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Survey of nutrient levels in apple trees and soil in four fruit growing regions in Norway

Results from the TerrApple project 'Precision fertilization to apple trees'

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Frank Maas[1], Tore Krogstad[2], Milica Fotirić Akšić[3] and Mekjell Meland[1]

[1]Division of Food and Society, Department of Horticulture/NIBIO Ullensvang
[2]Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences
[3]Faculty of Agriculture, University of Belgrade, Serbia

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FORFATTER(E)/AUTHOR(S)

Frank Maas, Tore Krogstad, Milica Fotiric Aksic and Mekjell Meland

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SAMMENDRAG/SUMMARY:

Denne rapporten omhandlar resultat frå kartlegging av næringsstatusen i norske eplehagar. Jord,- blad og fruktprøvar vart samla inn frå ulike eplehagar på Aust- og Vestlandet med variasjon i jordart, innhald og type organisk materiale i åra 2018-2020. Føremålet var å studera samanhengane mellom plantefysiologiske sider i epletreet relatert til jorda, treveksten, avling og fruktkvalitet. Resultat frå det treårige studiet om verknaden av gjødselpraksisar på opptak av mineral i blada, avling og fruktkvallitet hjå ulike eplesortar frå fire regionar er samla i denne rapporten.

This report is summarizing results from a survey analyzing the nutrient levels in fruit trees and soil in four fruit growing regions in Norway during the seasons 2018-2020. The aim was to study the relationship between main plant physiological principles in the tree, related to the soil, tree growth, yield, fruit quality, and fruit storage. The results of a three-year study of apple tree fertilization practices on orchard soil fertility, leaf mineral composition, apple tree yields and fruit quality of several apple cultivars in four main apple producing regions in Norway are compiled in this report.

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

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

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Preface

The aim of this project is to increase the total production of Norwegian produced apples of high quality produced in an environmentally friendly way. The total fruit consumption in Norway is increasing. Nevertheless, the Norwegian apple production is stable during the last ten years with some variations between the years.

The R&D partners Norwegian Institute of Bioeconomy Research (NIBIO Ullensvang), Norwegian University of Life Science (NMBU) and Faculty of Agriculture, University of Belgrade, Serbia in cooperation with the national fruit advising services will study and develop the fertilization recommendations of the Norwegian apple tree orchards. The main task was to study the relationship between main plant physiological principles in the tree, relate it to the soil, tree growth, yield, fruit quality, and fruit storage.

The results of a three-year study of apple tree fertilization practices on orchard soil fertility, leaf mineral composition, apple tree yields and fruit quality of several apple cultivars in four main apple producing regions in Norway are compiled and presented in this report.

The authors would like to thank Gaute Myren, Norwegian Agricultural Advising Service Viken

Rune Vereide, Norwegian Agricultural Advising Service Vestland, Sigurd Molvik, Njøs Fruit and Berry Center, and technical staff at NIBIO Ullensvang, for technical support conducting this survey.

Project owner is Hardanger Fjordfrukt in cooperation with the partners Nå Fruktlager, Sognefrukt, Innvik Fruktlager and their growers and Norwegian Agricultural Advising Service Viken.

NIBIO Ullensvang was R&D responsible by Mekjell Meland.

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Lofthus, 24.03.22

Mekjell Meland

Content

Summary

Important regions for apple production in Norway are located in Lier, Nordfjord, Sogn and Ullensvang. In 2018 a survey was started including several orchards and apple cultivars grown in different orchards in these regions to gain information on the growth, production and fruit quality of these apple cultivars. The main focus was to gain information about the differences in soil composition and soil fertility of the orchards in these regions and how these differences might be reflected in tree fruit nutrient status, fruit production and fruit quality. Apple cultivars 'Aroma', 'Discovery', 'Red Aroma', 'Summerred' and 'Rubinstep' were included in this survey. In most orchards trees on dwarfing rootstocks M.9 or B.9 were grown at a high density with 2500 to 3000 trees per hectare and with their final tree height maintained in between 2.5 and 3.0 m.

Soil composition, organic matter content, CEC-values, pH, nutrient concentrations and plant-available amounts of nutrients varied between orchards in all regions. Leaf and fruit mineral nutrient concentrations were fairly similar in all cultivars, orchards and regions. Leaf nutrient levels were mostly within or very close to the sufficiency levels reported for apple in literature. Fruit mineral nutrient concentrations were comparable with those reported for apples grown in Norway as well as Brazil and USA. In all orchards and regions a high percentages of good quality fruits were produced. Crop yields varied between orchard and years, more likely reflecting differences in tree ages and cultivation practices by growers than being caused by differences in soil composition and soil fertility.

1 Introduction

Apple tree orchards need adequate and timely applications of fertilizers to sustain tree growth and to annually obtain high yields of premium quality fruits. In order to apply to proper amounts of nutrients to the trees, fruit growers need to know how much nutrients to be applied to the soil and or leaves during the growing season. Soil type, soil organic matter content and soil pH are important factors affecting the uptake by the roots of nutrients present in the soil. Too low levels of nutrient uptake may cause specific physiological disorders in tree growth, fruit set and fruit quality, depending of the degree of deficiency and nutrient element. A review of the function and demands of apple trees for the different nutrient elements is given by Ličina et al. (2021). Information about the soil fertility and current status of tree nutrient status in the main regions of apple productions in Norway may be helpful to optimize future fertilizer applications and increase yields and fruit quality of apple orchards in these regions. To obtain this information, soil, leaf and fruit samples were taken several times during the growing season in 2018, 2019 and 2020. In addition tree fruit yields and tree growth were also monitored.

All soil samples were analyzed at two laboratories: Eurofins Agrotesting Norway (laboratory in Jena, Germany) and Eurofins Netherland. Both laboratories are used by fruit farmers and advisors in Norway, but with some differences in methods used and interpretation of results.

This study was carried out by NIBIO Ullensvang and Norwegian University of Life Sciences in cooperation with Viken Agricultural Advising and industry partners Hardanger Fjordfrukt, Nå Fruktlager, Sognefrukt, and their fruit growers.

The intention with the report is to give an overview of chemical and physical content of soils and plants in the investigated fruit districts for a 2-3 years period. More detailed relationships and discussions will be given in scientific papers.

2 Materials and methods

2.1 Trial protocol

The following criteria were used for the selection of orchards and the collection of soil and leaf samples.

2.1.1 Geographical region of orchards

- Buskerud (Lier, Svelvik, Eiker).
- Nordfjord.
- Sogn.
- Hordaland (Ullensvang).

2.1.2 Orchard selection criteria

- Orchard soil representative of region.
- Well drained and irrigated field.
- Well managed mature trees, 5-10 old filling their allotted space.
- High density orchard on dwarfing rootstock.
- Cultivar choice: Discovery, Summerred, Aroma and Rubinstep.
- Total number of orchards were 26.

2.1.3 Trial layout

In each orchard and for each cultivar three adjacent rows were selected representing the vigour and production of the trees in the orchard. Within each row 5 trees were selected and marked as observation trees for growth, fruit production of leaf analysis. Soil samples were taken from the soil within the same rows.

2.1.4 Weather conditions

Mean daily air and soil temperatures, global radiation and precipitation in the four fruit growing regions were recorded by the NIBIO weather stations at Lier, Loen (Nordfjord, Njøs (Sogn) and Ullensvang. Air temperatures were measured at 2 m above soil level, soil temperatures at 10 and 20 cm soil depth. Daily temperatures were averaged to give a mean monthly temperature, soil temperatures recorded at 10 and 20 cm were averaged and subsequently used to calculate mean monthly soil temperatures for 10 to 20 cm soil depth. Daily precipitation and global radiation levels were cumulated into total amounts per month.

2.1.5 Soil samples

Soil samples from 3 adjacent rows with uniform soil conditions

- 9 samples per row with auger (20 mm diameter) in depth 0-20 cm and mixed into a composite sample. Sampling points in row at least 2 m apart.
- Duplicate samples in each orchard for analysis in two different laboratories.

- Mark sample position on field map by GPS position.
- Parameters to be analyzed:
  - Eurofins Norway: loss on ignition, total C, total N, pH, Al-extractable Na, K, Mg, Ca, P, K-NO3; plant-available Cu, Zn, B, Mn, Fe and Mo
  - Eurofins Netherlands: Standard 'Spurway fruit growing' - Fertilization Manager Fruit.

2.1.6 Fruit growth and tree size measurements

- The course of fruit growth was determined by measuring fruit diameter on 10 randomly chosen and marked fruits per tree in 5 replications. The diameter was measured at the widest point of the fruits using digital calipers.
- Trunk diameter was measured at ca. 25 cm above graft union in two directions perpendicular to each other on each tree each spring.
- Tree height from the ground (dormant period).
- Number of branches per tree> 10 cm (optional Lier).
- No flower clusters per tree .
- Yield (kg) per tree, fruits larger and smaller than 60 mm diameter.
- Number of fruits per tree.
- Fruit quality – 20 uniform apples per plot to Lab for quality assessments and mineral analysis.
- Yield at commercial harvest time based on maturity levels (see paragraph 1.5).
- Return bloom 2021, no of flower clusters per tree.

2.1.7 Fruit yield

Collect all fruits from the same trees and three plots as used for leaf sampling. For each orchard and cultivar three trees per plot were harvested, giving three replicated yields.

2.1.8 Fruit samples

- Collected 10 apples per plot (i.e. 3 replicated samples of 10 fruits each per orchard and cultivar).
- Fruit quality parameters analyzed:
  a. Fresh weight per fruit
  b. Diameter per fruit
  c. Fruit firmness
  d. Background and Surface colour (index scale)
  e. Soluble solids content
  f. Total acidity
  g. Starch content (index scale)
  h. Number and weight of seeds per fruit

The background colour of the fruit skin was determined using an index scale of 1 (dark green) to 9 (light yellow), blush colour using an index scale of 1 (no red colour) to 9 (fruit skin completely red). Soluble solids content of juice pressed from the flesh of the apples was determined using a digital refractometer. Starch content was measured colorimetrically after staining the flesh of a halved apple with a mixture of 1% iodine and 4% potassium iodide and indexing the surface colour on scale of 1 (dark blue colour = high starch content) to 9 (no blue colour = no starch). Firmness was measured using a FTA penetrometer (www.aceindustrial.co.uk) equipped with an 11-mm plunger. The number of seeds per fruit was counted as a measure of successful pollination of the flowers and to establish a possible relation between thinning efficacy and seed number of the fruits.

- Fruit mineral analysis. NMBU, the laboratory at MINA Faculty: N was analysed by LECO CHN-628, all other elements by ICP-MS after Ultraclace decomposition in HNO_3:
  a. Macro-elements N, P, K, Mg, Ca, S.
  b. Micro-elements: B, Cu, Fe, Mn, Mo, Zn.

2.1.9 Leaf samples

- Marked 5 trees in same rows as used for soil sampling
- Sampleed leaves from each plot every second week from mid June until October 1.
- Collected the youngest, fully developed leaves from mid extension shoots from each tree at 1-1.5 m height (5 leaves per tree, in total 25 leaves per plot)
- Put each leaf sample in a paper bag, carefully marked with date, plot number, orchard and location.
- Sent samples to NIBIO Ullensvang for drying in an oven.
- Leaf mineral analysis. NMBU, the laboratory at MINA Faculty: N was analysed by LECO CHN-628, all other elements by ICP-MS after Ultraclace decomposition in HNO_3:
  a. Macro-elements N, P, K, Mg, Ca, S .
  b. Micro-elements: B, Cu, Fe, Mn, Mo, Zn.

Leaf nutrient concentration were compared to the critical nutrient concentrations for apple determined by Neilsen and Neilsen (2003) and shown in table 1. Fruit nutrient concentration were compared to those analyzed for 'Fuji' apple by Reid et al. (2018)

Table 1. Critical leaf nutrient concentrations for apple (from Neilsen & Neilsen, 2003).

Nutrient	Unit per dry weight	Deficiency`[1]	Normal	Toxicity
Leaf				
Nitrogen (N)	%	< 1.5	1.7-2.5	
Phosphorous (P)	%	< 0.13	1.5-3.0	
Potassium (K)	g/kg	< 1	15-25	
Calcium (Ca)	g/kg	< 0.7	12-20	
Magnesium (Mg)	g/kg	< 0.2	2.6-3.6	
Sulphur (S)	g/kg	< 0.1	1.0-3.0	
Manganese (Mn)	g/kg	< 25	25-120	> 120
Iron (Fe)	mg/kg	< 45 [2]	45-500	
Boron (B)	mg/kg	< 20	20-60	> 70
Copper (Cu)	mg/kg	< 5	5-12	
Zinc (Zn)	mg/kg	< 14	15-120	130-160
Molybdenum (Mo)	mg/kg	< 0.05	0.1-0.2	

[1]Severely deficient leaves can sometimes have unexpectedly higher leaf concentrations. [2]Leaf iron concentrations not correlated with iron deficiency.

Table 2. Leaf and fruit mineral concentrations of 'Fuji' grafted on M9 rootstock (from Reig et al., 2018).

Nutrient	Unit per dry weight	Range[1]	Mean ± sd	M.9
Leaf				
Carbon (C)	%	46.6 - 48.6	47.6 ± 0.4	47.9
Nitrogen (N)	%	1.9 - 2.4	2.18 ± 0.18	2.4
Phosphorous (P)	g/kg	1.6 - 2.9	2.14 ± 0.36	2.2
Potassium (K)	g/kg	11.8 - 18.7	14.8 ± 1.5	14.1
Calcium (Ca)	g/kg	8.3 - 19.9	13.8 ± 2.2	14.2
Magnesium (Mg)	g/kg	2.0 - 3.1	2.56 ± 0.29	2.9
Sulphur (S)	g/kg	1.6 - 2.0	1.80 ± 0.12	1.8
Manganese (Mn)	mg/kg	64.5 - 215.8	116 ± 33	105
Iron (Fe)	mg/kg	56.0 - 83.0	68 ± 7	80
Boron (B)	mg/kg	22.2 - 39.4	27.8 ± 3.8	24.9
Copper (Cu)	mg/kg	4.5 - 8.6	5.74 ± 0.68	5.6
Zinc (Zn)	mg/kg	17.2 - 33.4	22.1 ± 3.3	21.5
Molybdenum (Mo)	mg/kg	n.d.	n.d	n.d
Fruit				
Carbon (C)	%	41.0 - 41.9	41.4 ± 0.2	41.2
Nitrogen (N)	%	0.2 - 0.4	0.23 ± 0.05	0.2
Phosphorous (P)	g/kg	0.6 - 1.0	0.74 ± 0.10	0.7
Potassium (K)	g/kg	6.4 - 8.4	7.4 ± 0.4	0.7
Calcium (Ca)	g/kg	0.2 - 0.4	0.28 ± 0.07	0.3
Magnesium (Mg)	g/kg	0.3 - 0.4	0.30 ± 0.02	0.3
Sulphur (S)	g/kg	0.2 - 0.3	0 .23 ± 0.05	0.2
Manganese (Mn)	mg/kg	1.4 - 3.8	2.0 ± 0.5	1.8
Iron (Fe)	mg/kg	4.2 - 7.3	5.7 ± 0.8	5.8
Boron (B)	mg/kg	20.4 - 51.7	35.2 ± 7.0	35.3
Copper (Cu)	mg/kg	1.8 - 3.4	2.7 ± 0.4	2.7
Zinc (Zn)	mg/kg	0.9 - 1.7	1.2 ± 0.2	1.1
Molybdenum (Mo)	mg/kg	n.d.	n.d	n.d

[1]minimum and maximum values for 'Fuji' apples grafted on 49 different apple rootstocks. n.d. = not determined.

2.1.10 Coding of fruit growing regions and orchards

The orchards of the growers participating in this project were located in four different regions in Norway, 3 orchards in Nordfjord (coded N1 to N3), 4 orchards in Sogn (coded S1 to S4), 8 orchards in Lier (coded L1 to L8) and 11 orchards in Ullensvang (coded U1 to U11). An overview of the apple cultivars and age of the trees is given in table 3.

Table 3. Overview orchards used in the TerrApple project.

Region	Orchard code	Cultivar	Rootstock	Year of planting	Planting distance, m
Lier	L1	Red Aroma	M.9	2013	1,0 x 3,5
	L2	Red Aroma	M.9	2011	1,0 x 4,0
	L3	Red Aroma	B.9	2002	0,9 x 3,5
	L4	Red Aroma	M.9	2011	1,0 x 4,0
	L5	Discovery	MM.106	2008	2,0 x 3,5
	L6	Red Aroma	B.9	2010	0,9 x 3,5
	L7	Red Aroma	M.9	2009	1,0 x 4,0
	L8	Rubinstep	M.9	2012	0,8 x 3,5
Nordfjord	N1	Red Aroma	M.9	2012	0,8 x 3,5
	N2	Red Aroma	B.9	2014	1,0 x 3,5
	N3	Summerred	M.9	2012	0,9 x 3,5
Sogn	S1	Discovery	B.9	2013	4 x 0,9
	S2	Discovery	B.9	2014	3,5 x 1,0
	S3	Rubinstep	M.9	2012	3,5 x 0,9
	S4	Discovery	B.9	2013	4 x 0,9
Ullensvang	U1	Red Aroma	M9	2010	0.9 x 3,5
	U2	Discovery	M9	2004	0,6 x 3,5
	U3	Red Aroma	M9	2009	1 x 3,5
	U4	Summerred	M9	2012	0,8 x 3,5
	U5	Discovery	M9	2006	0,75 x 3,5
	U6	Red Aroma	M9	2017	0,8 x 3,5
	U7	Summerred	M9	2012	1 x 3,5
	U8	Aroma	M9	1999	1 x 3,5
	U9	Red Aroma	M9	2010	1 x 3,5
	U10	Summerred	M9	2009	1 x 4
	U11	Discovery	M9	2015	0,8 x 3,5

2.1.11 Statistical analysis

Data were statistically analyzed using the Minitab 17 ANOVA program (Minitab Inc., USA). In case of significant differences ($p<0.05$) treatment means were separated by Tukey pairwise comparison.

3 Results and discussion

3.1 Weather conditions Lier, Nordfjord, Sogn and Ullensvang

Monthly averaged values for air temperature, soil temperature, global radiation and total amounts of precipitation per month in 2019 and 2020 are presented in figure 1. Average air and soil temperatures were lower during the winter period in Lier region compared to the other regions. Global radiation levels were fairly similar in all region with slightly higher levels in summer in Lier region. The amounts of precipitation differed more strongly between region and between years. The highest amounts of precipitation were recorded between December 2019 and March 2020 in Ullensvang region, followed by Sogn region.

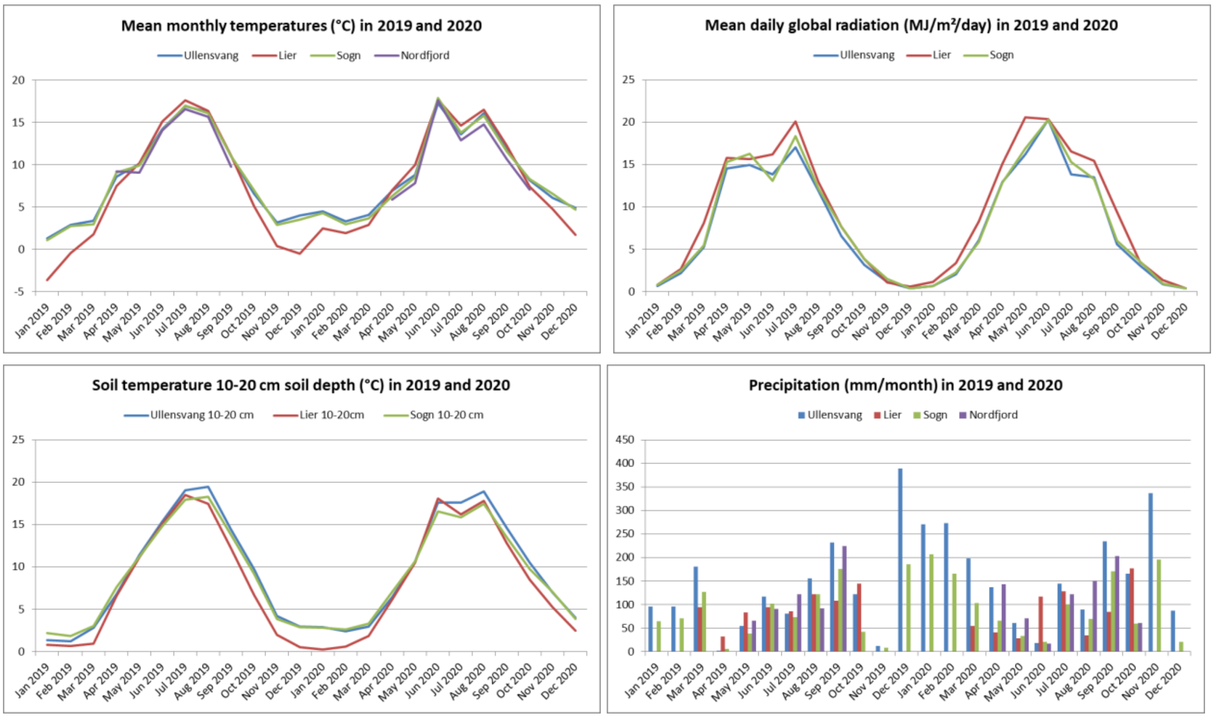


Figure 1. Weather conditions in regions Lier, Nordfjord, Sogn and Ullensvang in 2019 and 2020. Values are the monthly average of mean daily air temperature, soil temperature, global radiation and total amounts of precipitation per month.

3.2 Soil analysis

3.2.1 pH of orchard soils in Lier, Sogn, Nordfjord and Ullensvang regions

The pH of the soils of the orchards in the four different apple growing regions in Norway was determined by two different laboratories of Eurofins. The results of the samples taken in the years 2018, 2019 and 2020 are presented in figures 2 and 3. The pH of the soils of most of the orchards varied between 5.1 and 7.0 in the analyses of Eurofins Germany (Figure 2) and between 4.1 and 6.2 in the analyses of Eurofins Netherlands (Figure 3). In the Lier region the soil of orchard L2 had the highest pH and orchard L6 the lowest pH. In the Nordfjord region orchard N2 had the lowest pH but the difference in soil pH compared to the other two orchards was very small. In the Sogn region the soils of orchards S1 and S3 had a slightly lower pH than the soils of orchards S2 and S4 in the Eurofins

Germany analysis (Figure 2). However, hardly any differences between the pH of these soils was noted in the soil analysis of Eurofins Netherlands (Figure 3). The soil pH values of orchards in the Ullensvang region were highest for orchards U4, U5, U6 and U9.

At Eurofins Germany pH is measured in a suspension of soil and destilled water while at Eurofins Netherlands a 0.01 M $CaCl_2$ solution is used. This difference in method can explain the lower pH measured at Eurofins Netherlands compared to Eurofins Germany for almost all soils. The pH results are more sensitive for small variations when water is used. This is reflected in the results in figure 2 and figure 3.

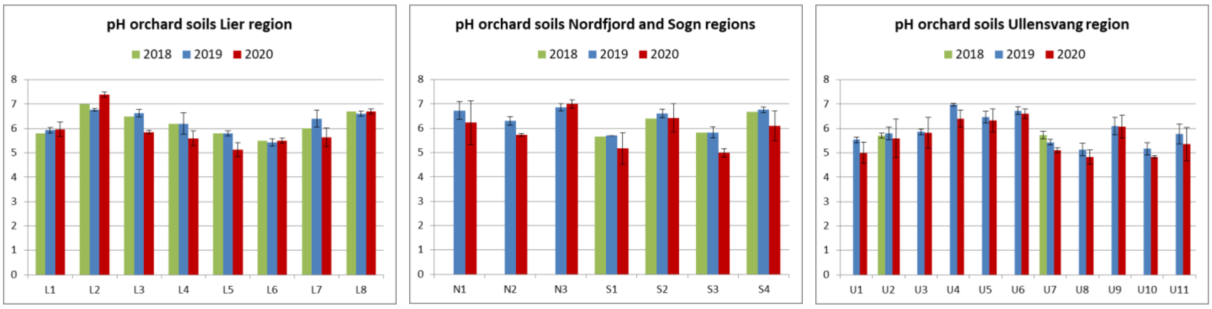


Figure 2. pH values of orchard soils determined by Eurofins Germany. Data 2019 and 2020 are the means of three replicated samples ± standard deviation.

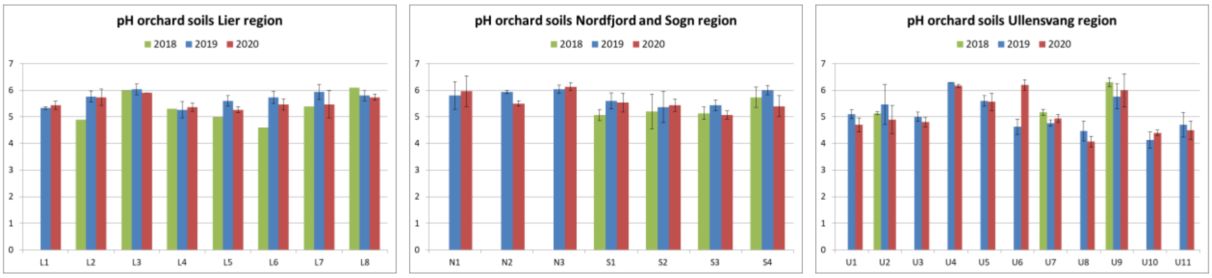


Figure 3. pH values of orchard soils determined by Eurofins Netherlands. Data 2019 and 2020 are the means of three replicated samples ± standard deviation.

3.2.2 Soil structure and organic matter of orchards in Lier, Nordfjord, Sogn and Ullensvang regions

The percentage organic matter in the orchard soils varied strongly between orchards in all regions. In Lier region it varied between about 1% to 5%, in Nordfjord region between 3% and 7%, in Sogn regions between 3% and 10%, and in Ullensvang region between 3% and 10% (Figure 4). The percentages of sand, silt and clay particles also varied strongly between soils of the orchards in all regions. For sand it varied between about 20% to 65% in Lier region, 50% to 70% in Nordfjord region, 30% to 70% in Sogn region, and 20% to 90% in Ullensvang region. For silt these percentages were 20% to 60%, 18% to 35%, 15% to 50%, and 0% to 55% for soils in Lier, Nordfjord, Sogn and Ullensvang region, respectively (Figure 4.). The percentages of clay were low in most of the orchards soil and varied between about 2% and 15% in all regions, except for the soil of orchard U2 in Ullensvang region that contained 30% clay. The percentage of total organic carbon in the orchard soils determined by Eurofins Germany showed the same variation in levels as determined for the percentage of organic matter by Eurofins Netherlands (Figure 4). The carbon content in soil organic matter is normally in the range of 50-55%.

By multiplying % organic carbon by a factor of 1.8-2 gives the content of soil organic matter which is well reflected in table 4 and table 5.

Figure 4. Organic matter, sand, silt and clay content of orchards soils in Lier, Nordfjord, Sogn and Ullensvang regions determined by Eurofins Netherlands in soil samples taken in 2019 and 2020. Data are the means of three replicated samples ± standard deviation.

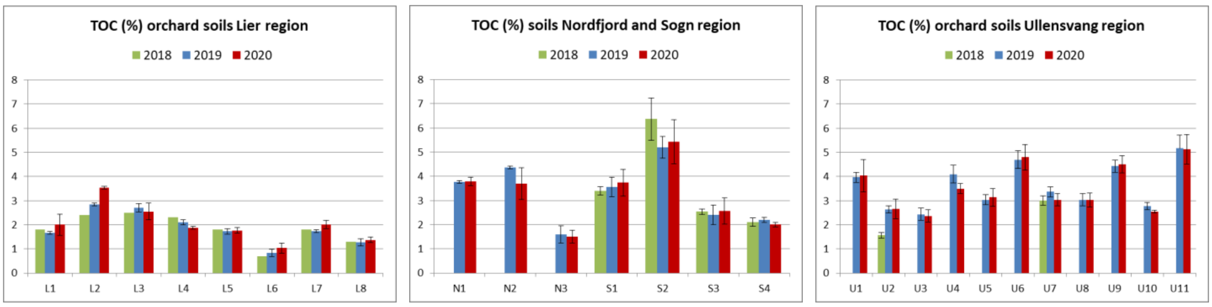


Figure 5. Percentage total organic carbon in soil of orchards in Lier, Nordfjord, Sogn and Ullensvang regions determined by Eurofins Germany in soil samples taken in 2018 to 2020. Data 2019 and 2020 are the means of three replicated samples ± standard deviation.

3.2.3 Cation exchange capacity (CEC) of orchard soils in Lier, Nordfjord, Sogn and Ullensvang regions

The cation exchange capacity (CEC) of a soil is a measure of the amount of positively charged ions (cations) like Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} and H^{+} that can be bound by negatively charged soil particles at the soil pH (Effective CEC). Clay and organic matter are the two most important soil components determining soil CEC. The analysis of percentage CEC saturation provides information about the extent the available negatively charged soil particles are occupied by positively charged base cations like Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} . If CEC saturation is lower than 100% it means that other cations than the base cations also occupied the exchangeable sites.

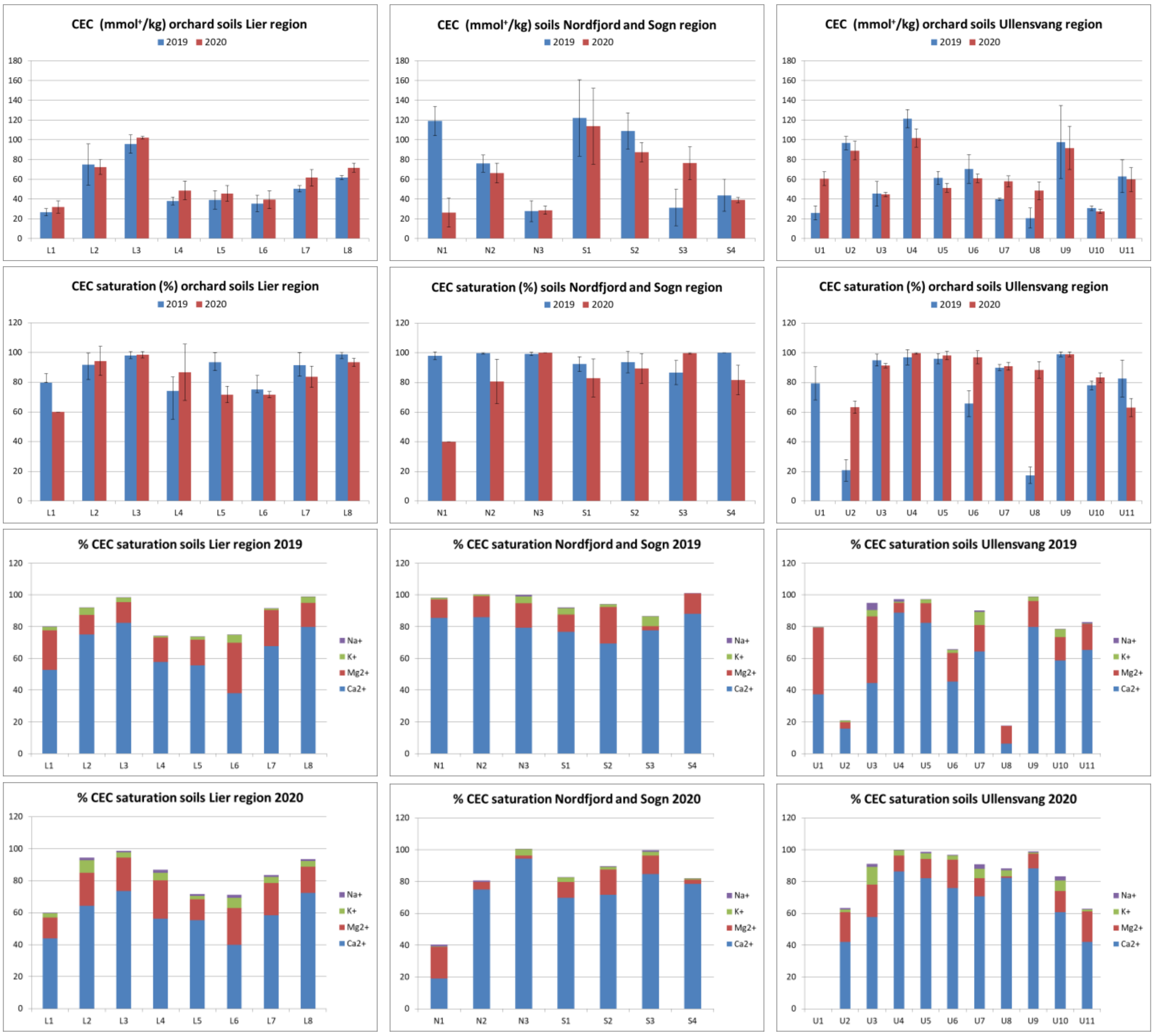


Figure 6. CEC values of orchards soils in Lier, Nordfjord, Sogn and Ullensvang regions as determined by Eurofins Netherlands for soil samples taken in 2019 and 2020. Data CEC and CEC-saturation are the means of three replicated samples ± standard deviation.

As shown in figure 6 the CEC values also differed strongly between orchards in all regions and varied between about 20 to 120 mmol+/kg soil. In most orchards CEC-saturation was 80% to 100% in both 2019 and 2020. However, soils of orchards U2 and U8 (Ullensvang), and L1 (Lier) and N1 (Nordfjord) showed much lower CEC saturation levels in either 2019 or 2020. In all soils calcium ions were the predominant ions and accounting for 40 to 90% CEC-saturation. Only soils of orchard U8 in

Ullensvang region in 2019 and N1 (Nordfjord) in 2020 showed relatively large contributions of magnesium ions in CEC-saturation in a situation in which total saturation levels were as low as 20 to 40%. A low level of CEC saturation indicates a low availability of cations for uptake by plant roots and a necessity to increase fertilization.

3.2.4 Macro and micro nutrient concentrations in orchard soils in Lier, Nordfjord, Sogn and Ullensvang regions

Soil nutrient concentrations in the orchard soils collected in orchards of the four fruit growing regions was analyzed by two different laboratories of Eurofins using different extraction procedures. The results of the ammonium lactate extraction method used by Eurofins Germany are presented in figures 7 and 9 for the macro and micro nutrients, respectively. The results of the extraction method used by Eurofins Netherlands are presented in figures 8 and 10. The results of the Eurofins Germany method are expressed per kg of soil, those of Eurofins Netherlands per ha of orchard. In addition to the total amounts of nutrients the Eurofins Netherlands method also gives a value for the amount of nutrients available for uptake by the trees taking into account soil properties like pH, CEC and soil structure.

Total nitrogen content of the orchard soils showed significant differences between orchards both within the same region as between regions (Fig 7). The total N content seems very well correlated with the content of organic matter shown in figure 4. Soils in the Lier region contained around 0.1% on average the lowest for orchard L6 and with about 0.28% the highest for orchards L2 and L3. In general the differences in %N between the years 2018 and 2020 were low and for most orchards less than 0.5%. In the Nordfjord regions the lowest N-content of 0.12% was found in soils of orchard N3, the highest of 0.35% for orchard N2. Also in the Sogn region the differences in N-content between soils was large and varied between 0.2% for orchard S2 to around 0.5% for orchard S2. A somewhat different picture emergences of the soil N-contents from the soil analyses made by Eurofins Netherlands and expressed as kg/ha total N. To convert an amount of 0.2 % N (2 g/kg soil) to an amount per ha a conversion factor for soil bulk is used. In the handbook Marschner's Mineral Nutrition of Higher Plants an example of such a calculation is given for a soil with a bulk density of 3 million kg soil/ha for the top soil layer of 20 cm (1.50 kg soil/dm^3). This means that concentration 2 g N/kg soil in the 20 cm of the soil contains 3,000,000 x 2 g = 6000 kg N/ha (Marschner and Rengel (2012).

Phosphate levels (P-AL) in soils in Lier region were generally between 100 and 200 mg/kg with small differences between the years 2018 to 2020. Orchard L2 had a much higher soil P-content of about 500 to 600 mg/kg (Figure 7). Soils in the Nordfjord, Sogn and Ullensvang regions also showed similar levels of phosphate content with the highest levels for orchards N1, S4, U4 and U9. Figure 8 shows the P-content of the soils expressed as kg/ha and the amounts available for plant uptake as calculated by the laboratory of Eurofins Netherlands. This data clearly show that P-availability is not directly related to the total P-content of the soil and is in most orchards only a few percent of the stock P-content. The results show, however, that the total P-stock and the standard Norwegian P-AL method (Figure 7) seems well correlated.

Potassium levels (K-AL) analyzed by Eurofins Germany were between 100 and 250 mg/kg in soils of Lier, Nordfjord and Sogn regions with relatively small differences between orchards and years (Figure 7). Orchard soils in Ullensvang regions were much more variable in K-content, both between orchards and between years and varied between 50 and 420 mg/kg. Total K-stock content of the same soil samples analyzed by Eurofins Netherlands gave a somewhat different result (Figure 8). Plant available K-content was generally very high. In many soils plant available K was even higher than the total K stock which should be impossible and show an uncertainty in the results reported by the laboratory.

Soil calcium contents (Ca-AL) varied between about 500 and 2500 mg/kg for orchards in Lier, Nordfjord and Sogn regions (Figure 7). Large differences in Ca-content were observed between orchard soils in Ullensvang region from 500 mg/kg for orchards U8 to 9000 mg/kg for U4. Remarkably, the results of total Ca-stock analyzed by Eurofins Netherlands did not show the same differences between the four regions. In all regions total Ca-stock varied from less than 500 up to about 5000 mg/kg. A high stock Ca-content did not always result in a high amount of plant available calcium. E.g. the high stock Ca-content of orchard N1 did not result in a higher amount of plant-available Ca than that of orchard N3 with a much lower total Ca-stock amount (Figure 9).

Magnesium content (Mg-AL) varied between 50 and 150 mg/kg (Figure 7) or 100 to 400 kg/ha (Figure 8) for most of the orchards soils in all regions. The results of the Eurofins Germany analyses gave the highest Mg content of 300 mg/kg for orchard S2 (Figure 7), whereas the results of Eurofins Netherlands gave the highest values for total Mg-stock of about 750 kg/ha for both orchards L3 and S2 (Figure 8). Plant available Mg varied between 150 and 400 kg/ha for most orchard soil in all regions with a maximum level of about 540 kg/ha for orchard S2 (Figure 9).

Total sulphur stock of orchards soils in all regions varied between about 500 to 1500 kg/ha (Figure 9). Plant-available sulphur was 10 to 30 kg/ha for orchards in Lier, Nordfjord and Sogn regions. In Ullensvang regions some orchards soils showed slightly higher levels of plant available sulphur and much higher available S-levels of 150 up to 250 kg/ha were found for soils of orchards U7 and U9 (Figure 9).

Soil contents of the micro nutrients Mn, Fe, B, Cu, Zn and Mo were very variable for soils in all regions and between orchards in each region (Figure 10). Particularly Fe and B showed large variation between orchard sites and between consecutive years. Remarkably these differences were far less in the results of the analyses done by Eurofins Netherlands (Figure 12). For Mo most of the results are apparently lower than the detection limit for the method used.

Figure 7. Macronutrient elements in soils of orchards in Lier, Nordfjord, Sogn and Ullensvang regions determined by Eurofins Germany. Data are the means of three replicated samples ± standard deviation.

Figure 8. Soil contents and plant-available amounts of macronutrient elements in orchards in Lier, Nordfjord, Sogn and Ullensvang regions in 2019 and 2020 determined by Eurofins Netherlands. Data are the means of three replicated samples ± standard deviation. Continued on next page.

Figure 9. (continued from previous page). Soil contents and plant-available amounts of macronutrient elements in orchards in Lier, Nordfjord, Sogn and Ullensvang regions in 2019 and 2020 determined by Eurofins Netherlands. Data are the means of three replicated samples ± standard deviation.

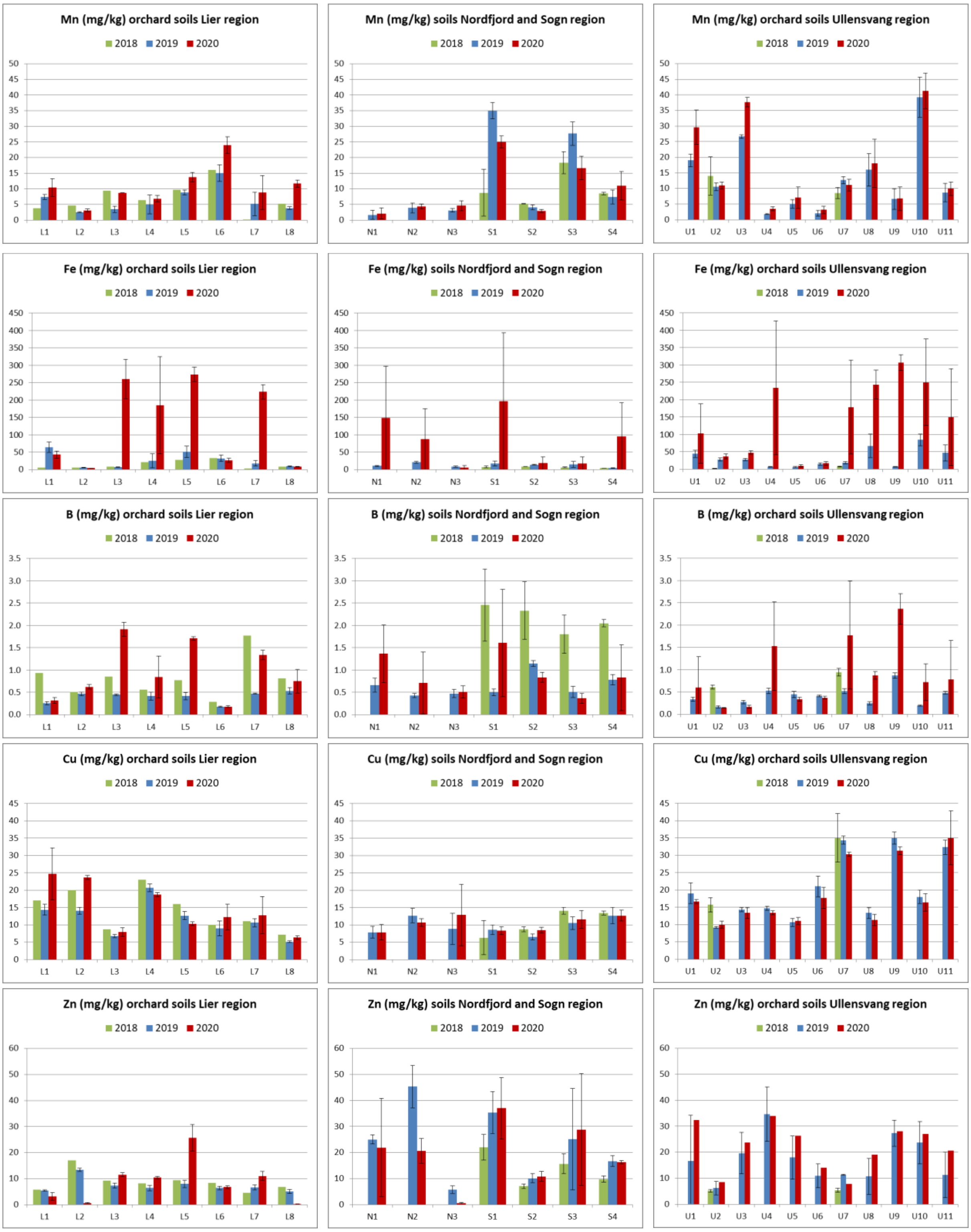
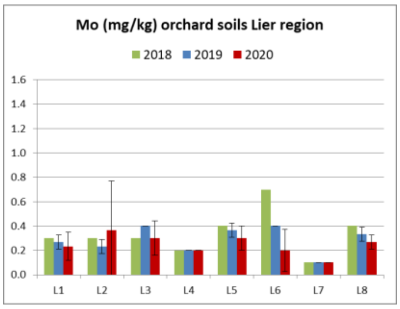
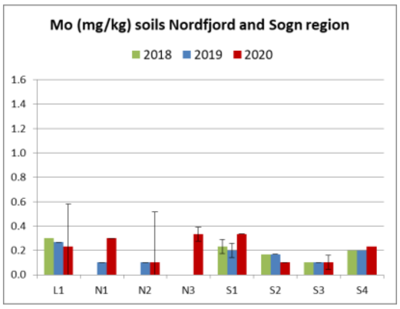


Figure 10. Micronutrient elements in soils of orchards in Lier, Nordfjord, Sogn and Ullensvang regions determined by Eurofins Germany. Data are the means of three replicated samples ± standard deviation. Continued on next page.





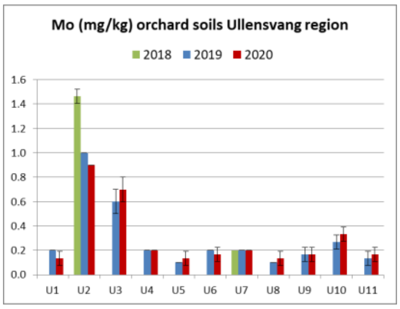


Figure 11. **(continued from previous page). Micronutrient elements in soils of orchards in Lier, Nordfjord, Sogn and Ullensvang regions determined by Eurofins Germany. Data are the means of three replicated samples ± standard deviation.**

Figure 12. Plant-available amounts of micronutrient elements in orchards in Lier, Nordfjord, Sogn and Ullensvang regions in 2019 and 2020 determined by Eurofins Netherlands. Data are the means of three replicated samples ± standard deviation.

3.2.5 Growth and flowering of apple trees in orchards in Lier, Nordfjord, Sogn and Ullensvang regions

The height and trunk diameter of the trees was measured annually at the end of the growing season. In most orchards the annual pruning limited the height of 2.5 to 3.0 m (Figure 13). Trunk diameters differed significantly between orchards which are most likely explained by the different age of the trees. In the regions Nordfjord, Sogn and Ullensvang the number of branches with a length of more than 10 cm was counted in 2019 and 2020. Nordfjord and Ullensvang some differences in numbers of branches was observed which may be related to differences in pruning strategies between growers or the result differences in tree vigour caused by soil nutrient availability, amounts of fertilizer applied or tree crop load levels.

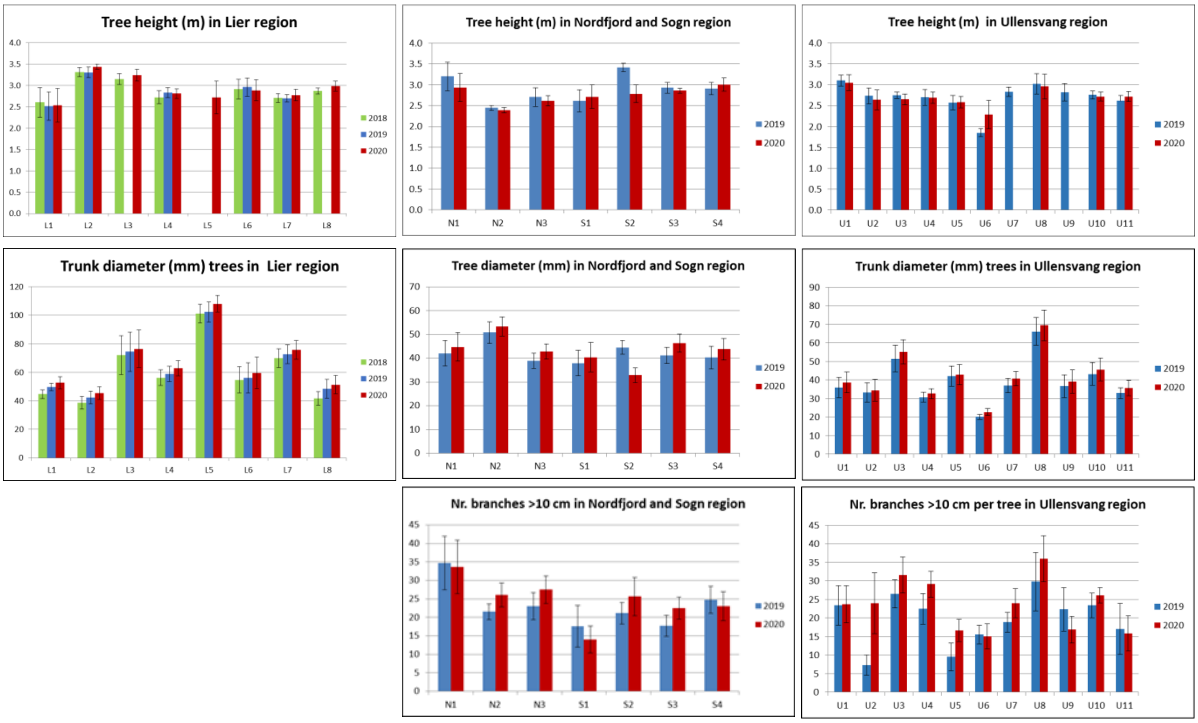


Figure 13. Tree height, trunk diameter and numbers of branches >10 cm per tree of apple trees in Lier, Nordfjord, Sogn and Ullensvang regions in 2018, 2019 and 2020. The data represent the means of the replicated plots ± standard deviation. See table 1 for coding of cultivars.

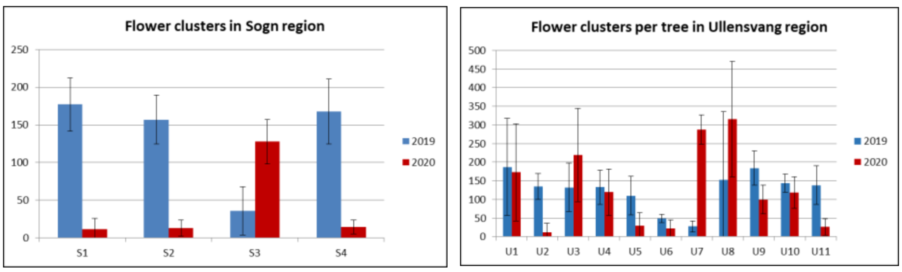


Figure 14. Flower clusters per tree of apple trees in, Sogn and Ullensvang regions in 2019 and 2020. The data represent the means of the replicated plots ± standard deviation. See table 1 for coding of cultivars.

Flower clusters of the trees were counted only in the orchards in the Sogn and Ullensvang region. All orchards in the Sogn region and several of the orchards in the Ullensvang regions showed a clear pattern of biennial bearing. In the Sogn region the 'Discovery' trees in orchards S1, S2 and S4 had high numbers of flower buds in 2019 followed by very low numbers in 2020. The reverse pattern was seen for the 'Rubinstep' trees in orchard S3 (Figure 14). In Ullensvang the 'Discovery' trees in orchards U2, U5 and U11 also flowered much more abundant in 2019 than in 2020. ‘Summerred’ trees in orchards U4 and U10 had about 120 flower clusters in both 2019 and 2020 while in orchard U7 ‘Summerred’ trees showed strong biennial bearing with only about 30 flower clusters in 2019 followed by almost ten times more flower clusters in 2020. The number of flower clusters and biennial bearing tendency in ‘Aroma’ trees in Ullensvang varied strongly between orchards. Trees in orchard U1 had about 175 flower clusters in both 2019 and 2020, trees in orchard U3 had on average t 140 flower clusters in 2019 followed by 210 in 2020. The ‘Aroma’ trees in orchard U8 showed very large differences in flower clusters between the trees. On average they had almost twice as many flower clusters in 2020 than in 2019 . However, the variation between trees was too large to make this difference statistically significant.

3.2.6 Yield of apple trees in Lier, Nordfjord, Sogn and Ullensvang regions

The numbers of fruits, total yield, average fruit weight and the percentage of the yield existing of fruits larger than 60 mm is presented in figure 15. In all four regions the numbers of fruits and total yield varied considerably between orchards and often also between trees in the same orchard. Unfortunately no data for number of fruits and yield were obtained for orchard S1 in Sogn region because the fruits were already harvested by the grower before the observations were made.

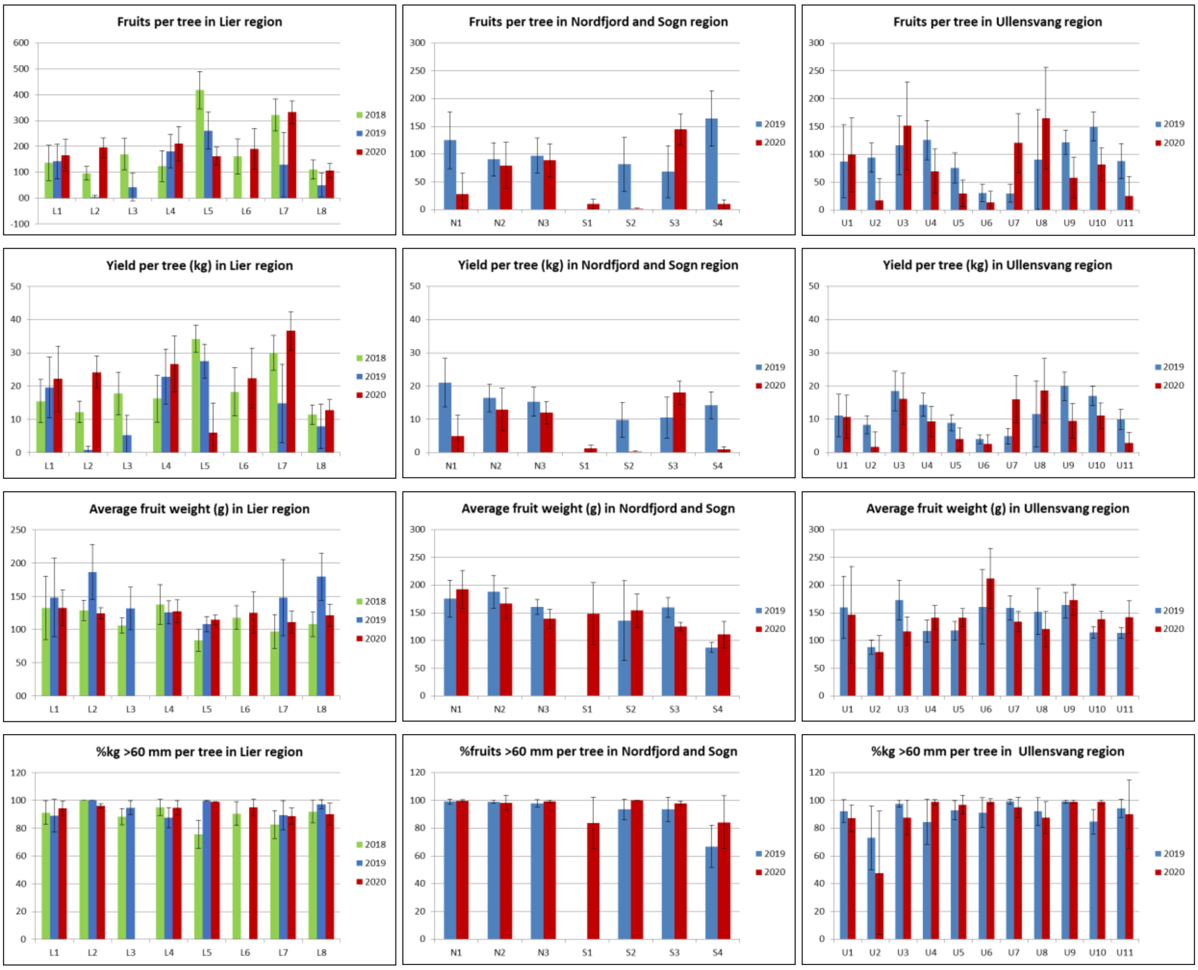


Figure 15. Fruits, yield, average fruit weight and %kg fruits >60 mm per apple tree in Lier, Nordfjord, Sogn and Ullensvang regions in 2018, 2019 and 2020. The data represent the means of the replicated plots ± standard deviation. See table 1 for coding of cultivars.

For the orchards where the flower clusters were counted (see figure 14), the numbers of harvested fruits and total yield were positively related to the number of flower clusters. Average fruit weight generally decreased with an increase in number of fruits per tree. In Lier regions the 'Discovery' trees in orchard L5 that had about the highest numbers of apples and yield. However, this high yields per tree resulted in an average fruit weight of only 84 grams and the lowest yield percentage of fruits larger than 60 mm. In Ullensvang region the 'Discovery' trees in orchard U2 had a surprisingly low average fruit weight and low yield percentage of fruits >60 mm considering the low crop load of the trees and the higher average fruit weights for 'Discovery' in orchards U5 and U11 which had about the same crop loads as orchard U2. Compared to U5 and U11 the soil in U2 is low in organic matter, low in P-AL, Mg-AL, Ca-AL and in Zn. All these factors may influence on the yield and the fruit weight.

3.2.7 Fruit quality of apples in Lier, Nordfjord, Sogn and Ullensvang regions

Fruit quality parameters were determined in 2019 and 2020. The results for the ground colour and blush colour of the apple peel, fruit firmness, seed content, contents of solids , acids and starch of the different cultivars grown in the Lier, Nordfjord, Sogn and Ullensvang regions are presented in tables 4, 5, 6 and 7, respectively. All fruit quality parameters varied considerably, not only between cultivars but also between orchards, regions and years. Fruit maturity at time of harvest can be determined on the basis of ground colour, firmness and starch content. For all varieties observed in these study high values for blush colour and soluble solids are a prerequisite for a high valuation their fruit quality by consumers. Seed number and total seed weight per fruit are an indication of effective pollination and fruit set in the orchards.

Table 4. Results fruit quality analyses apples orchards Lier region. Data 2019 represent a single sample, data of 2020 the means of a sample of 10 individual fruits each ± standard deviation or a combined sample of 10 fruits (soluble solids, acids).

Year Orchard Cultivar[1]	Ground Colour[2]		Blush Colour[3]		Firmness (kg)		Nr. seeds		Total seed weight (g)		Soluble Solids (°Brix)	Acids (g/l)	Starch[4]	
2019														
L1 - RA	5.7		7.2		6.2		2.4		0.14		11.6	8.9	-	
L2 - RA	3.2		3.5		6.0		1.7		0.10		14.5	10.6	-	
L3 - RA	-		-		-		-		-		-	-	-	
L4 - RA	4.4		6.6		6.4		0.4		0.03		12.6	8.9	-	
L5 - Di	-		-		-		-		-		10.6	5.9	-	
L6 - RA	-		-		-		-		-		-	-	-	
L7 - RA	6.3		6.3		5.7		3.1		0.18		11.6	8.5	-	
L8 - Ru	-		-		-		-		-		-	-	-	
F-test	n.a.		n.a.		n.a.		n.a.		n.a.		n.a.	n.a.		
2020														
L1 - RA	6.3	b	7.7	a	7.5	b	4.5	cd	0.14	cd	11.4	8.0	3.8	bcd
L2 - RA	4.2	c	6.6	ab	7.1	bc	6.9	bc	0.31	b	12.2	8.6	3.6	cd
L3 - RA	6.4	b	7.0	ab	7.8	b	6.1	bcd	0.27	bc	11.1	8.0	4.3	bc
L4 - RA	6.3	b	6.8	ab	7.3	bc	0.9	e	0.05	d	12.7	9.8	2.2	d
L5 - Di	5.3	bc	6.5	ab	7.7	b	7.6	ab	0.48	a	12.3	6.9	4.2	bc
L6 - RA	5.4	bc	5.6	b	7.4	bc	3.2	de	0.12	cd	10.3	8.2	3.8	bcd
L7 - RA	6.5	b	6.3	ab	6.7	c	5.3	bcd	0.27	bc	10.8	8.6	5.5	ab
L8 - Ru	8.3	a	7.8	a	8.7	a	10.3	a	0.41	ab	13.6	6.1	7.0	a
F-test	***		**		***		***		***		n.a.	n.a.	***	

[1]Cultivars: Ar = Aroma, Di = Discovery, RA = Red Aroma, Ru =Rubinstep. [2]Scores: 1 (=green) to 9 (=yellow); [3]scores: 1 (=no red blush) to 9 (=100% red blush surface colour); [3]scores: 1 (=100% starch) to 9 (no starch). Values within columns and year followed by different letters differ significantly at P<0.05 (*), P<0.01 (**) or P<0.001 (***). n.a.= not analyzed (single replicate).

Low numbers of seeds illustrate poor pollination conditions caused by either a lack of suitable pollinizer trees with overlapping flowering times, insufficient pollinating insects or poor weather conditions during bloom. In general, fruits with more seeds and better developed seeds are more capable of importing assimilates and will become larger with higher levels of soluble sugars than fruits with less seeds.

In Lier region statistically significant differences were observed in 2020 for all fruit quality parameters except total soluble solids and acids (Table 4). Fruits with the lowest values for ground colour, i.e. fruits with the greenest background skin colour, were observed in cultivar 'Red Aroma' grown in orchard L2, the highest values for 'Rubinstep' grown in orchard L8. Blush colour was lowest for 'Red Aroma' in orchard L7 and highest for 'Rubinstep' in orchard L8. 'Rubinstep' apples in orchard L8 had the highest values for firmness and number of seeds. Between the six 'Red Aroma' orchards in Lier region significant differences were observed in ground colour, blush colour, firmness, seed numbers, seed weight content.

In Nordfjord region ground and starch colour of 'Summerred' was significantly lower than that of 'Red Aroma' in 2019 (Table 5). This greener ground colour of 'Summerred' together with the significantly higher value of fruit firmness and lower starch index value (=higher starch content) indicate a less advanced ripening stage of 'Summerred' than of 'Red Aroma'. The reverse observations were made in 2020, i.e. a less green ground colour, a lower firmness and a higher starch content in 'Summerred' compared to 'Red Aroma' apples. Another remarkable observation was the very low seed numbers per fruit in both years for 'Summered', indicating poor pollination conditions in orchard N3.

Table 5. Results fruit quality analyses apples orchards Nordfjord region. Data represent the means of three replicated samples of 20 or 10 (soluble solids, acids) fruits each ± standard deviation.

Year Orchard Cultivar[1]	Ground Colour[2]	Blush Colour[3]	Firmness (kg)	Nr. seeds	Total seed weight (g)	Soluble Solids (°Brix)	Acids (g/l)	Starch[4]
2019								
N1 - RA	5.2 a	7.8	6.9 b	6.8 a	0.35 a	11.5	8.3	8.8 a
N2 - RA	4.9 a	7.7	6.7 b	5.0 b	0.27 b	11.3	8.2	8.6 a
N3 - Su	4.0 b	7.5	8.1 a	1.6 c	0.12 c	11.5	9.3	6.0 b
F-test	***	NS	***	***	***	NS	NS	***
2020								
N1 - RA	4.1 b	7.4	7.7 a	6.4 a	0.23 a	11.9	9.5 a	6.3 b
N2 - RA	4.7 b	7.1	6.7 b	3.7 b	0.15 ab	11.5	6.4 b	7.8 a
N3 -Su	5.7 a	7.4	6.4 b	2.2 b	0.13 b	12.4	9.1 a	7.4 a
F-test	***	NS	***	***	*	NS	**	*

[1]Cultivars: RA = Red Aroma; Su = Summerred. [2]Scores: 1 (=green) to 9 (=yellow); [3]scores: 1 (=no red blush) to 9 (=100% red blush surface colour); [4]scores: 1 (=100% starch) to 9 (no starch). Values within columns and year followed by different letters differ significantly at P<0.05 (*), P<0.01 (**) or P<0.001 (***). NS = not significant.

In Sogn region 'Rubinstep' in orchard S3 had a significantly lower blush colour, a higher firmness, higher seed number and seed weight, and a lower starch index value than those of 'Discovery' in orchards S1, S2 and S4 in 2019 (Table 6). In 2020 the differences in these fruit quality parameters between 'Summerred' and 'Discovery' were less pronounced. Seed numbers in 'Rubinstep' in orchard S3 were significantly higher seed numbers than 'Discovery' up to as high as more than 13 per fruit in 2019. Similar high numbers of 13 to 14 seeds per fruit were also found in 2018 in 'Rubinstep' grown in Lofthus-Ullensvang (Maas et al., 2020). As normally 10 seeds per fruit is the maximum seed number for apples, these exceptionally high seed number seem to be specific trait of 'Rubinstep'.

Table 6. **Results fruit quality analyses apples orchards Sogn region. Data 2019 represent the means of 20 fruits ± standard deviation or single combined sample of 10 fruits (soluble solids, acids). Data 2020 are the means of three replicated samples of 20 or 10 fruits (soluble solids, acids) fruits each ± sd.**

Year Orchard Cultivar[1]	Ground Colour[2]	Blush Colour[3]	Firmness (kg)	Nr. seeds	Total seed weight (g)	Soluble Solids (°Brix)	Acids (g/l)	Starch[4]
2019								
S1 - Di	-	-	-	-	-	-	-	-
S2 - Di	6.1 a	6.0 a	7.3 b	7.6 b	0.39 b	10.5	6.2	10.0 a
S3 - Ru	5.3 ab	2.3 b	10.6 a	13.4 a	0.67 a	11.5	6.9	8.3 b
S4 - Di	5.1 b	5.9 a	6.3 c	6.2 b	0.36 b	10.3	6.5	10.0 a
F-test	*	***	***	***	***	-	-	***
2020								
S1 - Di	5.3	6.2 a	8.5 ab	4.0 c	0.24 b	14.0 a	8.2 a	6.4 c
S2 - Di	5.6	6.7 a	7.9 b	5.9 b	0.35 ab	13.4 ab	6.5 b	8.9 b
S3 - Ru	5.9	5.8 a	8.9 a	9.5 a	0.37 a	12.8 b	6.9 b	9.9 a
S4 - Di	5.5	4.3 b	8.1 b	6.4 b	0.39 a	13.2 ab	7.0 b	8.8 b
F-test	NS	***	***	***	***	*	**	**

[1]Cultivars: Di = Discovery, Ru =Rubinstep. [2]Scores: 1 (=green) to 9 (=yellow); [3]scores: 1 (=no red blush) to 9 (=100% red blush surface colour); [4]scores: 1 (=100% starch) to 9 (no starch). Values within columns and year followed by different letters differ significantly at P<0.05 (*), P<0.01 (**) or P<0.001 (***). NS = not significant.

Table 7. **Results fruit quality analyses apples orchards Ullensvang region. Data represent the means of three replicated samples of 20 or 10 (soluble solids, acids) fruits each ± standard deviation.**

Year Orchard Cultivar[1]	Ground Colour[2]	Blush Colour[3]	Firmness (kg)	Nr. seeds	Total seed weight (g)	Soluble Solids (°Brix)	Acids (g/l)	Starch[4]
2019								
U1 - RA	5.6 cd	7.5 bcd	7.1 cd	4.1 gh	0.22 e	12.0 ab	8.2 bc	5.5 de
U2 - Di	5.4 d	7.6 bcd	7.3 c	7.8 ab	0.44 b	10.1 c	5.9 d	8.7 a
U3 - RA	6.3 ab	8.1 a	7.1 cde	6.0 cde	0.38 bc	11.1 abc	8.1 c	6.2 cd
U4 - Su	3.8 f	7.3 cde	8.7 a	5.3 efg	0.38 bc	10.8 bc	8.4 b	6.9 bc
U5 - Di	6.7 a	7.8 abc	7.8 b	8.6 a	0.59 a	10.1 c	6.1 d	7.4 b
U6 - RA	5.9 bcd	8.2 a	6.7 de	5.0 efg	0.27 de	10.9 bc	7.4 bcd	5.0 ef
U7 - Su	4.7 e	6.8 e	8.7 a	4.4 fgh	0.31 cd	12.8 a	11.0 a	6.1 cde
U8 - Ar	6.2 abc	8.0 ab	7.8 b	6.9 bcd	0.33 cd	12.0 ab	8.3 b	4.1 f
U9 - RA	3.4 f	5.5 f	6.6 e	3.2 h	0.19 e	10.8 bc	8.0 bc	7.6 ab
U10 - Su	4.0 ef	7.2 d	8.8 a	5.6 def	0.41 b	9.8 c	6.7 cd	7.0 bc
U11 - Di	5.7 bcd	7.7 abcd	6.6 e	7.0 bc	0.44 b	10.6 bc	6.1 d	7.6 ab
F-test	***	***	***	***	***	***	***	***
2020								
U1 - RA	4.3 de	7.1 b	6.8 cd	3.0 cde	0.20 cde	11.5 ab	5.8 c	7.0 abc
U2 - Di	5.7 ab	7.6 ab	10.4 a	7.3 a	0.33 b	11.3 ab	7.9 bc	4.2 d
U3 - RA	5.1 bc	8.1 a	7.2 c	4.8 b	0.24 bcd	10.4 ab	5.6 c	7.5 a
U4 - Su	6.0 a	7.4 ab	8.8 b	1.4 f	0.11 ef	11.8 ab	11.4 a	5.3 cd
U5 - Di	4.5 cde	5.6 cd	8.9 b	7.5 a	0.53 a	13.0 ab	8.7 ab	3.9 d
U6 - RA	3.8 e	7.2 ab	6.3 d	4.9 b	0.29 bc	12.5 ab	7.7 bc	6.6 abc
U7 - Su	5.3 abc	7.3 ab	7.2 c	2.2 def	0.13 def	11.5 ab	10.4 ab	7.0 ab
U8 - Ar	4.9 bcd	7.0 b	6.8 cd	3.4 bcd	0.27 bc	10.8 ab	5.7 c	7.9 a
U9 - RA	4.1 de	4.2 e	7.1 c	1.7 ef	0.04 f	-	-	6.2 abc
U10 - Su	5.4 ab	6.6 bc	8.6 b	2.6 def	0.20 cde	8.1 b	10.7 a	5.4 bcd
U11 - Di	6.1 a	5.5 d	8.3 b	4.4 bc	0.30 bc	13.9 a	8.7 ab	4.3 d
F-test	***	***	***	***	***	P=0.06	***	***

[1]Cultivars: Ar = Aroma, Di = Discovery, RA = Red Aroma, Su = Summerred. [2]Scores: 1 (=green) to 9 (=yellow); [3]scores: 1 (=no red blush) to 9 (=100% red blush surface colour); [4]scores: 1 (=100% starch) to 9 (no starch). Values within columns and year followed by different letters differ significantly at P<0.05 (*), P<0.01 (**) or P<0.001 (***).

In Ullensvang region fruit quality observations were made in five (Red) 'Aroma', three 'Discovery' and three 'Summerred' orchards (Table 7). In both 2019 and 2020 significant differences were noted in several fruit quality parameters in all three cultivars. The lowest values for ground colour (greenest skin background colour) were observed for 'Red Aroma' and 'Summerred' in orchards U4 and U9 respectively, in 2019 and for 'Discovery' and 'Red Aroma' in orchards U5 and U9, respectively, in 2020. 'Red Aroma' showed the highest blush colour orchard U3 and the least blush colour in orchard U9 in in both years. In 2019 the highest fruit firmness was measured in 'Summerred' apples, significantly higher than the firmness of 'Red Aroma' and 'Discovery' in any of the other orchards. This probably is more likely to reflect a difference in ripening at the time of harvest in 2019 than a cultivar specific trait as in 2020 the firmness as well as the ground colour of 'Summerred' was similar that observed in several 'Discovery' and 'Red Aroma' orchards. Seed numbers per fruit varied strongly between orchards and between years, indicating differences in pollination conditions. In general, seed numbers in most of the orchards were lower in 2020 than in 2019. Most likely, this was due to the less favourable temperature conditions during flowering time in early May in Ullensvang region in 2020 than in 2019 (Figure 16). At temperature below 10 °C bee activity is low, limiting flower pollination and fruit set of the apple trees.

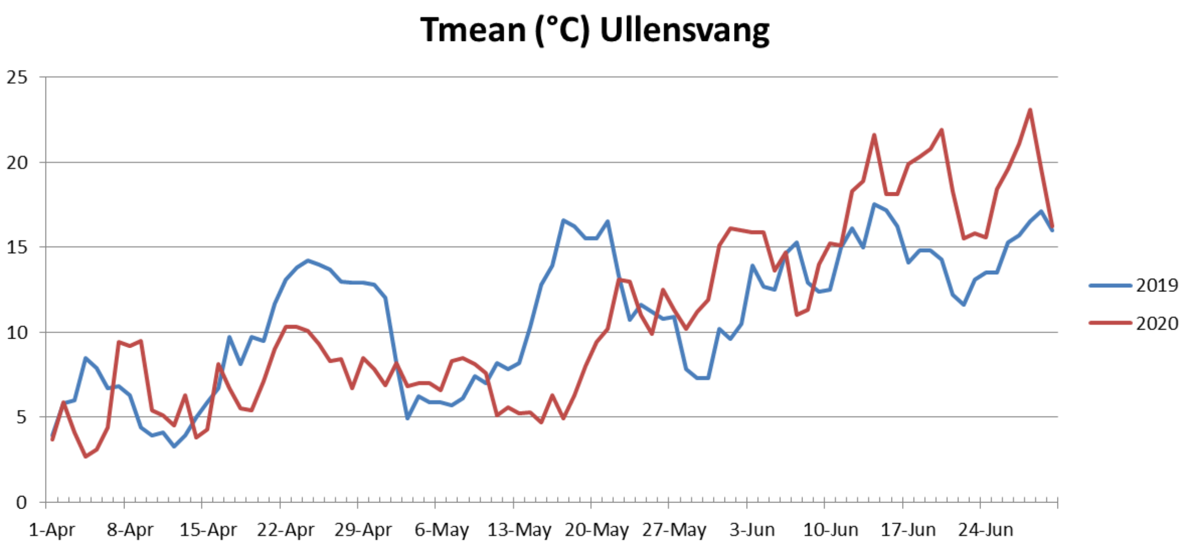


Figure 16. Average daily air temperature at 2 m above soil level in Ullensvang in April to June 2019 and 2020.

3.2.8 Leaf nutrient concentrations

Fruit tree growth, flower bud development, fruit set and fruit growth require adequate levels of nutrients for uptake by the trees. To determine the quantity of fertilizers to be applied to the orchard nutrient availability in the soil is needed. In addition the determination of leaf nutrients contents of leaves can be used to monitor if the uptake by the root systems has been adequate, too low or too high. In case of a deficiency in any of the necessary macro- or micronutrients an extra amount of this nutrient can be supplied to either the soil or leaves of the trees. Normally, leaf nutrient concentrations are measured by sampling of fully developed leaves of the middle part of annual shoots during in summer. Annual differences in weather conditions and crop load levels are known to give some fluctuations in leaf nutrient levels. Experiences for many studies with different cultivars and in different countries have resulted in target ranges for each of the macro- and micronutrients. In tables 7 to 9 the results of leaf concentrations of most important macronutrients C, N, P, K, Ca, Mg, Ca and S and micronutrients Mn, Fe, B, Cu, Zn and Mo are presented for leaves sampled in the orchards in the Lier, Nordfjord, Sogn and Ullensvang region. Results for any nutrient that are within the sufficiency range given in table 1, are marked light green in tables 8 to 10. Nutrient levels below sufficiency are marked in orange and those above the sufficiency range are marked dark green, respectively. Information on the physiological function and effects of deficiency of any of the macro- and micronutrients has been reviewed by Neilsen and Neilsen (2003) and Ličina et al. (2021).

Table 8. Leaf nutrient concentrations of trees in orchards Lier region. Data represent the means of 3 replicated samples of 25 leaves sampled 4 to 5 times in July to August. [1]Cultivars: Di = Discovery; RA = Red Aroma; Ru = Rubinstep.

Color coding critical nutrient concentrations: Below sufficiency | Sufficient | Above sufficiency

Orchard Cultivar[1]	C %	N %	P g/kg	K g/kg	Ca g/kg	Mg mg/kg	S g/kg	Mn g/kg	Fe mg/kg	B mg/kg	Cu mg/kg	Zn mg/kg	Mo mg/kg
2019													
L1-RA	47.5	2.1	2.1	16.7	6.3	3.1	1.3	54.2	41.7	17.0	7.5	39.5	0.21
L2-RA	47.3	1.8	2.1	19.9	7.1	2.6	1.1	59.3	41.6	38.0	4.9	22.7	0.20
L3-RA	47.8	1.9	2.1	16.6	8.0	2.4	1.3	30.2	60.6	15.4	4.7	11.0	0.29
L4-RA	48.1	2.4	2.2	17.2	6.6	3.4	1.4	71.4	44.0	18.0	6.5	15.8	0.11
L5-Di	48.2	2.5	2.7	16.1	8.2	3.3	2.1	82.8	56.0	29.8	8.8	35.9	0.10
L6-Ra	47.5	2.1	2.3	21.0	5.9	3.0	1.2	81.6	43.2	15.6	6.7	12.2	0.22
L7-RA	47.6	2.1	2.6	19.8	6.1	2.8	1.3	61.4	51.4	14.0	6.8	17.8	0.15
L8-Ru	48.6	2.0	1.7	15.6	7.0	2.7	1.1	35.2	51.8	23.6	7.5	12.3	0.24
2020													
L1-RA	47.8	2.3	1.8	16.0	7.4	3.2	1.3	51.3	37.3	24.3	6.1	35.5	0.25
L2-RA	47.7	2.8	2.0	14.3	12.8	3.1	1.7	139.0	46.8	32.0	6.3	67.0	0.32
L3-RA	48.2	2.1	2.2	17.3	9.9	2.1	1.3	30.0	60.8	17.5	4.5	11.3	0.45
L4-RA	47.6	2.2	1.9	16.3	7.1	2.9	1.2	84.5	46.3	31.0	5.5	75.0	0.27
L5-Di	47.9	2.1	2.1	17.3	6.7	2.5	1.6	56.8	36.8	24.0	6.4	15.3	0.09
L6-Ra	47.6	2.3	2.2	20.0	6.7	2.7	1.4	62.0	42.0	14.3	5.7	12.2	0.14
L7-RA	47.6	2.4	2.5	20.0	7.7	2.6	1.3	48.0	46.8	14.8	5.8	23.0	0.19
L8-Ru	48.3	2.0	1.9	16.5	9.2	3.0	1.5	69.5	72.8	30.8	5.7	21.5	0.19

Leaf carbon levels were very similar and were about 48% for all cultivars in all orchards in Lier and similar to the 47.9% found as average value for 'Fuji' on M.9 rootstock reported by Reig et al. (2018) (Table 2). Except for calcium (Ca), leaf nutrient concentrations for the apple cultivars grown in Lier region were mostly within their sufficiency range. Occasionally, levels were just below (mostly Fe and B or just above (Mo) the minimum or maximum level of the sufficiency range. In all cultivars and all orchards, except 'Red Aroma' in orchard L2 in 2020 the Ca-concentration was below sufficiency which may have a negative effect on the storability of the apples after harvest.

Leaves of the apple cultivars grown in Nordjord and Sogn regions had a similar carbon content of about 48% as in Lier region. Nitrogen, phosphate and sulphur content of the leaves were sufficient or just above sufficient in all cultivars and orchards in both years in Nordjord and Sogn (Table 9). Contrary to the orchards in Lier, potassium (K) and not calcium (Ca) was the nutrient most often below deficiency in Nordjord and Sogn in 2019 and to a lesser extent also in some orchards in 2020. Calcium was just below sufficiency in only two orchards in Nordjord in 2019 and one orchard each in Nordfjord and Sogn in 2020. Micronutrients zinc (Zn) and molybdenum (Mo) were deficient in 'Summerred' in orchard N3 in 2019. The low content of Zn is coincident with an extremely low content of Zn in the soil. High levels of molybdenum were observed in 'Discovery' and 'Rubinstep' in orchards S2, S3 and S4 in 2019 and in 'Red Aroma' and 'Discovery' in orchards N1, S2 and S4 in 2020. All other nutrients were within their sufficiency range or just a little bit below or above this range.

Table 9. Leaf nutrient concentrations of trees in orchards Nordfjord (N)and Sogn (S) region. Data represent the means of 3 replicated samples of 25 leaves sampled 4 to 5 times in July to August. [1]Cultivars: Ar = Aroma; Di = Discovery; RA = Red Aroma Ru = Rubinstep.

Color coding critical nutrient concentrations: Below sufficiency | Sufficient | Above sufficiency

Orchard Cultivar[1]	C %	N %	P g/kg	K g/kg	Ca g/kg	Mg mg/kg	S g/kg	Mn g/kg	Fe mg/kg	B mg/kg	Cu mg/kg	Zn mg/kg	Mo mg/kg
2019													
N1-RA	48.5	2.7	2.2	14.9	14.1	2.4	1.7	47.7	56.9	24.7	6.8	21.6	0.33
N2-RA	48.7	2.4	2.1	14.5	11.0	2.5	1.9	119.2	43.8	19.1	5.7	33.7	0.13
N3-Su	49.5	2.7	1.9	13.0	9.4	2.0	1.5	21.9	51.9	23.1	6.0	7.3	0.08
S1-Di	-	-	-	-	-	-	-	-	-	-	-	-	-
S2-Di	47.9	2.6	2.1	12.8	16.7	2.9	1.7	63.4	67.8	29.4	7.8	170.8	0.48
S3-Ru	47.6	2.4	2.0	12.8	16.0	2.5	1.6	79.8	67.9	27.3	7.8	97.5	0.36
S4-Di	48.0	2.7	2.2	12.8	17.6	2.7	1.6	70.8	67.8	25.6	7.4	38.0	0.50
2020													
N1-RA	47.5	1.8	2.3	18.5	12.0	1.9	1.2	20.9	47.9	21.4	4.5	10.6	0.41
N2-RA	48.1	2.3	2.0	14.8	13.0	2.6	1.6	100.7	47.2	19.4	5.6	49.7	0.17
N3-Su	48.8	2.5	2.1	12.5	11.7	2.1	1.5	17.1	48.5	24.8	5.7	10.9	0.10
S1-Di	48.2	2.4	2.0	18.9	11.1	2.5	1.5	66.5	90.1	23.3	6.0	23.2	0.17
S2-Di	47.8	2.6	2.3	15.5	16.6	3.2	1.7	54.0	87.2	31.5	7.8	41.7	0.52
S3-Ru	48.4	2.6	2.1	17.4	14.1	2.7	1.5	63.0	50.7	29.6	6.9	26.7	0.09
S4-Di	47.5	2.6	2.4	14.3	17.6	3.0	1.6	57.9	93.1	28.4	5.5	19.1	0.58

Leaf nutrient concentrations of the cultivars grown in Ullensvang region in 2019 and 2020 are presented in table 10. Leaf carbon contents were comparable with those of cultivars grown in Lier, Nordfjord and Sogn and amounted to 48% on average. Most of the nutrients were within or just a bit below or above their sufficiency ranges. Potassium (K), calcium (Ca) and magnesium (Mg) were the most often just below sufficiency in both years and molybdenum the often above sufficiency.

Table 10. Leaf nutrient concentrations of trees in orchards Ullensvang region. Data represent the means of 3 replicated samples of 25 leaves sampled 3 to 4 times in July to August. [1]Cultivars: Ar = Aroma; Di = Discovery; RA = Red Aroma; Su = Summerred.

Color coding critical nutrient concentrations: Below sufficiency | Sufficient | Above sufficiency

Orchard Cultivar[1]	C %	N %	P g/kg	K g/kg	Ca g/kg	Mg mg/kg	S g/kg	Mn g/kg	Fe mg/kg	B mg/kg	Cu mg/kg	Zn mg/kg	Mo mg/kg
2019													
U1-RA	47.9	2.2	1.8	10.6	16.9	2.9	2.0	94.2	68.4	30.1	8.4	61.7	0.26
U2-Di	49.0	2.5	2.2	14.6	12.5	2.9	1.8	57.6	57.8	21.7	10.6	24.3	0.52
U3-RA	48.8	2.3	2.1	15.8	12.2	2.3	1.7	63.8	73.9	23.2	5.9	27.8	0.48
U4-Su	49.0	2.5	1.8	11.1	13.3	2.2	1.7	29.3	66.8	22.3	6.5	13.8	0.21
U5-Di	48.5	2.4	2.0	15.8	11.9	2.4	1.6	54.8	65.6	26.3	7.8	17.9	0.20
U6-RA	49.1	2.5	2.4	17.8	12.8	2.6	1.9	35.8	69.2	17.8	7.3	18.3	0.90
U7-Su	48.9	2.1	1.9	17.9	8.2	1.6	1.2	50.8	54.9	26.5	7.3	15.6	0.18
U8-Ar	48.6	2.0	1.8	14.4	12.8	2.5	1.3	94.0	53.6	22.3	6.5	32.0	0.18
U9-RA	47.9	2.6	2.1	14.4	17.5	2.4	1.7	46.3	70.9	22.8	6.8	16.4	0.19
U10-Su	48.1	2.6	1.8	12.2	11.3	2.3	1.6	123.2	70.7	22.7	6.8	46.2	0.17
U11-Di	47.9	2.7	2.3	13.3	14.2	2.8	2.5	51.4	74.0	34.0	10.7	22.4	0.44
2020													
U1-RA	48.3	2.4	1.7	10.8	16.1	2.8	1.6	73.5	59.8	22.5	6.6	33.2	0.1
U2-Di	48.5	1.8	1.9	16.5	10.6	2.6	1.5	40.7	56.1	16.3	6.3	19.8	0.8
U3-RA	48.8	2.4	2.2	15.0	12.0	2.3	1.5	55.3	105.2	19.6	5.1	30.2	0.5
U4-Su	48.5	2.1	1.9	12.4	12.6	2.1	1.7	24.0	48.5	20.4	5.1	14.0	0.2
U5-Di	48.3	2.2	1.9	19.0	8.0	1.8	1.8	27.0	73.4	24.8	6.5	17.3	0.2
U6-RA	48.1	2.3	2.2	15.3	13.9	2.0	1.6	21.8	49.4	14.2	5.3	15.8	0.9
U7-Su	48.5	2.6	1.9	14.7	10.9	1.9	1.6	36.5	64.3	22.1	7.3	13.9	0.2
U8-Ar	48.6	2.4	2.1	16.7	11.0	2.5	1.8	89.3	53.8	20.4	7.6	24.4	0.2
U9-RA	47.6	2.0	2.2	16.6	15.3	2.1	1.3	33.3	54.2	19.5	4.8	13.7	0.3
U10-Su	48.8	2.6	2.0	13.4	9.8	2.0	1.5	90.3	59.2	16.7	6.6	34.1	0.3
U11-Di	48.5	2.3	2.1	18.5	10.6	1.9	2.1	34.1	61.6	23.0	7.3	19.7	0.5

3.2.9 Fruit nutrient concentrations

Compared to leaf nutrient concentrations, far less information is published about fruit nutrient concentrations. Reig et al. (2018) determined nutrient concentrations of 'Fuji' leaves and fruits sampled 90 days after full bloom from trees of a large trial with 49 different dwarfing and semi-dwarfing rootstocks. The results of these leaf and fruit mineral analyses are presented in table 2.

Fruit mineral nutrient concentrations in the apple cultivars studied in the Lier, Nordfjord, Sogn and Ullensvang regions in 2019 and 2020 are summarized in tables 11 to 13.

Fruit carbon levels of the apple cultivars in the four Norwegian fruit growing regions were about 41 to 42 %, similar to those observed for 'Fuji' on M.9 rootstock by Reig et al. (2018) and presented in (Table 2). Most of the macro- and micronutrients varied to some extent between cultivars, orchards and years but were within or close to the concentration ranges for the different nutrients observed for 'Gala' and 'Fuji' apples in Brazil (Amarante, 2008) and 'Fuji' apples in New York State, USA (Reig et al. (2018) (Table 2). In table 14 the average values for all cultivars and years 2019 and 2020 of each mineral is presented for the orchards in the regions Lier, Nordfjord, Sogn and Ullensvang separately and all regions taken together. The ranges of fruit macro nutrient contents for the four regions were: 0.31-0.35 %N, 0.71-0.80 g P/kg, 7.7 - 9.3 g K/kg, 0.33 - 0.39 g Ca/kg, 0.35-0.38 g Mg/kg and 0.23-0.28 g S/kg. The ranges for the fruit micro nutrients were: 3.1-3.6 mg Mn/kg, 7.6-10.2 mg Fe/kg, 14.3-18.6 mg B/kg, 2.4-3.0 mg Cu/kg, 1.9-2.3 mg Zn/kg and 0.07-0.11 mg Mo/kg (Table 14). These concentrations are in line with the values reported for macro nutrients in conventionally and organically grown 'Red Aroma' and 'Discovery' trees in Norway by Fotirić Akšić et al. (2020).

Table 11. Fruit nutrient concentrations of trees in orchards Lier region.

Orchard Cultivar[1]	C %	N %	P g/kg	K g/kg	Ca g/kg	Mg mg/kg	S g/kg	Mn g/kg	Fe mg/kg	B mg/kg	Cu mg/kg	Zn mg/kg	Mo mg/kg
2019													
L1-RA	41.4	0.35	0.91	9.0	0.26	0.41	0.28	3.6	7.1	14.0	3.1	1.8	0.05
L2-RA	41.6	0.35	1.10	10.0	0.15	0.41	0.28	3.1	8.2	21.0	2.0	1.3	0.07
L3-RA	42.2	0.28	0.59	6.7	0.34	0.33	0.22	2.6	9.3	25.0	2.0	1.9	0.07
L4-RA	41.4	0.36	0.85	8.3	0.23	0.40	0.26	3.5	6.4	16.0	2.3	1.3	0.05
L5-Di	42.0	0.41	0.79	8.1	0.27	0.44	0.36	3.3	11.0	30.0	3.0	2.2	0.13
L6-Ra	41.7	0.42	0.82	9.5	0.28	0.44	0.39	3.4	9.7	32.0	2.5	1.9	0.11
L7-RA	41.3	0.26	0.76	8.6	0.24	0.36	0.22	3.2	7.7	12.0	2.7	1.4	0.07
L8-Ru	-	-	-	-	-	-	-	-	-	-	-	-	-
2020													
L1-RA	41.9	0.33	0.57	7.4	0.38	0.37	0.23	3.8	6.3	14.0	4.0	2.6	0.06
L2-RA	-	-	-	-	-	-	-	-	-	-	-	-	-
L3-RA	42.2	0.28	0.74	8.1	0.65	0.37	0.25	3.7	12.0	13.0	2.9	1.9	0.08
L4-RA	42.1	0.33	0.64	6.7	0.41	0.39	0.23	4.3	6.6	21.0	3.2	2.9	0.06
L5-Di	42.0	0.34	0.73	9.8	0.24	0.32	0.25	2.5	8.5	23.0	3.8	1.2	0.02
L6-Ra	42.1	0.38	0.75	9.5	0.38	0.40	0.26	5.5	8.3	12.0	3.7	2.4	0.03
L7-RA	42.0	0.38	0.87	9.6	0.48	0.38	0.30	4.1	10.0	13.0	4.3	2.0	0.06
L8-Ru	42.1	0.30	0.55	7.7	0.26	0.36	0.21	2.7	12.0	14.0	2.3	1.4	0.05

[1]Cultivars: Di = Discovery; RA = Red Aroma Ru = Rubinstep. Data represent the concentrations of minerals from a single analysis of one combined sample of 10 fruits.

Table 12. Fruit nutrient concentrations of trees in orchards Nordfjord (N) and Sogn (S) region.

Orchard Cultivar[1]	C %	N %	P g/kg	K g/kg	Ca g/kg	Mg mg/kg	S g/kg	Mn g/kg	Fe mg/kg	B mg/kg	Cu mg/kg	Zn mg/kg	Mo mg/kg
2019													
N1-RA	41.5	0.29	0.74	7.5	0.27	0.35	0.23	2.2	8.1	14.7	2.4	4.4	0.11
N2-RA	41.7	0.28	0.76	7.3	0.29	0.38	0.27	4.5	7.2	12.3	2.6	2.5	0.05
N3-Su	41.4	0.27	0.59	9.0	0.34	0.33	0.20	2.7	11.7	16.7	2.9	1.9	0.05
S1-Di	-	-	-	-	-	-	-	-	-	-	-	-	-
S2-Di	-	-	-	-	-	-	-	-	-	-	-	-	-
S3-Ru	-	-	-	-	-	-	-	-	-	-	-	-	-
S4-Di	41.9	0.36	0.89	8.7	0.43	0.38	0.31	3.1	12.3	20.7	2.9	2.7	0.16
2020													
N1-RA	42.1	0.26	0.83	9.4	0.28	0.35	0.20	2.6	6.5	14.0	2.6	1.2	0.12
N2-RA	42.2	0.27	0.70	7.5	0.30	0.39	0.24	3.9	5.9	10.9	2.4	1.9	0.06
N3-Su	42.3	0.49	0.71	7.8	0.47	0.37	0.24	2.8	6.3	22.7	2.3	1.7	0.04
S1-Di	42.1	0.27	0.71	9.7	0.24	0.35	0.25	3.2	9.8	12.3	2.0	1.5	0.04
S2-Di	42.0	0.26	0.89	9.2	0.27	0.30	0.27	2.3	12.0	16.0	2.9	2.1	0.11
S3-Ru	42.4	0.33	0.67	8.9	0.48	0.41	0.22	5.2	7.1	21.7	2.3	3.4	0.05
S4-Di	42.0	0.36	0.86	10.0	0.26	0.30	0.34	2.7	9.7	17.7	2.1	1.6	0.18

[1]Cultivars: Di = Discovery, RA = Red Aroma, Ru =Rubinstep, Su = Summerred

Table 13. Fruit nutrient concentrations of trees in orchards Ullensvang region.

Orchard Cultivar[1]	C %	N %	P g/kg	K g/kg	Ca g/kg	Mg mg/kg	S g/kg	Mn g/kg	Fe mg/kg	B mg/kg	Cu mg/kg	Zn mg/kg	Mo mg/kg
2019													
U1-RA	41.5	0.27	0.65	6.6	0.32	0.34	0.22	3.7	6.9	18.0	2.1	1.9	0.03
U2-Di	41.4	0.38	0.65	7.9	0.41	0.32	0.24	3.4	9.5	7.7	3.6	2.3	0.12
U3-RA	41.6	0.25	0.70	7.3	0.23	0.35	0.21	2.8	8.2	12.0	2.1	2.0	0.13
U4-Su	41.5	0.44	0.83	9.6	0.35	0.38	0.28	3.3	10.6	20.3	3.1	1.4	0.07
U5-Di	41.8	0.38	0.66	7.6	0.53	0.41	0.27	4.8	11.3	13.0	2.6	3.3	0.10
U6-RA	41.4	0.30	0.60	7.1	0.39	0.31	0.23	2.3	6.9	9.0	1.9	1.7	0.18
U7-Su	41.7	0.41	0.64	7.0	0.46	0.38	0.25	2.5	7.8	22.7	2.1	1.1	0.03
U8-Ar	41.7	0.24	0.74	7.4	0.23	0.34	0.20	3.2	7.2	12.0	2.6	1.4	0.05
U9-RA	41.6	0.36	0.74	7.2	0.39	0.38	0.27	3.5	10.6	15.7	2.7	7.0	0.05
U10-Su	41.9	0.36	0.63	6.8	0.48	0.38	0.24	2.7	9.2	12.5	2.7	1.9	0.11
U11-Di	41.6	0.41	0.64	8.2	0.41	0.37	0.32	3.4	13.0	21.0	3.6	2.0	0.11
2020													
U1-RA	42.2	0.35	0.70	6.5	0.41	0.38	0.27	4.1	7.4	16.0	2.9	2.3	0.03
U2-Di	-	-	-	-	-	-	-	-	-	-	-	-	-
U3-RA	42.2	0.26	0.64	6.8	0.43	0.37	0.20	4.1	8.5	14.0	2.3	2.6	0.14
U4-Su	42.2	0.32	0.73	7.8	0.44	0.37	0.22	2.9	7.7	12.7	2.9	1.8	0.10
U5-Di	-	-	-	-	-	-	-	-	-	-	-	-	-
U6-RA	41.9	0.38	0.81	8.6	0.23	0.38	0.27	3.1	9.4	9.1	2.7	1.2	0.23
U7-Su	42.0	0.48	0.75	8.2	0.51	0.42	0.31	3.9	9.5	17.7	3.1	2.4	0.05
U8-Ar	42.3	0.30	0.77	7.4	0.40	0.42	0.26	5.8	8.2	12.7	3.1	2.6	0.07
U9-RA	41.9	0.27	0.84	9.2	0.33	0.32	0.22	3.3	6.9	14.0	3.0	1.4	0.07
U10-Su	42.2	0.48	0.74	8.5	0.49	0.39	0.28	4.9	31.4	10.7	3.4	3.6	0.10
U11-Di	-	-	-	-	-	-	-	-	-	-	-	-	-

[1]Cultivars: Ar = Aroma, Di = Discovery, RA = Red Aroma, Su = Summerred.

Table 14. Average fruit nutrient concentrations of trees in orchards Lier, Nordfjord and Ullensvang regions. Values are the means of all cultivars and samples taken in 2019 and 2020.

Mineral	Unit[1]	Lier	Nordfjord	Sogn	Ullensvang	all regions
C	%	41.9	41.9	42.1	41.8	41.9
N	%	0.34	0.31	0.32	0.35	0.34
P	g/kg	0.76	0.72	0.80	0.71	0.74
K	g/kg	8.5	8.1	9.3	7.7	8.2
Ca	g/kg	0.33	0.33	0.34	0.39	0.36
Mg	g/kg	0.38	0.36	0.35	0.37	0.37
S	g/kg	0.27	0.23	0.28	0.25	0.26
Mn	mg/kg	3.5	3.1	3.3	3.6	3.5
Fe	mg/kg	8.8	7.6	10.2	10.0	9.3
B	mg/kg	18.6	15.2	17.7	14.3	16.1
Cu	mg/kg	3.0	2.5	2.4	2.8	2.8
Zn	mg/kg	1.9	2.3	2.3	2.3	2.2
Mo	mg/kg	0.07	0.07	0.11	0.09	0.08

[1]per fruit dry weight

4 Conclusions

The survey of apple orchards in the apple growing regions Lier, Nordfjord, Sogn and Ullensvang showed orchards planted in soils with different amounts of clay, silt, sand, organic matter and with different amounts of plant-available nutrients. Contrary to these differences in soil composition and nutrient availability, the nutrient contents in leaves and fruits from the different apple cultivars grown in the different orchards in the four regions were very similar and also comparable to the concentrations found in an earlier study in Norway as well as in 'Fuji' apple grown in the Hudson Valley in the USA. Fruit quality traits peel background and blush colour, firmness and contents of soluble solids, acids and starch showed some variation between orchards and years but were more variable between orchard and harvest year in each region than between regions. Seed numbers in some years and some orchards were very low, indicating lack of sufficient pollinizer trees in the orchard or unfavourable weather for pollination and fertilization. Lack of sufficient pollinizer trees with overlap in flowering time is most likely the reason that the 'Red Aroma' fruits in orchard L4 in Lier region had on average less than 1 seed per fruit. On the other hand, unfavourable pollination conditions are the most likely cause for the low seed number in 'Summerred' fruits in 2020 as the same trees had much higher seed numbers in 2019.

The differences in cultivars, tree age and cultivation practices carried out by the different growers make it difficult to make direct comparisons between the growth and fruit production of the trees and the differences in soil composition and soil fertility. However, the survey clearly demonstrates that, despite the observed differences in soil composition and soil fertility, the fruit growers in the different regions are capable to adjust their cultivation practices to the local conditions and to produce good yields of high quality apples. Apart from adequate fertilization, sufficient irrigation, pruning strategy, crop load regulation and a good control of pest, diseases and weeds are also required to achieve high yields and excellent fruit quality.

References

Amarante, C.V.T., Steffens, C.A., Mafra, A.L., and Albuquerque, J.A. (2008). Yield and fruit quality of apple from conventional and organic production systems. Pesqui. Agropecu. Bras. 43 (3), 333–340.

Fotirić Akšić, M., Mutić, J., Tešić, Z. and and Meland, M. (2020). Evaluation of fruit mineral contents of two apple cultivars grown in organic and integrated production systems. Acta Hortic. 1281: 59-65.

Ličina , V. , Krogstad, T., Simić A., Fotirić Akšić, M. and Meland, M. (2021). Precision fertilization to apple trees. A review. Nibio report Vol. 7, no. 58. Norwegian Institute for Bioeconomy Research..

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

Marschner, P. and Rengel, Z. (2012). Nutrient availability in Soils. In: Marschner's Mineral Nutrition of Higher Plants, Third edition. P. Marschner (ed.), Chapter 12, pp. 315-330. Elsevier Ltd., London, UK.

Neilsen, G.H. and Neilsen, D. 2003. Nutritional requirements of apple. In: Apples. Botany, production and uses. D.C. Ferree and I.J. Warrington (eds), Chapter 12, pp. 267-302. CABI publishing, Cambridge, USA.

Reig, G., Lordan, J., Fazia, G., Grusak, M.A., Hoying, S., Cheng, L, Francescatto, P. and Robinson, T. (2018). Horticultural performance and elemental nutrient concentrations on 'Fuji' grafted on apple rootstocks under New York State climatic conditions. Scientia Hortic. 227: 22-37.

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Cover photos: The apple cultivars ‘Red Aroma’, ‘Summerred’, Discovery’ and ‘ Rubinstep’. All photos: Frank A. Maas

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