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Soil quality and fertiliser application in Norwegian apple orchards

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Abstract

Little research has been done on soil quality and fertilisation in fruit orchards in Norway in recent decades. This thesis investigates pH and nutrients in soil samples from 25 farms in the four main apple districts in Norway. The macronutrients nitrogen, phosphorous, potassium, calcium and magnesium and the micronutrient copper were chosen for investigation. Nutrient content in leaf and fruit samples from some of these apple orchards was also analysed. Some orchards have a lower pH than optimal. Based on levels of nitrogen, magnesium and potassium, fertilisation with these nutrients seems to be adequate. Because the plant available phosphorous content is unnecessarily high in several orchards, continued application of phosphorous seems to be unneeded there. The content of plant available copper is extremely high in some orchards, but it does not seem to have a negative effect on the apple trees. As has been done with other cultures, it would be advantageous to reassess the guidelines of phosphorous application to apple trees when the plant available phosphorous content in the soil is very high.

Sammendrag

Det har blitt forsket lite på jordkvalitet og næringstilførsel i frukthager i Norge de siste tiårene. Denne masteroppgaven undersøker pH og næringsstoffer i jordprøver fra 25 gårder i de fire viktigste distriktene for epleproduksjon i Norge. Det ble valgt å undersøke makronæringsstoffene nitrogen, fosfor, kalium, kalsium og magnesium og mikronæringsstoffet kobber. Innhold av næringsstoffer i blad- og fruktprøver i noen av eplehagene ble også undersøkt. I noen felt er pH-verdien lavere enn optimalt. Basert på nivåene av nitrogen, magnesium og kalium virker gjødslingen med disse næringsstoffene å være passende. Fordi nivåene av plantetilgjengelig fosfor er veldig høyt i flere felt virker det unødvendig å fortsette med fosforgjødsling der. Innholdet av plantetilgjengelig kobber er ekstremt høyt i noen felt, men det virker ikke som om dette påvirker epletrærne negativt. Det vil være nyttig å gjennomgå retningslinjene for fosforgjødsling ved svært høye nivåer av plantetilgjengelig fosfor i jorda, som man har gjort for andre kulturer.

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Kristin Nymoen Paulsen

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1 Introduction

Apple production is the largest fruit production in Norway. The last 10 years, high-density planting systems have become the norm, leading to increased area efficiency. With trees that crop earlier, yield more and have a weaker root system, nutrient management is important to ensure good tree growth and fruit quality (Cheng and Raba, 2009).

In Norwegian agriculture, nutrient management planning is mandatory (*Forskrift om gjødslingsplanlegging*, 1999), partly due to negative environmental consequences of fertiliser application. Every farm that receives economic support from the government must have a plan for fertiliser use in the growing season, based on soil analyses. However, little research has been done on fertilisation in orchards in Norway in recent decades.

This master's thesis seeks to add knowledge to the topic of fertilisation and nutrient status in apple orchards in Norway through investigating soil samples from 25 farms from the four main apple districts in Norway. Leaf and fruit samples from some of these orchards were also analysed. In the thesis, the macronutrients nitrogen, phosphorous, potassium, calcium and magnesium, and the micronutrient copper were investigated.

In 2017, a booklet on fertilisation in orchards, 'Gjødsling i frukthagar' (Vangdal, 2017) was published with input from the Norwegian Institute of Bioeconomy Research (NIBIO) and the Norwegian Agricultural Extension Service, *Norsk Landbruksrådgiving* (NLR). This publication provides the basis for much of the discussion, as it is the most updated information on fertilisation written for Norwegian fruit growers.

Before starting the work with the thesis, it was suspected that the pH value in some orchards was lower than optimal and that some nutrients were applied in excess of what the trees need. The following two hypotheses were therefore set up:

1. The pH in many orchards is lower than optimal for apple production.
2. Fertilisation practice today leads to an application of nutrients in excess of what the apple trees demand.

Before the results are presented, relevant information to discuss the topic is given in the background section. Apple production in Norway stands out from production in the rest of the world by being situated on the northernmost border for commercial apple production, and the background section starts with some general information on Norwegian apple production. In order to discuss the results, a brief literature review has been performed on current knowledge of the effects of the macronutrients on growth and development of apple trees. Historical application of copper to apple orchards has led to very different content of this micronutrient in the soil, and it was therefore also chosen for investigation in this thesis. Some information on the use of soil, leaf and fruit analysis in apple production and recommendations of fertiliser application in Norway is also presented in the background section.

2 Background

This chapter opens in section 2.1 with some general information on apple production in Norway in comparison to other European countries. How the macronutrients nitrogen, phosphorous, potassium, calcium and magnesium affect growth of apple trees and apple quality is discussed in section 2.2, in addition to information on the micronutrient copper. Section 2.3 consists of a brief overview of the use of soil analyses in apple production. In section 2.4 leaf sampling and analysis is discussed, and in section 2.5 fruit analysis. In the last section (2.6), some general information on the use of fertiliser in Norwegian apple orchards is presented.

2.1 Apple production in Norway and Europe

Apple production in Norway is restricted by the short season for plant production. Only a limited number of early apple cultivars might be grown, and only parts of the country is suited for commercial apple production.

The growing season is increasingly shorter farther north. When the temperature sum in the growing season is too low, the sugar content in the fruit becomes too low. The following year's flower bud formation might also be affected negatively (Tveito, Redalen and Engen-Skaugen, 2007). Inland, the winter temperature limits the suitable area for profitable fruit production. The infrequent harsh winters might kill or injure trees, reducing growth and yield. Climate changes has led to higher summer temperatures and a longer growing season the last years (Tveito, Redalen and Engen-Skaugen, 2007).

The municipalities where the main fruit districts in Norway are located are shown in Figure 1. The municipality furthest north (Innvik) is positioned at 62° north, while the municipalities furthest south are positioned at 59° north.

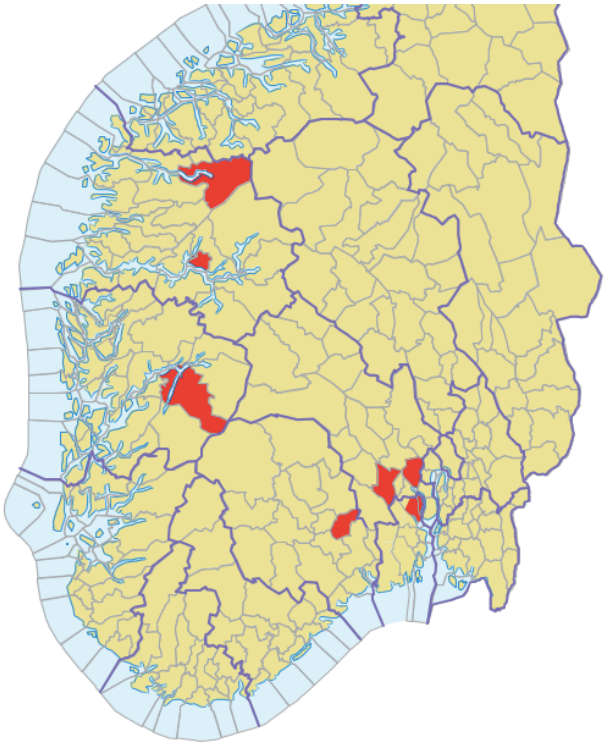

Figure 1. Municipalities where the main fruit districts in Norway are located (in red). The base map is from kartverket.no and the author marked municipalities.

The total area used for apple production in Norway has been around 14.000 daa the last years. The majority of the production has been for the fresh consumption market, while apples that do not meet the standards set for fresh consumption are used by the industry. Norwegian production accounts for about 10–14% of the total yearly apple consumption in Norway (Opplysningskontoret for frukt og grønt, 2018).

The nationwide average yield (kg/daa) has varied quite a lot from year to year as shown in Figure 2. Since the area has been quite stable, the total apple production has varied in the same way as the average yield. Counting both apples for fresh consumption and for industry the nationwide average yield has varied between 2011 and 2017 from a low of 604 kg/daa to a high of 970 kg/daa (Statistics Norway, 2018).

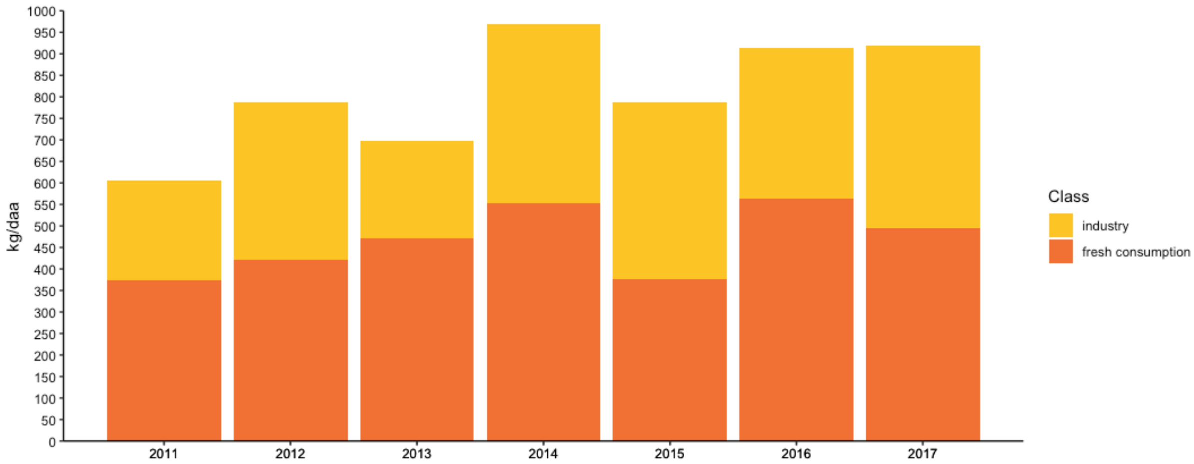

Figure 2. Average yield (kg/daa) in Norway to fresh consumption and industry from 2011–2017. Data from Statistics Norway (2018) on total production and from Grøntprodusentenes samarbeidsråd on fruit for fresh consumption (Eidhammer, 2018).

Most fruit producers in Norway deliver their apples to local sorting and packaging facilities. Figure 3 was made with data reported by Hardanger fjordfrukt and Ullensvang fruktlager and shows variation in average yield and distribution between classes for these two individual packaging facilities. These packaging facilities were the only ones providing information on average yield. The average yield varied a lot between different years for Hardanger fjordfrukt and Ullensvang fruktlager. In the years 2011–2017, the average yield for these packaging facilities was higher than the average for the whole country, except in 2015. According to Liv Sollesnes (personal communication, 22nd November, 2018), the best producers delivering fruit to Hardanger Fjordfrukt have a production of about 3500 kg/daa.

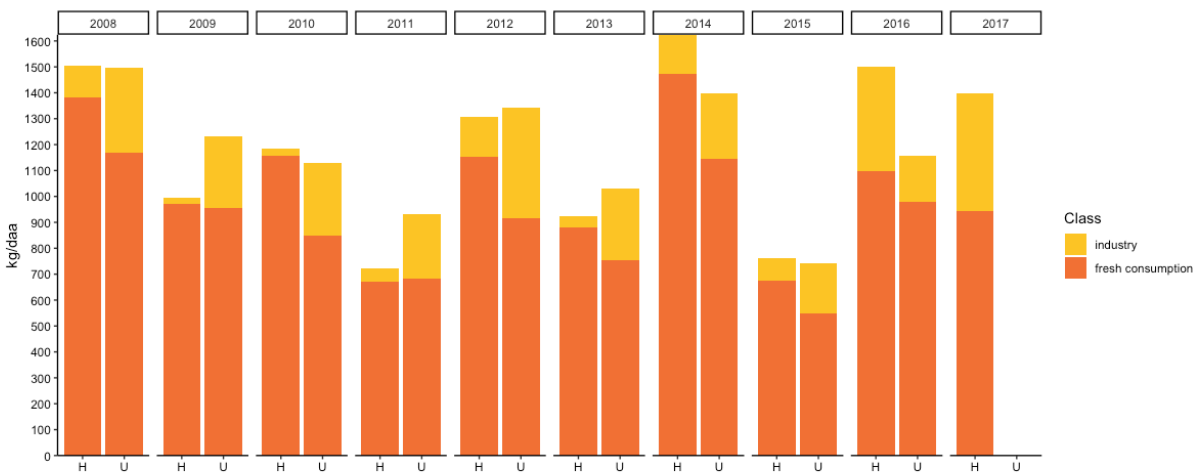

Figure 3. Average yield (kg/daa) to industry and fresh consumption reported by the fruit packaging facilities Ullensvang fruktlager (U) and Hardanger fjordfrukt (H) from 2008–2017.

The average apple yield (kg/daa) in Norway is low compared to many other European countries, as shown in Figure 4. To compare the yield in Norway to other European countries, the countries with the largest production volume were chosen, in addition to Norway's neighbouring countries Denmark and Sweden. The data used to plot the figure was downloaded from the database of the Food and Agriculture Organization of the United Nations (2018). The average yield was calculated based on reported values of total production area and total production volume per year.

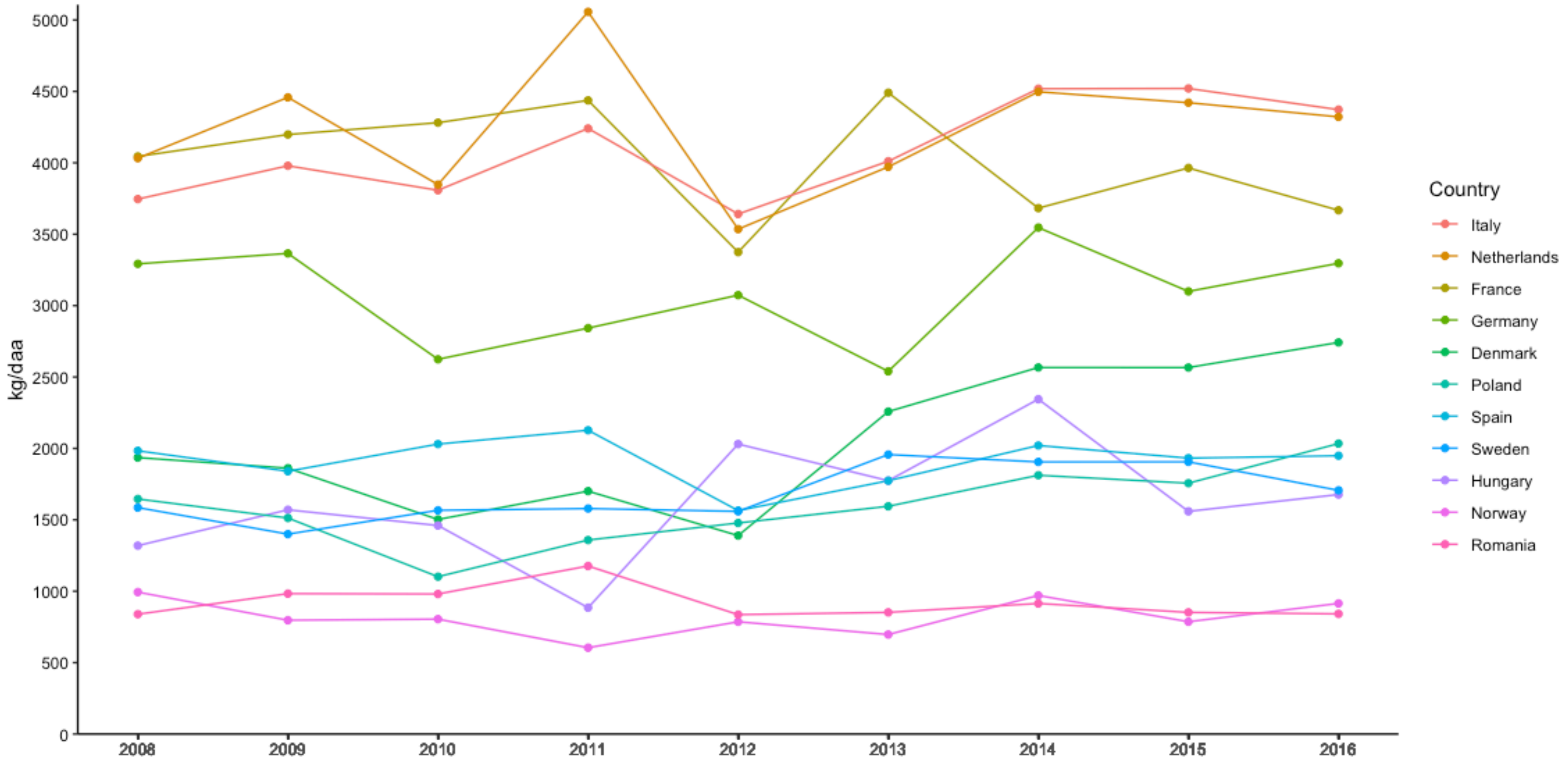

Figure 4. Average apple yield (kg/daa) for selected European countries from 2008–2016. Data downloaded from the database of the Food and Agriculture Organization of the United Nations (2018).

2.2 Effects of nutrients on apple trees

Nutrients affect the growth of trees, yield and fruit quality in different ways. A short description of the macronutrients nitrogen (N), calcium (Ca), potassium (K), phosphorous (P) and magnesium (Mg) and the micronutrient copper (Cu) follows.

2.2.1 Nitrogen

The total amount of nitrogen in the soil is directly related to the amount of organic matter, which is composed of approximately 5% nitrogen (Brady and Weil, 2009). Usually only a small share of the total nitrogen is in the form of mineral nitrogen, which is the form plants absorb.

Adequate nitrogen fertilisation is essential as it has a strong effect on tree performance. Excess or insufficient application might sometimes be distinguished by visual inspection of the trees. Nitrogen deficiency often causes light green leaves and poor shoot growth (Kvåle, 1995). Too little nitrogen might also cause poor fruit set, small fruit size and low yield (Cheng, 2010).

In soils with high organic matter, a combination of heavy late spring fertilisation and mineralization of the organic matter might for instance lead to excess nitrogen availability. Too much nitrogen might be distinguished visually by vigorous vegetative growth and persistent dark green leaves (Kvåle, 1995). It might also lead to poor colour development of the apples, poor fruit quality and storage problems. Excess nitrogen fertilisation might cause later maturation of fruits and adversely affect the winter hardiness of the trees. It is therefore especially important to be careful with the nitrogen fertilisation with late maturing cultivars in cold districts (Kvåle, 1995).

When deciding on the amount and timing of nitrogen application, the demand and supply relationship of the trees must be considered. The early season canopy development and fruit growth requires high nitrogen supply, while fruit quality development only requires baseline nitrogen supply (Cheng, 2010). The sources of nitrogen are reserved nitrogen in the tree from the previous season, nitrogen from soil mineralization and nitrogen fertiliser applied to soil or foliage. The capacity to supply nitrogen through soil mineralization depends on soil organic matter content, soil temperature, moisture, and aeration of the soil (Cheng, 2010).

The soil used for apple growing often has a coarse texture and the rooting densities of apple trees are low, which might give a low nitrogen use efficiency. The effect is reinforced by the use of dwarfing rootstocks. If the nitrogen is provided through fertigation, the nitrogen uptake efficiency is higher than if the fertiliser is spread on the orchard floor. Apple trees absorb nitrogen mainly as nitrate, which moves with water. In irrigated production systems, supply of water and nitrogen is closely linked (Neilsen *et al.*, 2002), and the irrigation should be managed to keep nitrate in the root zone.

2.2.2 Calcium

Calcium carbonate is the one of the most common types of agricultural lime, added to the soil to increase pH. Calcium is also very important in apple production as a plant nutrient and has a large impact on fruit quality. Of the total calcium content in the plant, at least 60% is found in the cell wall fraction. Around the middle of the 1930s, several researchers found that bitter pit was associated with low calcium levels in the fruit (Neilsen *et al.*, 2008). Bitter pit is small and soft necrotic spots in the fruit flesh. These collapse and lead to formation of pit cavities prior to or after harvest (Stiles and Reid, 1991). Low calcium content of the fruit is also often linked to incidences of internal breakdown, watercore, and low post-storage disease resistance.

Plants absorb calcium as its ion, Ca^{2+}, which is transported to growing tissue through the xylem. The concentration of calcium in the phloem sap is very low, which makes import of calcium through the phloem sap negligible. Fleshy fruits have a low transpiration rate and a low rate of xylem volume flow. To increase calcium content in growing fruits, it may be more effective to increase the transpiration rate of the fruits than to increase the calcium supply in the soil (Marschner, 2012). Practices that stimulate vegetative growth, such as excess pruning or nitrogen application could lead to more calcium in the leaves rather than in the fruit (Neilsen *et al.*, 2008). Early thinning of fruitlets has been found to be positive for calcium uptake in the fruit (Lakso and Goffinet, 2013). Drought stress might reduce calcium uptake and cause bitter pit.

The uptake of calcium in the fruit is usually more rapid in the first part of the season, during cell division. In combination with the low weigh gain during this period, it leads to an increase in calcium concentration, as illustrated by the dashed line in Figure 5. If the uptake slows down and the weight gain continues during cell expansion, calcium concentration declines towards harvest, even though the total calcium content increases.

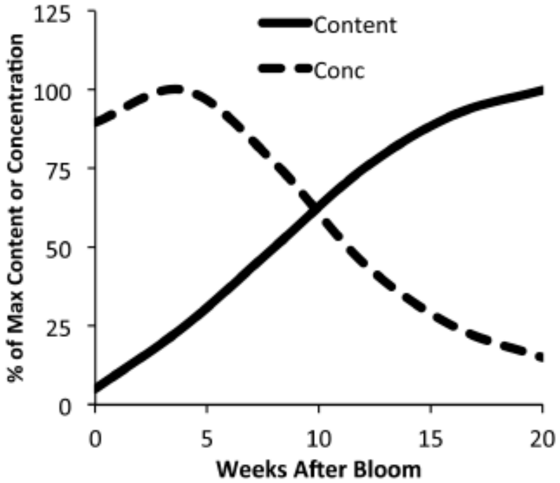

Figure 5. General diagram on calcium in apple fruit from Lakso and Goffinet (2013). It shows the amount of calcium per fruit and the concentration (% of weight) as percent of the seasonal maximum. If the uptake slows down and the weight gain continues during cell expansion, calcium concentration declines towards harvest, even though the total calcium content increases.

It has been difficult to ensure sufficient uptake of calcium, and most apple growing regions have recommendations for application of calcium sprays during the growing season (Neilsen and Neilsen, 2009). Despite considerable research, there is still some uncertainty related to how calcium affects bitter pit and the necessary threshold levels of concentration. Susceptibility to bitter pit also varies between cultivars. Neilsen *et al*. (2008) reported that bitter pit often is reduced by multiple sprays of soluble calcium and that the spraying usually increases calcium concentrations in subdermal cortical tissue. Spraying early in the growing season is often most effective at reducing bitter pit, while later applications are more effective at increasing fruit calcium concentration (Neilsen *et al.*, 2008).

2.2.3 Potassium

Plants absorb potassium as its ion, K^+. The total potassium content in soil is between 0.05–3%, dependent on the parent materials and the degree of weathering. But only about 0.02–2% of this content is available for plants (Havlin *et al.*, 2016). There is a dynamic equilibrium between the different fractions of potassium in the soil.

Potassium deficiency might lead to smaller fruit than normal with poor dull colour and a lack of acidity. Deficiency might also lead to more winter cold injury to the trees and spring frost damage to buds and flowers (Stiles and Reid, 1991). Moisture stress might limit availability, and drought early in the summer predispose the trees to develop potassium deficiency. Trees grown on light sandy soil might be at risk of developing potassium deficiency because the soil contains little potassium and is exposed to drought and leakage. Especially in areas with much precipitation, the leakage might be high (Kvåle, 1995).

Many experiments in Denmark showed a large increase in yield with increasing potassium fertilisation because the fruit size increased. Norwegian experiments lacked these high yield increases because the natural potassium content in the soil often was higher. According to Kvåle (1995), the emphasis on potassium fertilisation and excessive application caused magnesium deficiencies in many Norwegian orchards previously.

2.2.4 Phosphorous

The total phosphorous content in surface soil varies between 0.005%–0.15%, but the quantity has little or no relationship to plant available phosphorous (Havlin *et al.*, 2016). Diffusion of dihydrogen phosphate $[H_2PO_4]^-$, which the trees absorb is low compared to other ions. So to meet the demand of the trees, the soil volume explored by roots must have a sufficient supply of readily available phosphorous.

The amount of plant available phosphorous is dependent on many factors, especially soil pH. The availability is highest with a pH around 6.5 in most soils. With a lower pH, the adsorption of inorganic phosphorous to surfaces of iron and aluminium oxide and clay minerals is greater. More phosphorous also precipitates as iron and aluminium secondary minerals with a low pH (Havlin *et al.*, 2016). With a higher pH, the adsorption of inorganic phosphorous to surfaces of clay minerals and calcium carbonate is greater, and more phosphorous precipitate as calcium-phosphorous secondary minerals.

Phosphorous is quickly transformed to organic phosphorous compounds when absorbed. It is mobile in the plants and easily transported to growing tissue. Phosphorous in the fruit is important for the storage of apples, but there are few reports of positive responses to phosphorous fertilisation in apple orchards in the literature (Neilsen *et al.*, 2008). Some of the conditions identified when apples respond to phosphorous fertilisation are times when apple root length is limited, when trees are newly planted, when replant disorders further inhibit root growth and when low soil phosphorous levels limit phosphorous availability to roots (Neilsen *et al.*, 2008). According to Kvåle (1995), the phosphorous content in normal cultivated soil in Norwegian fruit districts is so high that deficiency has not been a problem.

If large amounts of phosphorous are applied to soil low in available zinc this might induce zinc deficiency. High phosphorous concentrations in soil might reduce mobility of zinc, but it is not always the case. Zinc deficiency enhances the phosphorous uptake and translocation to shoots and leads to high phosphorous concentrations in shoots (Marschner, 2012).

2.2.5 Magnesium

Magnesium is a part of the chlorophyll, and deficiency is visible as interveinal chlorosis, first on the old leaves (Kvåle, 1995). Some cultivars and rootstock combinations are more prone to develop magnesium deficiency than others. Magnesium deficiency might be caused by a low level in the soil, but according to Kvåle (1995), it has more often been induced by excess application of potassium in Norwegian orchards. Excess potassium fertilisation might reduce both the uptake and availability of magnesium in the soil. According to Kvåle (1995), it is not common with damage caused by excess magnesium.

Magnesium is absorbed as its ion, Mg^{2+}. If the magnesium level in the soil is low, dolomite, which also contains magnesium, should be used instead of calcium carbonate as a liming material (Havlin *et al.*, 2016). Liming in itself will also generally make magnesium more accessible for the trees because it reduces the saturation of negatively charged aluminium species. According to Havlin *et al.* (2016), availability of magnesium is more a function of the level of magnesium saturation than the quantity of exchangeable magnesium.

2.2.6 Copper

Copper is both a micronutrient for the fruit trees and a pesticide used to control several important fungi and bacteria in fruit growing. While clay often has enough copper, sand and soil from a parent material poor in copper might have a too low content. Copper is strongly bound to humus, which might lead to the risk of copper deficiency on soil with a high humus content (Krogstad, 1992).

Copper keeps the fungi spores from sprouting and prevents apple scab and fruit tree canker in apple (Serikstad, 2011). Copper has a preventive function and is considered an important resistance-breaker. It is one of the few agents that might reduce bacterial strains of *Pseudomonas*, *Erwina* and *Xanthomonas*. Copper is a heavy metal that that might be harmful to several organisms. Cu^{2+}, the active ingredient in most copper agents, is acute toxic to water living organisms in low doses (Serikstad, 2011).

Copper in the form of Bordeaux-liquid was first used as pesticide against fungi in wine grape growing in France around 1880. Bordeaux-liquid consists of copper sulphate, burned chalk and water. Later it became common to use it in fruit production. Use of copper as a pesticide in France for a long time has led to high values in the soil, and up to 200–300 mg/kg soil has been measured there (Mattilsynet, 2007). In apple orchards in the UK, measurements of up to 1500 mg copper/kg soil have been made.

It is almost 100 years since farmers started to use copper in fruit production in the west coast areas of Norway. Quite a lot of copper in the form of copper chalk and Bordeaux liquid was used previously (Serikstad, 2011). Today, one pesticide containing copper (Nordox) is allowed in Norway. Nordox contains copper oxide and is dangerous to inhale. The maximal dose allowed in Norway per culture and season is 400g/daa.

Copper does not decompose in the soil, and Cu^{2+} is relatively quickly bound to organic or inorganic ligands, producing more or less soluble complexes. Copper is strongly bound, and the bio-availability reduces with time. Only a small part of copper exist as hydrated copper in the soil solution (Mattilsynet, 2007).

High values of copper in the soil might affect earthworm populations. Mattilsynet (2007) considers the toxicity for earthworms to be moderate to limited acute poisonous (LC50) at a value of 217 mg/kg soil (Mattilsynet, 2007). This is based on the lowest value reported in the EU's Draft Assessment Report.

2.3 Soil analysis

Soil analyses have been developed to reflect the amounts of plant available nutrients in the soil and have been used for a long time to quantify the soil's capacity to supply nutrients through the growing season. When an orchard is established, soil analyses are essential to determine the amount and kind of agricultural lime needed, and the amounts of calcium, magnesium, potassium and phosphorous present. According to Stiles and Reid (1991) it might take several seasons before these nutrients reach the deeper parts of the root system of mature apple trees if they are applied by surface application after establishment, or they might never do so. Agricultural lime might have minimal effects on acidity below the depth of incorporation even at high application rates (Havlin *et al.*, 2016).

In Norway, soil analyses are usually taken every 4th–8th years in existing orchards. These are used to provide information to assist in making fertilisation programmes. Using traditional Norwegian methods for soil analysis, the values regarded as optimal in orchards of some elements are given in Table 1 (Vangdal, 2017). The methods used for extraction are described in the materials and methods section, as they are the same as the methods used for the samples in this thesis.

Table 1. Optimal soil analysis values reported in 'Gjødsling i frukthagar' (Vangdal, 2017).

Nutrients and extraction method	mg/100 g dry mineral soil
P_{AL}	8–12
K_{AL}	20–30
$K\text{-}HNO_3$	50–150
Mg_{AL}	10–12
Ca_{AL}	100–200

The availability of nutrients is affected by the soil pH, as shown in Figure 6. In 'Gjødsling i frukthagar' (Vangdal, 2017), the pH value regarded as optimal is evaluated according to soil texture, where three general classes of soil types are distinguished. The suitable pH for orchard soil is said to be 5.5–6 for sandy soil, 5.8–6.3 for silty soil and 6.0–6.5 for clay soil (Vangdal, 2017). According to Stine Huseby, fruit consultant working for NLR in Sogn (personal communication, 8th January, 2019), they advise farmers to raise the pH to 6.3 before the orchard is established, and recommend liming to increase the pH when it is below 5.8. Because the soil in Sogn mostly is a mixture, containing quite a lot of both sand and silt, they do not distinguish between optimal pH values for silty soil and sandy soil when they advise farmers. But the amount of agricultural lime needed to raise the pH to a certain value will depend on soil texture.

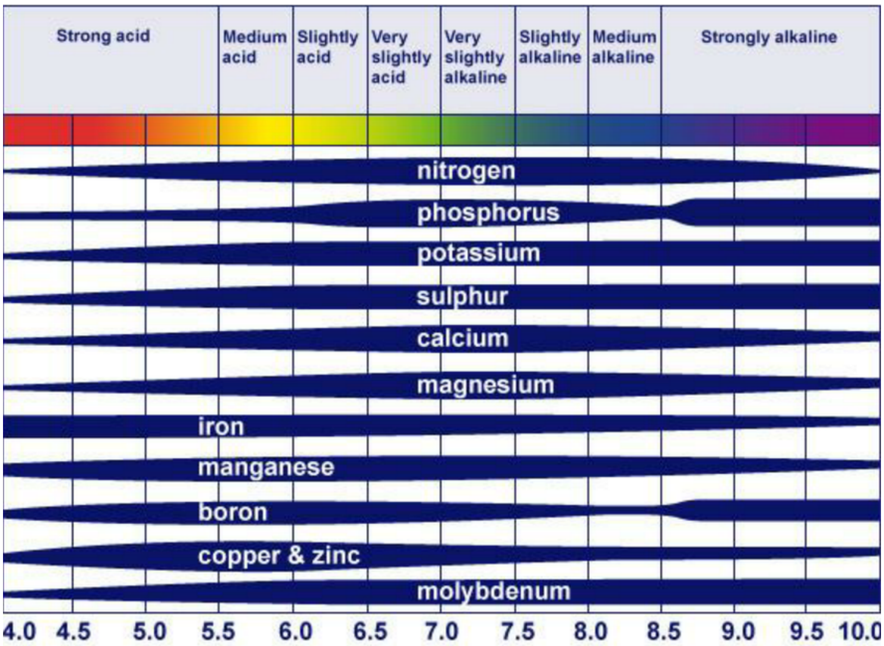

Figure 6. The effect of soil pH on nutrient availability. Figure from Roques *et al.* (2013).

2.4 Leaf analysis

Nutrient concentration in the leaves quantifies the elements absorbed and translocated to the leaves. Sampling and analysing leaves might be used in the process of optimizing fertilisation in this or the next growing season.

Generally for all species, leaf analysis to diagnose nutrition is based on an assumption that the plant's growth rate is affected by the nutrient concentration in the shoot dry or fresh matter (Marschner, 2012). A critical nutrient concentration can be used to interpret the results. This is defined as the concentration where the nutrient content changes from deficient to adequate (Havlin *et al.*, 2016). It is however difficult to establish an exact critical nutrient concentration, and a critical nutrient range is often used instead. At a specific growth stage, a nutrient concentration above this range is considered adequate, while below this range, nutrient deficiency occurs. However, there are limitations to this method, as several other factors can limit yield and alter nutrient concentration (Havlin *et al.*, 2016).

For trees with an irregular crop load, the average nitrogen content in dry matter in the leaves might be quite different between trees carrying a heavy crop and off-year trees. As described by Kvåle (1995), the average nitrogen content of many leaf samples from the cultivar

Gravenstein sampled at NMBU was 1.82% in off-year trees, and 2.64% in years with a high yield. The same tendency is seen for calcium, while the potassium content often is highest in off-year trees.

The nutrient content in the leaves differs through the season, to the greatest extent for calcium and nitrogen. The calcium content usually increases during the growing season, while the nitrogen content decreases from bud break to the end of shoot growth (Kvåle, 1995).

Standardized methods have been developed to be able to evaluate the results according to what is regarded as optimal. The apple leaves should be sampled in August, and well-developed leaves in the middle of the shoots should be chosen. A sample should consist of 100 representative leaves from trees with a normal yield and each cultivar should be sampled separately (Kvåle, 1995).

The nutrient concentrations regarded as optimal in the dry matter in the leaves in 'Gjødsling i frukthagar' (Vangdal, 2017) are reproduced in Table 2.

Table 2. Optimal nutrient concentrations in percentage of dry matter in apple leaves reported in 'Gjødsling i frukthagar' (Vangdal, 2017).

N	P	K	Ca	Mg
1.7–2.5	0.15–0.25	1.2–1.6	1.0–1.5	0.2–0.3

In Norway, the use of leaf sampling varies. Stine Huseby (personal communication, 14th November, 2018) informs that leaf analyses are used by some growers in Sogn, often the year before a new fertilisation plan is made. Traditionally, samples have been collected after the season, but the procedure might be changing to earlier sampling. If leaf samples are collected earlier, adjustments in fertilisation might be performed during the season. Leaf analyses are also used in cases where a nutrient deficiency is suspected, and the cause is not found by inspecting the trees.

According to Jop Westplate, fruit consultant for NLR in Telemark, (personal communication, 15th November, 2018) NLR does not use leaf analyses to advise farmers in Telemark. He sees leaf samples as a valuable "micromanaging tool" when yields are high (e.g greater than 4000 kg/daa). So far, few farmers achieve such a high yield in Telemark. With lower yield, he believes that a balanced spring fertilisation and balanced use of foliar sprays in combination with visual observations should be sufficient.

2.5 Fruit analysis

Quality and storability might be affected by nutrient content in the fruit. In some fruit-growing regions, fruit analyses are used to evaluate storability, what type of storage should be used and when the fruit should be sold (Tahir, 2014). It is not very common to perform fruit mineral analyses in Norway, but the levels that are stated as optimal in 'Gjødsling i frukthagar' (Vangdal, 2017) are given in Table 3.

Table 3. Nutrient concentration in percentage of dry matter in fruits stated as optimal in 'Gjødsling i frukthagar'(Vangdal, 2017).

N	P	K	Ca	Mg
0.36–0.5	> 0.09	0.93–1.2	> 0.03	< 0.035

2.6 Fertiliser application practice in Norway

NIBIO and Yara both provide recommendations of fertiliser application to various crops in Norway, including apples. The recommended application of nitrogen, phosphorous and potassium are given in Table 4, in addition to the recommendation from NIBIO/NLR in 'Gjødsling i frukthagar' (Vangdal, 2017).

Yara and NIBIO do not provide information on the yield level the advice is based on, while the advice in 'Gjødsling i frukthagar' (Vangdal, 2017) is based on a yield of 2000 kg/daa. The advice is to increase the nitrogen fertilisation with 2 kg/daa for a yield increase of 1000 kg, and the norms are based on soil that releases 10–12 kg nitrogen/daa per year.

Table 4. Recommended application of nitrogen, phosphorous and potassium to apple (trees in production) in kg/daa (Yara, 2018), (NIBIO, 2018), (Vangdal, 2017).

Advising agency	**N**	**P**	**K**
Yara (normal growth)	2–2.5	1.5–2	7–9
Yara (weak growth)	1.5–2	1.5–2	7–9
NIBIO	3–5	1–2	5–7
NIBIO/NLR (small fruits)	5.5–7.5	2	8–10
NIBIO/NLR (large fruits)	4.5–6.5	2	3.5–10

According to Gaute Myren (fruit consultant in NLR Viken), the cultivars Discovery and Rubinstep usually receives 5–6 kg nitrogen per daa and Aroma receives 3–5 kg nitrogen per daa (personal communication, 30th November 2018). The amount used will vary a lot depending on soil and tree vigour. According to Stine Huseby (personal communication, 22nd January, 2019), the amount of nitrogen fertiliser applied to the cultivar Summerred is usually somewhere between Discovery and Aroma.

It is common to apply nitrogen about four weeks before bloom in addition to some nitrogen two weeks before bloom (Vangdal, 2017). If fertigation is used, it is common to apply nitrogen from about four weeks before bloom until some weeks after bloom. It is also common to apply nitrogen as a foliar spray until mid-July.

When it comes to potassium, fertilisation might be reduced if the reserves are high. On light, sandy soils, the potassium fertilisation should be paid special attention to (Vangdal, 2017). The requirement is normally larger than for nitrogen.

It is advised to add some phosphorous every year, even though the soil analyses show that there are large reserves, because of its possibly strong absorption to soil particles (Vangdal, 2017). For potatoes, fruit, berries and vegetables, phosphorous fertilisation should be adjusted in accordance with the soil analysis values as shown in Table 5 (NIBIO, 2018).

Table 5. Advised correction of phosphorous fertilisation for potato, fruit, berries and some vegetables with different P_{AL} values (NIBIO, 2018).

P_{AL} value	% correction of phosphorous need
1	100
2	75
3	50
4	25
5 – 9	0
10–13	-25
14–15	-50
>15	-75

Norwegian farmers usually develop fertilisation plans with the consultants in NLR. The recommended amounts of the main nutrients have not changed much the last years, but fertigation and foliar sprays are increasingly used to give the trees more precise fertilisation (Vangdal, 2017).

Foliar application of potassium is often used until harvest to improve fruit quality. Application of magnesium is advised during bloom and 2–3 times afterwards (Vangdal, 2017).

According to Gaute Myren (personal communication, 22nd August, 2018), most growers spray with calcium several times to avoid bitter pit, usually 4–5 times before harvest. Because of the high temperature and risk of leaf burn, it was used a bit less in 2018.

According to Stine Huseby (personal communication, 21st September, 2018), the use of foliar sprays in Sogn is quite varied. Some growers follow a more intensive foliar spray programme, but with the exception of calcium, most growers only use foliar sprays if there are clear symptoms of micronutrient deficiencies. Some growers might spray with micronutrients at the same time as pesticides are applied.

3 Materials and methods

This chapter opens in section 3.1 with a description of the study sites and an overview of the type of data gathered in the different orchards. A description of the apple cultivars in the orchards in the project follows in section 3.2. In section 3.3, the procedure of soil sampling is described, and in section 3.4 an overview of the methods of soil analysis are given. A brief overview of orchard management is given in section 3.5, before the last part on sampling and analysis of leaves (section 3.6) and fruit (section 3.7).

All the data analysed in the thesis was provided through the project Precision Fertiliser to Apple Tree (TerrEple). TerrEple is a “user-driven innovation project” (brukerstyrt innovasjonsprosjekt) owned by Hardanger Fjordfrukt and mainly financed by The Research Council of Norway. The research in the TerrEple project is primarily performed by NIBIO Ullensvang and NMBU.

The data was not collected specifically for this thesis, so the choice of sites, types of data collected and methods used were decided by the project management in advance. The thesis investigated a part of the data in the project, and analysis was performed on this material for the first time.

3.1 Selection of orchards and type of material sampled

Apple production in Norway is localized in districts in the southern part of the country. Climate and soil type vary both within and between these districts and the study sites were chosen to capture this variation within the main apple districts in Norway.

In Figure 7, the red areas show the municipalities where the farms in the project are located. The fruit districts were numbered from 1–4 to be able to distinguish the results from the different areas. The municipalities Lier, Sande, Svelvik and Øvre Eiker in Buskerud and Vestfold county represent “district 1,” Leikanger municipality in Sogn og Fjordane county represent “district 2,” Ullensvang in Hordaland county represent “district 3” and Sauherad in Telemark county represent “district 4”. In the rest of the thesis, the name Viken is used for “district 1,” Sogn for “district 2,” Hardanger for “district 3” and Telemark for “district 4.”

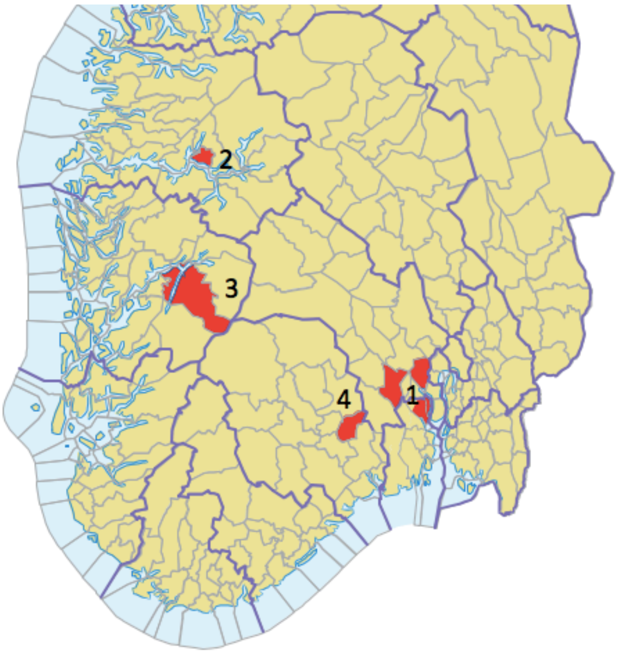

Figure 7. The apple districts where the farms in the project are located are marked with red. These are represented by the municipalities Lier, Sande, Svelvik and Øvre Eiker (1), Leikanger (2), Ullensvang (3) and Sauherad (4). The base map of counties was downloaded from kartverket.no and annotated by the author of this thesis.

The orchards in the project are well-managed, high-density plantings. The trees were planted 4–10 years ago and are in full production. The most common rootstock is the dwarfing rootstock M9. The semi dwarf rootstock B9 is also used. The rows are 3.5–4 meters apart and the trees are 0.8–1 meters apart. The cultivars in the orchards include Discovery, Rubinstep, Summerred and Aroma. One orchard has 1–3 cultivars. Most orchards are drip irrigated, while some in Viken are not irrigated. About half of the orchards are fertigated.

The type of data gathered for the project included soil samples, leaf samples and fruit samples. Table 6 gives an overview of the different types of data gathered in the different orchards. Each orchard was assigned a number according to the district, and then a random number for the orchard. The method of sampling differed between the districts, and a detailed description of the sampling procedure is given in the sections on soil, leaf and fruit sampling.

Table 6. Overview of the samples taken from the different orchards. If a sample was collected, it is marked with an x.

District	Orchard number	Soil samples	Leaf samples	Fruit samples
Viken	1.1	x	x	x
	1.2	x	x	x
	1.3	x	x	
	1.4	x	x	
	1.5	x	x	x
	1.6	x	x	x
	1.7	x	x	x
Sogn	2.1	x		
	2.2	x		x
	2.3	x		
	2.4	x		
Hardanger	3.1	x	x	x
	3.2	x	x	
	3.3	x	x	x
	3.4	x	x	
	3.5	x	x	
	3.6	x	x	x
	3.7		x	x
	3.8		x	x
Telemark	4.1	x		
	4.2	x		
	4.3	x		
	4.4	x		
	4.5	x		
	4.6	x		
	4.7	x		
	4.8	x		

Soil samples were taken from 25 sites: seven orchards in Viken, four in Sogn, six in Hardanger and eight in Telemark. From most farms, only one orchard was sampled. In Telemark, soil samples were taken from two or three orchards from the same farms.

Leaf samples were collected from 15 orchards: seven in Viken and six in Hardanger, where soil samples were also taken, and two in Hardanger, where soil samples were not taken.

Fruit samples were harvested from ten orchards: five in Viken, one in Sogn and five in Hardanger. In Viken, both soil and leaf samples were also collected. In Sogn, soil but not leaf samples were taken. In Hardanger, fruit was harvested from three orchards, where both soil and leaf samples were collected, and two orchards where only leaf samples were collected in addition.

3.2 Apple cultivars

A description of the apple cultivars Aroma, Summerred, Discovery and Rubinstep, which are grown in the orchards in the project, is given below. These are among the major apple cultivars produced in Norway. Figure 8 shows the average production for fresh consumption of the five most produced cultivars in Norway in the years 2011–2017. The cultivar Gravenstein is not grown in the orchards in the project.

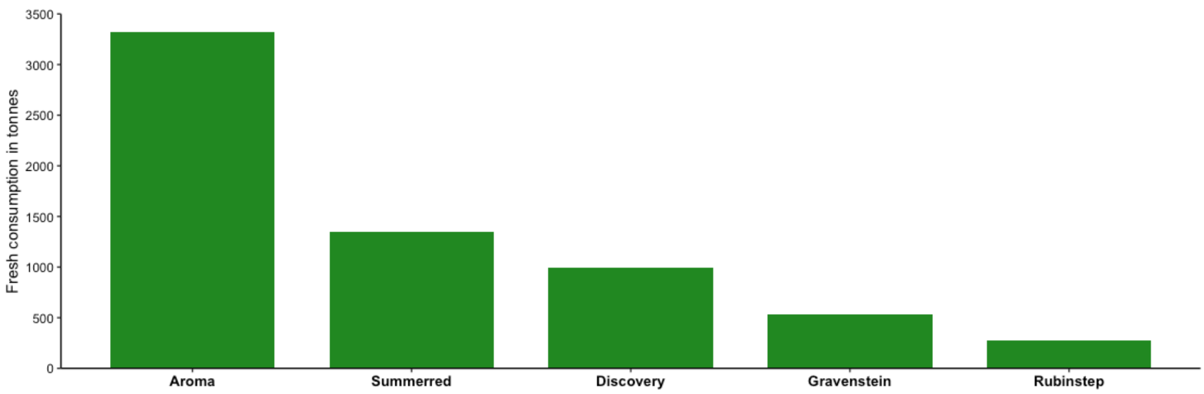

Figure 8. The five most produced cultivars in Norway. Average production for fresh consumption in tonnes from 2011–2017. Data from Grøntprodusentenes samarbeidsråd (Eidhammer, 2018).

Aroma

The cultivar Aroma was developed at the plant breeding centre Balsgård in Sweden and is a cross between Ingrid Marie and Filippa. It arrived in Norway in 1966 with the name BM 31021 and was introduced to the fruit industry in 1973 (Redalen and Vestrheim, 1991). It is one of the largest cultivars in Scandinavia measured in production volume (Meland, 2011). It is a high-yielding cultivar with medium to large apples. The background colour is yellow, and red colour develops in stripes. In Norway, red mutants are most common. The pulp is juicy with a mild, sweet and sour taste and a distinct aroma. The apples are usually harvested in the end of September/beginning of October (Kvåle, 1995). When stored at low temperature, they might be stored relatively long, but the cultivar is susceptible to lenticel rot (Redalen and Vestrheim, 1991). It flowers relatively late and the flowering lasts quite long. The pollen quality is very good and the amount produced very high.

Summerred

Summerred was developed in Summerland, Canada. It is a cross between McIntosh and Golden Delicious. It was introduced in 1964 and came to Norway the same year (Redalen and Vestrheim, 1991). The fruits are medium-sized and oval with a strong, dark red top coat. When the fruits are fully mature, the skin might get a bit waxy. The pulp is juicy and crisp with a medium strength. The cultivar is very prone to russeting for example from attack by apple rust mite. The trees start to produce fruit unusually early and without thinning it is prone to biennial bearing (Redalen and Vestrheim, 1991). It flowers early and the pollen quality is good, but the amount might be limited. It is susceptible to apple scab and fruit tree canker. It is relatively winter-hardy. The apples are usually harvested in the last part of September (Kvåle, 1995).

Discovery

The production of Discovery has increased in Norway recently. It is an English cultivar, a seedling of Worcester Pearmain, possibly crossed with Beauty of Bath. It was released in 1962 and brought to Norway in 1974 (Redalen and Vestrheim, 1991). It is one of the first cultivars on the market, usually harvested early in September in Norway (Kvåle, 1995). The fruits are medium sized with a conic shape. They have a yellow background colour almost completely covered with a crimson colour. The pulp is crisp and juicy with a distinct flavour and might be pinkish. The fruits stay on the tree quite long but do not store long. The tree starts to produce fruits early, but the yield is limited. (Redalen and Vestrheim, 1991). The growth is relatively weak, and the branches are rough. It is not too winter hardy. It is quite resistant to downy mildew and apple scab but susceptible to fruit tree canker. The flowering is quite early, and it is a good pollen donator.

Rubinstep

Rubinstep is a new cultivar in Norway. It is a licenced cultivar developed in the Czech Republic, a cross between Clivia and Rubin. In other countries it is known as Pirouette® (Myren, 2012). It has a crisp pulp and is a productive and early-bearing cultivar. It needs to be properly thinned. It matures in October, which is later than most of the other cultivars grown commercially in Norway. It needs to be stored after harvest to get softer and develop better background colour (Meland and Myren, 2014).

3.3 Soil sampling

Soil samples were collected from the 25 orchards to estimate nutrient reserves and pH in the soil. The sampling was done early in the spring, before any fertiliser was applied. In each orchard, three rows with a uniform soil type were chosen. Three samples were supposed to be analysed from each orchard, with soil from one row each. But due to a misunderstanding, only one sample from each orchard was analysed in Viken and Telemark, containing soil from all three rows. In Sogn and Hardanger, three soil samples from each orchard were analysed, with soil from one row each.

In the result section, the results of all the samples are presented separately, three samples from each orchard in Sogn and Hardanger, and one sample from each orchard in Viken and Telemark.

An auger with a diameter of about 20 mm was used to collect the soil. At least 9 soil columns in the depth of 0–20 cm were taken from each row, about 2 m apart. The top plant litter was removed before the samples were taken. The soil columns were collected in a plastic bucket and mixed well with a trowel. A half-litre cardboard box was filled with soil.

3.4 Soil analysis

The soil samples were analysed by Eurofins Norway. Mostly, standard Norwegian methods were used. These are described in detail in 'Metoder for jordanalyser' (Krogstad, 1992).

The soil samples were dried on trays at 40°C as quickly as possible when they were received by the laboratory. The soil was dried for further treatments, leading to a reduction or stop in the microbial processes. The temperature was not higher than 40°C because this might have influenced the analysis results.

Soil analyses were performed on the fraction of the soil with diameters less than 2 mm: clay, silt and sand. The soil therefore had to be sifted to be prepared for analysis. The soil was sifted through a steel sieve with 2 mm holes.

All the soil was dried and sifted, and a part of the soil from each sample was then used to perform each of the analyses described below.

3.4.1 Soil texture

The soil texture was measured for all the soil samples. Soil texture is a measure of the relative distribution of the soil particles in the clay, silt and sand fractions. The measurement of soil texture was done according to the Dutch standard. Clay is defined as particles less than 2 µm, silt particles from 2–50 µm and sand particles as 50 µm–2000 µm. The distribution between the different classes was found using a near-infrared instrument.

In Norway, the standard is to classify the silt fraction as 2–60 µm. The difference in classification between the Norwegian standard and the Dutch standard used here likely lead to an underestimation of the silt fraction in the samples compared to the result if the Norwegian standard had been used.

Eurofins reported the content of calcium carbonate and organic matter as a part of the physical composition of the soil. The sand, silt and clay content in the samples presented in this thesis were calculated so that these summed to 100%.

3.4.2 Dry matter and loss on ignition

The loss on ignition was measured to determine the organic matter content in the samples. The loss on ignition is the weight loss of a soil sample previously dried at 105°C when this is heated to a very high temperature for 3–4 hours. The temperature used by Eurofins was 500°C.

For organic soil, the loss on ignition gives a good measurement of the organic matter content, but for mineral soil, as these samples, the clay content must be considered. Clay contains chemically bound water, which is removed at temperatures higher than 150°C. A correction factor was subtracted from the measured loss on ignition value for all the samples, as given in Table 7. The correction factor is an average for a given range of clay content.

Table 7. Correction factor for different clay content (Krogstad, 1992).

Clay content	Correction factor
5–9%	1
19–24%	2
25–39%	2.5
40–59%	3.5
>59%	4.5

3.4.3 pH

The pH was measured using the standard Norwegian method. Ten ml dried and sifted soil was placed in a plastic cup with lid and 25 ml distilled or deionized water added. Eurofins used a ratio of soil to water of 1:5. The mixture was shaken and left at room temperature overnight. The next day the sample was shaken again and left for some minutes until most of the soil precipitated. The pH was measured in the liquid above.

3.4.4 Easily soluble phosphorous, potassium, magnesium and calcium

The easily soluble nutrients are those amounts of the nutrients the plant may absorb from the soil during a short period, such as during a growing season. Several different extraction methods are used. Since the 1960s, the standard method for soil analysis in Norway of easily soluble phosphorous, potassium, magnesium and calcium has been the ammonium lactate method (Krogstad, 1992).

For the extraction, 0.1 M NH_4-lactate and 0.4 M acetic acid with a pH of 3.75 was used. Four grams of soil was mixed with 80 ml solution. The bottles were put on a shaker immediately and left there for 90 minutes. The suspension was filtered immediately after the shaking.

Ammonium exchanged the cations from the soil particles, while lactate made a complex with iron and aluminium. The latter lead to an increased desorption of iron and aluminium ions from the soil particles, and phosphate ions dissolved.

The nutrients were measured in mg/100 g air-dried soil. The values were assigned to different classes to evaluate the plant available amount in the soil, as shown in Table 8 (Krogstad, 1992).

Table 8. Classes to determine plant available phosphorous, potassium, magnesium and calcium described in 'Metoder for jordanalyser' (Krogstad, 1992).

Class	Low	Medium	High	Very high
P_{AL}	0–2	3–6	7–15	>15
K_{AL}	0–6	7–15	16–30	>30
Mg_{AL}	0–2	3–5	6–9	>9
Ca_{AL}	<50	51–100	101–200	>200

3.4.5 Acid-extractable potassium (K-HNO_3)

The plants might use more potassium through the growing season than what is extracted with the AL-solution. The soil was boiled in 1M HNO_3 (Krogstad, 1992) which gave a measure of the reserves in the soil that might be released in the long term.

Five grams of soil was mixed with 50 ml extraction solution in a 200 ml Erlenmeyer flask. The flask was put on a thermostat-regulated hotplate, reaching the boiling point after 7 minutes. The flask was thereafter transferred to another hotplate for weak boiling for 10 minutes. It was left for cooling in a fume hood and when it reached room temperature it was filtered into a beaker. The concentration of potassium was measured in mg/l in the solution. This is equivalent to the concentration in mg/100 g air-dried soil, which is used in fertiliser planning.

To evaluate the plant available potassium in the soil, a combination of K_{AL} and K-HNO_3 is often used. The isolated values of K-HNO_3 were divided into classes as shown in Table 9 (Krogstad, 1992).

Table 9. Classes to evaluate the level of K-HNO_3. Described in "Metoder for jordanalyser" (Krogstad, 1992).

Class	Low	Medium	High	Very high
K-HNO_3	<30	30–79	80–119	>120

3.4.6 Plant available copper

Copper is the micronutrient that is most often analysed on cropland in Norway (Krogstad, 1992). This study used a complexing agent to extract copper. This imitated how plant roots absorb nutrients from the soil. When the complexing agent reacted with the copper in the solution, more ions dissolved. A combination of the complexing agent EDTA and NH_4Cl was used as extraction solution.

Plant available copper was measured in mg/kg air-dried soil and divided into classes to evaluate the plant available amount in soil as shown in Table 10 (Krogstad, 1992).

Table 10. Classes to evaluate the level of plant available copper. Described in "Metoder for jordanalyser" (Krogstad, 1992).

Class	Low	Medium	High	Very high
Cu	0–1.0	1.1–2.0	2.1–5.0	>5.0

3.5 Fertilisation and orchard management

Neither fertilisation practice nor orchard management was standardized for the sake of the project, meaning that the farmers applied fertiliser and managed the trees as they normally would have done. To get information on management of the orchards, a questionnaire was sent out to the farmers, with help from Stine Huseby and Gaute Myren. Almost all farmers in Sogn, Hardanger and Viken answered the questionnaire.

The amount added and the timing and method of fertiliser application differed between the orchards. Some farmers supplied nutrients only by spreading it on the orchard floor in the tree rows, while others supplied nutrients though fertigation in addition to or instead of this application. The use of foliar sprays varied a lot between orchards.

In most orchards, the amount of added nitrogen through the season was about 4–5 kg/daa. In two orchards, the amount added was about 9.5 and 7 kg/daa. Except for one orchard where phosphorous was not added, the amount of supplied phosphorous varied between 1–2 kg/daa. The amount of applied potassium varied between 3.5–7.5 kg/daa.

Most orchards were manually thinned, either by removing flowers or fruitlets.

3.6 Leaf sampling and analysis

To study nutrient uptake in the trees, leaves were sampled from some of the orchards in Viken and Hardanger. Leaves were sampled from the same three rows as the soil samples were collected. As was the case with soil samples, three samples were supposed to be analysed from each orchard, with leaves from one row each. But, due to the same misunderstanding, only one sample from each orchard was analysed from the orchards in Viken. In Hardanger, three samples were analysed from each orchard. The samples from Hardanger contained leaves from five trees from one row, while the samples from Viken contained leaves from five trees chosen from all three rows. In the results section, all the samples are presented separately.

The sampled leaves were the youngest fully-developed leaves from mid-extension shoots in 1–1.5 m height. Five leaves were collected per tree. The leaf samples analysed in this thesis were collected in August.

The leaves were put in a paper bag and delivered to the soil sciences laboratory at NMBU for analysis of dry matter content of macro- and micronutrients (nitrogen, phosphorous, potassium, magnesium, calcium and copper).

The leaves were dried at 60°C, and phosphorous, potassium, magnesium, calcium and copper were measured after parts of the samples were decomposed under pressure with concentrated nitric acid in an ultraCLAVE. The nutrients were measured with ICP-MS and the results reported as mg/kg dry sample. The results of the macronutrients were reported as g/kg dry sample and for copper as mg/kg dry sample. To be used in the result section the equivalent amount in percentage dry sample was calculated for the macronutrients and as ppm for copper.

Total nitrogen content was analysed with the instrument LECO Truspec CHN. Parts of the leaves collected in each sample were combusted at 1050°C so that all the nitrogen turned into NO_x gases. Measuring thermal conductivity after the NO_x gases were reduced to N_2 showed nitrogen content. The results were reported in percentage of the dry sample.

3.7 Fruit sampling and analysis

Apples were harvested from some of the orchards in Viken and Hardanger and one in Sogn, and the nutrient content was analysed in the dried fruit.

As with both soil sampling and leaf sampling, the fruit sampling procedure differed between districts. Twenty apples were supposed to be harvested from each of the three rows, in total 60 apples from each orchard. And three samples were supposed to be analysed from each orchard, containing apples from one row each. In Hardanger, this sampling procedure was followed. In Viken, 20 apples were sampled per orchard, resulting in one fruit sample from each orchard. Apples were only harvested from one orchard in Sogn. Four apples were harvested from five trees in each of the three rows, in total 60 apples. But when analysed, apples from only one tree was used in each sample, resulting in a total of 15 samples from this orchard.

The apples were sent to NIBIO Ullensvang, where they were prepared for analysis. From each orchard in Viken, 10 apples were chosen randomly for the analysis. From the orchards in Hardanger, 10 apples were chosen randomly from each of the three rows. The samples were composed of best quality apples. From the orchard in Sogn, the four apples that were harvested from each tree were used for analysis. This resulted in one sample from each orchard in Viken, three samples from each orchard in Hardanger and 15 samples from the one orchard in Sogn. In the results section, all the samples are presented separately.

All the apples were sliced once, across the apple. A slice diagonally with this cut was taken from each apple, including the skin, flesh and core. The slices were put in a bag and dried in a heating closet at 40–60°C. When the samples were dry (relative to the temperature), they were ground.

The analysis of dry matter content of macro- and micronutrients (nitrogen, phosphorous, potassium, magnesium, calcium and copper) in the apple powder was done at NMBU. The procedure was the same as for the leaf analysis.

4 Results

This chapter opens in section 4.1 with a presentation of the soil texture measured for the 25 orchards in the different districts. In section 4.2, the measured organic matter content in the same 25 orchards is presented in a bar chart, where each sample is shown as a separate column. The same applies to most of the other results from the soil, leaf and fruit analyses throughout this section. The samples are numbered according to Table 6. For the orchards where three samples were taken, these are named "subsamples" in this section, and each have been assigned an extra number in addition to the number for the orchard. In the special case of fruit sampling from separate trees in the orchard in Sogn, a fourth number is given to distinguish these samples. In the graphs where an average is used to represent the orchard, this is specified.

In section 4.3, the results on soil pH is shown. In section 4.4, the results of nitrogen in leaves and fruit is presented. It is not common to take soil samples of nitrogen content, so this was not done. The rest of the sections presents the results of the other sampled nutrients in soil, leaves and fruit: phosphorous (section 4.5), potassium, (section 4.6), calcium (section 4.7), magnesium (section 4.8) and copper (section 4.9).

In the bar graphs showing nutrient level in soil, the horizontal lines separate the classes of a low, medium, high and very high nutrient content in the soil, as described in 'Metoder for jordanalyser' (Krogstad, 1992). For the leaf and fruit analyses, one line indicates the optimal level described in 'Gjødsling i frukthagar' (Vangdal, 2017). Generally, above the demarcation is optimal, but for magnesium in fruit, lower is better. Two lines indicates a range of optimal values. In the case of copper in leaves, an optimal level was not described in 'Gjødsling i frukthagar' (Vangdal, 2017), and the reference level is instead taken from *Soil fertility and fertilizers* (Havlin *et al.*, 2016).

4.1 Soil texture

The measured soil texture for the different orchards is shown in Figure 9. For the orchards where three subsamples were taken, an average of the particle size distribution is used to represent the orchard. The samples are colour-coded according to the district. As shown in the figure, the soil texture varies quite a bit within and between the districts.

The variation in particle size distribution is greatest for silt and sand. The sand content varies from 73%–18%, while the silt content varies from 71%–26%. The clay content varies from less than 1%–18%.

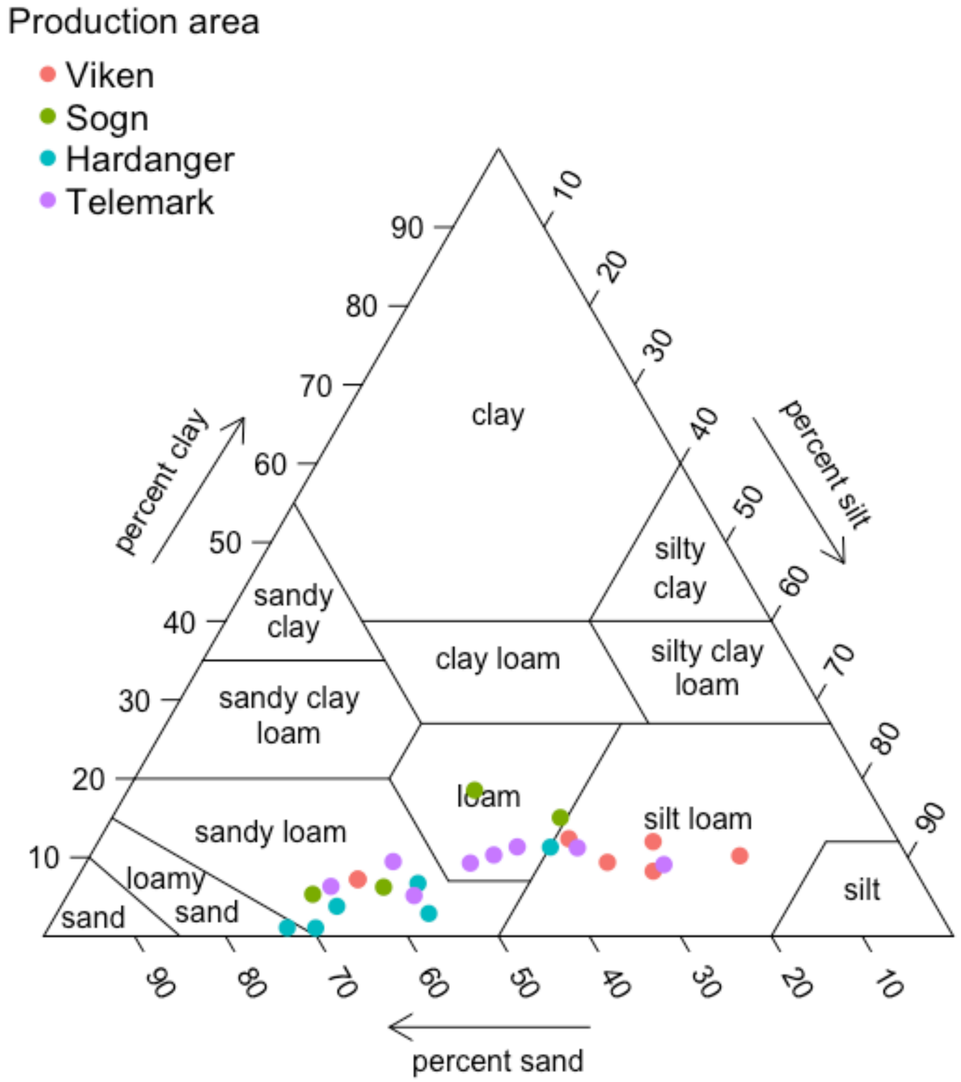

Figure 9. Soil texture in the different orchards. An average of the particle size distribution is used to represent the orchard where three subsamples were taken. The measurements of two orchards in Viken were exactly the same, therefore only six points from Viken are shown, there are two in the sandy loam category.

4.2 Organic matter

The plot of organic matter in the samples is shown in Figure 10. The organic matter was estimated by the loss on ignition, subtracted the correction factor for the class of clay content. There is a large variation in content, from almost nothing to about 12%. The samples with the lowest organic matter content have a low ability to retain nutrients.

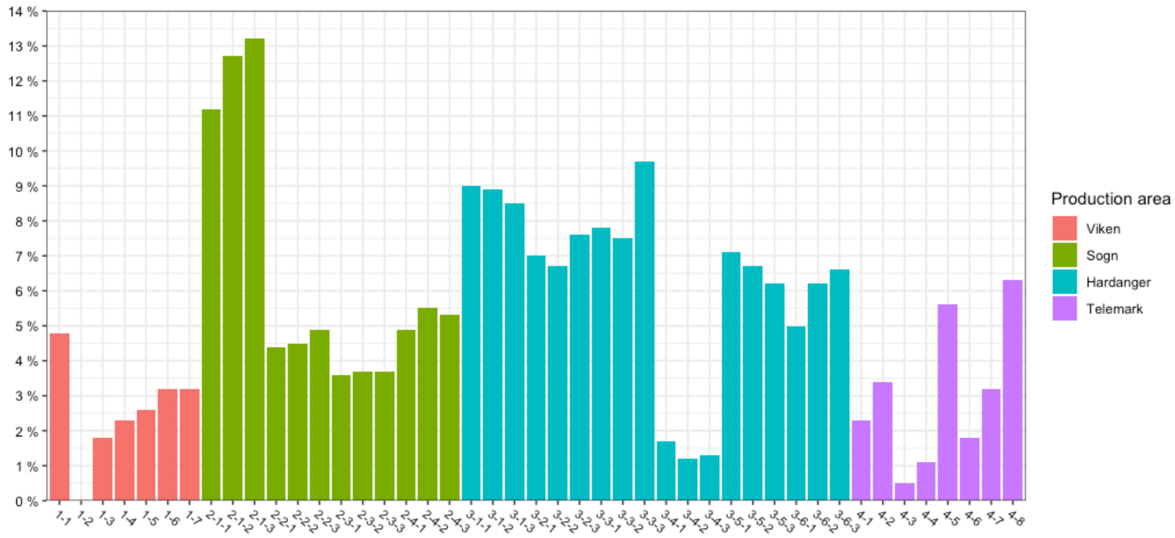

Figure 10. Organic matter content in the samples. The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3).

When the clay and organic matter content is plotted together (Figure 11), it shows that no samples have both a very low clay and a very low organic matter content. In this figure, an average is used to represent the orchard where three subsamples were taken. Both the clay minerals and organic matter contribute to the cation exchange capacity of the soil, but organic matter is most important, as it has a very high cation exchange capacity compared to the different clay minerals.

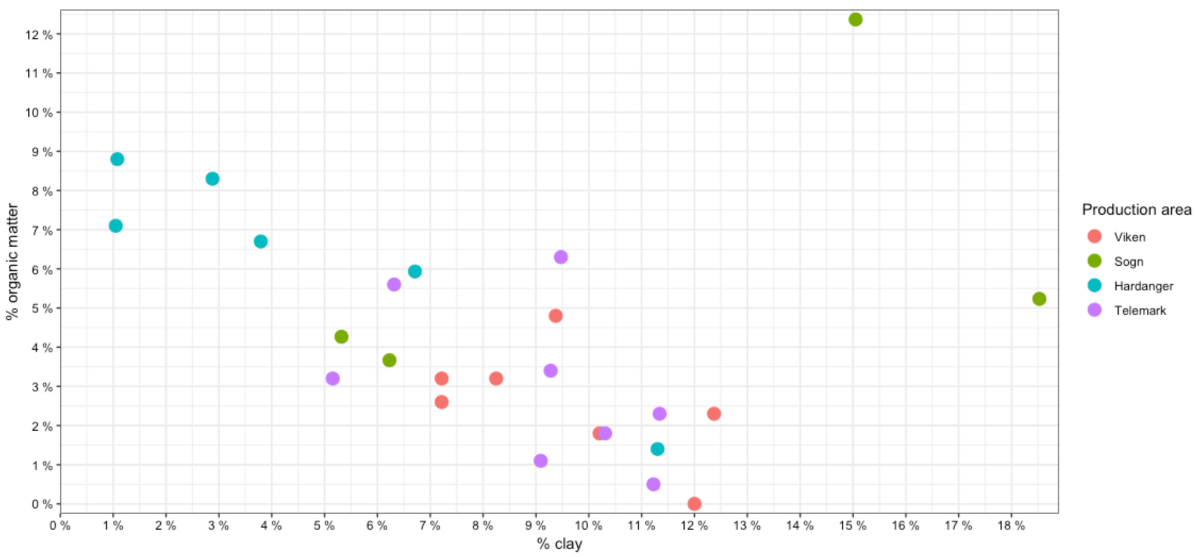

Figure 11. Clay and organic matter content in samples. An average is used to represent the orchard where three subsamples were taken.

4.3 pH

The measured soil pH values for all samples are shown in Figure 12. The pH values for the subsamples from the same orchard are encircled. In one of the orchards, the measured pH varies by 0.7 units between two of the samples.

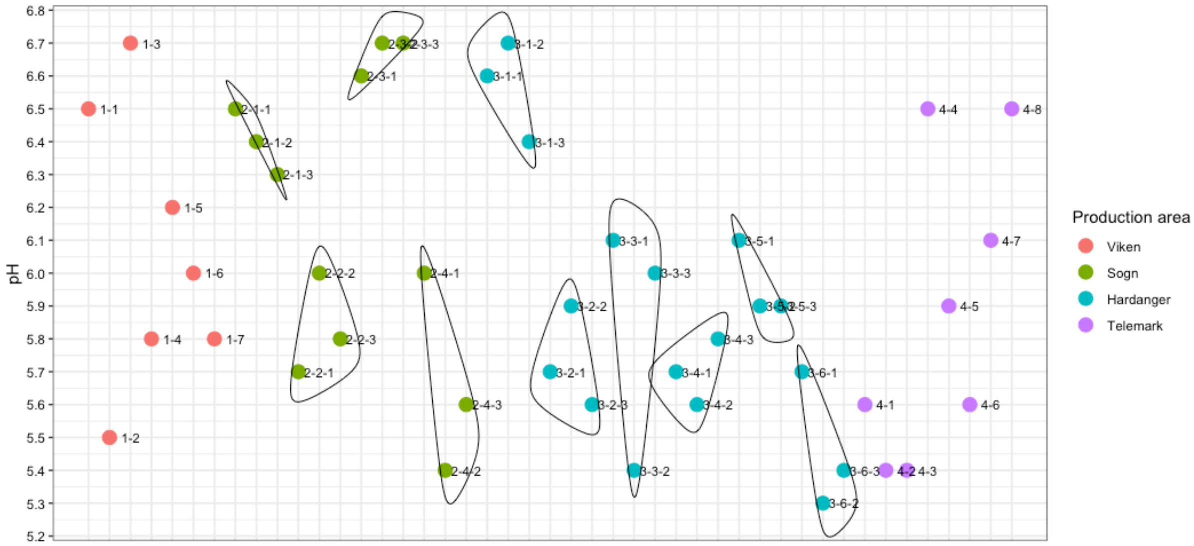

Figure 12. Measured pH for all samples. The pH value for the subsamples from the same orchard are encircled. The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3).

As described previously, the pH value regarded as optimal is evaluated according to soil texture in 'Gjødsling i frukthagar' (Vangdal, 2017). The classes of soil texture shown in Figure 9 are not used, but soil is divided into three general classes: sandy soil, silty soil and clay soil. To evaluate the pH in relation to these classes, the pH values are shown together with information on soil texture in Figure 13. As shown in Figure 9, none of the orchards in the project have a very high clay content. To divide the samples into sandy soil and silty soil, the samples with a sand content of more than 50% were named sandy soil, while the rest of the samples were named silty soil. The samples are ordered after pH value and colour-coded according to the soil texture. In this figure, an average of the pH values and soil texture is used to represent the orchard where three subsamples were taken. Among the samples with a low pH, a majority are in the silty soil class.

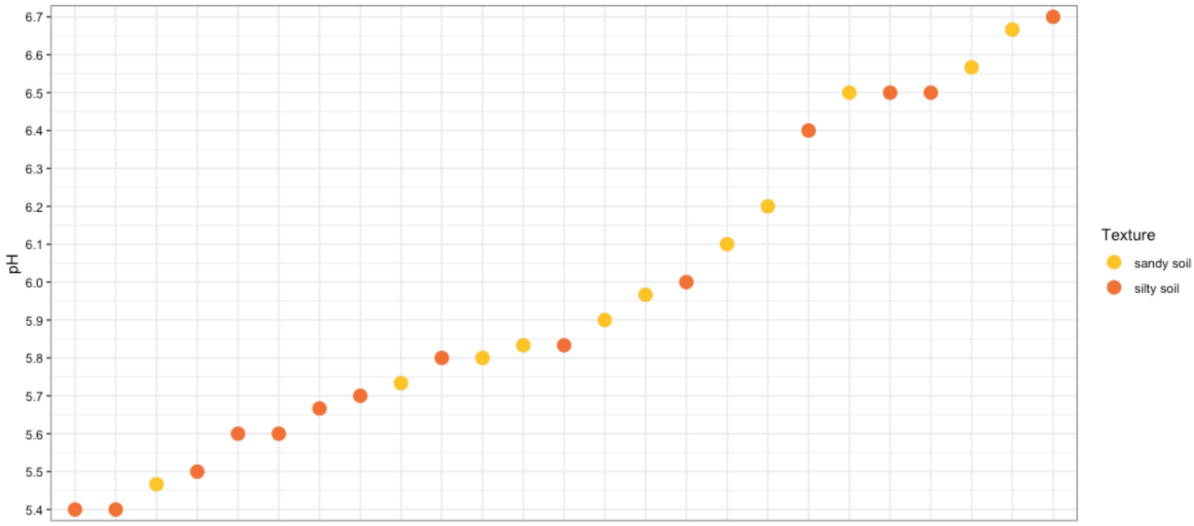

Figure 13. Ordered values of measured pH in orchards. An average of the pH values and soil texture is used to represent the orchards where three subsamples were taken. The samples are colour coded according to soil texture.

4.4 Nitrogen

4.4.1 Nitrogen in leaves

The measured nitrogen content in the dry matter in the sampled leaves is shown in Figure 14, which varies from about 2% –2.8%. The horizontal lines mark the boundaries of the level described as optimal in ‘Gjødsling i frukthagar’ (Vangdal, 2017). Most of the samples have a content within this interval; others are a little above.

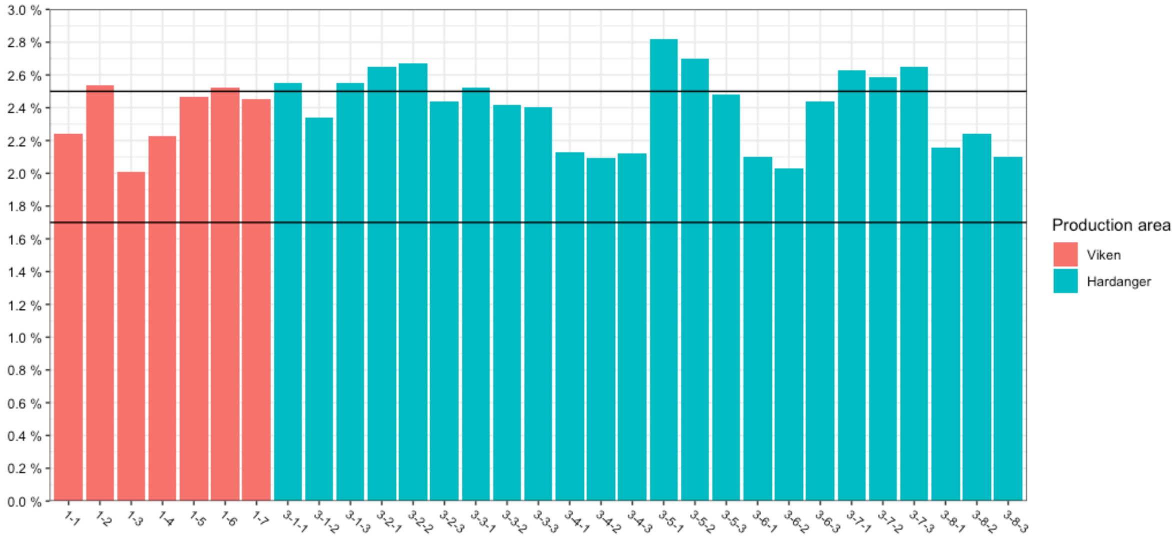

Figure 14. Nitrogen content as a percentage of dry matter in leaf samples. The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). The horizontal lines mark the boundaries of the level described as optimal in ‘Gjødsling i frukthagar’ (Vangdal, 2017).

4.4.2 Nitrogen in fruit

The measured nitrogen content in the dry matter in the sampled fruit is shown in Figure 15. Both the lowest content of 0.16% and the highest of 0.51% are found within the same orchard. The horizontal lines mark the boundaries of the level described as optimal in ‘Gjødsling i frukthagar’ (Vangdal, 2017), and most samples in this experiment measure below this value.

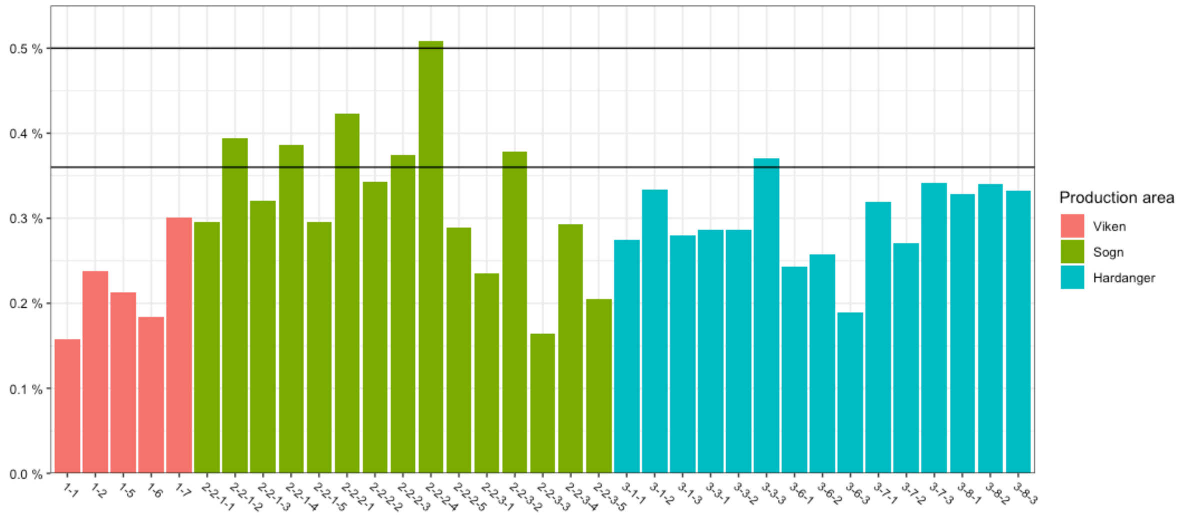

Figure 15. Nitrogen content as percentage of dry matter in fruit samples. The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). For the samples from Sogn, the fourth number is a number for the specific tree. The horizontal lines mark the boundaries of the level described as optimal in ‘Gjødsling i frukthagar’ (Vangdal, 2017).

4.5 Phosphorous

4.5.1 Phosphorous in soil

The measured plant available phosphorous content in all the soil samples is shown in Figure 16. The horizontal lines separate the classes of P_{AL} values in mg/100 g air-dried soil. Less than 2 is considered low, 3–6 is medium, 7–15 is high and greater than 15 is very high (Krogstad, 1992). All samples are in the high or very high class, and some orchards have extremely high values. The P_{AL} value of 96 in Telemark is due to excess application of manure from animals raised for fur.

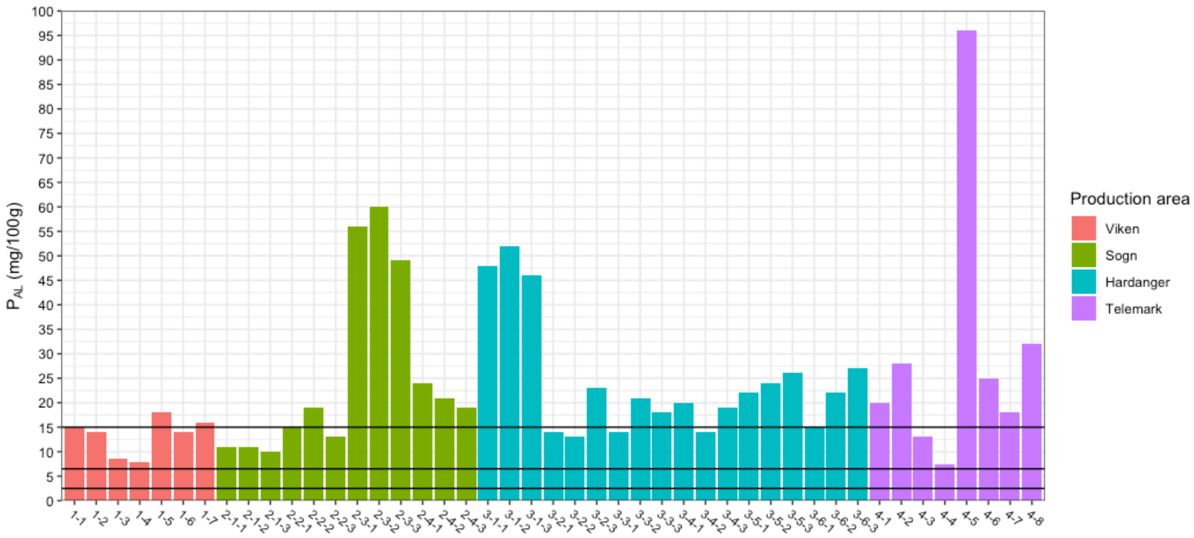

Figure 16. P_{AL} values in samples (mg/100 g air-dried soil). The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). The horizontal lines separate the classes of P_{AL} values. Less than 2 is considered low, 3–6 is medium, 7–15 is high and greater than 15 is very high (Krogstad, 1992).

4.5.2 Phosphorous in leaves

The measured phosphorous content in the dry matter in the sampled leaves is shown in Figure 17. The horizontal lines mark the boundaries of the level described as optimal in 'Gjødsling i frukthagar' (Vangdal, 2017), and most samples have a phosphorous content within this interval.

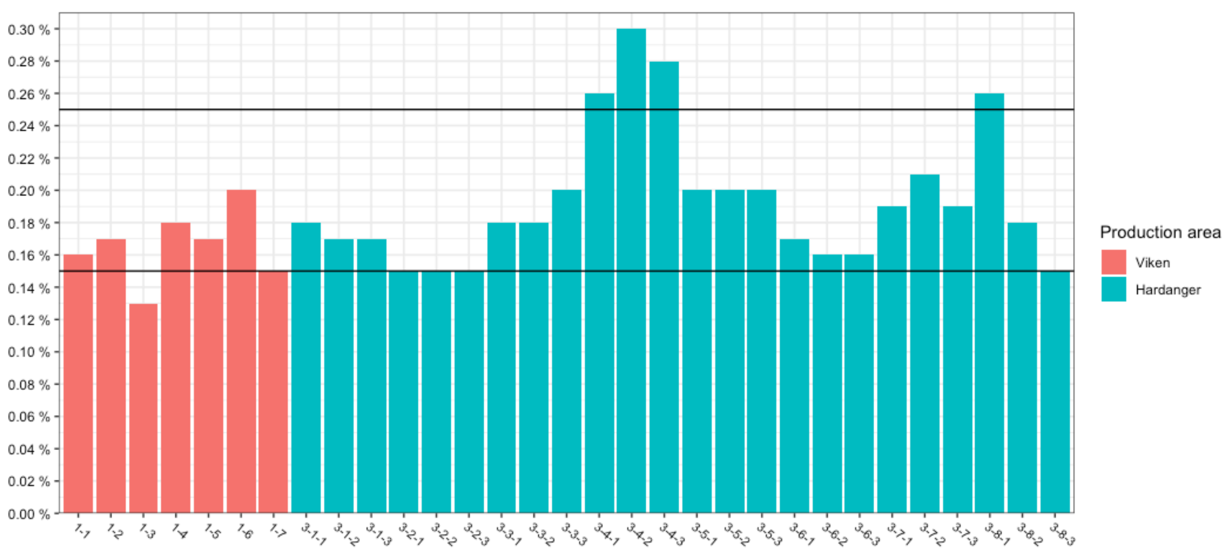

Figure 17. Phosphorous content as percentage of dry matter in leaf samples. The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). The horizontal lines mark the boundaries of the level described as optimal in 'Gjødsling i frukthagar' (Vangdal, 2017)

4.5.3 Phosphorous in fruit

The measured phosphorous content in the dry matter in the sampled fruit is shown in Figure 18. The phosphorous level considered optimal in ‘Gjødsling i frukthagar’ (Vangdal, 2017) is greater than 0.09%, marked by the horizontal line in the figure. All samples have a content lower than this.

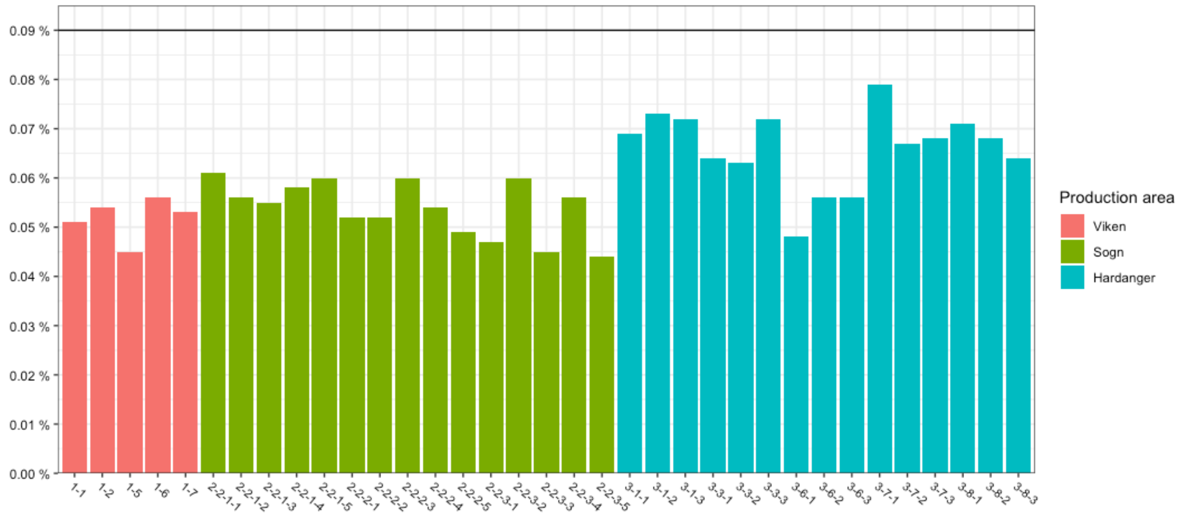

Figure 18. Phosphorous content as percentage of dry matter in fruit samples. The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). For the samples from Sogn, the fourth number is a number for the specific tree. The horizontal line at 0.09% is the phosphorous level considered optimal in ‘Gjødsling i frukthagar’ (Vangdal, 2017).

4.6 Potassium

4.6.1 Potassium in soil

The measured plant available potassium content in all the soil samples is shown in Figure 19. The horizontal lines separate the classes of K_{AL} values in mg/100 g air-dried soil. Less than 6 is considered low, 7–15 is medium, 16–30 is high and greater than 30 is very high (Krogstad, 1992). None of the samples have a low content, but several are in the medium range.

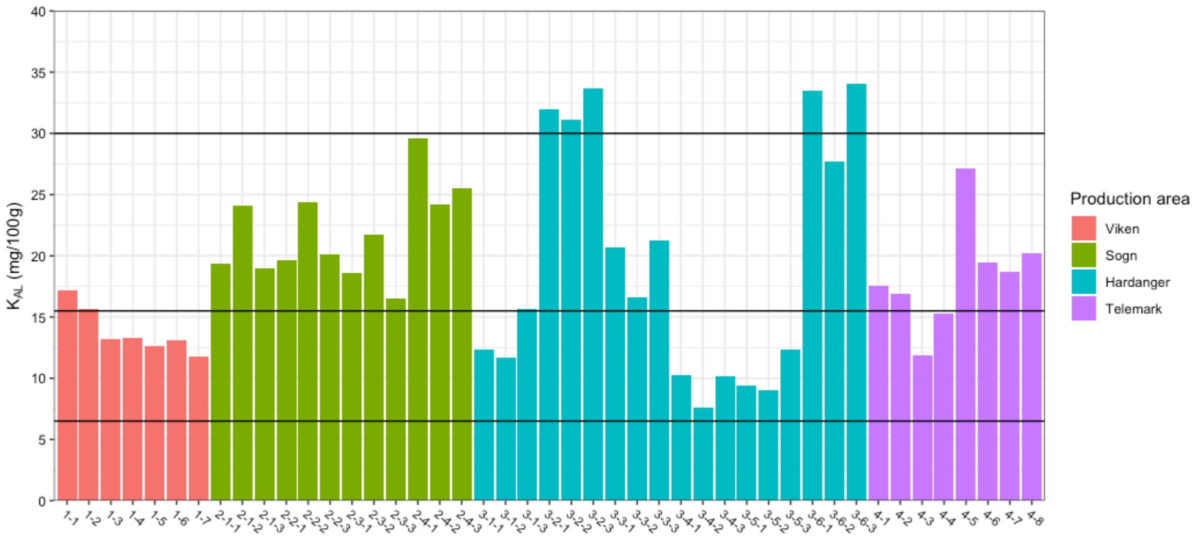

Figure 19. K_{AL} values in samples (mg/100 g air-dried soil). The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). The horizontal lines separate the classes of K_{AL} values. Less than 6 is considered low, 7–15 is medium, 16–30 high and greater than 30 is very high (Krogstad, 1992).

The measured acid extractable potassium content in all the soil samples is shown in Figure 20. The horizontal lines mark the classes of K-HNO_3 values in mg/100 g air-dried soil. When these values are considered alone, a value of less than 30 is classified as low, 30–79 is medium, 80–90 is high and greater than 120 is very high (Krogstad, 1992). Some soils have a low potassium supplying capacity, while others have a very high capacity.

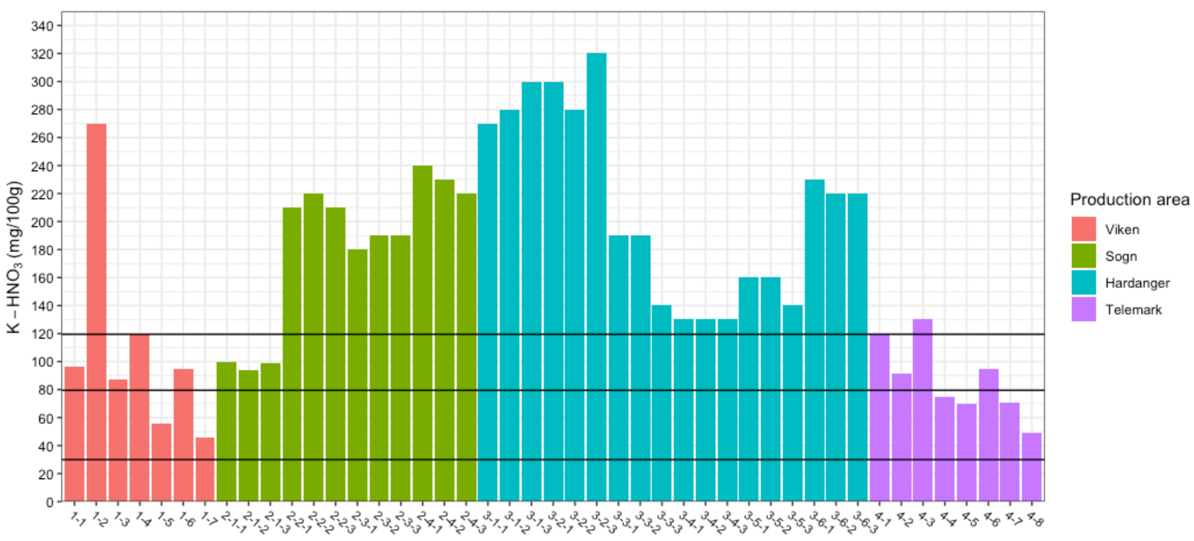

Figure 20. K-HNO_3 values in samples (mg/100 g air-dried soil). The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). The horizontal lines separate the classes of K-HNO_3 values. When these values are considered alone, a value of less than 30 is classified as low, 30–79 is medium, 80–90 is high and greater than 120 is very high (Krogstad, 1992).

4.6.2 Potassium in leaves

The measured potassium content in the dry matter in the sampled leaves is shown in Figure 21. The horizontal lines mark the boundaries of the level described as optimal in 'Gjødsling i frukthagar' (Vangdal, 2017). Most samples have a content within this interval, some a bit below, and others a bit above.

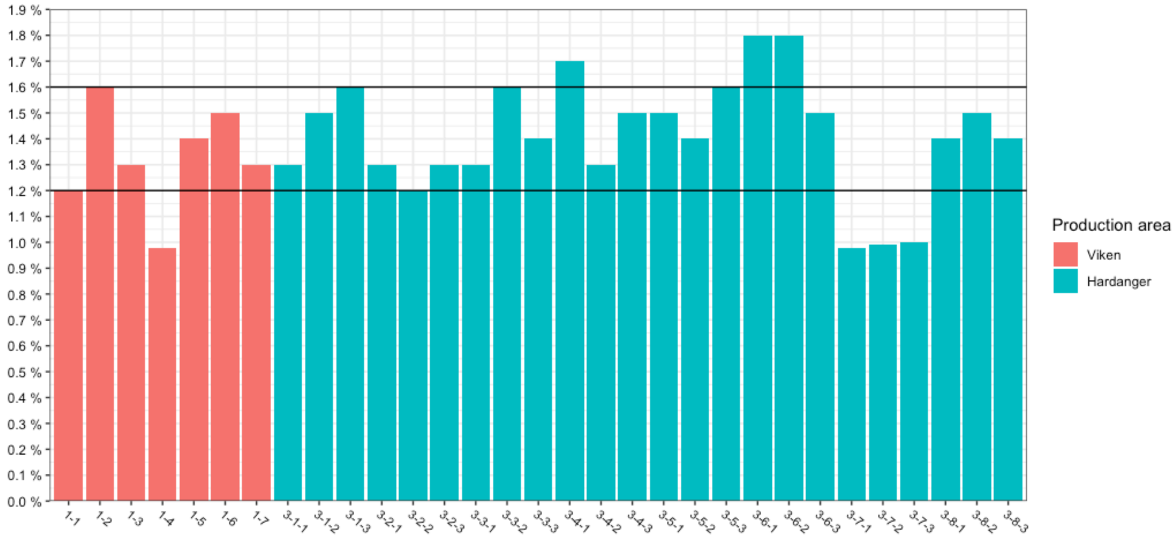

Figure 21. Potassium content as percentage of dry matter in leaf samples. The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). The horizontal lines mark the boundaries of the level described as optimal in 'Gjødsling i frukthagar' (Vangdal, 2017).

4.6.3 Potassium in fruit

The measured potassium content in the dry matter in the sampled fruit is shown in Figure 22. The horizontal lines mark the boundaries of the level described as optimal in 'Gjødsling i frukthagar' (Vangdal, 2017), and most samples have a content lower than this.

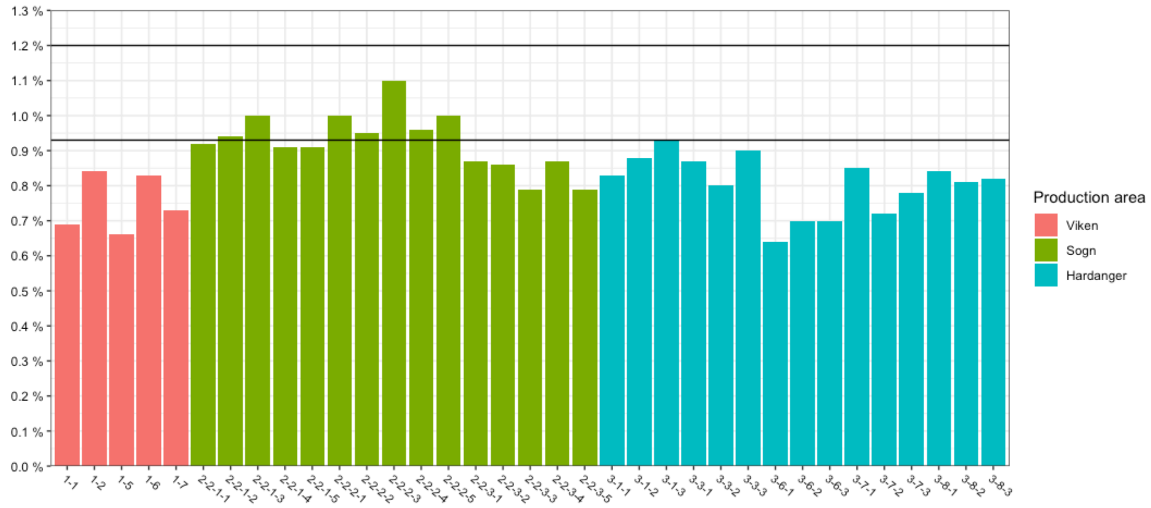

Figure 22. Potassium content as percentage of dry matter in fruit samples. The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). For the samples from Sogn, the fourth number is a number for the specific tree. The horizontal lines mark the boundaries of the level described as optimal in 'Gjødsling i frukthagar' (Vangdal, 2017).

4.7 Calcium

4.7.1 Calcium in soil

The measured calcium content in all the soil samples is shown in Figure 23. The horizontal lines separate the classes of Ca_{AL} values in mg/100 g air-dried soil. Less than 50 is considered low, 51–100 is medium, 101–200 is high and greater than 200 is very high (Krogstad, 1992). The level in the samples varies a lot, and some soil samples contain quite little calcium compared to what is recommended.

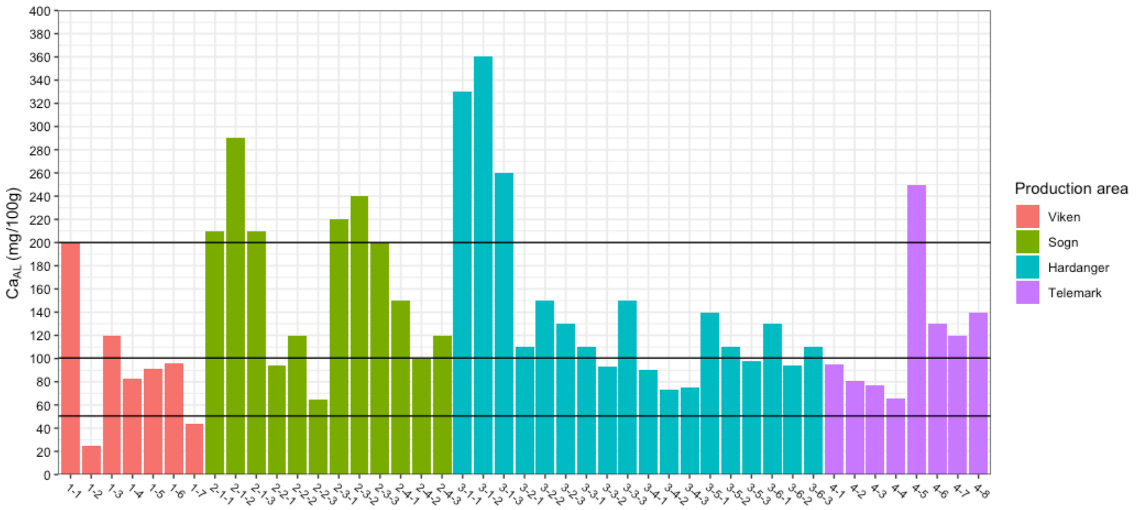

Figure 23. Ca_{AL} values in samples (mg/100 g air-dried soil). The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). The horizontal lines separate the classes of Ca_{AL} values. Less than 50 is considered low, 51–100 is medium, 101–200 is high and greater than 200 is very high (Krogstad, 1992).

4.7.2 Calcium in leaves

The measured calcium content in the dry matter in the sampled leaves is shown in Figure 24, which varies from 1%–2.8%. The horizontal lines mark the boundaries of the level described as optimal in ‘Gjødsling i frukthagar’ (Vangdal, 2017). All samples have a content above the lower limit, and some a content much higher than this.

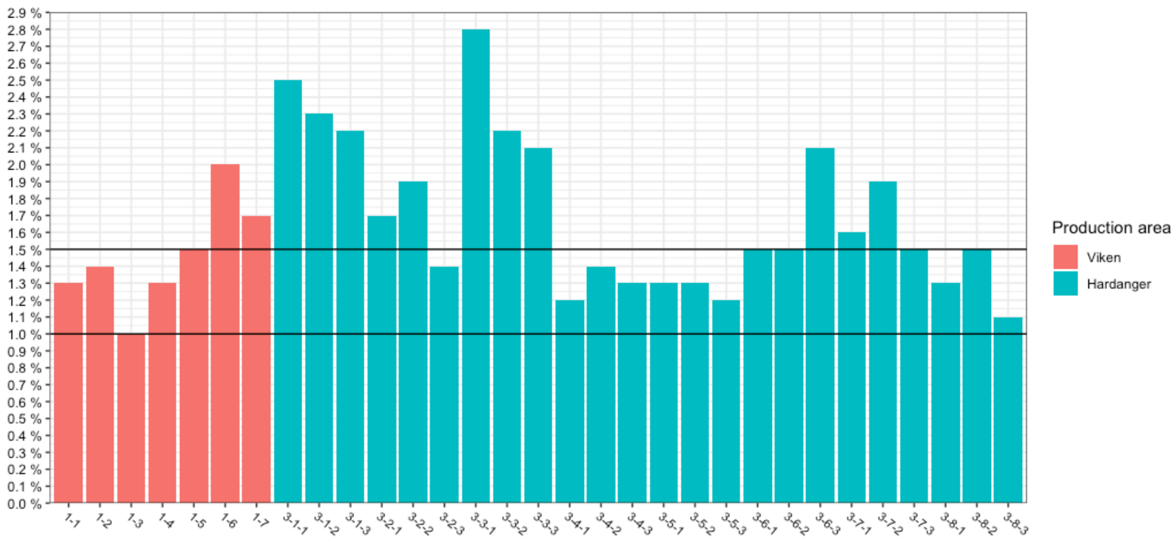

Figure 24. Calcium content as percentage of dry matter in leaf samples. The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). The horizontal lines mark the boundaries of the level described as optimal in ‘Gjødsling i frukthagar’ (Vangdal, 2017).

4.7.3 Calcium in fruit

The measured calcium content in the dry matter in the sampled fruit is shown in Figure 25. The calcium level considered optimal in 'Gjødsling i frukthagar' (Vangdal, 2017) is greater than 0.03%, marked by the horizontal line at 0.03% in the figure. Some samples lie below this value, and others above. Within the same orchard in Sogn, the content varies a lot.

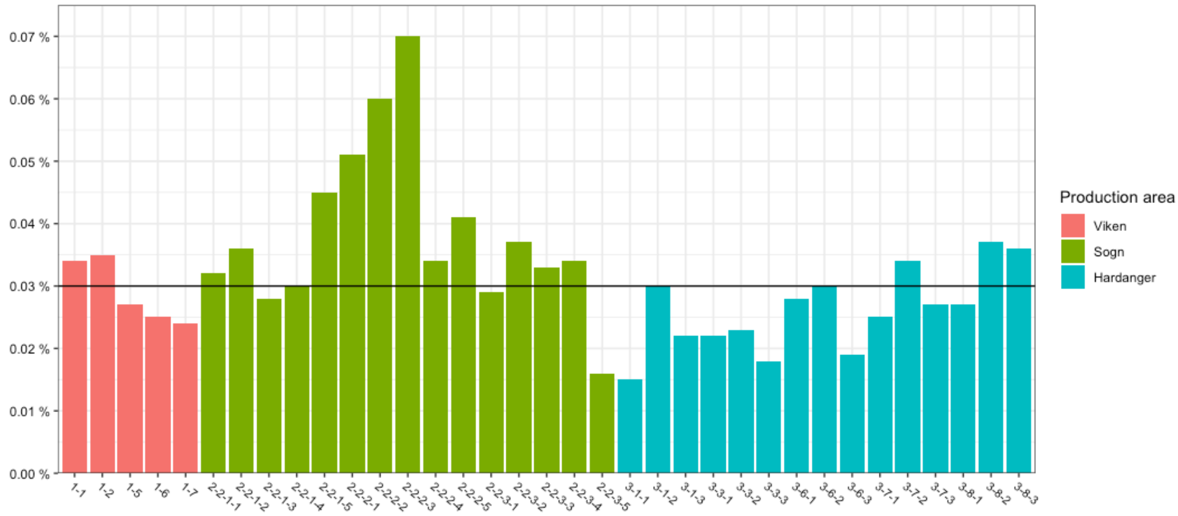

Figure 25. Calcium content as percentage of dry matter in fruit samples. The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). For the samples from Sogn, the fourth number is a number for the specific sampled tree. The horizontal lines mark the boundaries for the optimal calcium content. The calcium level considered optimal in 'Gjødsling i frukthagar' (Vangdal, 2017) is greater than 0.03%, marked by the horizontal line at 0.03%.

4.8 Magnesium

4.8.1 Magnesium in soil

The measured magnesium content in all the soil samples is shown in Figure 26. The horizontal lines separate the classes of Mg_{AL} values in mg/100 g air-dried soil. Less than 2 is considered low, 3–5 is medium, 6–9 is high and greater than 9 is very high (Krogstad, 1992). Most of the samples have a high content. There is a large variation, and some of the samples have much higher content than the rest.

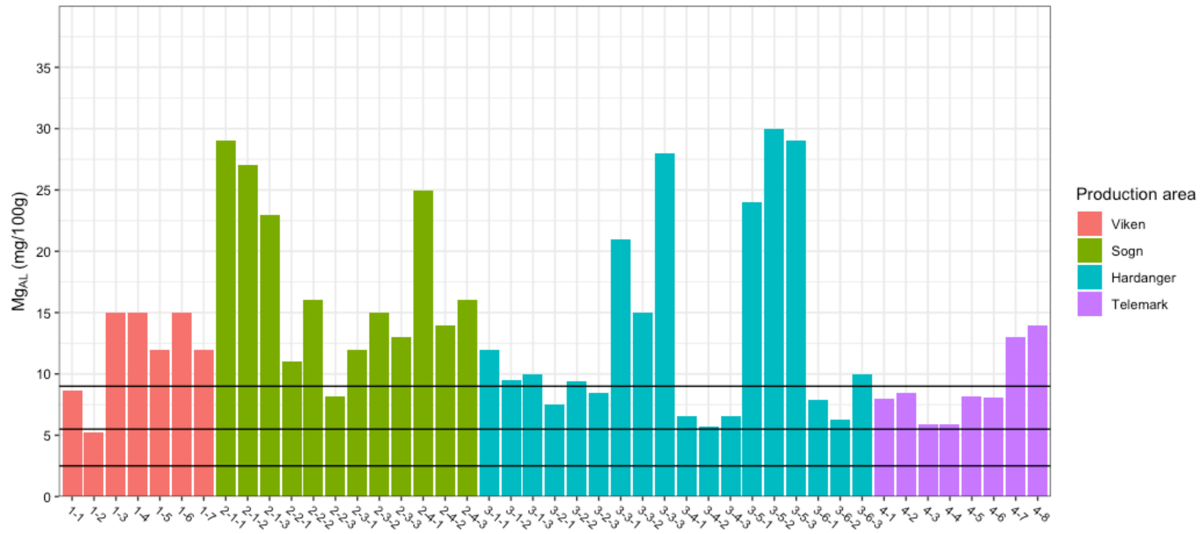

Figure 26. Mg_{AL} values in samples (mg/100 g air-dried soil). The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). The horizontal lines separate the classes of Mg_{AL} values. Less than 2 is considered low, 3–5 is medium, 6–9 is high and greater than 9 is very high (Krogstad, 1992).

4.8.2 Magnesium in leaves

The measured magnesium content in the dry matter in the sampled leaves is shown in Figure 27. The horizontal lines mark the boundaries of the level described as optimal in 'Gjødsling i frukthagar' (Vangdal, 2017). The measured content is below, within and above this interval. For orchard 3-6, the measured content varies from 0.14–0.3% within the same orchard.

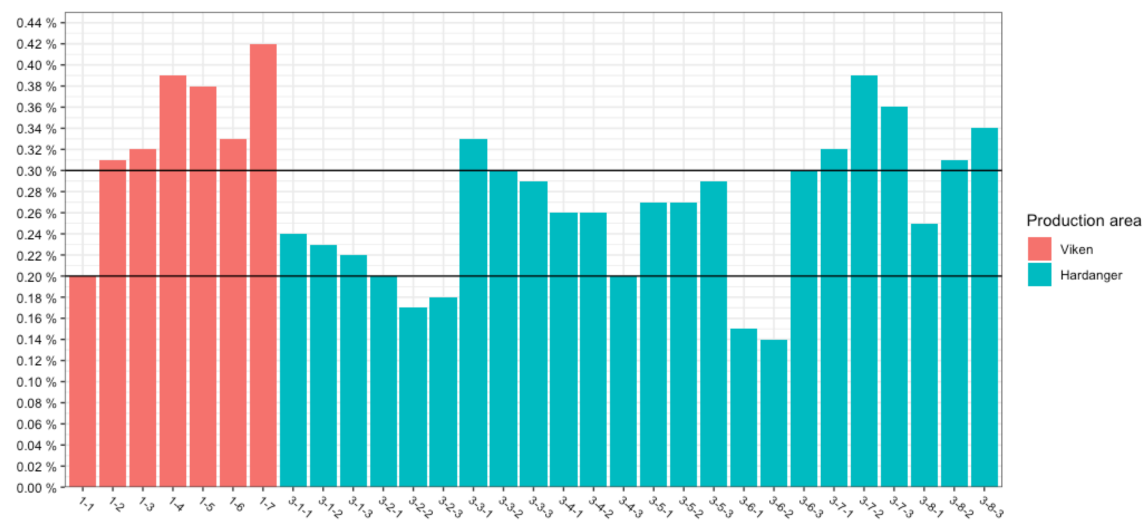

Figure 27. Magnesium content as percentage of dry matter in leaf samples. The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). The horizontal lines mark the boundaries of the level described as optimal in 'Gjødsling i frukthagar' (Vangdal, 2017).

4.8.3 Magnesium in fruit

The measured magnesium content in the dry matter in the sampled fruit is shown in Figure 28. The Mg_{AL} level considered optimal in 'Gjødsling i frukthagar' (Vangdal, 2017) is less than 0.035%. Some samples have a content a little above the value considered optimal. Both the lowest value of 0.028% and the highest of 0.053% are found within with the same orchard in Sogn.

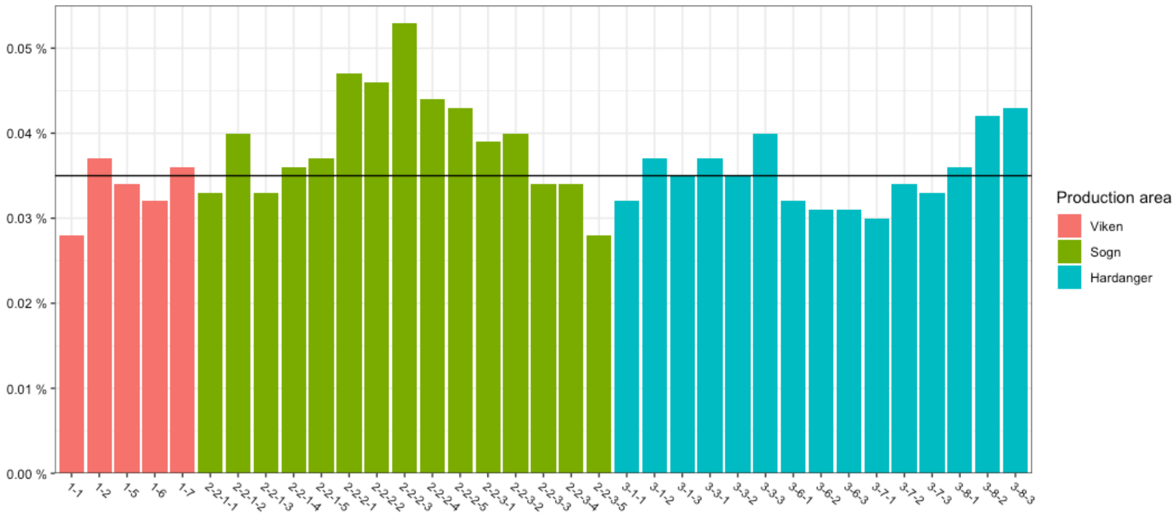

Figure 28. Magnesium content as percentage of dry matter in fruit samples. The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). For the samples from Sogn, the fourth number is a number for the specific tree. The Mg level considered optimal in 'Gjødsling i frukthagar' (Vangdal, 2017) is less than 0.035%, marked by the horizontal line at 0.035.

4.9 Copper

4.9.1 Copper in soil

The measured plant available copper content in all the soil samples is shown in Figure 29. horizontal lines separate the classes of copper values in mg/kg air-dried soil. A value of 0–1.0 is considered low, 1.1–2.0 is medium, 2.1–5 is high and greater than 5 is very high (Krogstad, 1992). There is a large variation, but almost all samples have high values. The samples from Hardanger stand out with extremely high values compared to the others.

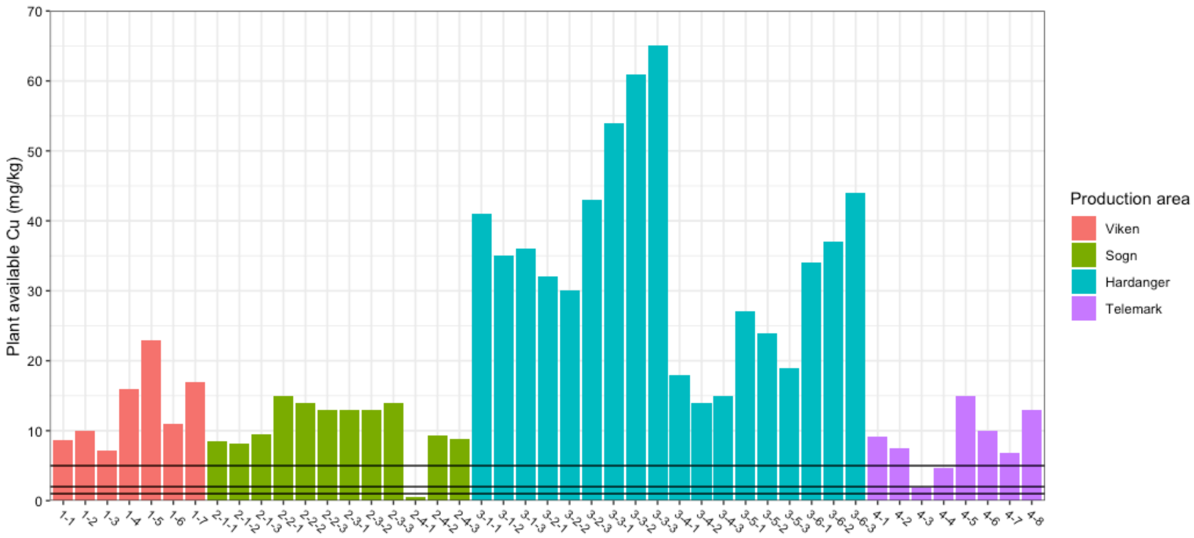

Figure 29. Plant available copper values in samples (mg/kg air-dried soil). The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). The horizontal lines mark the classes of copper values. A value of 0–1.0 is considered low, 1.1–2.0 is medium, 2.1–5 is high and greater than 5 is very high (Krogstad, 1992).

4.9.2 Copper in leaves

The measured copper content as ppm in the dry matter from the leaves is shown in Figure 27. The horizontal lines mark the boundaries of the level described as optimal in *Soil fertility and fertilizers* (Havlin *et al.*, 2016). Some samples have values a bit lower than what is considered optimal.

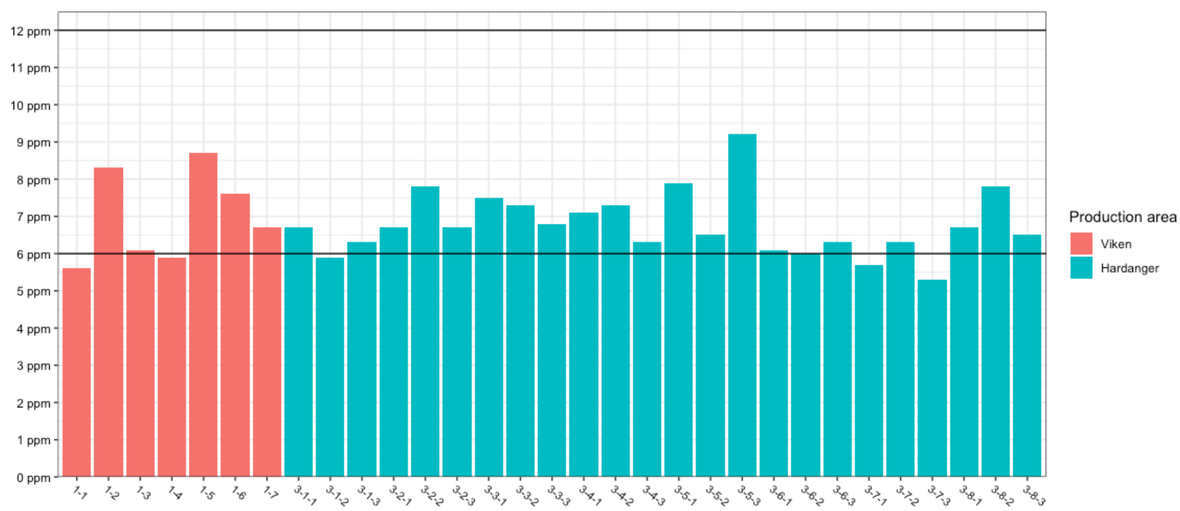

Figure 30. Copper content as ppm in dry matter from the leaves. The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). The horizontal lines mark the boundaries of the level described as optimal in *Soil fertility and fertilizers* (Havlin *et al.*, 2016).

4.9.3 Copper in fruit

The measured copper content in the dry matter in the sampled fruit is shown in Figure 31. The horizontal lines mark the boundaries of the level described as optimal in 'Gjødsling i frukthagar' (Vangdal, 2017). The content in all samples is very similar, and all lie below the wide interval considered optimal.

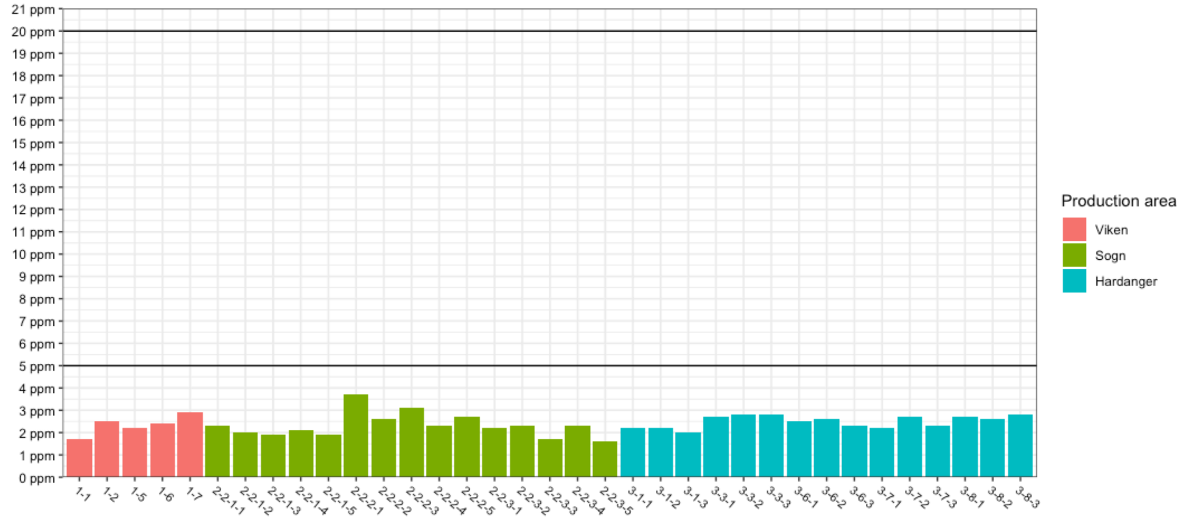

Figure 31. Copper content as ppm of dry matter in fruit samples. The samples are numbered by district and a number for the farm. The third number in the code is for the subsamples (1–3). For the samples from Sogn, the fourth number is a number for the specific tree. The horizontal lines mark the boundaries of the level described as optimal in 'Gjødsling i frukthagar' (Vangdal, 2017).

5 Discussion

The results from the soil and leaf analyses give a picture of the nutrient status in some apple orchards. In this chapter, the results are discussed in relation to the hypotheses, and whether or not they can be used to draw conclusions on fertilisation management in Norwegian apple orchards in general.

The chapter starts with the first hypothesis in section 5.1, where the results of soil pH are discussed. Because the primary calcium source is agricultural lime to raise pH, calcium is also discussed in this section. In section 5.2, the second hypothesis that the fertilisation is in excess of the trees' demand is discussed for each of the nutrients nitrogen, phosphorous, magnesium and copper separately.

5.1 pH

The first research hypothesis was that the pH in many orchards is lower than optimal for apple production. In Norway, uncultivated soil often has a pH between 4–5 (Salminen *et al.*, 2005), and agricultural lime must be added for a suitable pH for cultivation. The main problems for plant growth with too acidic soil are related to negative effects on root growth and reduced availability of nutrients (Havlin *et al.*, 2016). Different crops have different pH requirements, depending on their sensitivity to aluminium toxicity. A pH less than 5.0–5.5 might lead to problems with aluminium and manganese toxicity. This depends on crop and of the concentration of positively charged aluminium and manganese species, which is highest in soil with a high clay content. If the pH is less than 5.5 and the cation exchange capacity or base saturation is low, it might lead to problems with magnesium deficiency. According to Tore Krogstad (personal communication, 22nd January, 2018), aluminium toxicity has most often been tested on grass species, but it is expected to also have an effect on fruit trees. Adding too much agricultural lime might cause a decreased availability of micronutrients, which are less available with increasing pH, except for molybdenum (Havlin *et al.*, 2016).

As the effect of pH level has not been tested here, it might only be evaluated according to what is considered optimal for apples. Havlin *et al.* (2016) state that the optimal pH for apples is between 5.5–7. In 'Gjødsling i frukthagar' it is stated that the suitable pH for orchard soil is 5.5–6 for sandy soil, 5.8–6.3 for silty soil and 6.0–6.5 for clay soil (Vangdal, 2017).

As shown in the result section, the measured pH in the different orchards varies quite a lot (Figure 12), also within one orchard. Relatively high and low pH values are found within all apple districts, and Figure 13 shows that the same is the case for samples with a high sand content or a high silt content. The division of the orchards into silty soil and sandy soil is not done according to the standard soil texture classes but is useful as an overview of pH related to differences in soil texture. Of the samples in the lower range of the measured interval, most have a relatively high silt content. If the pH is evaluated after the criteria in 'Gjødsling i frukthagar' (Vangdal, 2017), it is too low for quite a lot of the orchards with a silty soil, while all but one of the sandy soil orchards have a pH considered high enough. Using these intervals as criterion, the pH is also considered too high in several of the samples.

The lowest pH value measured in a single soil sample is 5.3, while the highest is 6.7. If the samples are not evaluated according to soil texture, but rather the whole range of optimal pH values for all soil texture classes in 'Gjødsling i frukthagar' (Vangdal, 2017) is used (pH 5.5–6.5), some are still outside the range considered optimal. As previously mentioned, according to Havlin *et al* (2016), there might be problems with aluminium toxicity when the pH is lower than 5–5.5 and the availability of magnesium is reduced. Of the orchards in the project, aluminium toxicity might potentially be a problem in the orchards where the lowest pH values are measured. To avoid this risk, it seems like a good idea to add agricultural lime to increase the pH in these orchards, and preferably in other orchards before they reach values this low. Because the pH might vary a lot in the field, it could potentially be quite a lot lower than 5.3 in some areas of the orchards where the lowest pH values are measured. The pH might also be lower deeper in the soil which was not sampled, but where the roots reach.

The availability of the micronutrient boron, which is particularly important in apple fruit development, decrease especially at a pH greater than 6.5 (Havlin *et al.*, 2016). The highest pH value measured is 6.7, which is not an extremely high pH value, but the boron fertilisation should maybe be paid special attention to in the high-pH orchards.

In Figure 32, the measured pH values are plotted against the levels of calcium in the different orchards. An average represents the orchard where three subsamples were taken. As in the result section, the horizontal lines separate the classes of Ca_{AL} values in mg/100 g air-dried soil.

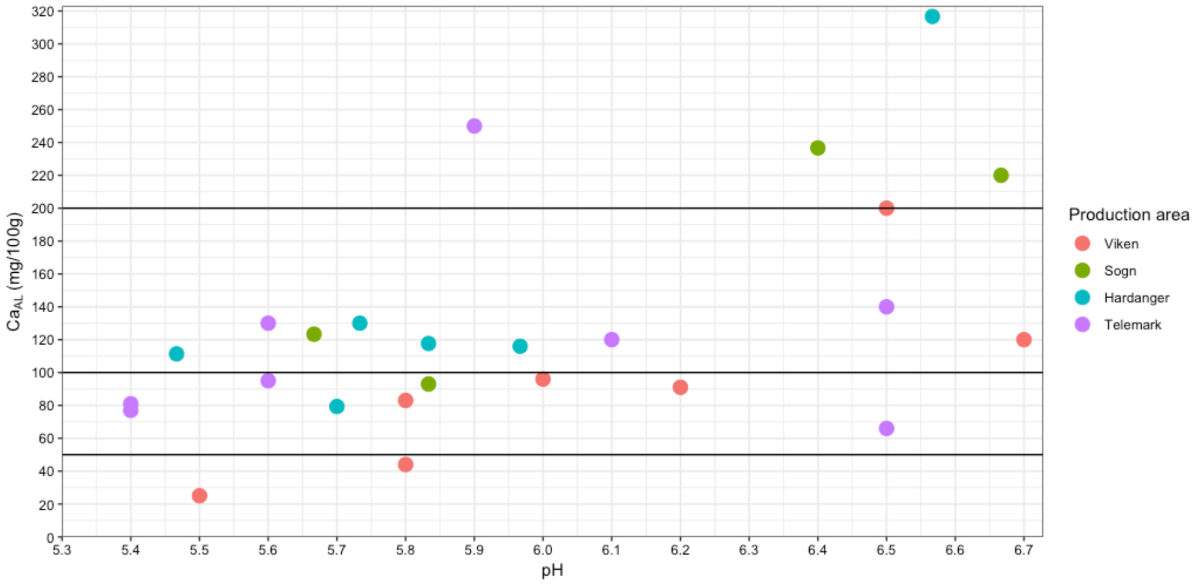

Figure 32. The measured pH against the calcium levels. An average is used to represent the orchard where three subsamples were taken. The horizontal lines separate the classes of Ca_{AL} values in mg/100 g air-dried soil. Less than 50 is considered low, 51–100 is medium, 101–200 is high and greater than 200 is very high (Krogstad, 1992).

The recommended Ca_{AL} level in 'Gjødsling i frukthagar' (Vangdal, 2017) is from 100–200. When considering the pH and calcium values together, it seems like liming to increase both the pH and calcium level in the soil is appropriate for several of the orchards. A high level of calcium in the soil is one of the factors that might reduce the risk of low-calcium related disorders in the fruit. Making sure the calcium level in the soil is high is an easy and cheap way to possibly increase the availability to the tree. But, as pointed out in the background section, other factors than calcium availability in the soil might be more important to secure enough calcium to the fruit. For example, in orchard 3-1, a high plant available calcium content in the soil does not lead to a high calcium level in the fruit. The Ca_{AL} values in the soil and leaf samples are very high, but in the apples they are relatively low (Figure 23–Figure 25).

When inspecting the leaf analyses (Figure 24), all the trees seem to have calcium levels considered high enough in 'Gjødsling i frukthagar' (Vangdal, 2017). Some samples have values higher than the recommended interval, but to the best of the authors' knowledge this should not represent a problem. Since foliar sprays with calcium is a common practice, it is impossible to know if the calcium was absorbed from the soil or originate from foliar sprays. Foliar sprays might also influence the calcium content in fruit.

It is known that the nutrient content in fruit might vary as much between apples on the same tree as it varies between apples on different trees (Waller, 1979). Especially for calcium, quite a lot of apples are needed in each sample to get a representative value for the orchard. Waller (1979) stated that thirty apples are more than enough to get a representative value for nitrogen, phosphorous and potassium, but that more apples are desirable for calcium. The fruit samples from orchard 2-2 are only composed of four apples each. The calcium content in these samples illustrate how the calcium content in the fruit might vary a lot within the same orchard (Figure 25).

The calcium content in the fruit is lower than recommended for several of the samples. More information on how calcium content in the fruit is related to keeping quality of these cultivars in the Norwegian climate would be needed to evaluate these results.

5.2 Fertiliser application

In Norway, the goal of fertiliser application is to add nutrients adjusted to the needs of the plants, which is as environmentally friendly as possible, secures quality of the products and is best economically for the growers. The second research hypothesis was that fertilisation practice today leads to an application of nutrients in excess of what the apple trees demand. Following is a discussion of the nutrients nitrogen, phosphorous, potassium, magnesium and copper.

5.2.1 Nitrogen

As discussed in the background section, excess nitrogen fertilisation might lead to vigorous vegetative growth and poor fruit quality while limited fertilisation in the early part of the season might cause poor fruit set. Soil samples of plant available nitrogen are not used in Norway to assess nitrogen availability because they only provide a snapshot of the situation, and the roots absorb nitrogen from deeper in the soil than soil samples usually are taken. Only leaf analyses might be used to evaluate nitrogen fertilisation, in addition to visual inspection of the trees.

When only evaluating the results of the leaf samples (Figure 14), the nitrogen content seems to be adequate for most of the trees. As discussed in the background section, the optimal content might vary with cultivar and yield, and more information is needed to properly assess the nitrogen fertilisation. Some samples have values a bit above the recommended level, but whether or not this is a problem for fruit quality is beyond the limits of this thesis.

The total nitrogen content in the soil is closely linked to the amount and quality of organic matter in the soil. The large difference in organic matter content between the orchards in the project (Figure 10) will cause large differences in the ability of different soils to supply nitrogen through mineralization. This should be paid attention to when applying nitrogen fertiliser.

The nitrogen content in the fruit samples varies a lot (Figure 15), as also seen for calcium. The largest variation is again found in the samples from orchard 2-2, where the samples are only based on four apples. It is interesting to note that very few of the samples have values within the interval considered optimal in 'Gjødsling i frukthagar' (Vangdal, 2017). Because neither fertilisation practice nor orchard management was standardized for the sake of the project, the results on nutrient content in dry matter in the apples might possibly give a representative picture of the general nutrient content in Norwegian apples of these cultivars. It seems like the interval considered optimal for nitrogen content in fruit is not representative for these cultivars in the Norwegian climate.

5.2.2 Phosphorous

According to Stiles and Reid (1991), fertilisation with phosphorous in orchards is often overemphasized. They state that trees usually get enough phosphorous even if the soil has low levels of phosphorous and if the soil pH is not too low, fertilisation with phosphorous at establishment should be sufficient for the entire life of the orchard. Phosphorous moves extremely slow down in mineral soil, and in trials in New York, surface application of phosphorous has not been financially viable (Stiles and Reid, 1991). Kvåle (1995) also states that the phosphorous content in Norwegian orchards normally is so high that there is rarely a need for yearly application.

Phosphorus is a non-renewable and scarce resource world-wide, and phosphorous flows is one of the planetary boundaries marked dangerous (Steffen *et al.*, 2015). The use should therefore be restricted. A very high phosphorous level in the soil represents an environmental problem because erosion and surface runoff might lead to eutrophication. In cases where the phosphorous levels are extremely high, leakage of phosphorous from the soil solution might also be a problem. If the quality or quantity of the apples is not increased by phosphorous fertilisation, it is cost-inefficient to apply it.

The recommendation in 'Gjødsling i frukthagar' (Vangdal, 2017) is a P_{AL} value of 8–12 mg/100 g air-dried soil. Most of the samples presented here have values higher than this, and several of the samples have extremely high values (Figure 16). Because phosphorus is strongly bound to mineral soil particles, an application in excess of what the trees use will lead to accumulation in the soil.

For several of the orchards which were sampled, the P_{AL} levels are so high that continued phosphorous fertilisation seems unnecessary. But in all cases where the questionnaire on fertilisation was answered, the farmers responded that the orchards in the project were fertilised with phosphorous, except for orchard 4-5.

The norm for adjusting phosphorous fertilisation with high P_{AL} levels in the soil was changed some years ago for cereals, oil seeds, meadow and pasture in Norway (Krogstad, Øgaard and Kristoffersen, 2008). Field trials had showed that the contribution of phosphorous to plants from the soil had been underestimated. Both the old and the new advices for correction of phosphorous fertilisation with different P_{AL} values are shown in Figure 33. The new advice is that no phosphorous should be applied if the P_{AL} value is higher than 14. It would be useful to reassess the advised correction of phosphorous fertilisation to fruit trees presented in Table 5 and at what P_{AL} value no phosphorous fertilisation is needed. Still, the advice is to add 25% of the recommended amount of phosphorous fertiliser when the P_{AL} value is greater than 15.

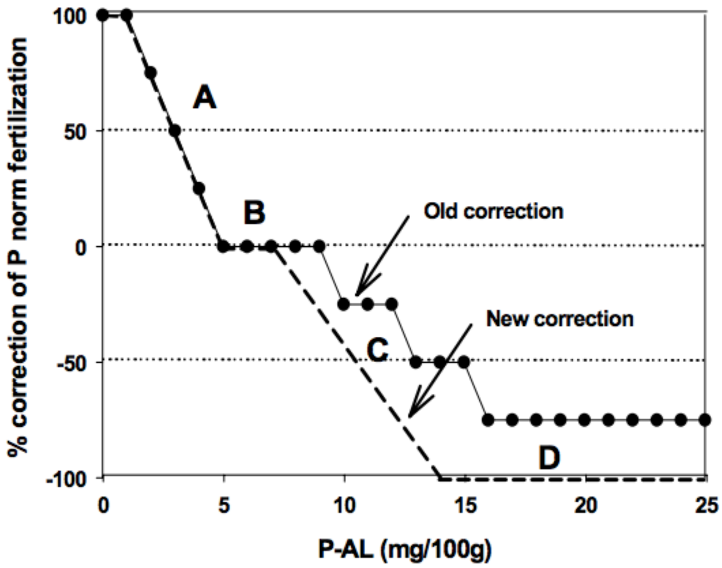

Figure 33. New and old advised percentage correction of the phosphorous norm fertilisation to cereals, oil seeds, meadow and pasture in Norway based on P_{AL} in the soil (Krogstad, Øgaard and Kristoffersen, 2008).

Most leaf samples (Figure 17) have a phosphorous content within the recommended interval. The sample from orchard 1-3 has a little lower value than recommended. A limitation with the leaf samples presented in this thesis is that each sample only consist of 25 leaves, while the standard is 100. The soil sample from orchard 1-3 indicates that the phosphorous access in the orchard is high, and more samples would be needed to check if the phosphorous content in the leaf sample is representative for the orchard. It is however unlikely that this decreased phosphorous content would affect the growth negatively.

Some leaf samples have values a bit higher than the recommended interval. As discussed in the background section, very high phosphorous content in soil with low zinc content could lead to uptake of phosphorous to toxic levels. But phosphorous levels considered toxic are much higher than the levels seen in these samples. Inspecting the results of the phosphorous values in the leaves gives no indication of problems with zinc deficiencies in the trees in these orchards.

The phosphorus content in the fruit (Figure 18) is lower than recommended in 'Gjødsling i frukthagar' (Vangdal, 2017) for all the samples. As for nitrogen, it seems like the level considered optimal for phosphorous content in fruit is not representative for these cultivars in the Norwegian climate.

5.2.3 Potassium

Both the plant available potassium (Figure 19) and the reserves (Figure 20) in the soil varies a lot between the orchards. The recommended K_{AL} level in 'Gjødsling i frukthagar' (Vangdal, 2017) is 20–30. Quite a lot of the samples have values lower than this, and a few have values above. According to Kvåle (1995) it is preferable not to fertilise with potassium for some years if the K_{AL} value is 30 or above, but if the K_{AL} value is between 10–15, it might be right to increase the potassium fertilisation for 2–3 years.

If the recommendations in 'Gjødsling i frukthagar' (Vangdal, 2017) and from Kvåle (1995) are to be followed, the fertilisation with potassium should be increased in some orchards. But it is important to note that the goal of fertilisation is not to increase the level in the soil per se, but rather make sure that the trees have access to sufficient nutrients throughout the growing season. Especially the soil in the orchards with a low cation exchange capacity will have a low ability to retain excess potassium fertilisation.

From inspecting the leaf samples (Figure 21), it seems like the potassium fertilisation secures a high enough nutrient access for most of the trees. Because it is common to apply foliar sprays with potassium this could affect the results. More samples would be needed to conclude on the relatively low potassium content in leaves in orchard 1-4. The level in the soil sample is not particularly low, but low water availability could, for instance, have reduced the access. In orchard 3-7, soil samples were not collected, and the leaf samples therefore cannot be evaluated based on knowledge of content in the soil. The relatively low potassium values from all the three rows sampled indicate that attention should be paid to potassium fertilisation in this orchard.

Soil with large reserves of potassium requires less fertilisation. When inspecting the $K\text{-}HNO_3$ values, it is seen that some orchards have low reserves of potassium, while others have very high. Variation in $K\text{-}HNO_3$ values reflects the variation in clay content and mineralogy more than fertiliser application. According to Kvåle (1995), $K\text{-}HNO_3$ values below 40 show that the potassium reserves in the soil are low, while values larger than 100 show that the reserves are large (Kvåle, 1995). In the orchards with the lowest reserves, potassium fertilisation should be paid special attention to.

Also for potassium, the level considered optimal in fruit in 'Gjødsling i frukthagar' (Vangdal, 2017) does seem to be a bit higher than what is representative for these cultivars grown in Norway (Figure 22).

5.2.4 Magnesium

The recommended Mg_{AL} level in the soil in 'Gjødsling i frukthagar' (Vangdal, 2017) is 10–12. The samples have both higher and lower levels than what is recommended (Figure 26). In several of the orchards where the Mg_{AL} levels in the samples are low, the pH values are also relatively low (Figure 12). If dolomite is used when liming these orchards, magnesium is also supplied and gives a higher plant available magnesium content in the soil.

According to Kvåle (1995), it is not considered advantageous to supply magnesium if the Mg_{AL} level is above 12. Following this recommendation, magnesium should not be applied to the orchards with the highest plant available magnesium content. According to (Stiles and Reid (1991), magnesium might compete with calcium uptake when soil supply of calcium is inadequate. As long as the calcium supply is good, the high magnesium content in some orchards will not likely cause problems.

The magnesium content in the leaves varies quite a lot (Figure 27). As with potassium, the application of foliar sprays with magnesium, which is common, could affect the results. The orchards where the samples with the lowest magnesium content in the leaves are found (3-2 and 3-6) are among the orchards where the highest K_{AL} values in the soil samples are also found (Figure 19). Excess potassium fertilisation could potentially lead to a decrease in magnesium uptake, but more information would be needed to conclude whether or not this is an issue here.

The magnesium content in fruit considered optimal in 'Gjødsling i frukthagar' (Vangdal, 2017) seems to be closer to what is actually common in these cultivars grown in Norway. Some values are a bit above the recommended level, while others are a bit below (Figure 28).

5.2.5 Copper

Copper is not commonly applied as fertiliser in Norwegian apple orchards, but it is rather used as a pesticide. The very high plant available copper values in the soil samples from

Hardanger (Figure 29) seems to be a consequence of the use of copper as a pesticide for several years with higher doses than what is used at present. Copper is very strongly bound to organic matter and accumulates in the surface layer.

One could believe that the extremely high availability of copper measured in some orchards would be negative for tree growth. A plant available copper level in the soil of greater than 5 mg/kg is considered very high, and the values measured in some of these samples are more than 10 times higher than this (Figure 29). According to Schachtschabel *et al.*(1976), a copper level in the soil higher than 50 mg/kg extracted with EDTA might be toxic to plants. This is the same extraction method used for the samples presented here, and the highest copper value measured in these samples is 65 mg/kg.

But the copper content is relatively equal in all the leaf samples. The extremely high plant available copper content measured in some orchards in Hardanger (Figure 29) has not resulted in accumulation of copper to toxic levels in the leaves (Figure 30). According to Marschner (2012), the critical toxicity level of copper in the leaves for most crop species is above 20–30 ppm.

The lower level considered optimal for copper in leaves in *Soil fertility and fertilizers* (Havlin *et al.*, 2016) is 6 ppm. Many of the leaf samples have a level close to this lower limit, and some have a content below what is considered optimal. This includes sample 3-1-2, which is collected from an orchard where the measured plant available copper content in the soil is among the highest measured in these samples. There seems to be no reason why the trees would not absorb sufficient amounts of copper if the access is very high. When evaluating both the results from the soil and leaf samples presented in the thesis, it seems like these cultivars do not need a copper content of 6 ppm in the dry matter in the leaves for optimal growth.

Results of apple-leaf analyses of copper performed by NLR in Hardanger also resulted in relatively low measurements of copper (Serikstad, 2011). Leaf samples from Hardanger and Telemark were analysed in the years 2005–2007, in total 76 samples. The average copper content in the dry matter in these samples was 6.12 ppm, the maximum value 9.9 ppm and the lowest 3.9 ppm. The laboratory considered 7.9% of the samples to have a normal content, while 92.1% of the samples were classified as having a too low copper content. It is likely that the copper access was high in many of these orchards too. The relatively low copper levels in these samples supports the view that the copper content in apple leaves in Norway generally is quite low.

The interval of the copper content considered optimal in fruit in ‘Gjødsling i frukthagar’ (Vangdal, 2017) does not seem to be based on a realistic content when inspecting the fruit samples (Figure 31). All the fruit samples have relatively equal values lower than the very wide range considered optimal. Analyses of copper content in the apple fruit has also been done in Hardanger (Serikstad, 2011), and all the apples had a low content.

6 Conclusion

The aim of this thesis was to increase the knowledge of the fertilisation and nutrient status in apple orchards in Norway and try to assess a part of whether the current fertiliser practice is optimal or not.

The first hypothesis was that the pH level in many orchards is too low for apple production. The effect of pH has not been tested here, so the evaluation of the measured soil pH values is done based on literature. Aluminium toxicity might potentially be a problem in the orchards where the lowest pH values were measured, so agricultural lime should be added to increase the pH in these orchards. Liming would also be a relatively cheap way to increase the calcium-availability to the trees and possibly reduce the risk of low-calcium related disorders. It is easiest to mix agricultural lime into the soil when the orchard is established, so it is important to increase the pH to a sufficient level at that time.

The second hypothesis was that fertilisation practice today leads to an application of nutrients in excess of what the apple trees demand. From the material assessed in this thesis, it seems like the fertilisation with nitrogen, magnesium and potassium is adequate in the orchards in this project. The content of plant available copper is extremely high in some orchards, but it does not seem to represent a problem for tree growth.

In the case of phosphorous, the P_{AL} values are unnecessary high in several of the orchards in the project. Very high phosphorous levels in the soil is probably representative for apple orchards in Norway in general. Experiments with surface application of phosphorous after establishment of orchards have rarely given positive effects on apple tree growth because the content in the soil was already high. Especially because phosphorous is a scarce resource world-wide, applying too much should try to be avoided. As has been done with other cultures, it would be advantageous to reassess the guidelines of phosphorous application to apple trees when the P_{AL} values are very high.

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