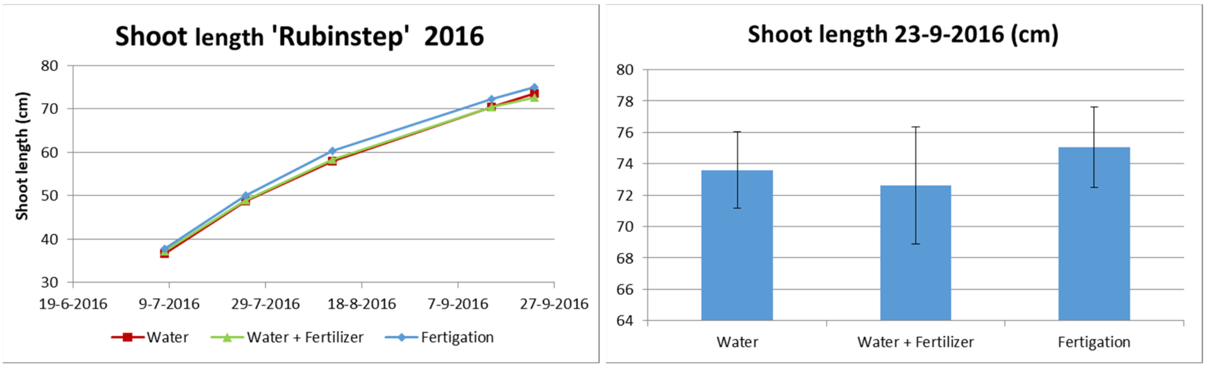

Figure 13. Shoot length development (left) and final shoot length on September 23 (right) of 'Rubinstep' trees at 3 different fertilization treatments in 2016.

In 2017, the second year of the fertilization treatments, the trees treated with fertilizer showed a trend of increasing numbers of flower clusters at bloom compared to trees given water only, with the highest numbers for the fertigated trees (Table 26). A similar trend was noted for the number of fruits and yield per tree. Due to the high variability between the observation trees, these effects of fertilization were not statistically significant. Nevertheless, the significant reduction in the average fruit weight in the fertigated trees is in line with the expected decrease in fruit weight in trees with a higher number of fruits. The decreases in background and blush colour and sugar content of the fruits of the fertilized and fertigated trees are also in line with the higher crop loads in these treatments (Table 27).

Table 26. Yield parameter of 'Rubinstep' trees grown at 3 different fertilization treatments in Lier in 2017.

Fertilizer treatment	Flower clusters/tree	Fruits/tree	Yield (kg/tree)	g/fruit	%kg >60 mm
Water	60	72	10.8	148 a	100
Water + Fertilizer	83	80	11.2	140 ab	100
Fertigation	97	118	15.9	132 b	100
F-test	NS	NS	NS	P<0.05	NS

Table 27. Fruit quality parameters of 'Rubinstep' grown at 3 fertilization treatments in Lier in 2017.

Fertilizer treatment	Ground colour	Blush colour	Firmness (kg)	No. seeds	Sugars (°Brix)	Acids (%)	Starch index
Water	6.9 a	6.2 a	10.1	10.7	13.2 a	-	6.0 c
Water + Fertilizer	6.0 b	5.5 ab	10.0	10.6	12.9 ab	-	7.3 a
Fertigation	6.3 ab	5.4 b	9.8	11.5	12.3 b	-	6.7 b
F-test	P<0.01	P<0.01	NS	NS	P<0.05	-	P<0.001

Leaf mineral analysis 'Rubinstep' fertilization trial 2017

The contents of macro and trace elements in the leaves of the 'Rubinstep' trees were analysed throughout the growing season in 2017. In figures 14 and 15 the leaf concentrations of the elements are shown together with the normal sufficiency range for each element. In general, the levels of most of the major nutrient elements were not or only slightly affected by the fertilization treatments. The levels of nitrogen (N) and phosphor (P) were within the range for sufficiency. Potassium (K) was generally at the minimum for sufficiency in trees that received water only and below sufficiency for both fertilization treatments. Magnesium (Mg) content was too low at the beginning of the growing season, but increased a bit between mid-July to mid-August and then decreased below sufficiency for the trees given water only or water plus ground fertilization. Only in the leaves of the fertigated trees the magnesium levels remained within the sufficiency range from about mid-July to the end of the growing season. Calcium levels were very similar for all three treatments. Levels were far below normal sufficiency at the beginning of July, increased somewhat during the rest of the growing season but remained too low in the trees given water only and in the fertigated trees and just approached the minimum sufficiency level in trees given water and ground fertilization. Sulphur (S) levels were below sufficiency level in the fertigated trees and trees given water only until the end of July and were within the normal range during the rest of the season for all treatments.

The nutrient trace elements were generally not or only slightly affected by the fertilization treatments (Figure 15). Copper (Cu) levels were within the normal sufficiency range during the entire sampling period and very similar for all three treatments except for a higher initial level in trees given ground fertilization and water. Manganese (Mn) was within the normal sufficiency range throughout the sampling period for all treatments. The levels in leaves of the fertigated and trees given water only showed some decline at the end of July but stayed above the minimum sufficiency level of 0.25 mg/kg leaf dry weight. The levels of zinc (Zn) were within the normal range at the beginning of July but decreased and remained below minimum sufficiency from the end of July onwards for all three treaments. Boron (B) leaf concentrations were generally similar for all treatments and at the low end of the normal sufficiency range. Molybdenum (Mo) levels were quite variable during the sampling period and reached values below the sufficiency range at various times during the sampling period for the different treatments. Leaf iron (Fe) concentrations were on average within but at the lower end of the normal sufficiency range for all three treatments. In the fertigated trees and the trees given water only the leaves showed the highest levels at the beginning of July and then leveled off slightly during the rest of the season, whereas it started just below the minimum sufficiently level in the trees given water plus ground fertilization and then gradually increased a bit during the next months.

In conclusion, the levels of most of the elements were within the normal sufficiency range during most of the sampling period between the beginning of July until the beginning of October. The application of fertilizers on the ground or via fertigation generally had little effect on leaf nutrient levels. For calcium, both fertilization methods were insufficient to obtain a level within the sufficiency range throughout the season. Fruit trees with a too low levels of calcium are prone to develop fruits showing physiological disorders such as bitter pit and reduced storability due to an earlier loss of cell wall integrity (Neilson and Neilson, 2003). Several foliar applications of calcium salts like calcium chloride or calcium nitrate are commonly carried out by fruit growers to increase calcium levels in the fruits and to prevent the occurrence of these physiological disorders.

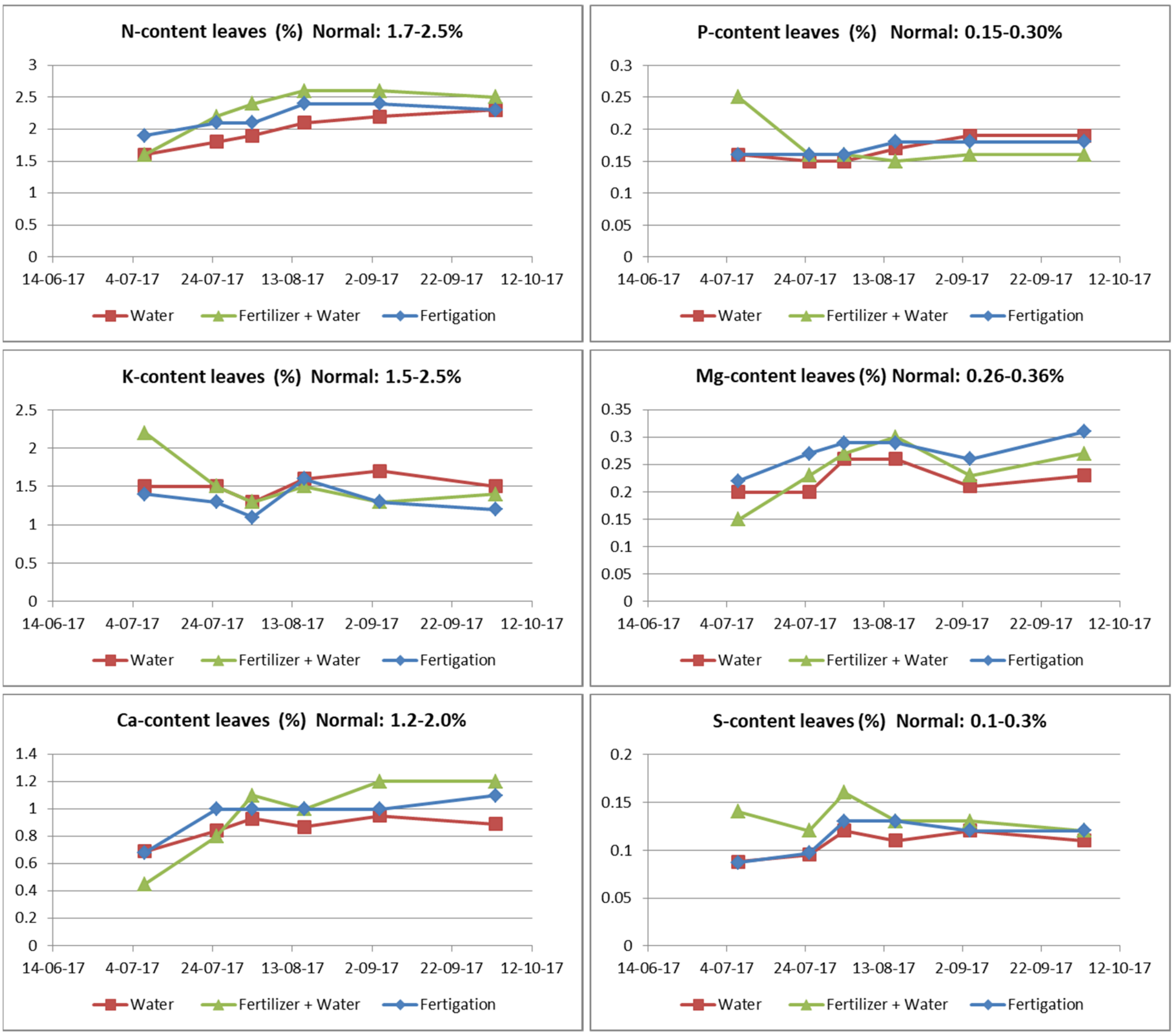

Figure 14. Levels of macro nutrients in leaves of 'Rubinstep' trees in 2017 after cultivation at 3 different fertlization treatments in 2016 and 2017. Elements are expressed on leaf dry weight basis. Sufficiency ranges for each element are listed as Normal in the title of every single chart.

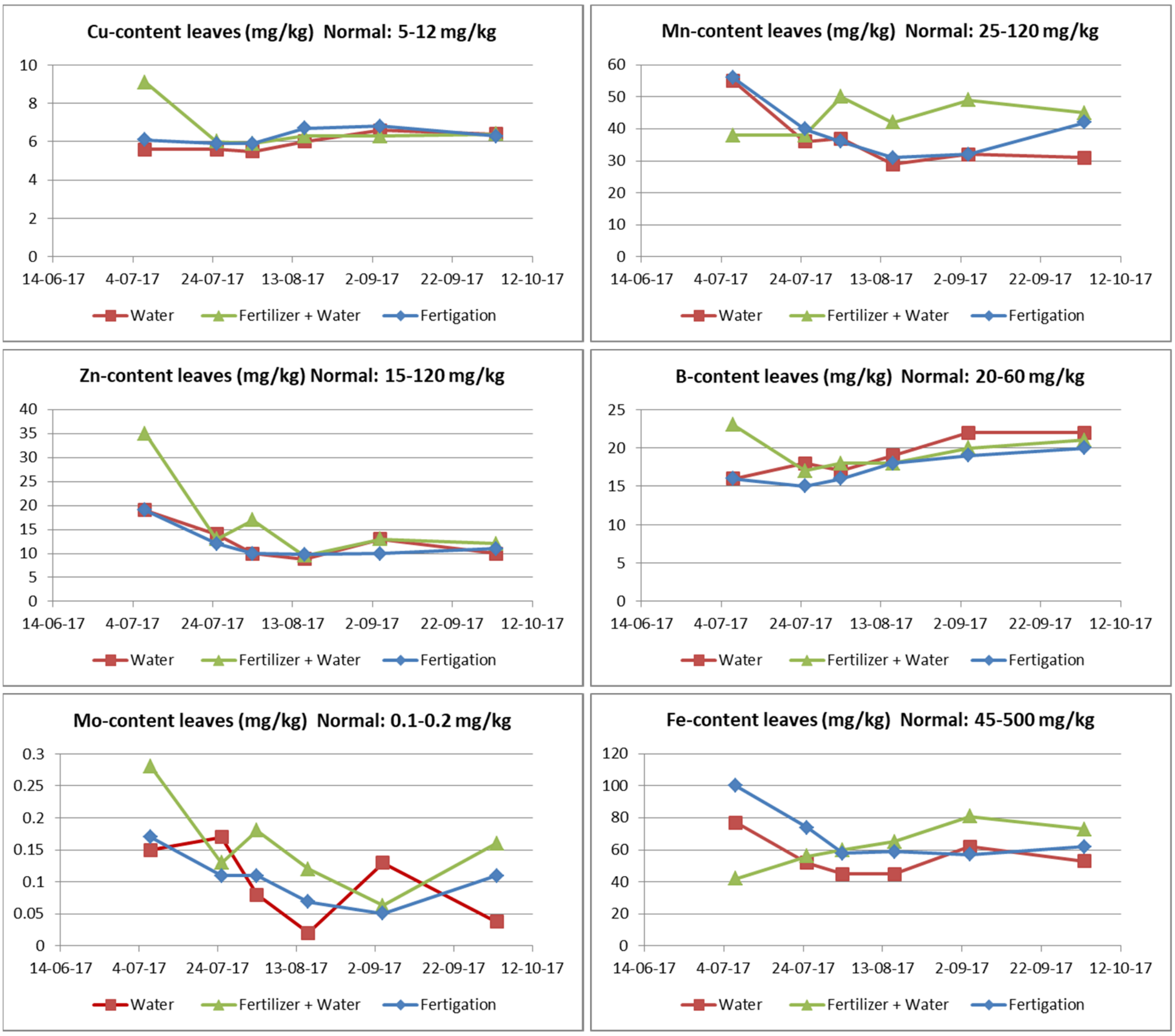

Figure 15. Levels of nutrient trace elements in leaves of 'Rubinstep' trees in 2017 after cultivation at 3 different fertlization treatments in 2016 and 2017. Elements are expressed on leaf dry weight basis. Sufficiency ranges for each element are listed as Normal in the title of every single chart.

In 2018, the third year of this fertilization trial, the trees grown without fertilization and irrigated with water only had the highest average number of flower clusters. However, the variation in flower clusters between the replicated plots of the trial was too large to make the observed differences in the mean numbers of flower clusters between the three treatments statistically significant. Also, no statistically significant differences were observed between the fertilization treatments in the number of fruits and yield, average fruit weight or percentage of the yield with a fruit diameter of 60 mm or more (Table 28). The fruit quality parameters of the harvested fruits did not show any significant differences between the treatments (Table 29. The harvest and fruit quality data of 2019 did not show any statistical differences between the three fertilization treatments (Tables 30 and 31).

Figure 16 illustrates the course of flowering, crop load, yield and average fruit weight of the 'Rubinstep' trees grown at the three different fertilization treatments from 2016 to 2019. The average values show a tendency of some alternate bearing from year to year. However, the error bars in the graphs clearly show the high variability between the replicated plots of the trials. As a result no statistical differences could be established between the fertilization treatments in any of the harvest and fruit quality parameters of 'Rubinstep' in any of the years of this trial.

Table 28. Yield parameter of 'Rubinstep' trees grown at 3 different fertilization treatments in Lier in 2018.

Fertilizer treatment	Flower clusters/tree	Fruits/tree	Yield (kg/tree)	g/fruit	%kg >60 mm
Water	70	46	4.4	93	86
Water + Fertilizer	61	28	2.8	104	94
Fertigation	38	31	3.4	112	96
F-test	NS	NS	NS	NS	NS

Table 29. Fruit quality parameters of Rubinstep grown at 3 fertilization treatments in Lier in 2018.

Fertilizer treatment	Ground colour	Blush colour	Firmness (kg)	No. seeds	Sugars (°Brix)	Acids (%)	Starch index
Water	7.4	7.5	9.4	12.5	14.9	0.58	3.6
Water + Fertilizer	7.3	7.1	9.3	13.3	15.6	0.67	3.6
Fertigation	7.4	7.3	10.2	12.3	14.6	0.73	3.0
F-test	NS	NS	NS	NS	NS	NS	NS

Table 30. Yield parameter of 'Rubinstep' trees grown at 3 different fertilization treatments in Lier in 2019.

Fertilizer treatment	Flower clusters/tree	Fruits/tree	Yield (kg/tree)	g/fruit	%kg >60 mm
Water	20	18	3.1	209	97
Water + Fertilizer	72	71	11.2	164	97
Fertigation	67	61	9.5	170	98
F-test	NS	NS	NS	NS	NS

Table 31. Fruit quality parameters of Rubinstep grown at 3 fertilization treatments in Lier in 2019.

Fertilizer treatment	Ground colour	Blush colour	Firmness (kg)	No. seeds	Sugars (°Brix)	Acids (%)	Starch index
Water	8.4	4.7	9.9	5.9	13.6	0.8	6.4
Water + Fertilizer	8.0	5.4	9.5	6.2	13.1	0.7	7.2
Fertigation	7.4	5.1	9.8	6.6	12.9	0.8	6.1
F-test	NS	NS	NS	NS	NS	NS	NS

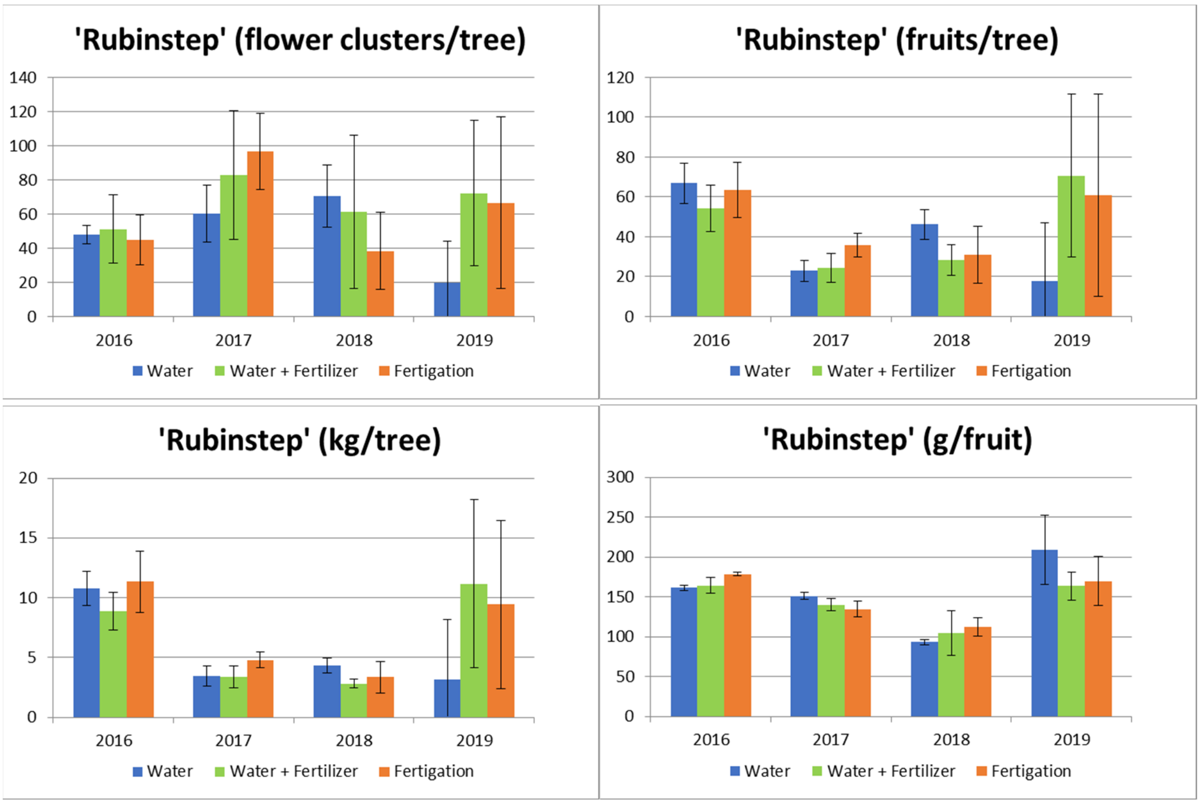

Figure 16. Flower clusters, fruits, yield and average fruit weight of 'Rubinstep' trees as response to 3 fertilization treatments in Lier from 2016 to 2019. Data are the mean of 4 replicated plots of 2 trees each± s.d.

Trunk diameter, determined as a parameter of tree vigour, increased equally for trees grown at the three fertilization treatments and did not show statistical differences between the treatments in any year during the course of the trial (Figure 17).

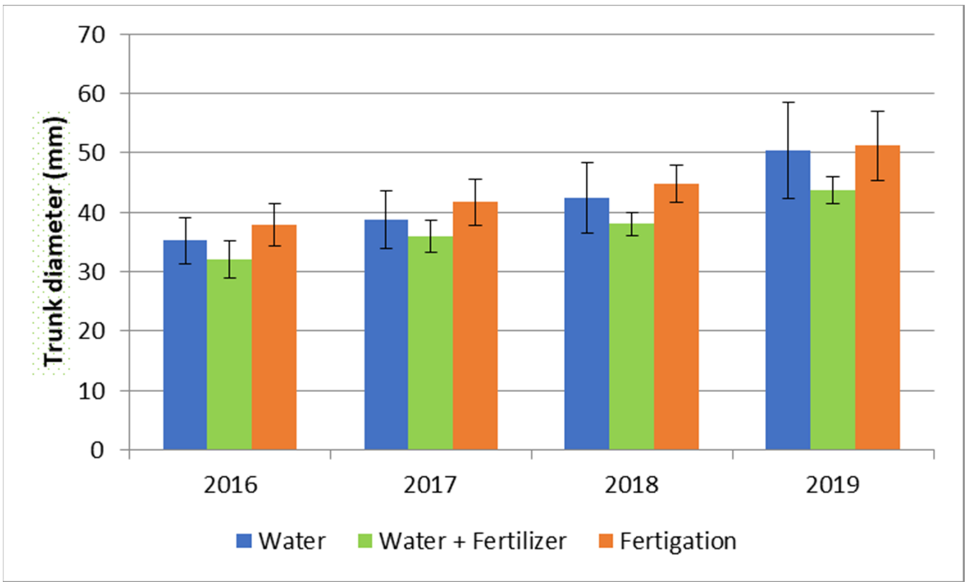

Figure 17. Trunk diameter 'Rubinstep' trees grown as response to 3 fertilization treatments from 2016 to 2019 in Lier. Data are the means of 4 replicated plots of 2 trees each ± SD.

Soil nitrate concentration in the orchard in Lier was determined at regular intervals during 2019. The highest levels were observed in the soil around the fertigated trees, with levels far above those of the trees given water only or trees given ground fertilization and water at the end of June and at the beginning of October (Figure 18). The peaks in soil nitrate levels in the soil around the fertigated trees correspond with the periods in the growing season with the lowest rain fall (Figure 19). Therefore, the increases in soil nitrate levels are most likely due to increased amounts of fertigation in these dryer periods.

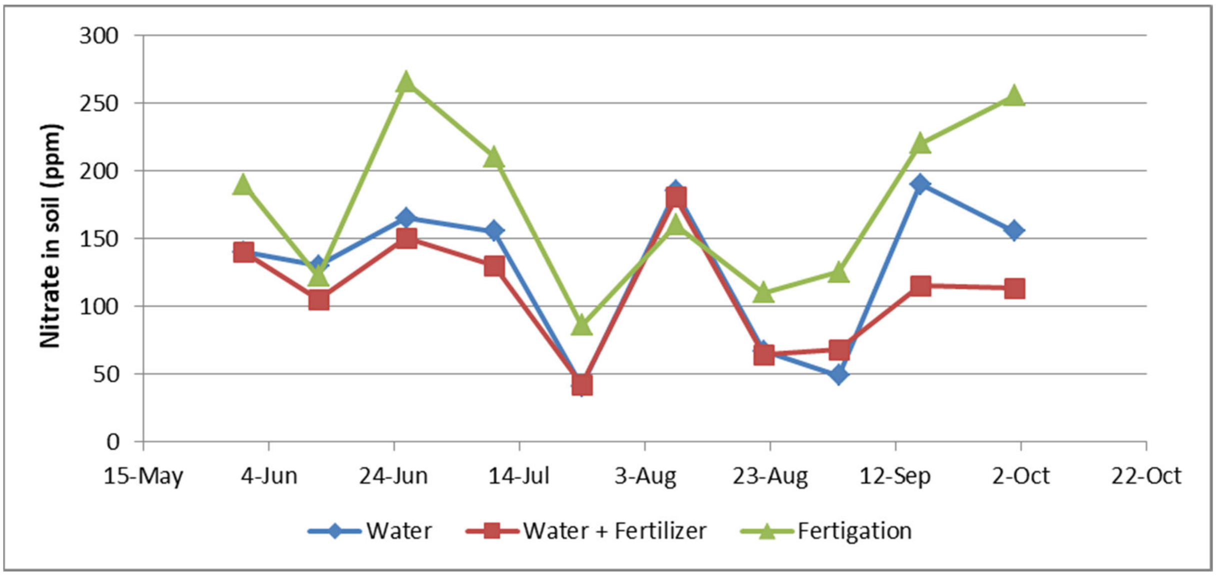

Figure 18. Nitrate levels in soil Rubinstep orchard in 3 different fertilization treatments in Lier in 2019.

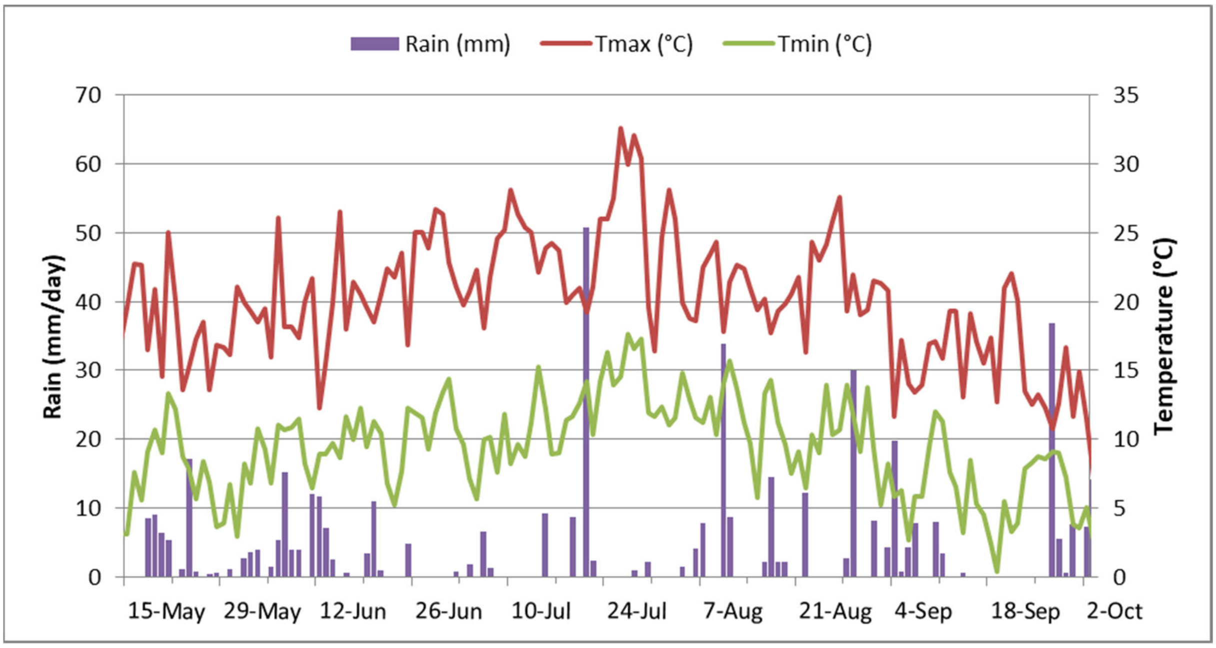

Figure 20. Minimum (Tmin), maximum (Tmax) daily temperatures and rain fall in Lier in 2019.

2.7.2 Fertigation trial 'Discovery' in Darbu 2016-2019

Year:	2016-2019
Cultivar/rootstock:	'Discovery'/MM.106
Planting distance:	3.5 x 1.0 m (2857 trees/ha)
Year of planting:	2008
Soil type:	light clay

2.7.2.1 Treatments in addition to a general broadcast spring fertilization

1. Only water
2. Solid fertilizer low N + water
3. Solid fertilizer high N + water
4. Fertigation low N
5. Fertigation high N

General applied spring ferlization applied to all treatments: 35 kg/ daa NPK 12-4-18.

Table 32. Fertilization scheme in addition to general spring fertilization.

Treatment	fertigation lines	N	P	K	Mg
1. Only water		3.5	1.2	5.3	0.5
2. Two times solid fertilizer low N		6.5	1.2	8.0	1.1
3. Two times solid fertilizer high N		8.5	1.2	8.0	1.1
4. Fertigation low N	1	6.5	1.2	8.0	1.5
5. Fertigation high N	2	8.5	1.2	8.0	1.5

In 2016, the first year of the fertilization trial, no significant effects were observed of the different fertilizer treatments shown in Table 32 on the fruit production, yield or average fruit weight of the 'Discovery' trees (Table 33). Fruit quality parameters were also not affected by any of the fertilizer treatments (Table 34). Fruit production, yield, fruit weight or fruit quality were also not significantly affected by any of the treatments after the second year of fertilizer application (Tables 35 and 36).

Table 33. Yield parameters of 'Discovery' trees at 5 different fertilization treatments in Darbu in 2016.

Fertilizer treatment	Fruits/tree	kg/tree	g/fruit
1. Water	216	25.5	119
2. Water + low N fertilizer	199	27.4	139
3. Water + high N fertilizer	211	28.8	137
4. Fertigation low N	243	30.3	125
5. Fertigation high N	244	26.4	109
F-test	NS	NS	NS

Table 34. Fruit quality parameters of 'Discovery' grown at 5 fertilization treatments in Darbu in 2016.

Fertilizer treatment	Ground colour	Blush colour	Firmness (kg)	Sugars (°Brix)	Acids (%)	Starch index
1. Water	5.6	6.8	5.8	12.0	0.55	10.0
2. Water + low N fertilizer	5.5	5.4	5.6	11.1	0.47	10.0
3. Water + high N fertilizer	5.7	6.5	5.7	11.7	0.42	10.0
4. Fertigation low N	5.0	6.2	5.1	11.4	0.44	10.0
5. Fertigation high N	5.1	6.6	4.9	11.3	0.45	10.0
F-test	NS	NS	NS	NS	NS	NS

Table 35. Yield parameters of 'Discovery' trees at 5 different fertilization treatments in Darbu in 2017.

Fertilizer treatment	Fruits/tree	kg/tree	g/fruit	%kg >60 mm
1. Water	290	32.6	113	97 a
2. Water + low N fertilizer	284	33.5	118	96 a
3. Water + high N fertilizer	252	29.0	116	99 a
4. Fertigation low N	389	38.2	98	85 b
5. Fertigation high N	307	31.7	105	93 ab
F-test	NS	NS	NS	P<0.01

Table 36. Fruit quality parameters of Discovery grown at 5 fertilization treatments in Lier in 2017.

Fertilizer treatment	Ground colour	Blush colour	Firmness (kg)	Seeds/ fruit	Sugars (°Brix)	Acids (%)	Starch index
1. Water	6.4	6.3	7.4	6.0	12.1	0.64	9.1
2. Water + low N fertilizer	5.9	6.0	6.6	6.0	12.0	0.60	8.5
3. Water + high N fertilizer	5.8	6.9	6.8	6.0	12.4	0.63	9.2
4. Fertigation low N	6.0	6.6	6.3	7.7	12.6	0.54	8.3
5. Fertigation high N	5.7	6.3	6.5	6.8	12.7	0.62	8.6
F-test	NS	NS	NS	NS	NS	NS	NS

In 2018 two additional fertilization treatments with OPTI-KAS plus Patentkali were included into the trial, one in combination with irrigation only and the other one in combination with low-N fertigation. None of the fertilizer treatments significantly affected the crop load and yield of 'Discovery' in 2018 (Table 37). However, the trees given Water + OptiKAS (treatment 7) produced significantly fewer fruits than trees given Water + high N fertilizer (treatment 3) or Fertigation low N (treatment 4). As the lower crop loads resulted in a higher average fruit weight the yield of the trees was not affected. No significant effects of any of the fertilizer treatments were observed on the fruit quality characteristics determined in 2018 (Table 38).

Fruit growth development in 2018 was similar for all seven fertilization treatments (Figure 21). Fruit diameter increased almost linear between the end of June until harvest. The average rate of fruit diameter increment was about 0.52 mm per day (Figure 22).

Soil nitrate levels determined at regular intervals during the growing season in 2018 showed a strong increase from mid to end June for the treatments Water + low N and Water + high N (Figure 23). A possible explanation for these increased levels could be the rainfall just before this period (Figure 24) causing the dissolving of the ground applied nitrogen fertilizer and washing it into the soil

Table 37. Yield parameters of 'Discovery' trees at 5 different fertilization treatments in Darbu in 2018.

Fertilizer treatment	Fruits/tree	kg/tree	g/fruit
1. Water	446 ab	32.2	72 b
2. Water + low N fertilizer	412 ab	37.4	92 ab
3. Water + high N fertilizer	463 a	36.5	79 ab
4. Fertigation low N	481 a	34.3	71 b
5. Fertigation high N	362 ab	30.5	85 ab
6. Fertig. low N + Opti-KAS	433 ab	35.4	82 ab
7. Water + Opti-KAS	329 b	33.2	106 a
F-test	P<0.05	NS	P<0.05

Table 38. Fruit quality parameters of 'Discovery' grown at 5 fertilization treatments in Lier in 2018.

Fertilizer treatment	Ground colour	Blush colour	Firmness (kg)	Seeds/ fruit	Sugars (°Brix)	Acids (%)	Starch index
1. Water	6.4	6.0	9.0	7.9	14.8	0.77	6.5
2. Water + low N fertilizer	5.9	5.5	8.1	8.1	14.2	0.67	7.2
3. Water + high N fertilizer	6.3	6.2	8.7	7.7	13.9	0.70	7.5
4. Fertigation low N	6.3	6.6	9.0	8.7	13.9	0.62	7.7
5. Fertigation high N	6.2	6.2	8.2	8.7	13.1	0.60	8.6
6. Fertig. low N + Opti-KAS	6.2	6.6	8.8	8.7	13.7	0.61	8.0
7. Water + Opti-KAS	6.0	5.9	8.1	7.7	13.8	0.66	6.9
F-test	NS	NS	NS	NS	NS	NS	NS

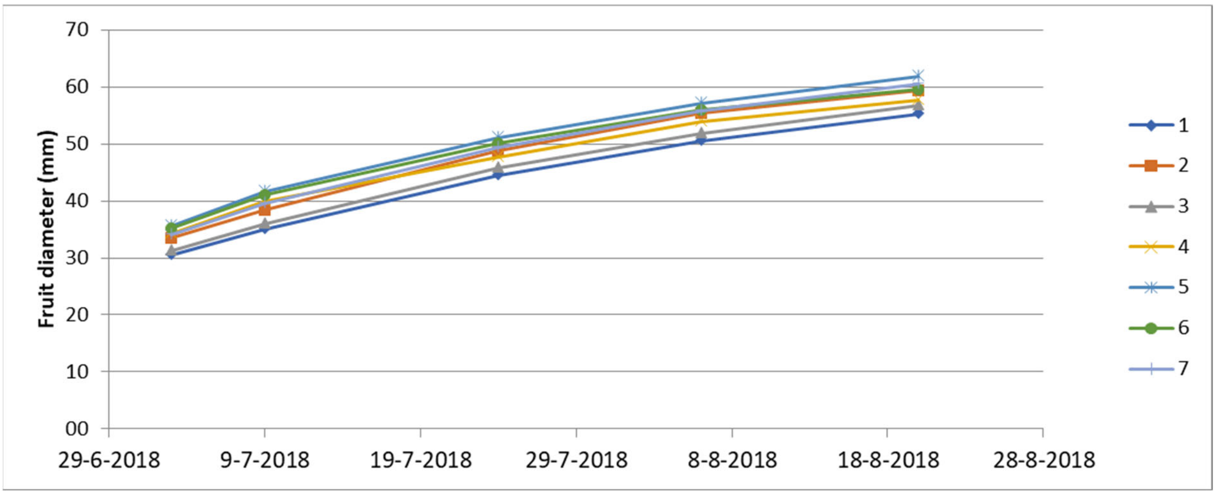

Figure 21. Fruit diameter development Discovery apples grown at 7 different fertilization treatments in Darbu in 2018. See table 37 for description treatments.

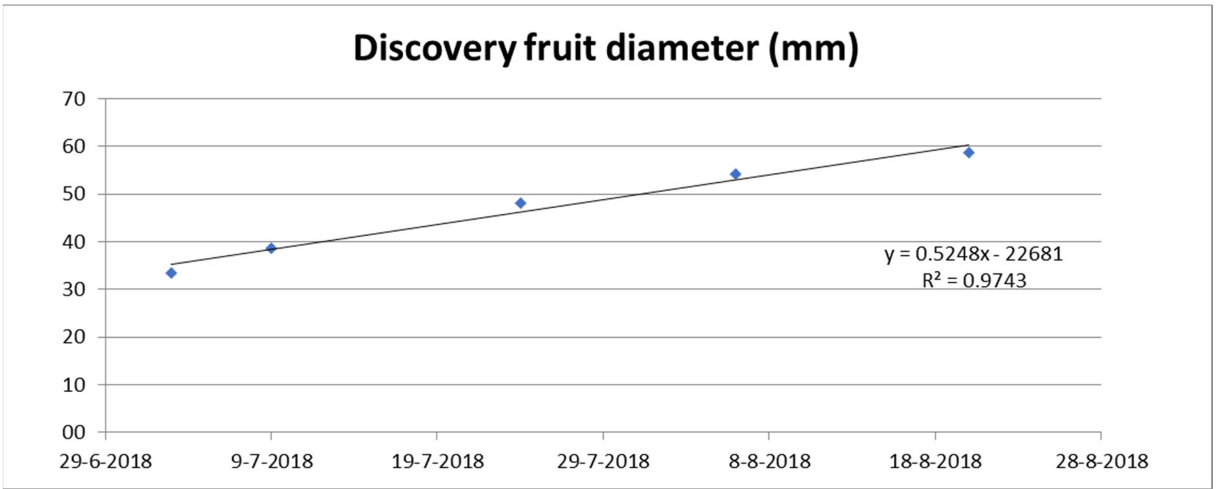

Figure 22. Average fruit diameter development 'Discovery' apples grown at 7 different fertilization treatments in Darbu in 2018.

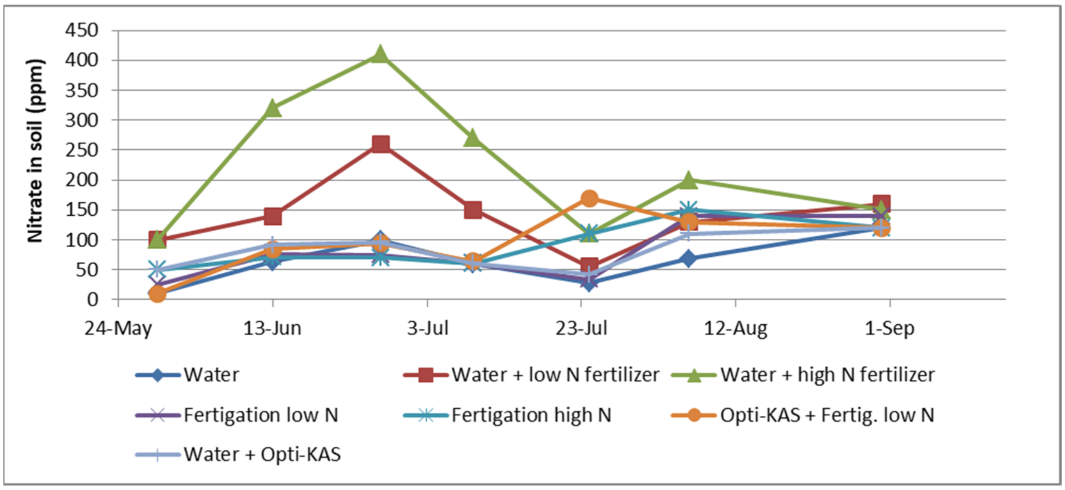

Figure 23. Nitrate levels in soil 'Discovery' orchard in 7 different fertilization treatments in Darbu in during 2018 season.

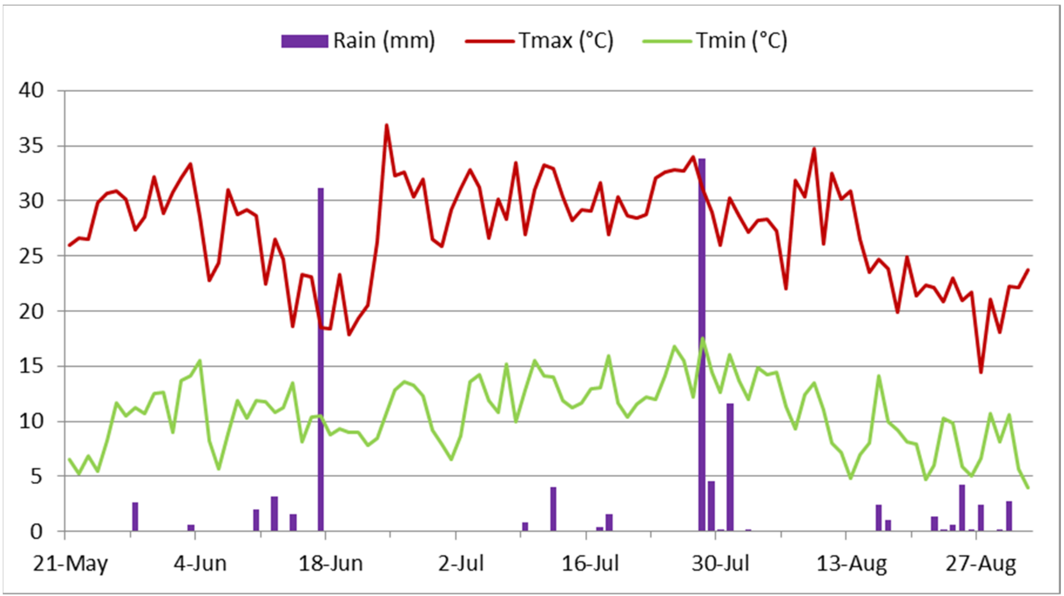

Figure 24. Minimum (Tmin), maximum (Tmax) daily temperature and rain fall in Darbu in 2018.

In 2019, the fourth year of the fertilization treatments, the trees given water only (treatment 1) and water + high N fertilizer (treatment 3) produced the largest numbers of fruits, significantly more than the trees fertigated with low or high N (treatments 3 and 4) or with OpitKAS combined with low N fertigation (treatment 6) (Table 39). The highest yields were observed for trees with the highest crop load. Significantly more kg per tree was harvested from the trees of treatments 1 and 3 compared to those of the fertigation treatments 4 and 5. Average fruit weight was highest for the trees with the lowest crop load. The trees given water only had a significantly lower fruit weight than the fruits of any of the fertigation treatments 4 to 6 (Table 39).
The fruit quality characteristics presented in table 40 did not show any significant differences between the fertilization treatments. The high starch index values demonstrate the fruits hardly contained starch any longer and were harvested at a very mature ripening stage.

Table 39. Yield parameters of 'Discovery' trees at 5 different fertilization treatments in Darbu in 2019.

Fertilizer treatment	Fruits/tree	kg/tree	g/fruit
1. Water	360 a	33.2 a	93 c
2. Water + low N fertilizer	273 ab	29.9 ab	110 abc
3. Water + high N fertilizer	338 a	32.5 a	97 bc
4. Fertigation low N	203 b	23.1 b	114 ab
5. Fertigation high N	212 b	23.3 b	112 ab
6. Opti-KAS + Fertig. low N	220 b	26.5 ab	122 a
7. Water + Opti-KAS	267 ab	28.7 ab	108 abc
F-test	P<0.01	P<0.01	P<0.01

Table 40. Fruit quality parameters of Discovery grown at 5 fertilization treatments in Lier in 2019.

Fertilizer treatment	Ground colour	Blush colour	Firmness (kg)	Seeds/ fruit	Sugars (°Brix)	Acids (%)	Starch index
1. Water	5.6	6.4	5.3	7.7	11.9	0.60	9.7
2. Water	6.1	6.2	5.0	7.7	10.8	0.53	10.0
3. Water + low N fertilizer	5.8	6.1	5.6	7.5	11.3	0.60	9.8
4. Water + high N fertilizer	6.2	5.9	6.1	8.4	11.8	0.61	9.8
5. Fertigation low N	5.9	6.3	6.0	8.4	11.4	0.64	9.5
6. Fertigation high N	6.1	6.3	5.8	7.5	11.2	0.57	9.7
7. Opti-KAS + Fertig. low N	5.6	6.5	5.2	6.8	11.1	0.59	10.0
F-test	NS	NS	NS	NS	NS	NS	NS

Soil nitrate levels showed a sharp increase at the end of May to the beginning of June and at the end of the growing season around the trees that had received high N ground fertilization and water (Figure 25. This is very similar to the observation made for the same treatment in 2018 and was probably the result of washing the nitrate into the soil by the rain fall in this period (Figure 26).

Figure 27 summarizes the course of fruit production, yield and average fruit weight of 'Discovery' trees in the orchard in Darbu as a response to the different fertilization treatments applied between 2016 and 2019. Generally, the annual fruit production and fruit weight were hardly affected by the different fertilization treatments in any year. From 2016 to 2018 the trees showed an increase in fruit production. However, the higher numbers of fruits and yields were accompanied by a decrease in average fruit weight. Further, it is remarkable that none of the fertilizer treatments resulted in a significant improvement of the fruit production and fruit quality of the trees, indicating that the fertility of the soil was sufficient to sustain a good tree growth and fruit production without the application of additional fertilizers.

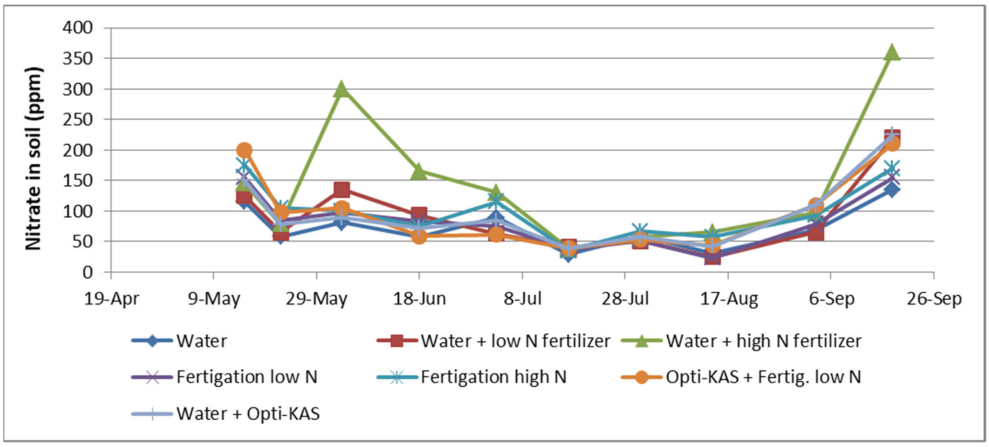

Figure 25. Nitrate levels in soil 'Discovery' orchard given 7 different fertilization treatments in 2019.

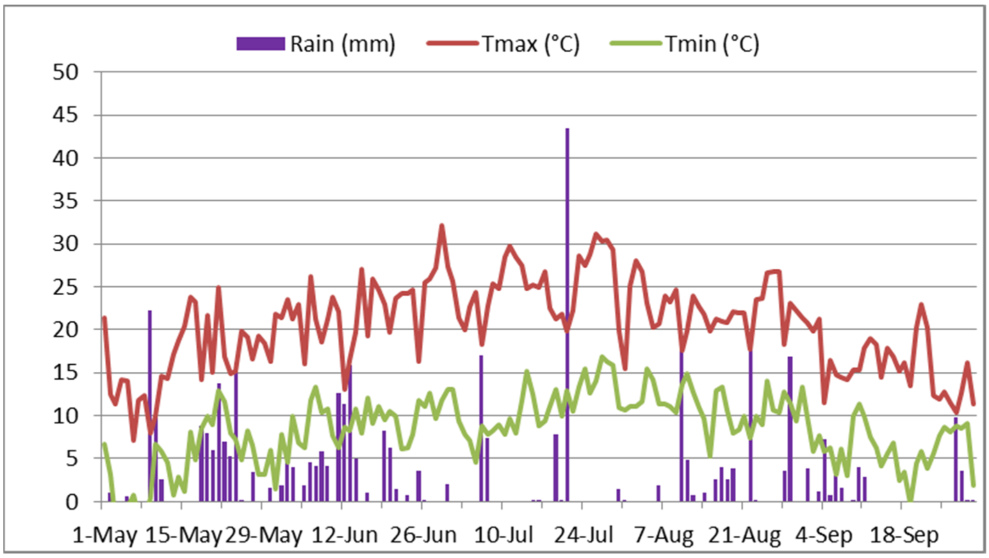

Figure 26. Minimum(Tmin), maximum (Tmax) daily temperature and rain fall in Darbu in 2019.

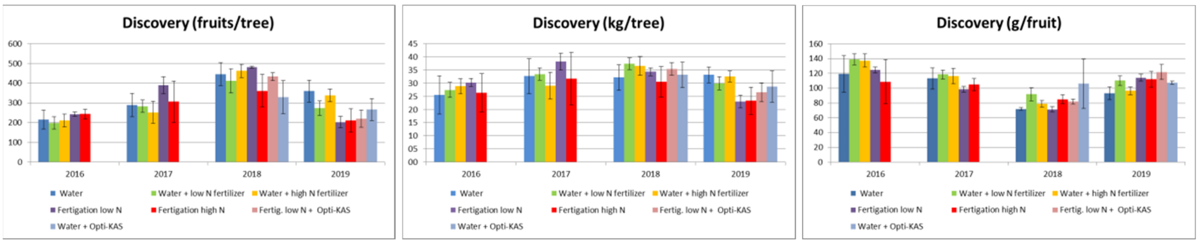

Figure 27. Fruits, yield and average fruit weight of 'Discovery' as response to 3 fertilization treatments in Darbu from 2016 to 2019. Data are the mean of 4 replicated plots of 2 trees each± s.d.

2.7.3 Results and discussion Fertigation trial 'Summerred', Kvitavoll-Ullensvang

Figure 28. 'Summerred' orchard with fully matured apples in orchard at Kvitavoll-Ullensvang in 2014. (photo: Frank Maas, 01-09- 2014).

This trial was started in 2012. The results of the growth and fruit production in 2013 and 2014 have been published (Meland et al. 2016). Figure 28 shows the trees and apples of the 'Summerred' at time of harvest of the trial orchard Kvitavoll in Ullensvangs in 2014. Bloom in 2016 was similar for the trees in all treatments and was on average 100 flower clusters per tree (Table 41). The aim was to manually adjust the crop load to about 30 apples per tree in the low crop treatments and about 60 apples in the high crop load treatments. Consequently, yields at harvest were significantly lower in the low crop treatments than the high crop treatments and were accompanied by higher and lower average fruit weights, respectively. Yield and fruit weight were not affected by the amount of nitrogen applied via fertigation at either crop level. At all treatments, almost all harvested fruits had reached a diameter of 60 mm or more. Fruit firmness was somewhat lower in trees with the higher crop load at all three nitrogen fertigation levels (Table 42). However, only without nitrogen and with low nitrogen this difference was statistically significant. The lower firmness at the higher crop loads was accompanied by a higher starch index value, indicating that the loss in fruit firmness was caused by a more advanced ripening of the fruits.

The final tree height, trunk circumference at 25 cm above the graft union and the number of shoots per tree with a length of more than 10 cm was not affected by the crop load level and N-fertigation level in 2016 (Figure 29). In figure 30 trees of the different crop load and N-fertigation levels are shown at the time of harvest in 2016.

Table 41. Harvest data fertigation trial 'Summerred' in Ullensvang in 2016.

Treatment	Flower clusters/tree	Fruits/tree	Yield (kg/tree)	g/fruit	%kg >60 mm
1. no N - low crop	98	34 b	6.9 c	201 ab	100
2. no N - high crop	109	67 a	11.4 a	171 c	99
3. low N - low crop	105	38 b	8.0 bc	210 a	100
4. low N - high crop	94	60 a	10.9 a	181 bc	99
5. high N - low crop	95	33 b	6.8 c	209 a	100
6. high N - high crop	97	57 a	10.2 ab	177 c	99
F-test	NS	P<0.001	P<0.001	P<0.001	NS

Data represent the means of 4 replicated plots of 9-12 trees each per treatment. Means that do not share a letter are significantly different. NS = not significant.

Table 42. Fruit quality parameters 'Summerred' grown at 3 nitrogen fertlization and crop levels in Ullensvang in 2016.

Treatment	Ground colour	Blush colour	Seeds/ fruit	Firmness (kg)	Sugars (°Brix)	Acids (%)	Starch Index
1. no N - low crop	4.5	7.2	4.0	7.4 a	11.7	0.91	8.0 b
2. no N - high crop	4.8	7.2	4.0	6.9 b	12.1	0.90	9.2 a
3. low N - low crop	4.6	6.9	3.8	7.3 a	11.5	0.88	8.1 b
4. low N - high crop	4.7	7.5	4.3	6.9 b	11.2	0.82	8.9 ab
5. high N - low crop	4.9	7.4	4.3	7.2 ab	11.4	0.90	8.5 ab
6. high N - high crop	4.7	7.0	3.9	6.9 b	11.7	0.85	8.9 ab
F-test	NS	NS	NS	P<0.01	NS	NS	P<0.01

Data represent the means of 4 replicated plots of 9-12 trees each per treatment. Means that do not share a letter are significantly different. NS = not significant.

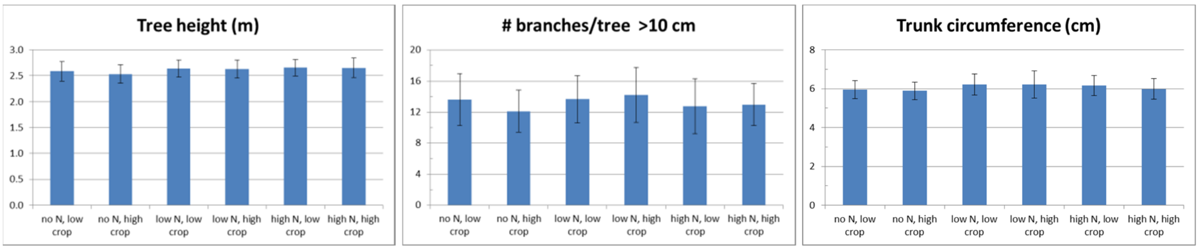

Figure 29. Tree height, number of branches longer than 10 cm and trunk circumference of 'Summerred'/M.9 trees grown at three nitrogen fertilization levels and two crop load levels in Ullensvang in 2016.

In 2017 the number of flower clusters per tree was strongly reduced compared to the 100 flower clusters per tree on average in 2016. In the 2016 low crop treatments it was reduced to about 35 flower clusters per tree in 2017, in the 2016 high crop treatments to about 20 flower clusters per tree (Table 43). This difference in return bloom e between the low and high crop load treatments indicates a negative effect of a general overcropping per tree in 2016 with the highest crop loads resulting in the lowest return bloom in 2017. To achieve two different levels of crop load again in 2017, the aim was to manually adjust the number of fruits per tree to about 15 and 30 in the low and high crop load treatments, respectively. This resulted in slightly higher yields for the higher crop load treatments that received no additional nitrogen via fertigation during the growing season. However, only at the high nitrogen level applied the difference in yield between the low and high crop level was statistically significant. No effect of crop load and nitrogen fertigation levels on any of the fruit quality characteristics of the apples harvested in 2017 was observed (Table 44). The lower starch index values, the higher fruit firmness and the greener background colour of the fruits clearly indicated the fruits were harvested at a less advanced ripening stage in 2017 than in 2016.

Table 43. Harvest data fertigation trial 'Summerred' in Ullensvang in 2017.

Treatment	Flower clusters/tree	Fruits/tree	Yield (kg/tree)	g/fruit	%kg >60 mm
1. no N - low crop	34 a	18.0 bcd	3.0 b	165	94 a
2. no N - high crop	18 b	25.5 ab	3.9 ab	154	90 ab
3. low N - low crop	34 a	16.8 cd	2.9 b	171	90 ab
4. low N - high crop	19 b	24.9 abc	3.9 ab	157	88 ab
5. high N - low crop	39 a	17.4 cd	3.2 b	192	87 b
6. high N - high crop	23 b	30.2 a	4.5 a	151	92 ab
F-test	P<0.001	P<0.001	P<0.01	NS	P<0.05

Data represent the means of 4 replicated plots of 9-12 trees each per treatment. Means that do not share a letter are significantly different. NS = not significant.

Table 44. Fruit quality parameters 'Summerred' grown at 3 nitrogen fertlization and crop levels in Ullensvang in 2017.

Treatment	Ground colour	Blush colour	Seeds / fruit	Firmness (kg)	Sugars (°Brix)	Acids (%)	Starch Index
1. no N - low crop	7.0	7.0	2.6	9.4	11.3	0.63	4.8
2. no N - high crop	6.2	6.4	2.0	9.4	11.6	0.61	5.6
3. low N - low crop	6.6	6.8	2.7	9.4	11.4	0.57	5.3
4. low N - high crop	6.4	6.7	1.9	9.3	11.5	0.60	5.5
5. high N - low crop	6.4	6.6	2.2	9.3	11.6	0.60	5.2
6. high N - high crop	7.2	6.7	2.1	9.4	11.3	0.58	5.6
F-test	NS	NS	NS	NS	NS	NS	NS

Data represent the means of 4 replicated plots of 9-12 trees each per treatment. Means that do not share a letter are significantly different. NS = not significant.

Figure 30. Crop loads of different Nitrogen fertilization – Crop level treatments in 'Summerred' apple in Ullensvang in 2016. (photos: Frank Maas, 11-09-2016).

2.7.4 Fertigation trial apple trees in pots in polyhouse in Særheim

The variable conditions of the soil and weather outside in the orchard make it difficult to determine to precise amounts of water and nutrients an apple tree needs to optimize its development, fruit production and fruit quality. Growing trees in containers in a homogeneous substrate and controlling the amount of water and nutrients applied to the trees application is a useful research method to study the demands for nutrients and water of an apple tree.

Figure 31. Trial setup of 'Discovery'/M.9 trees in pots in greenhouse at NIBIO Særheim.

Trial design

Two-year old feathered 'Discovery'/ M.9 trees were planted in 20 liter containers in spring 2016 and placed outside the greenhouse. The containers were filled with a substrate consisting of 75% peat and 25% perlite substrate to which 0.75 g/m² of a stock nutrient mixture was added and the pH was adjusted to a value between 5.5 and 6.0. The potted trees were placed inside the greenhouse in spring 2017 (Figure 31) and the treatments with three EC fertigation levels were started. Fertigation treatments were carried out with fertigation water containing all necessary nutrients elements but at different amounts to obtain fertigation solutions of EC 0.7, EC 1.3 and EC 1.9. Each EC treatment was given to a single row of 12 trees divided over 2 gutters with 5 trees each and 2 short gutters with one tree each (Figure 31) to collect the drain water from the pots. The volume, EC and mineral composition of the applied fertigation solutions and drain water were measured at regular intevals during the growing seasons in 2017 and 2018.

Tree size and fruit production in 2017 after one growing season in the greenhouse are shown in Table 45. No significant differences were observed in tree height, the number of branches longer than 10 cm, trunk circumference, fruits per tree, yield and average fruit weight between the trees grown at the three different EC-fertigation levels. On average the trees produced 1.6 fruits per tree. Although not statistically different, a distinct trend of increasing yields and mean fruit weights is visible in trees grown at increasing EC-fertigation solutions. Fruit quality characteristics determined at harvest did not show any significant differences between the three EC treatments (Table 46).

Table 45. Size and fruit production of 'Discovery' apple trees in 2017.

Treatment	Tree height (cm)[1]	# shoots > 10 cm / tree[1]	Trunk circum-ference (mm)[1]	Fruits/ tree	Yield (kg/tree)	g/fruit
EC 0.7	168	11.8	60.1	1.8	0.23	133
EC 1.3	184	11.9	62.9	1.3	0.25	163
EC 1.9	171	13.2	59.6	1.8	0.32	176
F-test	NS	NS	NS	NS	NS	NS

Values are the means of 4 replicated plots of 3 trees each. [1]Observation May 24; [2] Observations August 24; NS = not significant.

Table 46. Fruit quality parameters of Discovery apples grown at 3 EC fertigation leves for 1 year in a polyhouse at NIBIO-Særheim.

Treatment	Ground colour	Blush colour	Seeds/ fruit	Firmness (kg)	Sugars (°Brix)	Acids (%)	Starch index[1]
EC 0.7	6.1	4.9	7.5	7.5	13.0	0.94	5.7
EC 1.3	6.1	4.5	7.1	6.9	13.1	0.99	6.7
EC 1.9	6.5	4.5	7.2	6.8	13.0	0.83	6.8
F-test	NS	NS	NS	NS	NS	NS	NS

Fruits were analysed in August 2018.The data represent the means of 16 to 22 apples per treatment (7 to 9 apples for Sugars and Acids). [1]Starch index (1 = high starch content to 10 = no starch); NS = not significant.

The applied amounts of fertigation solutions and tree water use in 2017 were very similar for all three EC-fertigation treatments and showed a fairly clear relationship with global radiation measured at Særheim during the growing season (Figure 32).

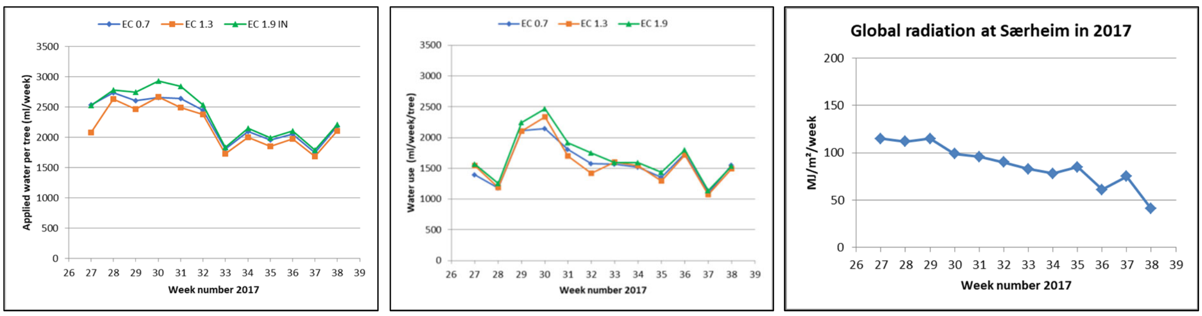

Figure 32. Applied volumes of EC fertigation and water use of 'Discovery' trees in pots grown in a greenhouse at NIBIO Særheim in 2017. Global radiation outside the greenhouse (source: NIBIO LandbruksMeteorologisk Tjeneste, https://lmt.nibio.no/station/48/).

At the lowest EC level of 0.7 mS the EC values of the drain water was below that of the fertigation solution applied to the trees for most of the growing season (Figure 33, left). At week 35 the level of fertilizers in the solution was reduced, which was followed by a somewhat delayed decrease in EC value of the drain water. The drain water of trees given the EC 1.3 fertigation solution showed EC values above those of the applied solution from week 30 onwards, indicating the plants took up relatively more water than nutrients from the applied fertigation solution thereby increasing the concentration of nutrients in the drain water (Figure 33, middle). The peak value in EC at week 30 corresponds well with the peak of water use in this week shown in figure 32. At the highest EC-fertigation level of 1.9 mS the drain water showed a much higher EC value than the applied solution from week 29 onwards (Figure 33, right), indicating that from week 28 onwards the water uptake from the solution was much higher than the nutrient uptake and that the amounts of nutrients applied were much higher than the demands of the tree. In the long term this may harm the growth of the trees as the accumulation of nutrient salts in the substrate may rise to a level that is toxic and will inhibits the water uptake by the roots of the trees.

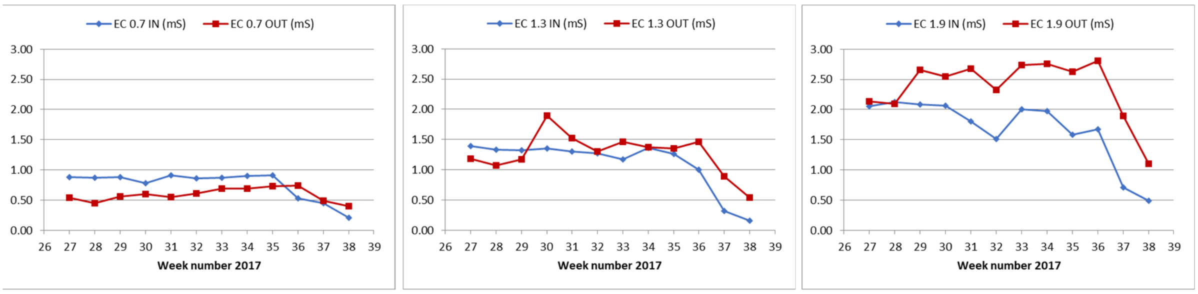

Figure 33. EC level of the applied (IN) and drain water (OUT) of the nutrient solutions at three levels of EC (0.7, 1.3 and 1.9 mS) given to 'Discovery' trees grown in pots in a greenhouse at NIBIO-Særheim in 2017.

At the end of 2018, after two years of cultivation of the trees, no significant differences in tree height, number of shoots per tree with a length of more than 10 cm, trunk circumference at 25 cm above the graft union, fruit production and average fruit weight were observed between the three applied EC fertigation levels (Table 47). Fruit quality was also not affected by the EC level of fertigation solution (Table 48). The values for blush colour and starch index were a bit lower than for the apples harvested in 2017, indicating a somewhat less advanced ripening stage of the fruits at harvest in 2018.

Table 47. Size and fruit production of 'Discovery' apple trees in 2018.

Treatment	Tree height (cm)	# shoots > 10 cm / tree	Trunk circum-ference (mm)	Number fruits/tree	Yield (kg/tree)	g/fruit
EC 0.7	225	41.6	91	14.5	2.6	179
EC 1.3	235	53.0	94	16.7	3.1	183
EC 1.9	228	50.9	89	15.0	2.7	189
F-test	NS	NS	NS	NS	NS	NS

Values are the means of 4 replicated plots of 3 trees each determined at harvest; NS = not significant.

Table 48. **Fruit quality parameters of 'Discovery' apples grown at 3 EC fertigation leves for 1 year in a polyhouse at NIBIO-Særheim.**

Treatment	Ground colour	Blush colour	Seeds/ fruit	Firmness (kg)	Sugars (°Brix)	Acids (%)	Starch index[1]
EC 0.7	6.7	3.2	4.3	7.1	13.0	1.05	3.8
EC 1.3	7.0	4.2	4.9	7.0	13.7	1.00	3.8
EC 1.9	6.5	2.9	4.3	6.7	13.6	0.87	4.9
F-test	NS	NS	NS	NS	NS	NS	NS

Fruits were analysed in August 2018.The data represent the means of 16 to 22 apples per treatment (7 to 9 apples for Sugars and Acids). [1]Starch index (1 = high starch content to 10 = no starch); NS = not significant.

The amounts of fertigation solution applied to the trees during the growing season in 2018 were very similar for all three EC-treatments and matched with the level of global radiation measured outside the greenhouse in Særheim (Figure 34). The EC level of the drain water was similar to that of the applied fertigation solution with EC 0.7 mS, with slightly lower values from May to June and somewhat higher levels in August (Figure 35, left). In the EC 1.3 treatment the EC level of the drain water started to increase that of the applied fertigation solution from about mid-June onwards and the difference with the applied solution was larger than in the EC 0.7 treatment (Figure 35, middle). At the highest EC level of 1.9 mS, the EC value of the drain water already surpassed that of the applied solution from the beginning of May and onwards (Figure 35, right). These observations indicate that in the EC 1.3 and EC 1.9 treatments the trees took up more water than nutrients from the fertigation solutions resulting in a more concentrated drain water solution.

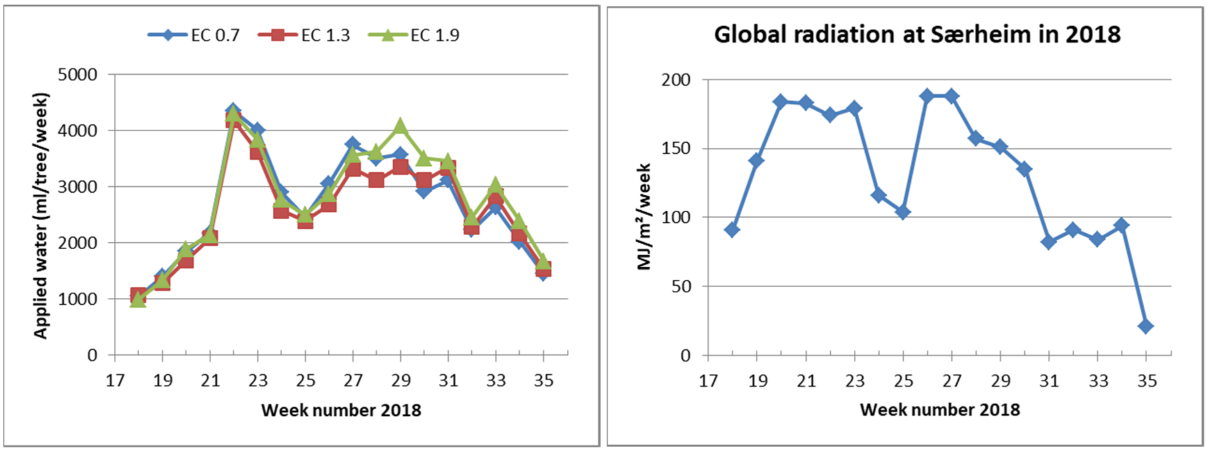

Figure 34. **Global radiation and applied water volume to 'Discovery' trees grown in pots in a greenhouse at NIBIO-Særheim in 2018.**

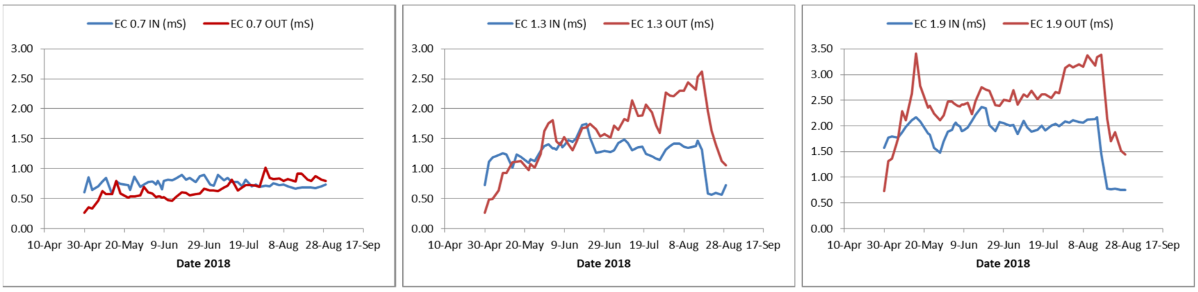

Figure 35. EC level of the applied (IN) and drain water (OUT) of the nutrient solutions at three levels of EC (0.7, 1.3 and 1.9 mS) given to 'Discovery' trees grown in pots in a greenhouse at NIBIO-Særheim in 2017 (left side) and in 2018 (right side).

After two years, the 'Discovery' trees grown at the three EC-fertigation levels were destructively harvested after leaf fall and separated into branches, trunk and roots. No significant effect the three EC fertigation treatments was observed for neither the fresh weight nor the percentage of dry matter of the different plant parts (Figure 36). These results demonstrate that even at the lowest EC level of 0.7 mS, tree growth was not limited by a shortage in nutrients in the applied solution. This conclusion is in agreement with the observation of a similar to slightly higher EC value in the drain water compared to the applied fertigation solution in the EC0.7 treatment. Further, the results of the concentration of the different macro and trace nutrient elements in the applied fertigation solutions and drain water of the three EC treatments determined in 2017 and 2018 presented in Appendix 1 and 3, respectively, clearly show that in all EC treatments sufficient nutrients were applied to the trees as even at EC0.7 none of the nutrients was fully depleted and they were still present in the collected drain water. Also, the results of the leaf analyses presented in Appendix 2 and 4 showed similar concentrations of all major and trace nutrients in the leaves in both 2017 and 2018 that they were mostly within the respective sufficiency ranges for normal tree development in apples.

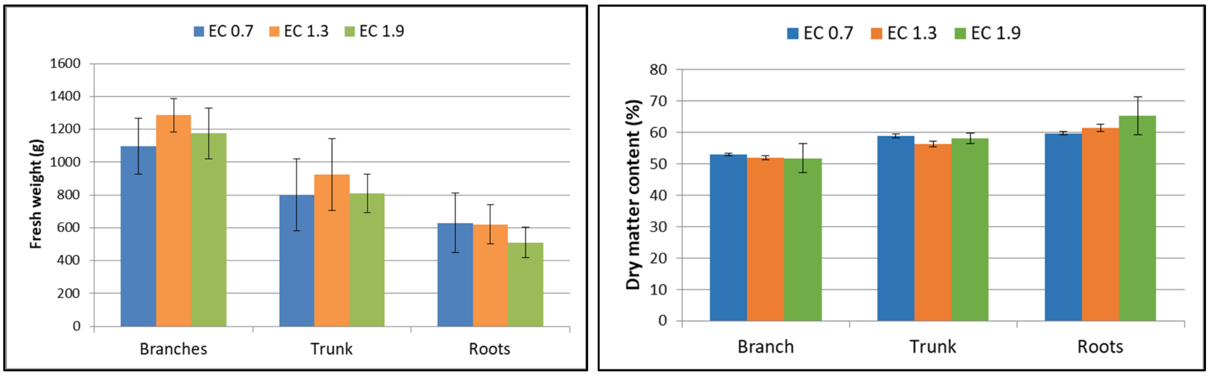

Figure 36. Fresh weight (left) and dry matter content (right) of branches, trunk and roots of 'Discovery' trees grown for two years in pots at three EC-fertigation levels. Values are the means of 4 replicated plots of 3 trees each ± SD.

In Appendix 1 and 3 the pH and the concentration of the different nutrient elements of the applied fertigation solutions and the drain water collected from the trees at regular intervals during the growing seasons 2017 and 2018 are presented in figures A1.1 to A1.4 and A3.1 to A3.4, respectively.

Generally the course of the measured values during the season was fairly similar for both years.

The pH of the applied solutions in week 29 were 7.1, 6.5 and 5.1 for the solutions with an EC level of 0.7. 1.3 and 1.9 mS, respectively. At each EC level, the pH of the drain water showed a slight increase during 2017. The largest increases were observed for the EC0.7 and EC1.3 treatment, the smallest for the EC1.9 treatment (Figure A1.1). In 2018 the pH of the drain water remained almost constant but at a slightly higher value than the pH of the applied water (Figures A3.1). The EC levels in the drain water reflect the levels of the applied fertigation solutions. From week 29 onwards the EC level of the drain water increased a bit, with the smallest increase for the EC0.7 and the highest for the EC1.9 treatment.

The nitrate concentration in the drain water of the EC0.7 treatment was less than 10% of that in the applied water, demonstrating most of the nitrate was taken up by the trees. In the EC1.3 treatment the nitrate content in the drain water varied between 30 and 50% of that in the applied water, indicating at least 50% of the nitrate was taken up by the trees. In the EC1.9 treatment the nitrate concentration in the drain water from week 31 onwards was higher than in the applied water. This demonstrates the applied nitrate exceeded the nitrogen demand of the trees. Ammonium analysis gave some erratic readings but generally the levels in the drain water were low and not exceeding those of the applied water.

Phosphate concentrations in the drain water were in line with the concentrations in the applied water.

The levels of potassium and magnesium in the drain water were also resembling those of the applied water, but in the EC1.3 and EC1.9 treatment their concentrations surpassed those of the applied water with the highest increase for the EC1.9 treatment.

Calcium concentrations in the drain water surpassed those of the applied water in the EC1.9 treatment from week 31 onwards. In the EC0.7 and EC1.3 treatment the calcium levels in the drain water were about constant from week 27 to 37 and were about 50% of the level in the applied water in 2017. In 2018 the calcium levels were also constant and in line with the levels in the applied water but at relatively higher levels than in 2017. In the EC0.7 treatment the levels in the drain water were very similar to those in the applied water. In both the EC1.3 and EC1.7 treatments the drain water levels were about 1.3 times those of the applied water.

Sulphur levels in the drain water resembled the concentrations in the applied water for all three EC fertigation treatments, but were substantially higher in the drain water in both years of the trial.

The concentration of manganese measured in the drain water was generally lower for all EC treatments, demonstrating that most of the higher amounts of manganese applied in the EC1.3 and EC1.9 treatments was taken up by the trees or bound to the substrate.

Iron (Fe) concentration in the drain water showed a linear decrease in all three EC treatments in 2017. Initially the levels in the drain water were higher than in the applied water but a decline to slightly lower concentrations was observed towards the end of the growing season in week 37. Contrary, in 2018 the levels in the drain water were more constant during the whole sampling period and more in line with the levels in the applied water.

In both 2017 and 2018, the boron (B) concentrations in the drain water were very similar to those in the applied water for all three EC-fertigation treatments. The drain-water levels were fairly constant over time in 2017 but showed a transient small increase around week 33 in 2018. This increase may be due to the increased amounts in the applied fertigation solutions in week 30.

Copper (Cu) concentrations in the drain water were generally close to those of the applied water. Only in the EC1.9 treatment in 2017 the levels declined to lower values from week 29 onwards. In 2018 drain water levels were also quite similar to those of the applied water. As observed for boron levels in 2018, the copper levels also showed a transient increase around week 33. This may also be explained by the higher levels of copper in the applied fertigation solutions in week 30.

Zinc (Zn) levels followed the levels in the applied water in both years in all three EC treatments and were fairly constant during the season.

At the start of the sampling period in 2017 the levels of sodium (Na) in the drain water were about four times higher than in the applied water. Eventhough the sodium levels in the drain water showed a small decrease during the following weeks, they were still about three times higher than in the applied water at the end of the growing season. The same elevated levels were observed in the drain water during the entire 2018 sampling period. A similar pattern was observed for the levels of chloride (Cl). Most likely the substrate contained a high amount of sodium chloride which was gradually leached out during the course of the trial.

Molybdenum (Mo) levels in the drain water were somewhat variable in 2017 but were generally within the same range as their level in the applied water of the three EC treatments. Both in 2017 and 2018 the levels in the drain water of the EC0.7 and EC1.3 treatment were higher than in the drain water of the EC1.9 treatment even though this latter treatment contained the highest concentration of Molybdenum.

The concentrations of silicon (Si) found in the drain water were at least ten times higher than those in the applied water in 2017. In 2018 the levels were on average about 7 times higher in the drain water than in the applied water for all three EC treatments. Most likely silicon is released from the compost in which the trees have been planted.

Small and quite similar levels of Aluminumaluminum (Al) were measured in both the applied and drain water. In 2017 the aluminum levels in the drain water declined over time and at the end of the sampling period the levels in week 37 were about the same as those of the applied water in week 35. In 2018 the aluminum levels in the drain water remained constant for the EC1.9 treatment but declined during the season in the EC0.7 and EC1.3 treatments in agreement with the lower concentration of aluminum in the applied water in week 36.

Leaf mineral contents were analyzed in 2017 and 2018. The results of these analyses are shown in Appendix 2 and 4. For each major and trace nutrient element leaf samples were taken at regular intervals between week 27 and 39 and between week 21 and 36 in 2017 and 2018, respectively. In the graphs showing the course of the nutrient elements during these periods, the sufficiency ranges for each nutrient element are shown in the header of the graphs.

Generally, the concentration of most of the nutrient elements increased with the increase in EC levels of the applied fertigation solution, except for the concentrations of silicon, aluminum and chloride. Also, the amounts of sodium in the applied solutions did not allways correspond directly with the EC levels of the applied fertigation solutions in 2017 and 2018. Contrary to the different amounts of most of the major and trace nutrients elements in the three EC fertigation treatments (Figures Appendix 1 and 3), the concentrations of these elements in the leaves of the 'Discovery' tree were generally fairly similar (Appendix 2 and 4) and within the sufficiency ranges for normal tree development. However, in 2017 the levels of the major elements magnesium and calcium were clearly below the minimum sufficiency range (Figure A2.1). For calcium the levels in 2018 had increased to within the sufficiency range but those of magnesium remained below the minimum sufficiency level on most of the sampling dates. Even for the EC1.9 treatment containing the highest level of magnesium in the applied fertigation solution and showing an even higher concentration in the drain water than in the applied solution, the leaf concentrations remained below the sufficiency range. A possible explanation of these low leaf magnesium contents may the lower irradiance levels inside the greenhouse compared to the normal outdoor light conditions. At lower light conditions leaves generally contain lower amounts of chlorophyll and of the carbon dioxide fixating enzyme Rubisco.

As magnesium is a necessary component of both these molecules leaves grown at a lower light intensity may have a reduced demand for magnesium, thereby lowering the levels of sufficiency range for magnesium. Bould and Parfitt (1973) and Rom (1994) reported lower minimum threshold values for magnesium in apple leaves for normal tree development of 0.15% and 0.2%, respectively than the minimum value of 0.26% reported by Neilson and Neilson and listed in the graphs of figures A2.1 and A4.1.

Of the trace nutrient elements, the concentrations in the leaves were below the minimum sufficiency range for boron and copper at most sampling dates in both 2017 and 2018 irrespective of the increased amounts of boron applied in the treatments with the higher EC levels.

Zinc concentrations were mostly below minimum sufficiency in 2017 but mostly within the sufficiency range in 2018.

Sodium concentrations in the leaves showed very large differences between 2017 and 2018. The levels in 2017 were on average about 10 times higher than in 2018. This is in line with the higher sodium levels in the drain water in 2017, indicating the sodium in the leaves was not only coming for the applied fertigation solution but also from an additional uptake of sodium that was already present in the substrate.

3 Publication information from the project

Scientific Articles

Maas, F. and M. Meland. 2016. Thinning response of 'Summerred' apple to Brevis ® in a Northern climate. Acta Hortic. 1138: 53-59.

Meland, M, Maas, F and C.Kasier. 2016. Effects of Fertigation on Yield, Fruit Quality and Return Bloom of Young Apple Trees. Third Balkan Symposium on Fruit Growing. Acta Hort. 1139:445-450.

Meland, M. and C.Kasier. 2016. Growth Regulation of Apple Trees by Prohexadion-Ca application in a Nordic Climate. Acta Hort. 1139:519-522

Kasniqi, A.L. , Blanke, M., Kunz, A. and M. Meland. 2017. Alternate bearing in fruit tree crops: past, present and future. Acta Hort. 1177: 241-248

Fotirić Akšić, M., J. Mutić, Ž. Tešić and M. Meland. 2020. Evaluation of fruit mineral contents of two apple Cultivars Grown in organic and integrated production systems. Acta Hort.1281: 59-65

Maas, F.M. , M Fotirić Akšić and M. Meland. 2020. Response of 'Rubinstep' apple to flower and fruitlet thinning in a northern climate. Acta Hort. 1295:41-47.

Abstracts at scientific meetings

Meland, M, Maas, F and C.Kasier. 2015. Effects of Fertigation on Yield, Fruit Quality and Return Bloom of Young Apple Trees. Third Balkan Symposium on Fruit Growing . September 16-18, Belgrade, Serbia. Book of Abstract. P 105

Meland, M. and C.Kasier. 2015. Growth Regulation of Apple Trees by Prohexadion-Ca application in a Nordic Climate. Third Balkan Symposium on Fruit Growing . September 16-18, Belgrade, Serbia. Book of Abstract. P. 118.

Meland, M., Maas, F and C. Kasier. 2016. Effects of three rates of nitrogen fertilizer on seasonal variations of leaf mineral concentrations of 'Summerred' apple in a Nordic climate. 45th Conference of ESNA 6-8th Sept 2016. Belgrade, Serbia. P.39

Fotirć Akšić, M, Dabić Zagorac, D., Tešić, D., Natić, M. Mutić, J. and M. Meland. 2016. Polyphenolic profile of organic and conventional apple cultivar grown in cool, mesic climate of Norway. 45th Conference of ESNA 6-8th Sept 2016. Belgrade, Serbia. P.25.

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Fotiric Aksic M., Tosti T., Maas F., Tesic Z., Meland M. 2018. Sugar analysis of apple leaves treated with metamitron (Brevis®) for fruit thinning. IHC2018 - Symposium 9: Evaluation of Cultivars, Rootstocks and Management Systems for Sustainable Production of Deciduous Fruit Crops. 30th International Horticultural Congress (IHC2018) was held in Istanbul-Turkey from 12-17 August 2018, OS 4-4.

Fotiric Aksic M., Mutic J., Tesic Z., Meland M. 2018. Evaluation of fruit mineral contents in two apple cultivars grown in organic and integrated production systems. IHC2018 - Symposium 9: Evaluation of Cultivars, Rootstocks and Management Systems for Sustainable Production of Deciduous Fruit

Crops. 30th International Horticultural Congress (IHC2018) was held in Istanbul-Turkey from 12-17 August 2018, P 22.

Horvacki, U. Gašić, T. Tosti, I. Ćirić, M. Fotirić Akšić, M. Meland, Ž. Tešić, Polyphenolic and sugar profiles of apple leaves treated with metamitron (BREVIS®). 3rd International Conference on Plant Biology (22nd SPPS Meeting), 9-12 June 2018, Belgrade. Book of abstract, pp. 166. Poster No. PP5-41

Popular articles (in Norwegian)

Myren, G. og M. Meland. Vekstregulering, tynning og gjødselvanning
Norsk Landbruksrådgiving Viken, forsøksresultater 2018: 235-244

Myren, G. og M. Meland. Vekstregulering i eple.
Norsk Landbruksrådgiving Viken, forsøksresultater 2018

Myren, G. og M. Meland Gjødselvatning til eple
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Myren, G. og M. Meland. Vekstregulering i eple.
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Myren, G. og M. Meland Gjødselvatning til eple
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Lecture presentations (Oral and Poster presentations national and international meetings

Maas, F., M. Meland og G. Myren. Kjemisk tynning av eple under våre tilhøve. Kva fungerer? Chemical thinning of apple under Norwegian conditions. What works. Oral presentation at Fruit growers meeting in Drammen, March 22, 2017.

Maas, F., M. Meland og G. Myren. Vekstregulering hjå eple, fysisk og kjemisk, Rotskjæring eller sprøyting? Growth regulation of apple, mechanical or chemical? Oral presentation at Fruit growers meeting in Drammen, March 22, 2017.

Meland; Mekjell; Fotiric Aksic, Milica; Maas, Frank. 2020. Thinning response of Rubinstep apples in a Nordic climate. Eufrin WG thinning, Belgrade, Serbia

Myren, G. 2020. Vårmøte i frukt. Foredrag fruktprodusenter via Teams 2. april

Myren, G. 2020. Webinar økologisk fruktdyrking. Foredrag nye produsenter via Teams 4. november

Myren, G. 2020. Optimal tynning. Foredrag fruktprodusenter via Teams 27. april

Myren, G. 2020. Oppsummeringsmøte for fruktdyrkere. Foredrag fruktprodusenter via Teams 26. November

Myren , G. 2019 Regalis i eplefelt med frostskade. Oppsummeringsmøte for fruktdyrkere. Lier

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Appendix 1 – Water analyses 2017

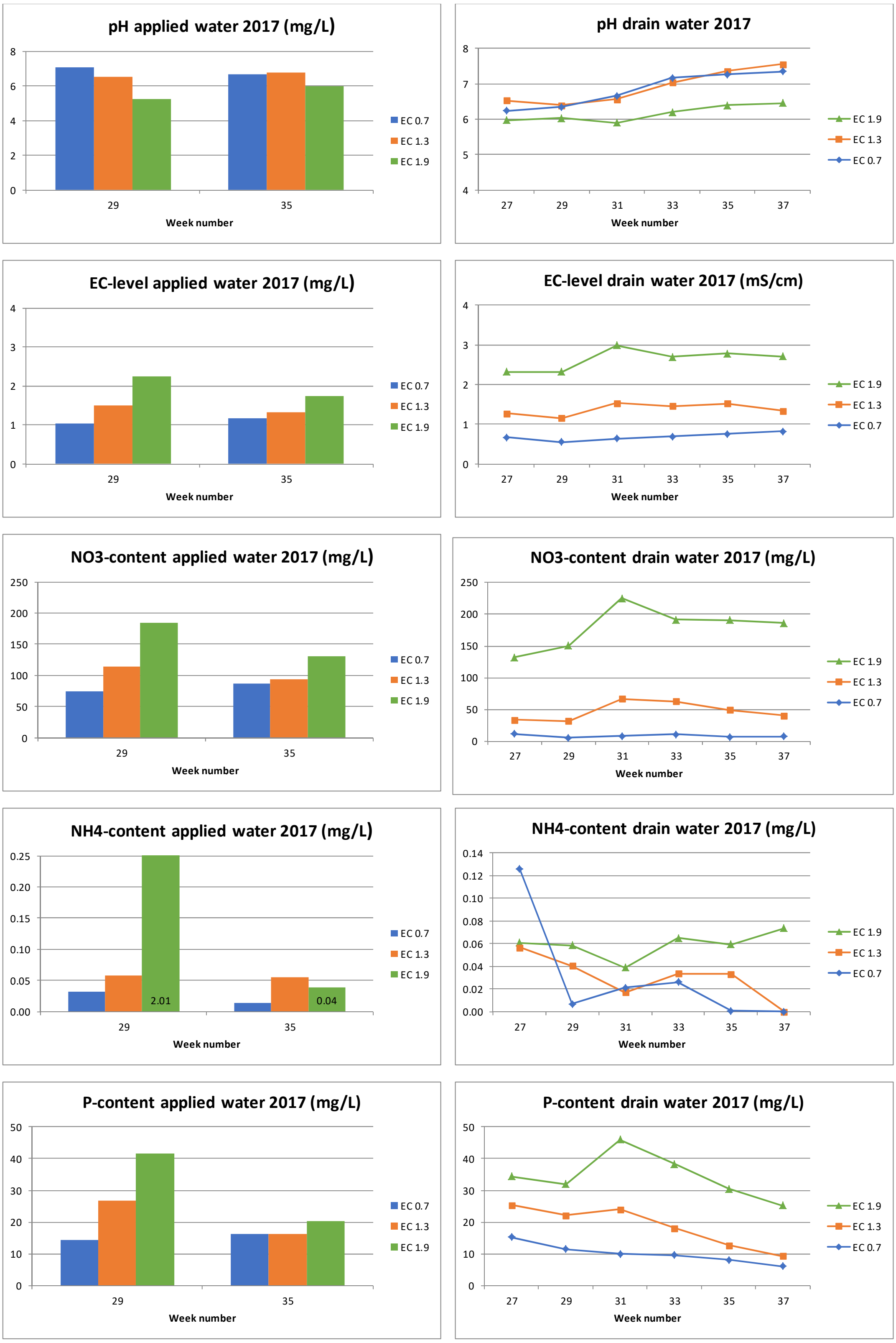

Figure A1.1. Course of pH, EC and levels of nutrient elements in applied drip and drain water of 'Discovery' trees grown at three levels of EC- fertigation in pots in a greenhouse at NIBIO-Særheim in 2017.

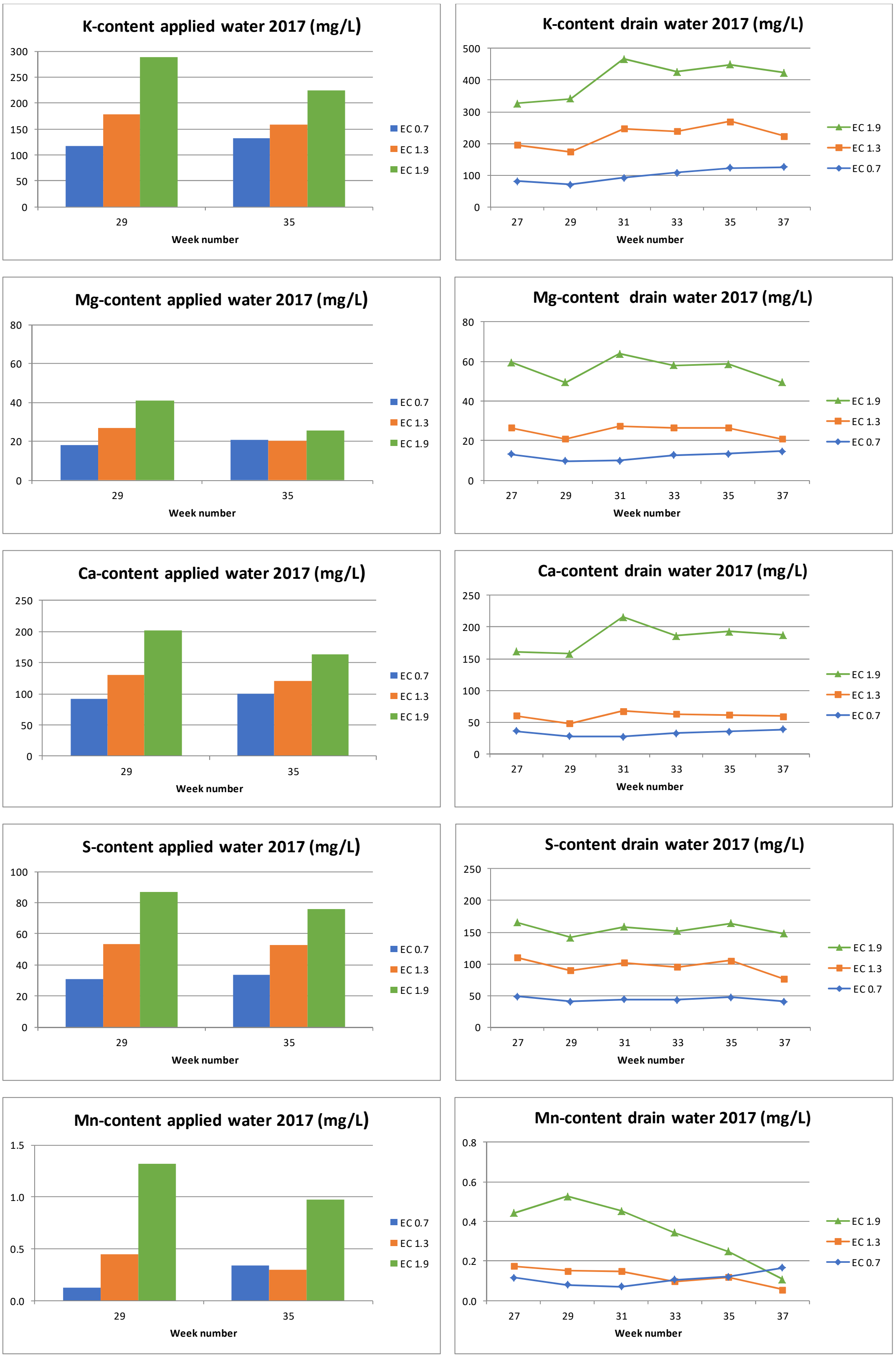

Figure A1.2. Course of nutrient elements in applied drip and drain water of 'Discovery' trees grown at three levels of EC- fertigation in pots in a greenhouse at NIBIO-Særheim in 2017.

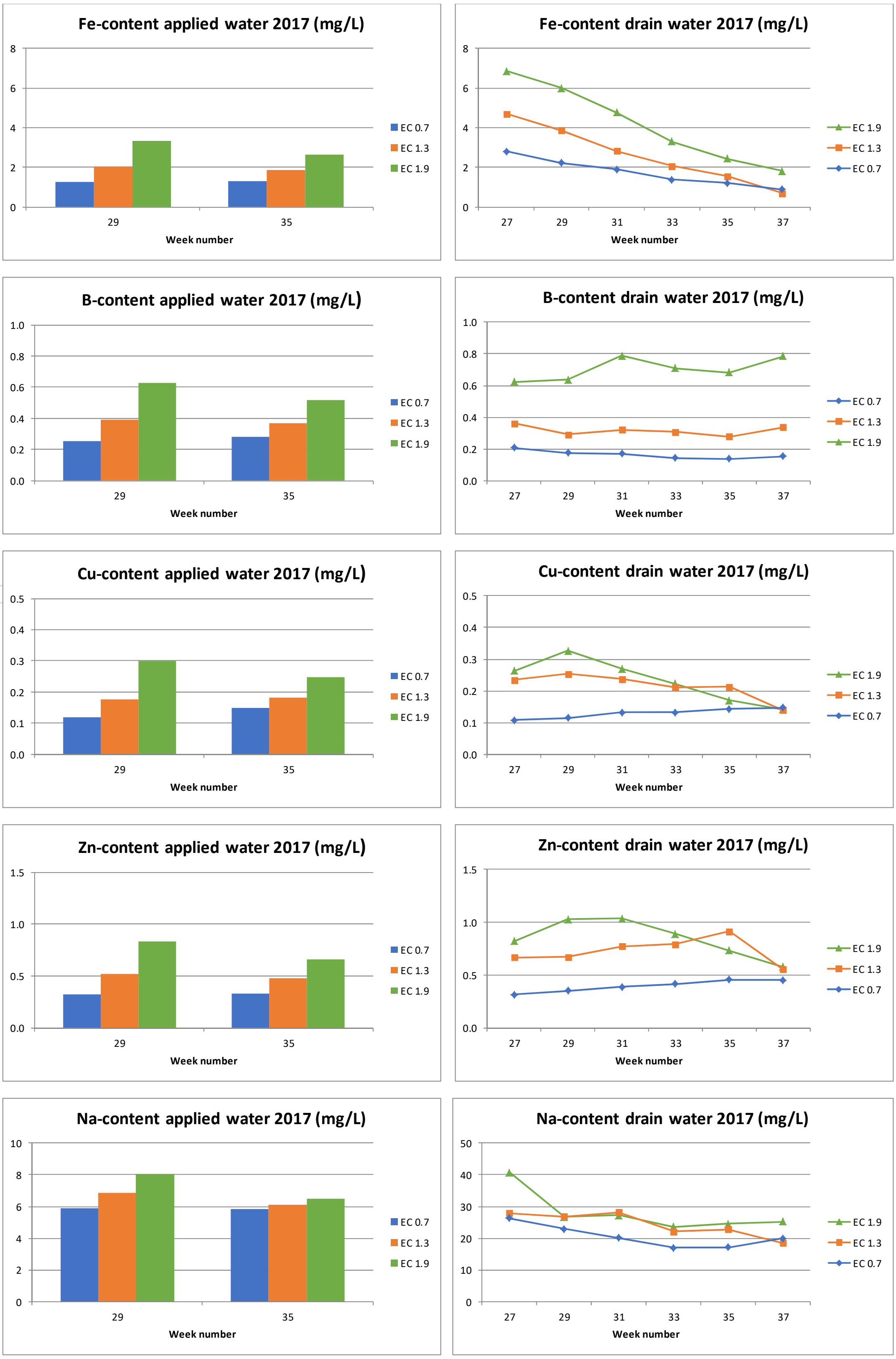

Figure A1.3. Course of nutrient elements in applied drip and drain water of 'Discovery' trees grown at three levels of EC- fertigation in pots in a greenhouse at NIBIO-Særheim in 2017.

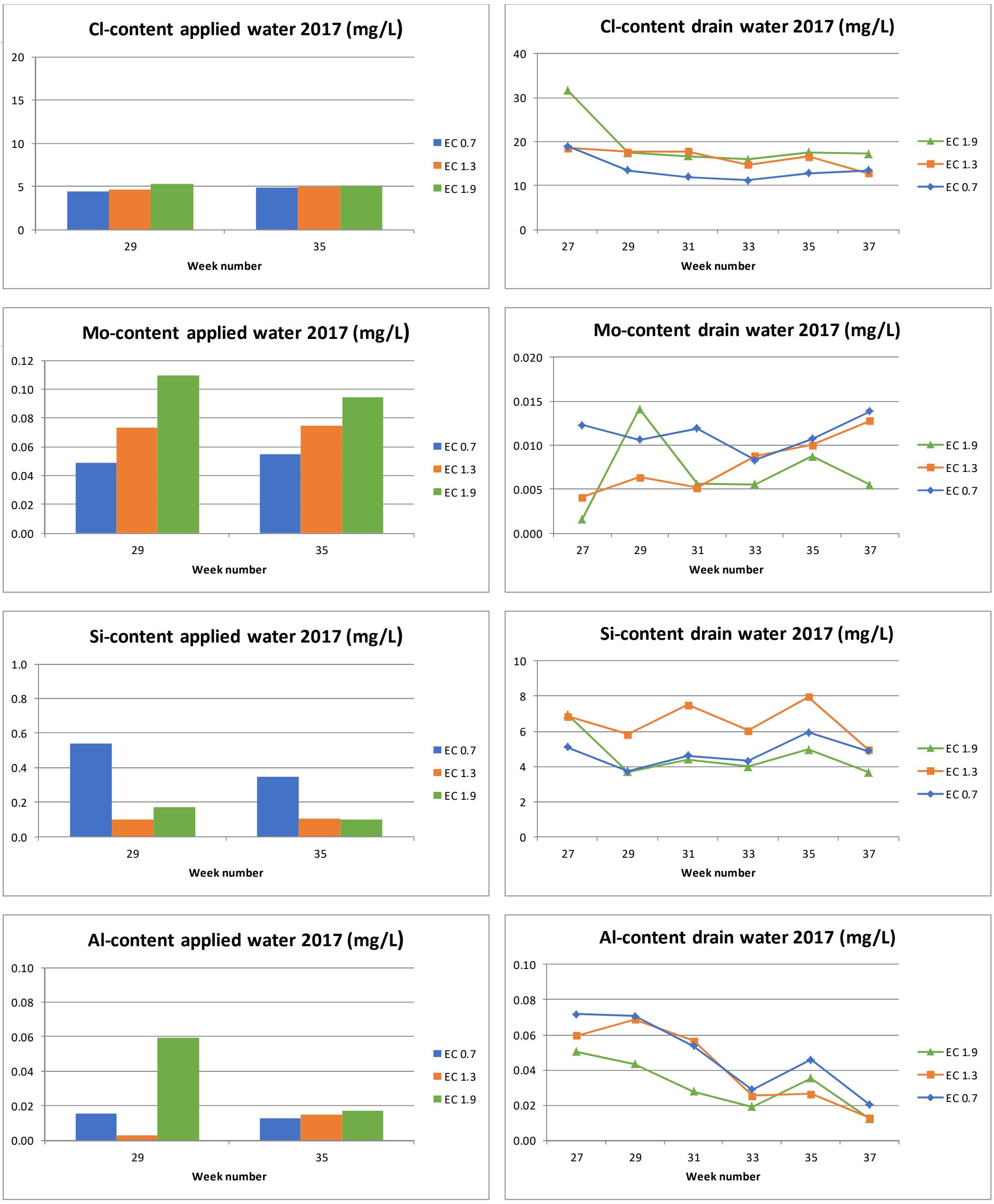

Figure A1.4. Course of nutrient elements in applied drip and drain water of 'Discovery' trees grown at three levels of EC- fertigation in pots in a greenhouse at NIBIO-Særheim in 2017.

Appendix 2 – Leaf analyses 'Discovery' 2017

Figure A2.1. Course of major nutrient elements in leaves of 'Discovery' trees grown at three levels of EC- fertigation in pots in a greenhouse at NIBIO-Særheim in 2017.

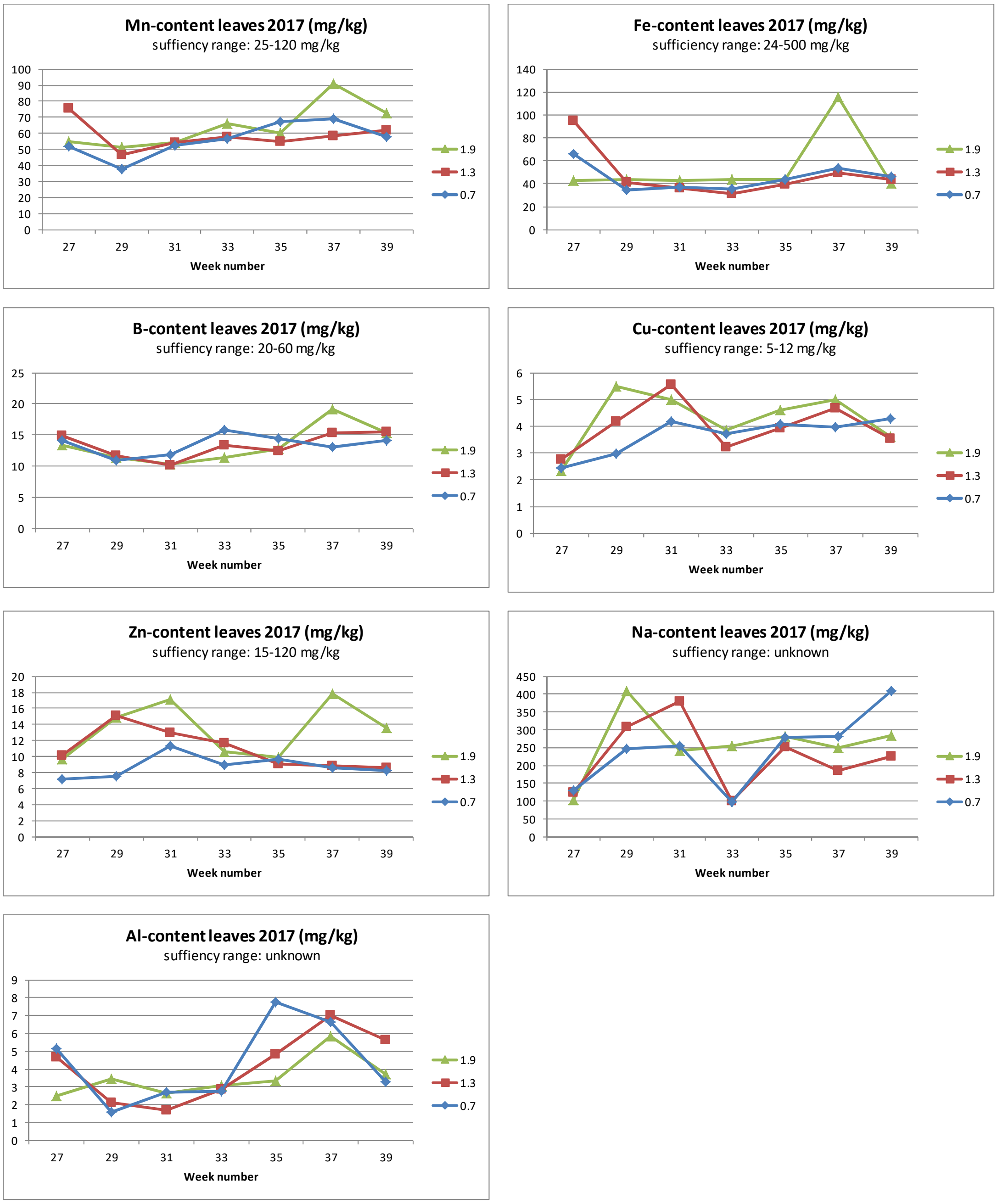

Figure A2.2. Course of trace nutrient elements in leaves of 'Discovery' trees grown at three levels of EC- fertigation in pots in a greenhouse at NIBIO-Særheim in 2017.

Appendix 3 – Water analyses 2018

Figure A3.1. Course of pH, EC and levels of nutrient elements in applied drip and drain water of 'Discovery' trees grown at three levels of EC- fertigation in pots in a greenhouse at NIBIO-Særheim in 2018.

Figure A3.2. Course of nutrient elements in applied drip and drain water of 'Discovery' trees grown at three levels of EC- fertigation in pots in a greenhouse at NIBIO-Særheim in 2018.

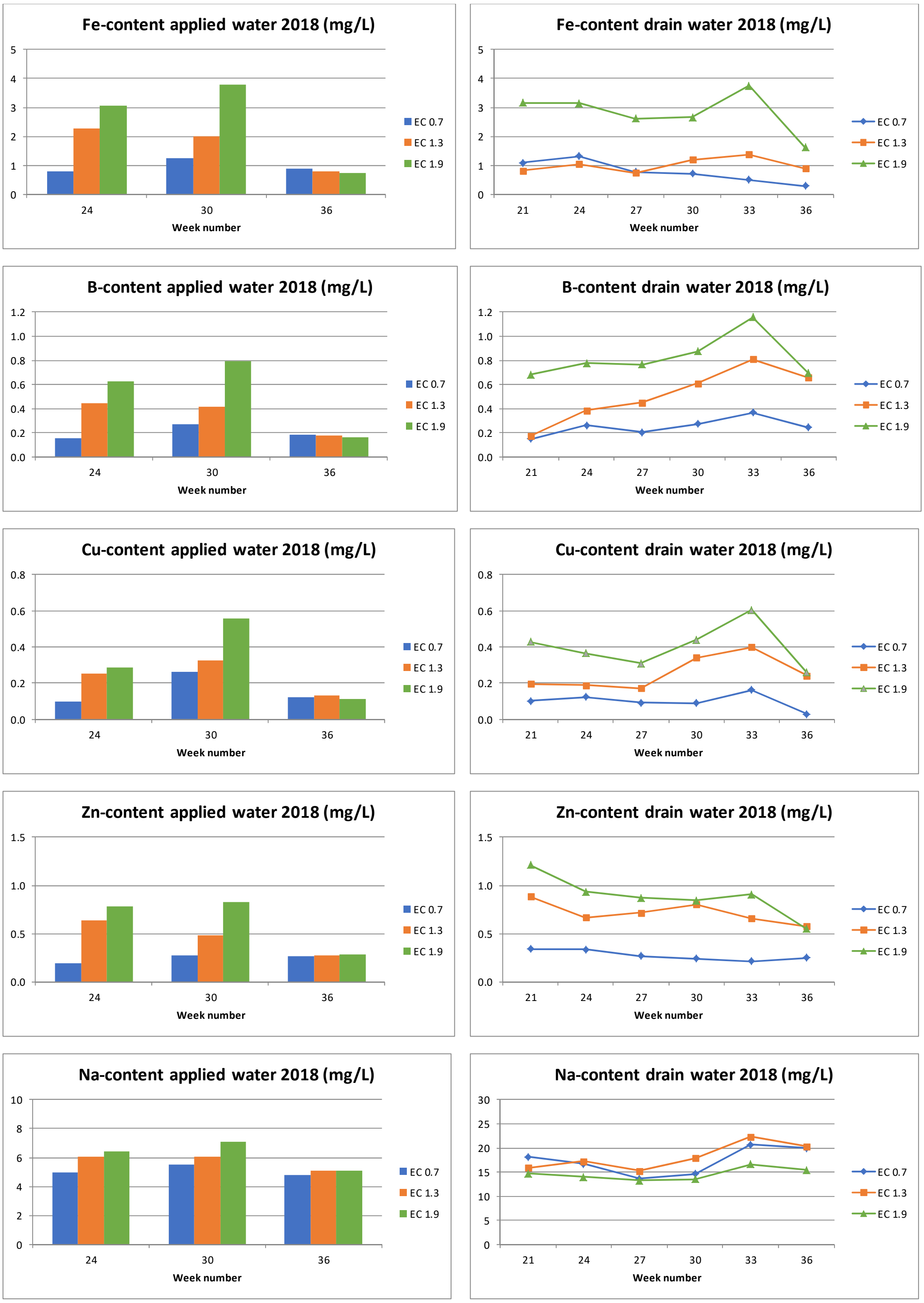

Figure A3.3. Course of nutrient elements in applied drip and drain water of 'Discovery' trees grown at three levels of EC- fertigation in pots in a greenhouse at NIBIO-Særheim in 2018.

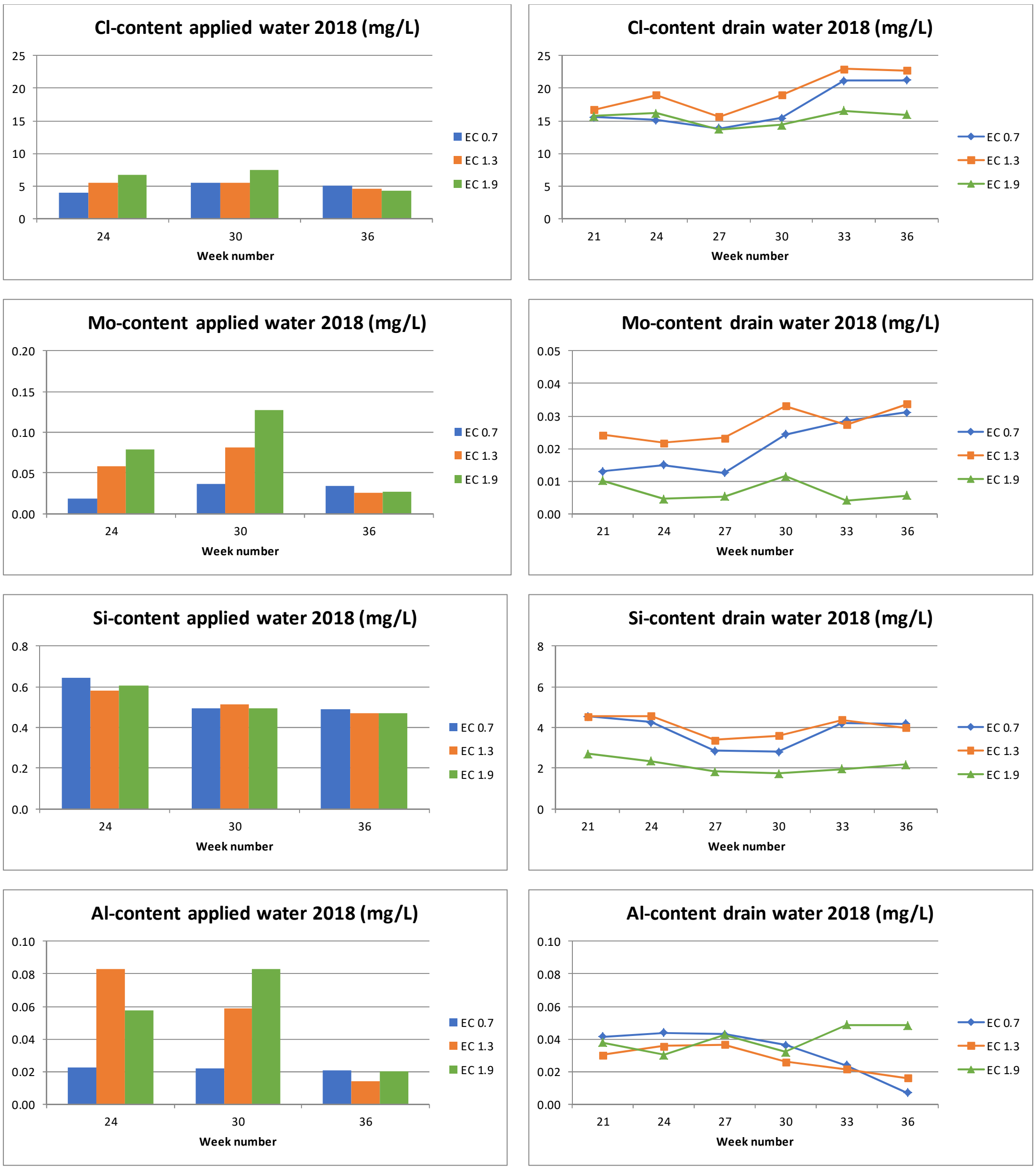

Figure A3.4. Course of nutrient elements in applied drip and drain water of 'Discovery' trees grown at three levels of EC- fertigation in pots in a greenhouse at NIBIO-Særheim in 2018.

Appendix 4 – Leaf analysis ‘Discovery’ 2018

Figure A4.1. Course of major nutrient elements in leaves of ‘Discovery’ trees grown at three levels of EC- fertigation in pots in a greenhouse at NIBIO-Særheim in 2018.

Figure A4.2. Course of trace nutrient elements in leaves of 'Discovery' trees grown at three levels of EC- fertigation in pots in a greenhouse at NIBIO-Særheim in 2018.

NIBIO
NORWEGIAN INSTITUTE OF BIOECONOMY RESEARCH

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Cover photo: First row: 'Summered' high density apple orchard. Second row from left: Flowers, fruitlets and 'Summerred' apples'. Photos: Frank A. Maas and M. Meland

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