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Review

Apple Growing in Norway—Ecologic Factors, Current Fertilization Practices and Fruit Quality: A Case Study

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Abstract: This paper presents some features of apple production in Norway, the northernmost apple-growing country in the world. Acceptable growing conditions prevail along the fjords in western Norway and around the lakes in eastern Norway at 60° north. These specific mesic climate conditions are associated with very long summer days (18 h daylight mid-summer) and short winter days (6 h daylight), with frost rarely occurring in the spring along the fjord areas. The present apple-growing technique in Norway is similar to that of other developed apple-growing countries, taking into account that all local growing phases involve a considerable delay in progress (1.5–2 months). Therefore, high-density planting systems based on the use of dwarf rootstocks (mainly M.9) with imported early maturing international apple cultivars are used in most orchards. The most common soil type has high organic matter content (2–18%), which persists due to the cool climate and low mineralization, and a clay content of <15%, which results from the formation of the soil from bedrock. The increase in average temperatures caused by current climatic changes leads to a complex combination of different physiological effects on apples, which can have positive or negative effects on the phenology of the trees. The main advantage of Norwegian apple production is that the quality and aroma of the fruit meet the current demands of the local market.

Keywords: *Malus domestica* Borkh.; soil; climate change; minerals; cultivar

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1. Introduction

The environment includes both biotic and abiotic factors, but temperature, heat and chill requirement periods and global warming, besides nutrient deficiency or water stress, play a crucial role in plant growth [1,2]. These factors limit the growth of species according to their ability to respond to a particular temperature regime. In fact, plant species respond by changing their phenological phases, which affects their life cycle events along seasonal temperature changes. This is especially observed in areas where unfavorable extreme weather conditions prevail, such as low temperatures in northern European countries. This generally outlines a type of crop production in such countries, such as Norway, which is recognized as a commercial apple-growing country.

Climate has an indirect limiting effect on plant production, as it has a strong influence on the mineralization of soil organic matter. In this way, the soil plays an important role in supplying the apple trees with nutrients. The cold climate limits the mineralization of nitrogen, which is a limiting factor for apple production. The soils in Norway are predominantly podzolic, resulting in a low pH, which is also a growth-limiting factor for crop production in general, especially in clayey soils. The temperature-limiting effect of nitrogen mineralization in Norwegian soils on the nutrient supply of apple trees has recently been studied and published on [3].

In this country, where only 2.7% of the land is considered arable and only 2.2% of the high national GDP income comes from agricultural production—mainly barley, wheat, potatoes, pork, veal, milk and fisheries—the question about the sustainability of Norwegian fruit production is currently open [4,5]. In Norway, whose climate and landscape have no significant horticultural potential, fruit production, especially apple production, is not even close to other leading countries in Europe/the world. However, the existence of apple production in Norway has not only economic and commercial value, but is also a social, environmental, traditional and even political issue. Thus, the annual apple production in Norway is constantly increasing and is now an important factor in Norwegian agriculture. In the period from 2018 to 2022, apple orchards ranged from 1.3768 ha to 1.5795 ha and produced an annual yield of about 6829 t in 2018 to 9469 t in 2022, with a significant decrease in 2020 (6.792 t) [6]. However, there are forecasts that apple production will increase in the coming years, as with most other types of crop production in Norway, and this is mainly based on the planting of new orchards at higher altitudes due to climate change and temperature increase [7] and high market demand. Organic fruit production in Norway in total took up 292 ha in 2023. Apple production is carried out on 172 ha (58% of organic fruit production land) [8].

The first limiting factor for apple production in Norway is temperature. Therefore, much attention has been paid to the biodiversity of local apple cultivars that have high potential for the domestic market or other northern markets [9]. Indeed, current Norwegian apple production is mostly targeted to the local population, for which all domestic fruits have an advantage over imported fruits. Due to the specific factors of apple production, growers rely on experiences from other countries, but mainly on numerous domestic scientific works that are trying to improve this type of production [10–16]. The aim of this article is to present some characteristics of Norwegian apple production related to specific ecological factors (climate and soil) in combination with current fertilization practices and fruit quality, which all together could contribute to better apple production.

2. Climate Change and Apple Production in Norway

Locations of apple orchards in Norway perfectly illustrate the influence of natural factors on orchard location. Commercial apple production in Norway is limited to small regions along the fjord areas in the southwest part of the country and around lakes or near the sea in the southeast part, which has the most favorable climate of the country. There is a marinate climate in the western part with relatively cool summers and mild winters. Western winds from the Atlantic Ocean bring clouds, rain and wind throughout the year. The majority of the rainfall appears during the wintertime, mostly as rain, but there is some snow from time to time. The growth period from May to September can be relatively dry and all orchards have trickle irrigation to supply the trees with enough water during the summer. Orchards which are located near water do not freeze over and rarely suffer from winter frost and blossom frost. The main challenge is the low summer temperatures, which limit the length of the vegetation season, large yields and good fruit quality. In southeast Norway, areas with fruit production have a more continental impact on the climate, with colder winters and warmer summers. Severe winter frost can occur. When snow cover is absent, the cold can damage or kill the trees or the rootstocks. From time to time, spring frost during blossom time can happen, especially during springs which have early flowering. The orchards are modern and maintained at an international standard with high density plantings (3–4000 trees per ha), with cultivars grafted on dwarfing rootstocks (M9) and trickle-irrigated with fertigation. However, Norway's ecosystem is under big pressure because due to the climatic change, many problems with plant diseases and pests are expected in the future [17].

The problem of low temperatures in Norway is not comparable with the neighboring countries with exposed Nordic climates. The reason is that the apple-growing areas in Norway are located in fjord areas and around lakes that have a unique warm Gulf Stream, and plant-rich settlements are like oases in the southern part of the country. However, comparing some key climate factors in Norway at 60° North (Ullensvang) with the fruit production area in neighboring Sweden located at 56° North (Kristianstad), we find that the temperatures during the growing season (May–September) are not too different—14.3 °C (Norway) versus 15.2 °C (Sweden). July is the warmest month in both locations, with 16.1 °C versus 17.9, and January the coldest, with 1.3 °C versus 0.5 °C, respectively. There are differences in the number of rainy days and the amount of precipitation. The annual accumulated precipitation is 1870 mm and the average for the growing season is 541 mm (Norway), but less for Sweden—715 mm for the year and 339 mm for the growing season. May is the driest month in Norway and April is in Sweden. Meanwhile, Sweden leads with 2044 h of sunshine per year, while Norway lags behind with only 1168 h, mainly due to tall mountains shading the sun, especially during the winter [18], which is of great biological importance for fruit growth and ripening [19,20]. Meanwhile, this average of climatic factors varies among micro-sites, which makes the local Norwegian climatic conditions more complex. Therefore, a set of similar climatic data with low temperatures in winter and especially during the apple-growing season in Canada, Russia, Denmark, Japan and others cannot be easily compared. It is predictable that different growing conditions will at least produce different fruit quality characteristics, including sugar nutrient content, texture, flavor and aroma [18–22].

In general, agricultural production in Scandinavia may become more important globally in the future due to climate change and temperature rise, as predictions show more positive impacts than elsewhere in the world [23,24]. Changing climate and weather variability are expected to contribute to a longer growing season and provide opportunities for agriculture to increase crop yields and production [25,26]. On average, there was a linear trend of a 0.27 days/year earlier growing season start, a 0.37 days/year later growing season and an overall effect of a 0.64 days/year longer growing season between 1982 and 2006 for all so-called "Fennoscandian counties" [27]. This may have an overall positive effect on Norwegian agriculture [28]. A recently published study shows a significant increase in the length of the thermal growing season in four of seven studied catchments over a 27-year period (1991–2017) in southeastern, southwestern and northern Norway [29]. Warmer temperatures have increased organic matter turnover and increased the mineralization of nitrogen, which is important for plant growth. As far as apple production is concerned, this increase in outdoor temperature is more likely to affect the southern parts of Norway due to the north–south orientation of the country. As a result, the flowering time of apple trees advanced for nine days in the period from 1986 to 2016 [30,31]. It is undisputed that a long growing season is essential for maximum apple fruit growth, but it also has a complex combination of different physiological effects that can have positive or adverse effects on tree phenology. The current results suggest that the overall frost risk for apple crops in such warmer regions remains and may even be more pronounced in early spring due to meteorological blocking events ("stable high pressure systems"), and this has been shown to be one of the triggering factors for the spring cold snap [32]. This could make Norwegian apple production more vulnerable to the tendency for orchards to face the risk of frost more frequently than they do today. However, this tendency has been adopted by climate models obtained from studies in cooler European apple-growing regions such as Austria, northern Italy and Switzerland, where any obtained predictions require additional study related to apple plant behavior in relation to long-term climate change. For this reason, many modeling studies have found that the general underrepresentation of atmospheric blocking in climate models can lead to an underrepresentation of predicted outcomes in simulation runs [33–35]. Accordingly, the study conducted in Norway at five orchard sites (Landvik, Ås, Ullensvang, Kapp and Stjørdal) where the local climates are very different showed that flower bud formation, as a specific phenological phase of the apple, is influenced by many factors other than air temperature [21]. So, climate change in Norway could be just another unpredicted treat for apple production, but not a global challenge for its production in the country. This is confirmed by the research conducted in the last two decades (1981–2000), where the measured temperature increase affected the growing season (GS) and growing degree days (GDDs), with only minor differences in the length of the GS (<10%) and GDDs value (<10%) [36]. However, the same authors also expected that the temperature increase in Norway during the next fifty years would occur throughout the country during the entire growing season.

According to the latest studies of [37], climate change in the last several decades has brought some expansion in the spatial distribution of the areas with favorable heat conditions for apple growing. In the future, it will spread the most in the southern parts of south and east Norway and in the western parts of western Norway. Vujadinović Mandić et al. [38] stated that by the middle of the century, heat conditions will be adequate for cultivating many more cultivars in the south and southeast coast, expanding inland in the southeastern part of the country, as well as along the western coastline and locally along continental areas of fjords in the western and northwestern region. By the end of the century, apple production will be organized up to 63.5° N.

3. Apple Cultivars and Apple Rootstocks in Norway

The main problem of apple growing in Norway is the unfavorable climate. However, the fjord areas in western Norway are one of the northernmost tree fruit growing areas in the world. Therefore, sweet cherries (*Prunus avium* L.), apples (*Malus domestica* Borkh.), European plums (*Prunus domestica* L.) and pears (*Pyrus communis* L.) have been grown in this fertile, arable soil for centuries [39]. Because of the mild climate in the fjords, which are warmed by the Gulf Stream [40], the fruits can be grown at sea level and up to about 200 m above sea level. All these factors combined with very long summer days (18 h with daylight at midsummer) make the mesic climate suitable for tree fruit production, where winter and spring frosts are rare [41]. Consequently, a large discussion about the effects of climate change on countries' agriculture is to be expected, and some observations have been made that the real temperature increase should be more drastic than what is presented [42–44], especially during the last two decades [45].

In recent decades, modern, high-density orchards with international cultivars have replaced old orchards with traditional cultivars in Norway. Because of this, local apple cultivars have almost disappeared from current production. The last decade's early-maturing international cultivars are dominating, and the acreage increased especially after 2015, when large quantities of nursery trees were allowed to be imported from mostly The Netherlands and Belgium, while production and sales of Norwegian apple trees decreased significantly [46]. As a result, the long history of growing and eating old (wild) apple genotypes in Norway was practically erased from people's and science's memory. The "crab apple" (*Malus sylvestris* Mill.) had some significance for the Vikings, as the queen buried in the Viking ship Oseberg was sent to the afterlife with a whole bucket full of them. It may sound strange, therefore, that this wild apple species still occurs in Norway, commonly referred to as authentic and separate from all other European "crab apple" cultivars. However, scientists fear that the special genetic profile of this old exotic cultivar with an extremely sour and bitter taste may disappear and be transformed into hybrids. A comprehensive survey of the crab apple *Malus sylvestris* in Norway was carried out during the period 2008–2013. This project was carried out by the Natural History Museum of the University of Oslo, the University of Agder and NIBIO (Norwegian Institute of Bioeconomy). The study revealed extensive hybridization between ornamental apples and garden apples and highlighted the need to implement conservation measures for *Malus sylvestris* in Norway [47]. For this reason, a genetic conservation unit for *Malus sylvestris* (crab apple) was established in 2020 as part of the Jomfruland National Park in southern Norway [48,49].

Important assessments of apple cultivars in the ex situ collection in Norway have been carried out. According to [50], it was determined that 81 apple cultivars should be permanently preserved. However, in production, these cultivars do not generate income for farmers and are mostly conserved as a source for further breeding. Meanwhile, the diversity of apple cultivars in private orchards is much greater than in commercial apple orchards [51], which is due to the traditional cultivation of all native cultivars. This great effort unfortunately resulted in a large amount of confusing data, as each native cultivar has at least two to three names, depending on where it is grown [52,53]. Defining the genetic base and sublimating the heterogeneity of the collected apple germplasm so that these cultivars can be used in future selection represents an important task for the future. Currently, it is reported that over 400 apple cultivars are grown in Norway [54], with the predominant cultivars being a mixture of native and imported cultivars. These cultivars are: 'Geneva Early', 'Vista Bella', 'Julyred', 'Raud Prins/Kronprins', 'Discovery', 'Katja', 'Sunrise', 'Summerred', 'Gravenstein', 'Raud Gravenstein', 'Åkerø', 'Delcorf', 'Aroma', 'Raud Aroma', 'Lobo', 'Red Ingrid Marie/Karin Schneider', 'Elstar' and 'Rubinstep', but the most important for today's commercial production are 'Discovery', 'Summerred', 'Gravenstein', 'Aroma' and 'Rubinstep' and their red variants [55,56]. The cultivars are grouped according to the period of fruit maturity and harvest date, but they also differ in other morphological and qualitative characteristics, such as the time of flowering, the quantity and distribution of flowers, fruit flavor and fruit appearance [57]. As can be seen, despite the long history of growing and consuming different local apple cultivars in Norway, the dominant apples on the market today are a mixture of imported or crossbred cultivars, but this still gives a major competitive advantage to local products. It can be assumed that the criteria for the domestic market are higher today, so that apples grown in Norway should be of at least comparable quality to imported apples.

Today, one of the most important requirements for apple rootstocks is the ability to control tree vigor in order to achieve high planting density. Trees grafted on suitable rootstocks in high-density plantations with applicable tree types, and on good locations, produce large fruits and more fruit per hectare, making them a very important economic factor in apple orchard profitability [58–60]. On the other hand, the rootstock can affect not only productivity but also orchard life, which significantly affects the economic aspects for orchard owners. In addition, dwarf and low-height trees can be targeted to accurately apply crop protection sprays, avoiding the overuse of pesticides and unwanted spray coasts that have negative impacts on the surrounding environment.

As a result, modern orchards in Norway are planted on dwarf and semi-dwarf rootstocks. The rootstock 'M.9' has gained acceptance in apple production because of its suitability for dense plantings in Norway as well as in the rest of the world. This is undoubtedly the result of intensive scientific cooperation with leading apple producers worldwide, who know that the root system of the plant is one of the most important factors in quality and yield formation, but also the most sensitive organ of the plant to low temperatures, which is protected here by the soil mass [61–63]. However, there are also a considerable number of other rootstocks suitable for apple production in Norway. They were mostly selected for this region in the past because of their cold hardiness, such as 'A2' ('Alnarp A2', Swedish rootstock), 'Antonovka' (Russian rootstock), 'Budagovsky 9' ('B 9', Russian rootstock) and recently 'Geneva 16' (selection from the USA), which resulted in genotypic variation among a large number of rootstocks studied [64–67]. Nevertheless, the positive growth progress of the 'M.9' rootstock practically displaced all other rootstocks.

4. Special Features of Orchard Soils in Norway

The overview of Norwegian bedrock formation is very complex [68], but it could give a good indication of the soil properties that formed during phedogenesis, as well as the potential of the soil for agricultural use and the nutrient potential for crop production. Therefore, different soil types with different mechanical fractions/properties, different pHs and different nutrient contents can be found in Norway. In relation to apple production, the different regions (southern parts) (Figure 1) are expected to differ in terms of soil properties and nutrient potential for crop supply compared to the western parts [69]. Production in the western part is mainly located in the municipalities (from southwest to south north) Hjelmeland, Ullensvang, Sogndal, Gloppen and Stryn. On the southeast side, the main production is located in the municipalities Midt-Telemark, Øvre Eiker, Lier and Drammen.

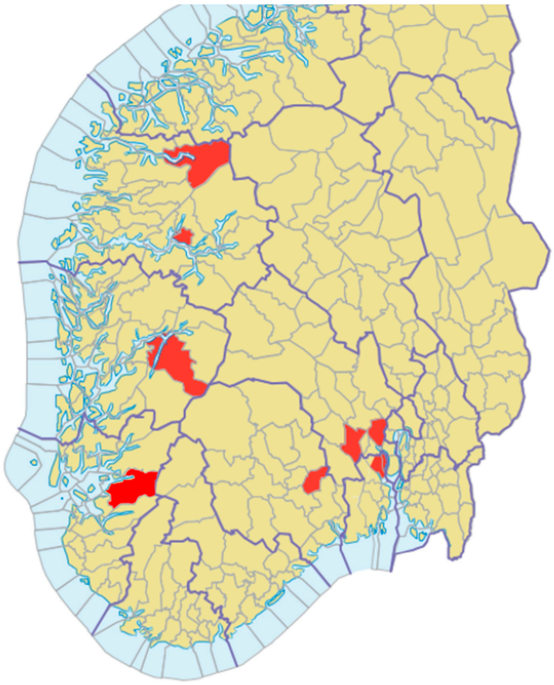

Figure 1. Municipalities where the main apple-producing districts in Norway are located (in red). From the top of the map, the regions Nordfjord, Sogn and Hardanger, western Norway. The districts of Telemark and Viken are in the southeast [69].

However, the first association about the soil appearance in Norway is related to the winter conditions, where "frost and snow-free" lead to thick layers of frozen soil, which keep soil temperatures low through spring even though the other conditions favor an early start to the season. Increased precipitation combined with more variable temperatures in winter cause snow to melt and refreeze, increasing problems with ice cover and encasement [70,71]. Such overwintering problems are common in some coastal regions of Norway [72], but for the most part, soil properties for apple production are not very different from those of other orchard soils in the world, with the exception of some desert, sandy or young skeletal soils. The reason for this is mostly the presence of clay as a result of soil formation from bedrock and the presence of a high content of organic matter, which in Norway is the product of slower mineralization due to the cooler climate or slower decaying plant material. Soil organic matter content is a part of the normal soil formation process in which total organic carbon (TOC) content increases as the soil matures. It is also highly dependent on climate, with warm and dry conditions resulting in low TOC content, while wet and cold conditions result in high TOC content [73]. In general, these two soil components are critical to plant nutrition. Both can be sources of nutrients, with clay being a source or carrier of cations/anions derived from its crystal lattice, while TOC releases nutrients after its microbial mineralization [74]. Figure 2 shows how organic matter content and clay content can vary in the labelled apple areas. Fruit trees are mainly grown on soils with clay content less than 15%, while the range of organic matter in the first 20 cm of soil depth is from very low (0.5% in Viken) to high 8.90% (in Hardanger) [69].

An important factor of Norwegian soils is the presence of some nutrients derived from the parent rock or its sediments. Due to their alkaline and metamorphic character, agricultural soils have slightly elevated concentrations of some nutrients [68]. In general, these are primary metals such as iron, potassium, manganese and magnesium, while other metals are also present, usually in micro amounts. Their presence and quantity in the soils could be closely related to the clay content, since a large part of the Scandinavian countries has a so-called "clay belt" [68]. Therefore, it is expected that the high Fe contents are due to the outcrops of mafic and ultramafic rocks and the presence of significant iron ore deposits in these countries. In addition to Fe, iron ores are also a rich source of Mn and to a lesser extent of Mg, so agricultural soils are enriched with those two elements [75,76]. The issue of potassium is also closely related to clay content [74]. On average, Norwegian soils have higher K contents than soils in Sweden and Finland [68], which is important for apple production [77].

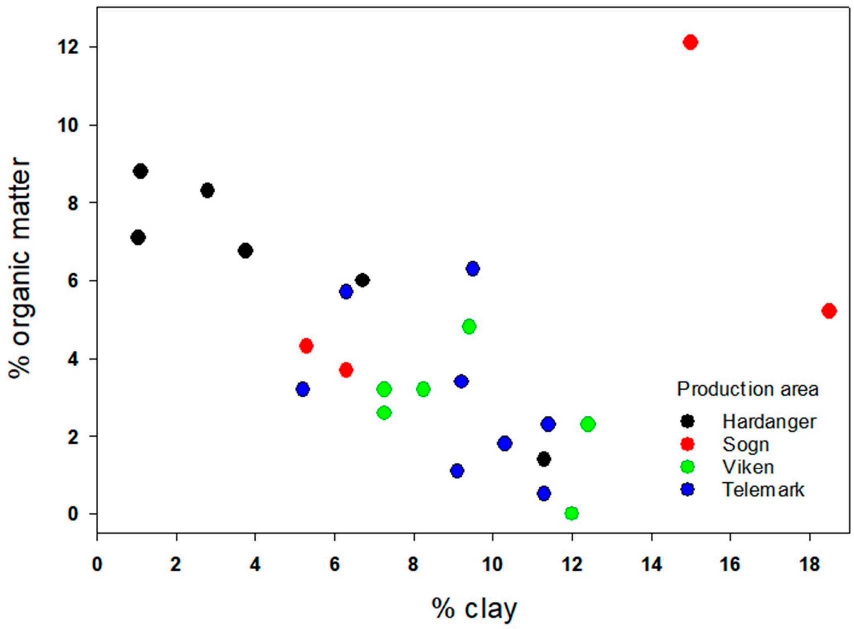

Figure 2. Clay and organic matter contents in apple orchard samples in four regions: Viken, Sogn, Hardanger and Telemark [69].

All agricultural soils in Norway are under special scrutiny because their potential for crop production is of public interest, especially if they contribute to nature conservation and provide sufficient income to farmers [78]. Therefore, soil investigation is an important part of government activities, and soil monitoring has received considerable attention [79]. The Norwegian Soil Information System provides data based on key soil properties, climate and classification in the 'Soil Taxonomy classification system' [80,81]. In addition to regional land use planning and management, soil mapping in Norway aims to preserve this natural value by reducing soil erosion and all other aspects of landscape management (flooding, soil salinization and others). These trends are also reflected in the fertilizer and pesticide restrictions that are regulated at the state level [82], through regulations that aim to limit fertilizer/pesticide application. Therefore, fertilizer use is one of the most important issues in Norwegian apple production, as excess nitrogen and phosphorus can affect the natural environment [83]. Therefore, the goal of this production is to use the natural potential of nutrient reserves in the soil of each orchard, as nutrient variability varies by region and location [68].

5. Fertilization Practice in Apple Production

5.1. Fertilization Application

In Norwegian agriculture, nutrient management planning is mandatory [84], partly because of the discussed negative environmental effects of fertilizer use. Therefore, every farm receiving economic support from the state must prepare a plan for fertilizer use during the growing season based on soil analyses. In practice, soil analyses in existing orchards are usually carried out every four to eight years and serve as a basis of information for the preparation of fertilizer programs. Using traditional Norwegian methods for soil analysis (AL method of Egner et al. [85] using ammonium lactate at a pH of 3.75; the pH is measured in the water extract at a soil-to-water ratio of 1 to 2.5 v/v), the values considered optimal for apple orchards for some elements are listed in Table 1.

Table 1. The four classes [1] of macro elements in Norwegian agriculture soil analyses and optimal values [2] in apple orchards [86–88].

Content	Low [1]	Medium [1]	High [1]	Very High [1]	Optimal Values [2]
P-AL (mg/100 g) [3]	0–4	5–7	8–14	>14	8–12
K-AL (mg/100 g) [3]	0–6	7–15	16–30	>30	20–30
K-HNO3 (mg/100 g) [4]	<30	30–79	80–119	>120	50–150
Mg-AL (mg/100 g) [3]	0–6	3–5	6–9	6–9	10–20
Ca-AL (mg/100 g) [3]	<50	50–99	100–199	>200	100–200

[3] AL is the ammonium lactate method [85]. [4] K-HNO3 is acid soluble potassium.

The measured pH in apple orchards in the studied regions (Viken, Sogn, Hardanger, Telemark) varies between pH 5.5 and pH 7 [69], which affects the availability of nutrients, especially phosphorus (Table 2). However, the values given by [87,88] in Table 1 for P content are close to the optimum or are high, which could be a consequence of the high content of organic matter (Figure 3), which constantly supplies the soil with this element.

Table 2. Soil analysis for macro nutrients in the main fruit districts of Norway [69]. The results are an average of samples from the orchards in Figure 3. All results are given in mg/100 g soil.

	P-AL [1]	K-AL	K-HNO3 [2]	Mg-AL	Ca-AL
Viken	13	14	110	12	92
Sogn	25	22	157	18	168
Hardanger	24	19	211	15	146
Telemark	30	18	89	9	117
Mean	23	18.25	141.75	13.5	130.75

[1] AL is the ammonium lactate method [85]. [2] K-HNO3 is acid soluble potassium.

In most Norwegian apple orchards, nitrogen supply during the season is about 40–75 kg/ha, with a maximum of 90 kg/ha, while the average phosphorus supply is between 10 and 20 kg/ha and potassium is between 35 and 75 kg/ha [3,69,89]. Compared to the leading apple-producing countries, it can be said that the mentioned fertilizer applications are low or moderate, which allows for relatively low yields compared to yields in other apple-producing countries. One of the reasons for this limited nutrient supply is the richness of orchard soils in organic matter, which meets the plants' needs for mineralized nutrients and creates perfect physical conditions for root growth and adsorption. As mentioned earlier, the organic matter content in Norwegian orchards is >10%, and the normal content is in the range of 5–8% even in sandy soils (Figure 3). The relatively large variations in organic matter content within regions are related to local climatic conditions, but also to the use of compost and animal manure as "natural" fertilizers for soil improvement. This is supported by the regional extension services NLR (Norsk Landbruksrådgiving), which emphasize the importance of organic matter for apple growth and claim that a high carbon-to-nitrogen ratio (C:N = 12–18) may be a positive indication of high N release [87]. Some other factors that affect the release and loss of plant-available nitrogen are also important, such as the increase in soil temperature in the spring and leaching after a wet winter, which contrasts with a stable cold winter during which frost keeps nutrients (N) in profile [87,90].

Since not all soil tests for Norwegian soils indicate the amount of available nitrogen forms (NH_4^+ and NO_3^-), the exact dosage of nitrogen is a problem. Basically, some peculiarities of the local climatic conditions in Norway affect the availability of nitrogen, which limits the possibility to calculate the exact amount of available nitrogen for plants and possible N correction by fertilizer addition [91]. In practice, this means that nitrogen fertilizer recommendations from leading apple-growing countries are not easily transferable. In the reports of the soil testing laboratories NMBU (Norwegian University of Life Sciences) and NIBIO (Norwegian Institute for Bioeconomy), nitrogen is calculated as "total N" without precise interpretation help, and tested soils are classified into those with low, medium, high and very high nitrogen concentrations. Precise interpretations of the results are made by fruit consultants in cooperation with farmers. The other interpretations of the obtained analytical results (EUROFINS) are presented as "soil N total stock", where "N supplying capacity" should be in accordance with the "target value", also with the possibility of a rather high N demand or N surplus [92].

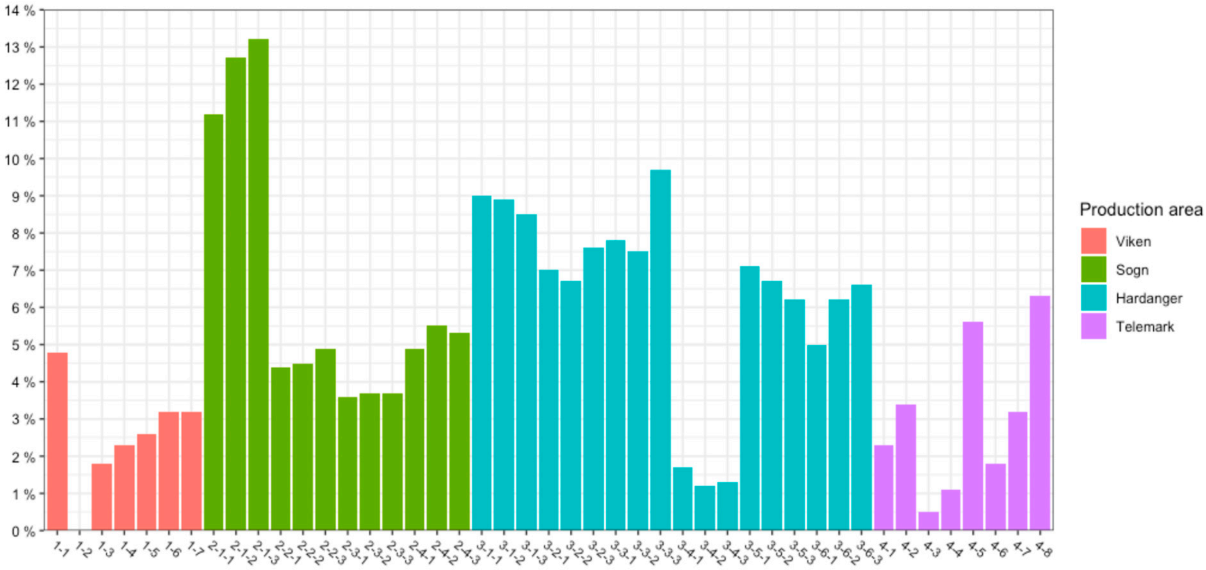

Figure 3. Examples of organic matter contents in apple orchards in four production regions sampled in 2018 in Norway [69].

Given the current situation, a study should be carried out to highlight the degree of mineralization of organic matter in the soil. It would help to quantify the potential of CO_2 respiration rates and the release of NO_3^-, NH_4^+, SO_4^{2-} and PO_4^{3-}. These results should also incorporate climatic variations (temperature, leaching, moisture and others) that strongly influence this process, especially in subsequent years. Consequently, a scientific need for this type of study has already been identified, and a large number of soil samples from orchards in different locations should be subjected to an incubation process to study the degree of mineralization under different conditions. This could provide additional data on apple fruit nutrient supply [3]. This could also include phosphorus potential, since phosphorus in the soil is mostly in organic form and is only applied in small amounts to apple orchards in Norway [73].

In apple growing, special attention should always be paid to potassium supply, which is the most abundant cation in apple tissue among all other minerals [93]. This element is responsible for photosynthesis, protein synthesis, all types of sugar content, enzyme activation (about 60 catalytic activities), osmoregulation, stomata movement and cell expansion [70]. Secondary metabolites are also strongly dependent on the potassium content in the cytoplasm [94]. The main problem of potassium in Norwegian apple production is that soil organic matter is not considered a reservoir for this element and potassium should be supplied according to plant needs [77,95]. Therefore, the demand for apples should be met by the use of fertilizers, since the potassium available in the soil varies between the studied soils from low to extremely high [69]. Therefore, the practice of potassium fertilizer recommendations should balance this polarity, because according to [87], it has been highlighted in the past that excessive potassium supply has led to magnesium deficiency in many Norwegian orchards.

5.2. Fertigation of Apple Orchards

The application of liquid fertilizer through an irrigation system (fertigation) is considered the most efficient way of increasing apple yield with the greatest influence on fruit quality [96,97]. For this reason, fertigation has been introduced as a regular fertilization method in Norwegian apple production, following the modern trend that is fully integrated in the world's orchard production.

Fertilization efficiency depends on soil properties and nutrient character. This is shown by the different behaviors of the various nutrient ions in the soil and the different effects of the fertilizer solutions applied. In the first place, the program of fruit nutrition by fertigation depends on the soil characteristics, with some of its physical properties such as porosity and the ability to bind the supplied nutrients being the most important. The behavior of added ions in the soil is also highly dependent on soil properties, and the presence of large amounts of added ions after dissolution should be fine-tuned by the presence of clay or organic matter as the core of soil colloids and soil solution [74]. As highlighted earlier, apple orchard soils in Norway are strongly influenced by these two important soil components, which require a precise and effective way of nutrient application through liquid fertilizers [42,90,93,98].

The main objective of all fertilizer injection systems is to distribute the diluted fertilizer to the roots of the plants at a constant concentration. Generally, these concentrations are very low (0.1–0.2%), but the solution is distributed through all fertilizer lines at a constant rate, allowing the plants to be supplied throughout the growing season. The advantage of these liquid fertilizers is the permanent and maximum supply of nutrients based on the current needs of fruit trees. This is closely related to the development of vegetation, which is quite independent of the dynamics of apple growth in the rest of the world. In Norway, the same cultivar ripens about 1.5–2 months later than in the rest of the world's apple-growing regions, which requires good knowledge of the timing of each phenophase in order to meet the plants' needs. However, apart from the amount and type of fertilizer used, some parameters must be taken into account, such as its solubility, effects on acidity, compatibility and, finally, cost.

After planting, a regular fertigation program for apple orchards is implemented in Norway. To fill the gap in nitrogen requirements, this element is given in a considerable amount of 60–80 kg/ha during the first two years, together with an adequate supply of phosphorus (10–20 kg/ha) and potassium (50–80 kg/ha) [99]. This is responsible for the intensive growth of young trees in the first two years, while the third year is subject to the standard fertilization regime [69]. As in other apple-growing countries, the total amount of applied nutrients is drastically reduced in Norway, which tends to be eco-acceptable and to not overdose applied nutrients. In practice, this means rational management with three existing sources of nutrients for the trees. The first source is the soil reserves resulting from previous fertilization and mineralization of soil organic matter, the second source is the nutrients stored in the storage organs of the trees, and the third source is the amount of nutrients/fertilizers applied during vegetation. All three factors should be considered when recommending fertilizer after soil analysis.

5.3. Nutrient Application by Foliar Nutrition

As in other apple-growing regions, orchards in Norway receive additional foliar fertilizers [88]. In general, the purpose of such nutrient applications is not to correct nutrient deficiencies, but to promote plant growth and improve fruit quality. This positive nutrition trend is now growing and spreading to all types of crop production in Norwegian agriculture.

In practice, foliar agrochemicals are commonly used, usually from fertilizer manufacturers, and differ in chemical composition and efficacy. Manufacturers also offer a complete foliar fertilizer program that includes its prior enhancement for apple production (Table 3). Thus, any farmer can make his own salt solution and treat his plants in the orchard. With all these solutions, care should be taken that the concentration is not too high, as salts can only be absorbed by the leaves to a limited extent. The concentration should be between 0.1 and (at a maximum) 0.5% [100]. In addition, foliar sprays in Norwegian orchards should be applied when the daytime temperature does not exceed 22 °C or more during the first hours after treatment. All these treatments should be adapted to the growth phase of the plants, since apple vegetation in Norway is delayed by about 1.5 to 2 months compared to Central European countries.

Table 3. Apple foliar fertilization program proposed by consultants and researchers in Norway.

Period	Foliar Application	Salts and Products
Before blooming	B foliar fertilizer	*Bortrac* ("Yara Vita")
Flowering—beginning of June	Mn^{+2} foliar fertilizer Mg^{+2} foliar fertilizer	$MgSO_4$ 2–3 sprays after flowering 25 mL *Mantrac* ("Yara Vita")
Mid June–early August (leaf diagnostic mid-August)	Ca^{+2} foliar fertilizer K^{+} foliar fertilizer	400–700 g/ha $CaCl_2$, (total 4–6 times) ("Yara Vita") 50 mL *Aminosol* ("Lebosol") 50–70 mL *Zintrac* ("Yara Vita")
Late August	Ca^{+2} foliar fertilizer K^{+} foliar fertilizer	Two sprays of *MKP mono-potassium phosphate* (mono potassium phosphate) ("Haifa Chemicals"—Israel, or, "Van Iperen International"—Germany) before harvesting (about 7 days) to improve color and firmness
	Urea 5%—for few times or 10–15 kg/ha as total amount Foliar fertilization with boron (and zinc if necessary)	Urea

Although foliar fertilization is treated as supplemental nutrition, the response to foliar fertilizer sprays in apple orchards can be significant [101,102]. This is especially true for elements with low phloem mobility such as Ca, B, Fe, Mn or Zn in the early growth stage when their foliar fertilization in negligible amounts could have a major beneficial effect. Another significant advantage of foliar fertilization is its simulative effect on plant metabolism, as it is less corrective to nutrient deficiencies. Therefore, a widespread practice of foliar feeding in apples, followed by scientific research and practical application, should support specific growth stages, such as bud break, pink bud stage, flowering, cell division, fruit growth and ripening, harvest and post-harvest [88].

So, in general, such a recommendation represents significant professional input. This is particularly emphasized for one of the world's leading fertilizer manufacturers "Yara", a Norwegian company (Table 4). Considering its continuous development and current reputation as a manufacturer, it can be assumed that all recommendations given are knowledge-based and previously tested, and therefore likely to be very useful [103–107]. Consequently, it can be assumed that the company "Yara" has a great impact on apple producers (and all other agricultural productions) in Norway as a local fertilizer consultant (Yara Apple Program). The most important comment on these recommendations concerns the relatively high cost of complete treatment, which includes all other manipulative costs of soil/leaf fertilization.

Table 4. Recommended application of nitrogen, phosphorous and potassium to productive apple tree in kg/day (kg/1000 m^2) and kg/ha in Norway [88,108,109].

	N		**P**		**K**	
	kg/day	**kg/ha**	**kg/day**	**kg/ha**	**kg/day**	**kg/ha**
Yara	2–2.5	20–30	1.5–2.0	15–20	7–9	70–90
NIBIO	3–5	30–50	1.0–2.0	10–20	5–7	50–70
NIBIO/NLR	4.5–6.5	45–65	2.0	20	3.5–10	35–100

6. Apple Fruit Mineral Content and Its Quality

The Norwegian apple-growing area is the northernmost area in the world, and the quality and aroma of the fruit meet the current demands of the local market. This may be due in part to the harmonious, adequate mineral composition, which differs only minimally from the usual characteristics of apple fruits from other countries (Table 5).

Table 5. General properties of apple fruits of three cultivars ('Red Aroma Orelind', 'Discovery', 'Summerred') grown in Ullensvang, western Norway [19].

Cultivar	Diameter	Length	Weight	Back Ground Color *	Surface Color **	DA-Meter	Soluble Solids Content	Titratable Acidity	Vitamin C
	mm	mm	g	L*a*b	L*a*b	I_{AD}	%	mg/L	mg/100 g Fresh Weight
'Red Aroma Orelind'	69.8	64.4	137.7	5.1	6.65	0.965	12.5	5.83	21.1
'Discovery'	73.9	61.4	150.0	5.15	6.55	0.426	13.0	6.10	22.6
'Summerred'	71.6	60.8	141.9	5.7	5.75	0.311	12.8	5.76	20.8

* Background: 1 = green to 9 = yellow ground color. ** Surface: 1 = no red blush to 9 = 100% blush surface color.

As shown in Table 3, none of these studied parameters is in conflict with apple fruits from different growing regions [110–112]. In terms of size and appearance, apples from this specific growing region are quite similar to other producers from other countries, and this may be the reason why the lowest yields (<10%) from Norwegian orchards are supplied to the industry [113]. The length, diameter and weight of the apple, with a reasonable coloration comparable to fruits from warmer areas, as well as sufficient firmness and freshness, make this product attractive and remarkable.

As expected, the mineral composition of the fruit was strongly influenced by soil properties, with the presence of various nutrients in the soil supporting the quality of the grown fruit. The consumption of apples as fresh fruit is associated with the intake of various minerals that affect different metabolic processes in the human body [114]. Meanwhile, the particular role of each nutrient in apple/plant physiology has been subjected to numerous studies to outline plant nutrient requirements and fertilizer use, which is an important part of pomology textbooks [63,115,116]. However, current knowledge and scientific attention are focused on compounds synthesized in apples that have beneficial effects on human health, such as sugars (fructose, glucose, sucrose and sorbitol), organic acids (malic acid, citric acid, shikimic acid, fumaric acid and quinic acid), phenolic compounds (quercetin glycosides, procyanidin B2, chlorogenic acid, picatechin, phloretin glycosides), vitamins (in particular vitamin C and vitamin E), volatiles (esters, alcohols, aldehydes and ketones), dietary fibers (cellulose, hemicellulose and pectin), chlorophyll, carotenoids, volatile organic compounds, fatty acid derivatives, benzoids, phenylpropanoids, amino acid derivatives and others [41,117–121]. These phytochemicals in apple fruits have been thoroughly researched, highlighting that these minerals are responsible for supporting human body functions by maintaining electrolytic balance and also participating in the metabolism of carbohydrates, lipids, proteins, vitamins and enzymes [119,122]. A number of other benefits of synthesized substances from apples have also been confirmed, especially when it comes to the prevention of human diseases, for which apples are recommended as an important part of the diet [123–126]. Another privilege of this fruit is its excellent storability and, therefore, its easy availability, making it convenient throughout the year.

The existing role of apple fruit nutrients for humans is the result of their absorption mainly from the soil, and less so from fertilizers. There is an obvious difference between the mineral content of the peel and pulp, generally due to the precise location of the presence and activity of nutrients in these separate parts of the fruit (Table 6). Some advantage should be conceded to the peel as a collector of minerals, since a considerable amount of minerals is lost when an apple is eaten without the peel. Another previously confirmed property of the apple peel is its antioxidant capacity, which has a higher content of polyphenols and anthocyanins compared to the pulp, which is of great benefit to the consumer [127].

Table 6. Mineral content (µg/g) of the peel and flesh of different apple cultivars ('Red Aroma Orelind', 'Discovery' and 'Summerred') grown in Norway orchard (Ullensvang), western Norway [114].

Cultivar		As	Ca	Cd	Co	Cr	Cu	Fe	Hg	K	Mg	Mn	N	Ni	P	Pb	S
'Red Aroma Orelind'	Peel	0.124	213.6	0.016	0.003	0.354	4.86	2.22	0.085	995.5	58.4	0.66	522.5	0.58	47.9	0.18	38.3
	Flesh	0.023	172.3	0.016	0.001	0.017	8.31	0.97	0.001	780.4	23.0	0.32	318.9	0.10	53.9	0.16	14.6
'Discovery'	Peel	0.021	200.6	0.030	0.013	0.024	7.94	3.06	nd	925.3	63.9	0.39	470.1	0.93	51.5	0.31	47.0
	Flesh	0.005	156.8	0.016	Nd	0.031	4.75	1.53	0.123	938.5	33.7	0.18	317.9	0.13	72.0	0.57	26.2
'Summerred'	Peel	0.063	163.5	0.044	Nd	0.022	2.41	2.34	0.002	980.9	26.7	0.24	453.2	0.55	55.5	0.09	18.8
	Flesh	0.041	180.3	0.019	0.005	0.069	5.19	1.04	0.031	744.3	48.1	0.390	372.1	0.73	59.7	0.18	38.8

As can be seen from Table 6, the results of the mineral composition of Norwegian apples are similar to those of other fruits grown in other apple/growing regions of the world [114,119,128]. Soil, fertilization and cultivars definitely influence composition, but mineral content has been found to vary not only between cultivars but also between years [129]. This has also been confirmed in Norway, where variations strongly depend on the year of cultivation, as climatic effects cause variation in the phenological development of apple trees and consequently in the mineral uptake capacity [130].

All the minerals present in the apple peel and pulp affect physiological functions in plant metabolism, with some elements present in significant amounts while others play a minor role. As mentioned earlier, potassium is most abundant in fruit tissues (peel, pulp), and this organ is a strong sink for K, while nitrogen, as a building block, links the uptake of all other elements in fruit tissues [131–134]. It is confirmed that the apple peel has a slightly higher to several times higher content of many bioactive compounds compared to the fruit pulp. This is especially true for calcium in the peel tissue, the concentration of which is important because low concentrations in apples can cause physiological disorders such as bitter pit [135]. The concentration of magnesium and sulfur also differed between the peel and flesh, but no data could be obtained for phosphorus content. All microelements studied varied in content between the two parts of the fruit, with the peel being the dominant sink for Fe. Other microelements (Cu, Mn, Co) combined with metals (As, Cd, Cr, Hg, Ni, Pg) were randomly distributed between these two organs, which is of great importance since they belong to the group of "heavy metals" potentially toxic to humans. None of them exceeds a threshold value, which denies that the soils in Norway are formed on alkaline and metamorphic bedrock, which usually contains a large amount of metals. This measurement confirms that the accumulation of nutrients in plants is mainly controlled by a complex bioregulation of growing plants, especially when they have to meet the adsorption, transport and storage capacity of perennial organs according to genetic, environmental and agronomic factors.

Lately, the organic production of apples is increasing in Norway because consumers are developing a preference for this kind of production due to the environmentally friendly alternatives which encompass the sustainable use of energy and natural resources [121]. Apple production in Norway is conducted on 164 ha (11% of organic land) [8]. The most abundant element in eleven apples cultivars grown under organic production from Norway was potassium (K), followed by phosphorus (P), magnesium (Mg) and calcium (Ca) [136]. According to Fotirić Akšić et al. [41], who compared fruits from organic and integrated production, both 'Discovery' and 'Red Aroma Orelind', in both peel and flesh, scored higher levels of potassium in organic production compared to conventional (Table 7).

When it comes to Ca, the peel from 'Red Aroma Orelind' had a higher level of this mineral when fruits were grown organically, while flesh from integrated production accumulated higher a level of calcium. Phosphorous amounts in the peel ranged from 47.90 µg/g fresh weight (FW) ('Red Aroma Orelind' from integrated production) to 70.70 µg/g FW ('Discovery' from organic production) and in the flesh from 54 µg/g FW ('Red Aroma Orelind' from integrated production) to 72.2 µg/g FW ('Discovery' from organic production). Generally, organic fruits had an elevated level of P compared to integrated production (both in peel and flesh), which is expected since the application of animal and green manures and compost in organic production increases soil biological activity, which positively influences the colonization of mycorrhizal fungi that aid in phosphorus solubility [137]. Also, organic fruits had higher levels of Mg, which was much higher in the peel than the flesh. On the other side, the iron content was cultivar-dependent; the cultivar 'Red Aroma Orelind' stored a higher level of Fe in organic fruits, while 'Discovery' did in integrated production. The mentioned study showed that the highest values of K/Ca, (K + Mg)/Ca and Mg/Ca were obtained for 'Discovery' under organic production (both in peel and pulp), which suggests that those fruits might be less prone to physiological disorders during storage.

Table 7. Content of single minerals (μg/g) and ratio between some minerals in organic and conventionally produced apples [19].

Cultivar	Apple Part	Production	P	K	Ca	Mg	Fe	Ca/K	K/Ca	(K+Mg)/Ca	Mg/Ca
'Red Aroma Orelind'	skin	organic	67.1	968.7	228.3	77.0	3.6	0.2	4.2	4.6	0.3
		conventional	47.9	995.6	213.7	58.5	2.2	0.2	4.7	4.9	0.8
	mesocarp	organic	55.5	780.9	163.6	26.8	1.4	0.2	4.8	4.9	0.2
		conventional	54.0	680.4	172.3	23.8	1.0	0.3	3.95	4.1	0.1
'Discovery'	skin	organic	70.7	1233.0	163.5	68.8	2.5	0.1	7.54	8.0	0.4
		conventional	51.6	925.3	200.7	63.9	3.1	0.2	4.61	4.9	0.3
	mesocarp	organic	59.0	1032.6	143.9	32.7	1.25	0.1	7.18	7.4	0.2
		conventional	72.1	938.5	156.9	33.7	1.53	0.2	5.98	6.2	0.2

7. Conclusions

The modernization of fruit production in Norway has improved apple-growing technology by replacing old traditional orchards with high-density plantings with modern rootstocks and international cultivars. The result has been a steady increase in production to meet the demand of the local market during the autumn and winter months and the ever-growing interest in this domestic product. However, the base of apple production is a very small area in the western and eastern parts of the country, which are suitable for apple production due to the influence of the fjords, the warmth from the Gulf Stream and the mild winters combined with very long days in summer. The special feature is that winter and spring frosts rarely occur in the fjord.

Like everywhere else in the world, climate change is taking place in Norway. The temporal development in this northern country could be considered a positive phenomenon for the acceleration of any kind of crop production. For example, a nine-day shift in the timing of apple tree flowering in response to a rise in temperature during a long-term period has been noted, and apple flowering has been affected earlier by higher temperatures. All these interactions between climate and plants should be carefully monitored. Climate change in Norway should be considered as just another unforeseen factor for apple production, not a global challenge for apple production.

Although the soil characteristics for apple growing in Norway do not differ significantly from those in other parts of the world, two features should be emphasized: the high organic matter content and the presence of clay. Indeed, both could be sources of nutrients—clay as a source or carrier of cations/anions, while the organic matter releases nutrients after its microbial mineralization. However, the potential of these two sources to provide nutrients for fruits has not yet been successfully explored. More testing of orchard soils, along with the predicted mineralization of available nitrogen and exploration of the potential for storage of potassium by clay minerals, would be a successful approach for accurately estimating the nutrient reserves of the metamorphic subsurface. The more knowledge we obtain for these two soil factors, the better the fertilization practice will be, even if the standard Norwegian analysis procedure is used.

Recently, the nutritional and health benefits of apples have increasingly become the focus of scientific and public interest. A large number of the compounds studied in the apple are products of specific chemical processes unique to this type of fruit. This is partly due to its mineral content, with most of the nutrients coming from the soil rather than from fertilizers. It is therefore predictable that apples from the Norway region are rich in minerals adsorbed by mineral substrates from alkaline and metamorphic bedrock. Certain pedogenetic soil factors (frost, precipitation, warming and others) have generally contributed to their occurrence in the soil and most probably in the fruit.

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