Precision fertilization to apple trees
A review

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Nutrition and fertilizer application to apple trees - a review

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SAMANDRAG/SUMMARY:

Denne rapporten gjev eit litteraturoversyn ved ulike sider av næringsopptaket av ulike mineral og tilførsel til epletre. Det er omtalt dei fysiologiske sidene av næringsopptaket hjå grunnstammer og sjølve sorten, transporten gjennom sil- og vedvev og funksjonen til dei ulike minerala i epletreet. Bladanalysar er eit viktig diagnoseverktøy for vurdering av næringsstatusen i treet. Terskelverdiar for dei ulike minerala er vurderte og tiltak for å retta opp eventuelle mangelsymptom ved hjelp av eit bladgjødslingsprogram. Tilsvarande er eigenskapar ved jorda vurderte, normer for jordanalysar omtalte og tilråding om kalking. Siste bolken omhandlar ulike måtar og mengder for å tilføra gjødsel til frukthagen. Dette gjeld gjødsling til jorda, gjødselvatning i dropevatningsystemet i trerekkja og bladgjødsling.

Literature data is reviewed for physiological aspects of nutrients adsorption by apple tree rootstocks, their storage in perennial scion parts and their mobilisation during the vegetative growth. Nutrients functions and needs are also presented and discussed. Although it is well known that several nutrients can influence fruit quality and disorder of apple and their efficiency, accumulation and storage in trees organs become a scope of many investigations. Therefore, the common tool used in fruits improvement concerns adequate use of soil fertilizers, foliar fertilizers, and finally, fertigation, as measured regularly used in apple growing practice.

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Preface

The aim of this project is to increase the total production of Norwegian produced apples of high quality produced in an environmentally friendly way. The total fruit consumption in Norway is increasing. Nevertheless, the Norwegian apple production is stable during the last ten years with some variations between the years. The R&D partners Norwegian Institute of Bioeconomy Research (NIBIO Ullensvang), Norwegian University of Life Science (NMBU) and Faculty of Agriculture, University of Belgrade, Serbia in cooperation with the national fruit advising services will study and develop the fertilization recommendations of the Norwegian apple tree orchards. The main task was to study the relationship between main plant physiological principles in the tree, relate it to the soil, tree growth, yield, fruit quality, and fruit storage. The international literature about fertilization of apple trees is studied which is compiled in this report.

Project owner is Hardanger Fjordfrukt in cooperation with the partners Nå Fruktlager, Sognefrukt, Innvik Fruktlager and their growers.

NIBIO Ullensvang was R&D responsible by Mekjell Meland

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Mekjell Meland

Content

1 Introduction

Apple represents the 3rd most important fruit crop worldwide (comes immediately after watermelons and bananas) and it's the most important deciduous fruit tree. As a fresh fruit, it is consumed daily throughout the year. In addition, apple fruits can be used to the various forms of processing (juice, food pastes, jellies, jams, concentrate, apple cider, cheese syrup etc.). According to FAOSTAT (2017), world apple production is 89,329,179 tons with increasing tendency from the past few decades. The largest producer is China, representing around 48% of the world's total production. The USA is the second largest producer with 6.1% followed by Poland (3.8%), India (2.9%), Turkey (2.9%) and Italy (2.9%). The apple production started long time ago, around 4000 BC. Central Asia, Himalayan regions of India, Pakistan including western China is believed as centre of apple origin (Muzher et al., 2007). Nowadays, over 63 countries produce apple with a great variability of growing conditions, by utilizing about 7500 of mostly local cultivars which usually serves as row material for breeding or variety selection (Dobrzañski et al., 2006).

In the past few decades, world apple production is characterized by intensified growing technology with more than 2.000 trees per hectare, high yield per tree and/or unit area, introduction of new cultivars and dwarfing rootstocks and satisfactory fruit quality. However, apple growing requires demanding technology, making this culture one of the most difficult fruit species to cultivate. systems/technologies during the past period. Demanding fruit hand picking has been partly solved or compensated by cultivation of small trees, which has been achieved by the use of low-vigour growing rootstocks selected for spur types of apple cultivars. In the meantime, climate changes and increased disease pressure underline an urgent need for new, highly productive apple cultivars that are resistant to biotic and abiotic stresses. Besides the selection of cultivars adapted to the climatic stresses which are common in apple worldwide production, the selection and breeding of new resistant cultivars to various pathogens nowadays are dominant, facilitating their application in apple production. Therefore, apple breeding and selection has been done more intensively than any other fruit in the world. As a result of spontaneous and planned hybridization, over 10.000 noble apple cultivars are developed and constantly new and better one is being developed.

One can imagine that apple fruits with large size, good coloured peel, shapely and marked aroma which has a high market value are the highest demanding task for breeders. However, this fruit contains numerous bioactive primary and secondary compounds with potentially valuable nutritive, health and pharmacological potential (Lv, 2016, Kviklys et al., 2014, 2017). All this nutritive, health and pharmacological beneficial of apple fruit has been concisely given in an old Welsh proverb that most of us are familiar with: "An apple a day keeps the doctor away". That is to say that apples are widely consumed as a rich source of phytochemicals, while epidemiological studies have linked the consumption of apples with reduced risk of some cancers, cardiovascular disease, asthma, and diabetes (Manach et al., 2004). In the laboratory, apples have been found to have very strong antioxidant activity, inhibit cancer cell proliferation, decrease lipid oxidation, and lower cholesterol. Apples also contain a variety of phytochemicals, including quercetin, catechin, phloridzin and chlorogenic acid, all of which are strong antioxidants. The phytochemical composition of apples varies greatly between different varieties of apples, and there are also small changes in phytochemicals during the maturation and ripening of the fruit (Boyer and Liu., 2004). Recent studies have shown that the cultivar may substantially influence the fruit chemical properties, especially phenolic content and total antioxidant activity reflecting a qualitative genetic control (Drogoudi et al., 2008). Therefore, apple breeding/selection has diverse tasks related to better fruit quality, better pomo-technological properties, different ecological and phytosanitary constraints, and, finally, to the products with higher nutritional and health value (Nikolić and Akšić, 2009). That is specially aimed for varieties which undergo organic production, recently one of the trendiest ways of apple production. The improved health beneficial of organically produced apples has been sufficiently documented in numerous scientific publications (Peck, 2004, Grzyb et al., 2012, Heinmaa et al., 2017).

1.1 Trends in apple production

Over the last 60 years apple production around the world was subjected to the radical modification by changing traditional production systems to the production with the use of dwarfing rootstocks and smaller tree row space, means, modern orchards now range from 1,000 up to the 6,000 trees/ha. A fertigation system is used as mandatory. Besides, high density orchards have been conducted to the renewal pruning and specific treatments with growth regulators aimed for fruit thinning, which result in high, steady yields and first-class fruit quality. The transition in apple production historically took significant time and usually lasted for years, where the final acceptance and adoption for practice have happened after full review of apple tree behaviour during the application of introduced technologies. Principally, economic interests and labour engagement are the major driving force for efforts in developing new technological trends in apple production.

Currently applied dwarfing rootstocks are mostly results of systematic and severe work of two world famous rootstock Research Stations (East Malling Institute, Merton and John Innes Institute, both England), which basically gave the frame of rootstock traits in selection, also transferring proposed demands to the other breeders worldwide (US, Canada, UK, Sweden, Russia, Poland, Germany, the Czech Republic, Israel, Romania and Japan). As a result, it could be said that today's huge world's apple production is based on dwarfing rootstocks use and great number of trees per square area. In such modern high-density orchards, some other beneficial of renewed apple production has been emphasized like a large effect on tree precocity (flowering and cropping in the early years), as well as more exposed labour efficiency in high density orchards. Apple trees in those orchards also influence the partitioning of the trees resources between vegetative growths and large cropping, what is a absolutely new challenge tendency in apple scions'/rootstock botanical behave. Other characteristics that also have become important include improvement of fruit size, tolerance to diseases (fire blight, phytothphora, apple scab, apple mildew, apple replant disease and crown gall), tolerances to insects and tolerances to abiotic stresses (drought, water excess, spring frost and winter cold tolerance). Naturally, such spur apple grafted trees include some limitations, such as a lack of winter hardiness, poor anchorage, root suckers, sensitivity to some apple disease and fragile graft unions. Some others disadvantage of minor importance could be also present at some selections of the rootstock.

2 Apple rootstock properties

The function of roots include anchorage, the absorption of water and mineral nutrients, and synthesis of various essential compounds, such as growth regulators, and usually serves as storage organ for plant's nutrients. Also, root serves as an active bridge between live and solid phase of the soil, being a primary zone of contact with soil organisms. In perennial crops, such as apple, grafting is used to join the matching root systems (rootstocks) to shoots (scions) that produce the harvested products. Rootstocks varieties vary substantially in architecture and function, both within and between selected rootstock species, and they are a crucial component in coordinating plant responses to a range of abiotic and biotic factors, mainly influencing the growth and their mechanical strength as an important factor in preventing overthrow of trees by wind and winter injury. The selection of rootstock for certain apple production must be evaluated in order to choose the rootstock that shows the best characteristics for specific soil and ecological conditions.

Nowadays, one of the most important rootstock requirements is their capacity to control tree vigour that allows high-density planting. The easiest method of tree vigour control, a rootstock selection is the most important factor for high density apple orchards that produce large fruits and more fruits per hectare serving thus as a very important economical factor influencing the profitability of fruit growing (Autio et al., 2000; Tworkoski and Miller, 2007; Webster and Wertheim, 2003). On the other hand, besides the productivity, the rootstock can also affect lifetime of the orchards, therefore affecting economical aspects for plantation owners. Dwarf trees and low height can be targeted to fulfil the crop-protection sprays accurately, therefore, to avoid excessive use of pesticides and undesirable spray coast, which has negative side effect on surrounding environment.

Modern orchards are established on dwarf and semi-dwarf rootstocks. The rootstock M.9 has become the most dominant for apples for its suitability in high-density plantings. At present, more than 25 sub-clones of M.9 are bred in Europe (Kosina, 2010). Consequently, the greatest interest in tree size control is the use of rootstock that produces trees near the size of M.9 (Crassweller et al., 2001). Over the last 20 years new selections of M.9 has been made and developed in many countries. Pajam 1 and Pajam 2 were selected in France (Masseron, 1986). Rootstocks Jork 9 (Faby et al., 1986), Burmenger 984 (Baab, 1998) and Supporter 1, 2, 3, and 4 (Fischer, 1997) were promoted in Germany. A clone such as NAKB T 337 has been propagated in the Netherlands (Kosina, 2002).

2.1 Effect of rootstock on scion features

Grafting typically employs two individuals, where usually rootstock and scion, possess a desired variety feature. Clone genetic copy rootstocks and sexually produced scions are typically used during the cultivar breeding and selection process. Therefore, the root systems accomplish these two units, having a mutual impact on both grafted parts. Much is known about many scion traits in general (fruit characteristics, variety patterns, yield formation). However, the impact of rootstocks on these scion phenotypes remains unclear. For example, each apple rootstock has its own distinct characteristics, regarding such aspects as winter hardiness, anchorage, insect and disease resistance, site and soil adaptability, and also controls various aspects of the scion such as degree of dwarfing, precocity and productivity (Lauri et al., 2006, Tworkoski and Miller, 2007, Ferree et al., 2001b, Ferree et al., 2001a, Hirst and Ferree, 1995, Hirst and Ferree, 1996, Tubbs, 1974, Webster et al., 1985, Drake et al., 1988, Fallahi et al., 1985). Due to graft incompatibility, not all rootstocks are compatible with all scions, the special attention in rootsock selection has been paid to a wide range of possible scion use.

It is still not clear how rootstocks achieved their effect on scion vigour and shoot growth. This question trigs numerous investigations which can give the answer not only about "dwarfing effect" but also about the rootstock effects on all other positive physiological consequences which kept grafting as regular practice in seedling production for years (abundance of flowering, fruit set, high yields and yield quality). Early investigation simplified these effects claiming that the lower scion loading with water and nutrients has been induce by rootstock or its imperfect graft interconnection union with scion. Also, it has been suggested that this distorted xylem settings imposes an axial resistance to water flow resulting in shoot water deficits which limited a shoot growth (Warne and Raby, 1938; Beakbane, 1956; Tubbs, 1973). Later, all these approaches include a water hydraulic rootstock/scion imbalance made by grafting, focusing on differences existing in root part, which is lower, then in above ground apple parts (Cohen and Naor, 2002). The recent studies, however, emphasized the changes in the production and movement of plant hormones within the tree brought about using the rootstock. The theory is that the rootstock, or possibly its graft union with the scion, alters the ratios and concentrations of the growth-promoting hormones, such as auxins, gibberellins or cytokinins, and the inhibiting hormones, such as abscisic acid, which are translocated within the tree (Ferree and Warrington, 2003). As a result, shortage of the stimulatory effect of indole acetic acid (IAA) in xylem development and cambial activity in woody species exist (Sundberg et al., 2000). Greater phloem differentiation rather than xylem was observed in more dwarfing rootstocks (Aloni, 1995). As an approach related to the influence of plant hormones on plant growth, a rootstock also modifies morphology or phenology of different growth habits of scion including branch orientation. This change in shoot or branch orientation are based on a fact that more horizontal branches have less growth then vertical. All this regulation derives from apical dominance and apical control, as a tissue points where the growing substance, preferentially hormones, are transfer and focused (Miller and Tworkoski, 2003). A smaller growth and regulated apical dominance has been partly regulated by smaller auxin efflux from the rootstock. Also, a shortening of internodes, consequently, the appearance of the flower buds, could be explained as a hormonal allocation from the scion parts (Webster, 2001; Tworkoski and Miller, 2007). These above brief points are presented to emphasize the variety of evident parameters which can influence a formation of spur type of scion apple trees. Therefore, “dwarfing effect” of rootstocks is a very complex process, which include intern cumulative and interactive metabolic outcomes which operate simultaneously in both plant parts.

Besides the importance of the use of spur type in apple production, there are certain criteria common to all good clonal (vegetative propagation) rootstocks, which could be essential to seedling producers and fruit growers. Some of them are crucial. It should be said that the most important is freedom from virus and bacterial diseases. Nowadays, it is fully accepted that orchards should be planted without seedling which possess a bacterial disease crown gall (*Agrobacterium tumefaciens*) and collar rot *(Phytophtora spp.)*, which induces limitations to established new plantings. Today, however, there are more serious threats to the apple orchards, since many of them are planted on dwarfing rootstocks as M.9 and M.26. They are highly susceptible to the bacterial disease fire blight (*Erwinia amylovora* Burill.). This bacterial infection starts during blossom time, passing through blooms, resulting leaves and branch dieback, leading in the most cases to the death of the whole tree just in a couple of days. Accordingly, after blossom infection, bacteria can penetrate the branches, passing down toward the trunk showing no symptoms before getting to the rootstock. The susceptibility of different scion varieties was not observed, but the high susceptibility of rootstocks M.9 and M.26 can endanger not only the new plantings, but also present high density orchards (Roberts et al., 1998; Norelli et al., 2003; Russoet et al., 2007). Regardless that the apple fire blight poses as a serious threat to the whole world apple production, problem arises with the fact that disease symptoms are not very familiar to the apple growers due to that the prone diseases areas/countries are not well and systematically defined. However, it is worth to stress that this bacterial disease in a close past, literary cleaned huge arias of planted quince and pear, relatively in a very short period what was generally officially not announced.

Some other demands are also present in rootstock production and distribution. It should have an easy propagation and good bud or graft compatibility with the scion. The chosen rootstock should be capable of controlling the vigour of the scion trees to the level required by the grower, followed by the consistent and abundant cropping of large high-quality fruits. Today the rootstock resistance/tolerance to biotic stress factors (high/low temperature, water deficiency) are specifically emphasized, which are posing as a general problem related to the climate changes. Also, if possible, the rootstocks should have the smallest production of suckers, which create a practical problem to the apple grower.

3 Apple rootstocks supply

3.1 Nutrient adsorption - Transport mechanism

One can imagine that given genetic visible diversity of apples varieties as a different fruit shape, fruit taste, its dissimilar colour or a different biomass and specific tree architecture, could be applied also to the "hidden" below ground rootstock system. Such differences in properties of rootstocks are not expressed at the level of above ground parts. Besides its evident impact on developed scion vigour, rootstock differs in their ability to absorb nutrients from the soil and in the ability to transport them to the above ground portions of the trees (leaves and fruit). Another phenomenon that has been described in the literature and perhaps discussed by producers is the effect of rootstock on fruit quality and storage. It makes sense that if rootstocks have a significant effect on nutrient concentration in fruit, they may play a role in the supplying trees with nutrients as a plant reserves aimed mostly for starting vegetation and in the case of nutrient deficiency.

The rootstock supplies the apple plant with nutrients and water. Concerning that water use is a special issue between plant species, apple rootstocks varieties/clones differs in water adsorption capacities due to their wide range of root biomass and spreading capability in soil profile. As a live mediator between solid phase and water in soil, rootstock biological system has been powered by the energy stored in different form of chemical compounds as sugars and other energy rich molecules. Generally, this energy use influences the capability in nutrient adsorption by breaking their chemical bondage. This is the reason why the intensity of photosynthesis has a direct or indirect effect on the nutrient supply.

A basic function of taking up nutrients by the rootstock system could be compared to the mining operations. The certain nutrients require little energy and are easily available, whereas others require quite a bit more energy because they are either tightly held by the chemistry of the soil particles or because they are rare in the soil. Trees have developed several mining strategies to get what they need from different soil profiles. For example, for a relatively abundant nutrient, like potassium ions after fertilizer application, apple trees in general, allow them to be absorbed into the roots by so called "passive transport", with no energy use. This "passive transport" also occurred at regular calcium absorption by apple trees generated by transpiration stream. The concentration of potassium ions in the plant tissues is usually hundred or thousand times higher than in the soil solution, and as a consequence energy is needed for its adsorption. This energy consuming adsorption is called "active transport". For the most of nutrients that may not be so readily available, apple roots may employ a combination of energy dependent mining and passive transport. This includes processes of activation of formed "ion channel" in the root membrane enabling a "*passive transport*", and the use of structural membrane constituents of "carrier proteins" and "ion pumps" in cell membrane ("*active transport*"). Such specific protein structural creation in the membrane structure refers to so called "integral proteins" or "trans-membrane proteins" (TMP). They pass through whole cell membranes, and they are crucial for ion adsorption, ion selectivity and energy consumption. In general, the whole process of plant nutrition is based on the activity of these membrane constituent parts.

Such particular structure of the root membrane, made from rigid parts of cellulose microfibrils, embedded in a matrix of polysaccharides (hemicelulose and pectin substances), and bonded with specific structural protein chains, made existing specific transmembrane proteins (TMP) responsible for most of the nutrient transfer held at the root surface. Therefore, while membrane porosity mostly regulates a transfer of small molecules of water and gases (oxygen, carbon dioxide) with no electrical charges through membrane, nutrient intake is generally regulated. However, it should be always keep in mind that water makes up to 60% to 70% of the total weight of the cell wall (Hall et al., 1982), making membrane structures soaked into the water medium. The presence of water and the presence of these active protein complexes in the form of integral, peripheral and anchored proteins at the root surface, made this plant parts very dynamic in soil media.

3.2 Rhizosphere effect

Surrounding soil, which coated a root system as a thin soil layer, is not inert. It could be said that this surrounding soil with thickness about 1-2 mm are influenced by living root and it is called rhizosphere. This root-soil interface has been named by the German phytopathologist Lorenz Hiltner in 1904. The rhizosphere has some features which indicate the root transmembrane protein activities like an acidification of its area achieved by proton and organic acids exclusion. Namely, the living roots have this ion/proton extrusion permanently, which happens in nanoseconds, and this extrusion works looks like a firework. Consequently, this proton extrusion makes a disbalance between ion concentration and electric charge surpass/deficit in root cell (cytosol) and exterior rhizosphere space (apoplasm/rhizosphere). As a result, a rhizosphere pH may differ from the bulk soil pH by up to two units, what could be of great importance for the pH-dependent solubility of some nutrients, especially micronutrients. However, the most important factor for root-induced changes in rhizosphere pH is the uptake of nutrients, which is coupled with proton (H^+) extrusion through root membrane. This driving force for nutrient uptake by root cells is a creation an outward positive gradient in electro potential and pH between the cytosol (pH 7–7.5) and the apoplasm (pH 5–6). Transmebrane protein complex responsible for this proton exclusion is ATPase (PM-ATPse), as a protein channel which creates different electrochemical potential gradient by exclusion of charged protons. The anion uptake has been creating by proton–anion co-transport (symport) and cation uptake via proton–cation counter transport (antiport).

Dispute on the effects on pH in rhizosphere, plant roots can modify the rhizosphere chemistry in several ways: a) by release and uptake of organic compounds, b) by gas exchange (CO_2/O_2) related with respiration of roots and rhizosphere microorganisms, and c) by root uptake as well as release of water and nutrients (Neumann and Römheld, 2011). Roots also can modify the physical properties of the rhizosphere, such as aggregate stability, soil water capacity and numbers and size of micropores by their growth through the soil as well as release of different organic substances. In the mining process for nutrients and water, a root makes a constant pressure on solid phase which reaches up to the 6 bars, as an average of 1-3 bars (Curl and Truelove, 1986), what can be compared by the used force per squared millimetre during concrete drilling. Besides the organic compound release and the influence of growth process on organic residue root debris in rhizosphere, a root system also excludes substances which serves as chelators or ligands which promotes a nutrient availability. Such organically packed metal nutrients generally are disabled to react with soil solution anions, also, their capability for transport through the soil solution is much easier.

The rhizosphere effects in soil are spaced in radial and longitudinal orientation along the roots zone. Depending on the rhizosphere processes considered (exudation of organic compounds, respiration, uptake of mobile nutrients and water) the radial extent of the secretion effect declines with increasing distance from the roots. The distance of diffused or excluded substance largely depends on soil properties and adsorption characteristics of the compounds. Adsorption depends on a type of molecular compound excluded, its molecular weight and its electrical charge, where ones with low-molecular-weight easily could be transferred to the respect distance from the root (1-2 cm), or it could be blocked by its charge on close soil particles or on root wall. Concerning that these organic substances are food for microorganisms, proportionally its number decline from the axe of the root.

3.3 Root anatomy-radial and longitudinal gradient of root

The capacity of nutrient uptake greatly depends on the radial gradient of root. The nutrients mobility and their solubility influence its transfer through the rhizosphere, where poorly mobile nutrients such a P, K, ammonium and micronutrients with low concentrations in the soil solution are frequently depleted in the rhizosphere by rapid root uptake, whereas soluble nutrients, for example Ca and Mg, may accumulate close to the roots surface (Hinsinger et al., 2009).

The longitudinal gradients of roots are strongly related to its morphology. Along the roots axe are present four different root zones, changing from soft meristematic tissues up to the firm woody parts of the root branches, depending upon the degree of maturation and activities taking place in each area. These regions, starting at the tip and moving upwards towards the stem, are the root cap, zone of active cell division, zone of cell elongation, and zone of maturation. The root cap is cup-shaped and loosely covered by a mass of parenchyma cells that covers the tip of the root. It is quite large in some plants, while in rootstocks is invisible or nearly absent. This cap presents a unique feature of roots, with structure not comparable with any part of root or stem. From its shape, structure and location, its primary function is to protect the other root cells under their abrasion and assists the root in penetrating the soil. Replenish and rebuilt a great number of such cap cells are produced to replace those which are damaged or lost during the root mining process in soil. The movement is assisted by a slimy substance, mucigel, which is produced by cells of the root cap and epidermis. After the root growth and its work in root penetration it has been observed that this cell residue stays as a microbial food which is associated with the root live phase of this boring tip.

A mass of actively dividing cells lies behind the root cap called zone of cell division or root apical meristem. Similarly, to the other meristems, dividing the cells gives the growth and body of the root, and this is happening behind the root cap. The parenchyma cell of the meristem is small with high density, where the most of cell divisions occur along the edges of the root core. This built up the columns of cells arranged parallel to the root axis. The apical meristem of the root is organized in three primary meristems: protoderm, which gives rise to the epidermis; procambium, which produces xylem and phloem; and the ground meristem, which produces the cortex.

The region of elongation, which joins with the apical meristem, usually is not visible as a distinct part of the root. It extends about one to three centimetres or less from the tip of the root of perennial plants. At this zone, the cells grow and become several times bigger reaching somewhat of their original length or wider. Cellular expansion in this zone is responsible for pushing the root cap and apical tip forward through the soil. In the root of perennial plants, this zone is marked as a zone of calcium absorption. This could be explained as a need of plants to use of Ca to build and to support the firmness and grown wall structure. If embedded in cell wall, calcium makes bridges between glycoside units of the neighbour microfibre chains, taking over the role of the element charged for regulation of other ion membrane transfer.

In nutrient and water adsorption apical maturation root zone plays an important role. The cell character developed at this root part, which belongs to the endodermis and exodermis tissues, are relatively incomplete barrier to dissolve and attached ions and molecules, but still with the ability to control their transfer into tissues. This possess only membranes of living organisms. The presence of root hairs in this sub-apical root zones increases the absorption surface area for nutrients and water. Their increased membrane activity is usually responsible for an increased release of protons and organic compounds into the root zone. Generally, the capabilities of a nutrient uptake and water adsorption have been attributed exclusively to the root hairs. However, nutrient adsorption is also present at the other part of roots, even much older and with more complex anatomy, which do not belong to the apical zone (Kong et al., 2014). Probably, the great influence on such nutrient adsorption plays a present microbial population, which digest organic compounds excluded or released from root cells or thrown fragments of cell walls. They make low molecular ion organic complexes in the root vicinity, suitable for ions release and later their uptake. Therefore, the statement that root hairs play a primary role in nutrient and water adsorption could be attributed only for the cereal or one-year plants, which significantly contribute to the adsorption of some low soluble and low mobile elements (phosphorus). It seems that the role of root hairs to water and mineral absorption is variable and deserves more study especially at the perennial plants.

3.4 Vascular system in perennial woody parts of the apple tree

The inner parts of wooden structure of the apple rootstocks have a cell configuration and vessel transport construction which is similar to other wooden species. It means that they possess increased lignin content as a main distinction between plant common cell wall and membrane and plant cell wall of wooden trees. This difference exists within increased lignin content and its participation up to 30% in cell wall structure. This given firmness of the wooden plant cell wall is unique for plants. On the contrary, the wood phase in root tissues and root structure supports a hardness of this organ, while it plays a minor role in nutrient adsorption process. This process generally belongs to the "soft tissues" as already described. In this tissue, two ways of nutrient and water transport are possible: *symplast* transport, transport from cell to cell via plasmodesmata (protein channels between cells), or, away from the leaving cells, via *apoplast* transport, means, by the use intracellular spaces. First one is very slow and used between adjacent cells, while symplast is a way of connecting cells mostly in tissue of organs, like in a root, leaves, fruits, flowers, etc.

After adsorption, water and nutrients are transported upwards. This transport takes place in the vascular system of xylem and phloem. If this transport concerns a transport of solutes from root to the shoot, it is called a long-distance transport. In woody plants, predominantly it occurred in non-living xylem vessels. Main forces which create a xylem transport are a gradient of hydrostatic pressure (root pressure) and gradient in water potential. Besides, many other factors contribute to this water and solute transport, mainly presented in literature as result of pure physical calculations an complex formulas. If we simplified this, it could be said that if pure free water has a potential of zero, the values for other solutes are usually negative and becomes less negative from atmosphere up to the root cells and soil solution. As a result, this potential discrepancy generates the upward solute movement. In days when plants transpired a great amount of water from the soil, this water potential gradient between roots and shoots grow quite steep. This is usually happening during hot days when stomata are open and plants by intensive transpiration regulate their temperature regime. So, the water in the plant can be considered a continuous hydraulic system, connecting the water in the soil with the water vapor in the atmosphere. This permanent suction power of roots makes possible a crucial supply of plants with other quantities of water and nutrients.

In contrast to the xylem, long-distance transport in the phloem takes place in the living sieve tube cells. In phloem vessels transport goes in one direction or bidirectional. Practically it means that phloem connects shoots and roots, transferring elements and synthesized organic compounds to every part of the plant. Sometimes this transfer of elements and organic solutes concerns extensive exchange processes and include internal cycling. However, these vertical connections in trees can indicate a nutritional status of above ground parts to the root. This is usually explained as a "*signalling*". Such substances which are sensitized in the green parts and reach a root system are largely investigated. Between substances detected, in signalling processes are hormones, sugars, nitrogen compounds and some secondary metabolites.

3.5 Xylem sap

The chemical composition of xylem sap is greatly dependent on different factors. The presence of cations and anions mixed with different organic salutes in xylem sap are result of rootstock activities, assimilation of nutrients from soil and metabolic pathways by which they were subjected in plant organs. The concentration of salutes is also influenced by dilution by water, having therefore a close connection with the water uptake and plant's transpiration rate. The amount of salutes greatly depends on the plant age season when the sap control is carried out. This is especially visible in apple tree in the spring, when stored reserves of nutrients and organic compounds are remobilized for the growing season. It's also important to say that character of the xylem sap is changeable during the season, even during the time of the day of measuring.

The present metals in the xylem sap exist as separate ions but mainly in organic form complexes with organic acids. Amino acids (asparagine, aspartic acid, glutamine, glutamic acid and arginine), special peptides, small proteins and other different organic acids (malic, citric, oxalic and succinic acid) serve as a carrier of metals in plant xylem system. Therefore, their presence in xylem sap influences pH, and the reactivity of present ions. Calcium, Mg, Fe, Mn and Zn are likely to be transported in the xylem as cations or cation complexes with organic acids. Between them, ionic calcium, as measured by an ion selective electrode, was about 50 per cent of the total calcium. The remainder of the soluble calcium was present as complexes with citric and malic acids. Iron is transported mainly as Fe citrate, zinc can also be transported as a histidine complex, and Zn, Cu, Mn and Ni can be transported as nicotianamine complexes. Nitrogen is mostly present in the xylem in its inorganic forms (NO_3, NH_4), although amino acids and amides have been also observed (Peuke, 2010). The proportions of the various N fractions in the xylem sap depend on the form of N supply (NO_3, NH_4) and the major site of nitrate reduction (roots or shoots). Except at very high external NH_4 supply, usually the concentration of NH_4 in the xylem is very low (Van Beusichem et al., 1988) and much less then nitrate anions. Similarly, phosphate and sulphate are the dominant forms of P and S in the xylem. Besides all other elements, potassium is adsorbed and transported as separate ion. In apple species, high concentrations of sugars may also occur and sugars may account for about 15% of the total organic carbon in the xylem sap. Phytohormones are a normal constituent of xylem sap, particularly cytokinin which are mainly synthesized in the roots. The special attention was paid about the concentration of abscisic acid (ABA) in xylem sap, as a possible chemical signal to the shoot of root water status.

3.6 Phloem loading

Vascular system in plants allows the cycling of nutrient within the plants. By this way, nutrients are loaded in the stem and the leaves and then shared between growing organs (shoots, fruits and root). This process of tissue supply, named as a phloem loading, after salutes processing are more saturated even up to the 15-25% of dry matter, having a higher pH (7–8). This increase of concentration for all nutrients, with exception of Ca, is usually being several times greater in phloem exudate than in the xylem exudates. The main organic component of phloem sap is usually sucrose, which may participate up to 90% of the solids. Besides the sucrose, a high concentration of amino compounds is present in phloem sap (Peuke, 2010), where the amides of glutamine and asparagine represent 90% of this fraction. On the other hand, the concentrations of nitrate and ammonium are usually low (Van Beusichem et al., 1988). Organic acids such as citrate and malate are also present in the phloem sap, and, succinate concentrations may reach the same concentration as total amino-N. A whole range of other organic compounds are also found in phloem sap, for example secondary metabolites, hormones, proteins and RNA (Turgeon and Wolf, 2009). Having in mind that the phloem long distance transport takes part in sieve tube elements, a part of phloem salutes is transported between cells through the symplast pathway across the *plasomdesmata* (“protein channels between cells”). By phloem sharing of digested nutrients between organs, it is reflected a whole status of tree fruits nutrition. The amount of supplied and transferred phloem content reflects an initial process of nutrient adsorption.

One of the most important things in apple nutrition understands a nutrient storage and nutrient distribution within plants. A crucial thing is to create a difference between nutrient movement and storage in perennial plant, just like it’s happened in apple tree, and nutrient turnover in one-year old greenish plants. In cereals, like corn, wheat, rye, etc., most of the adsorbed nutrients go in the aboveground parts and this amount reach up to 90%, where only 10% remain in roots. So, when nutrient reserves are depleted from the initial seed reserve, the growth of young sowed plants completely depends of the soil nutrient uptake, namely, plant goes heterotrophic nutrition. After the development of cereal’s third leave, an absolute plant’s supply depends on root activity and nutrient reserves in soil, usually stocked by autumn/winter fertilization (P, K) and spring nitrogen dressing. Plant’s development and yield formation are entirely coupled to the amount of added fertilizers, or nutrients which are present or exist in soil. After adsorption, nutrients mainly go up, making the mentioned distribution ratio between aboveground and root organs. New growth or a new start of greenish plants growth, is, in general, related to the external nutrient reserves, where some additional supply of nutrients, besides fertilization, is obtained by plant's residue mineralization. So, concerning that a large portion of biomass of sowed plants has destiny as a plant's residue, the obtained by mineralization of soil's nutrients should not be underestimated or neglected.

On the contrary, perennial plants have "storage organs" with absorbed nutrients. This means that some plants parts or organs have an additional role in the nutrient transfer from root to the top. Storage and nutrient transfer of the wooden parts of plants could be compared to the "swimming pool". This "pool" keeps all adsorbed nutrients, managing their distribution and finally ruling their stocked amount. This means that this "pool" will release collected nutrients according to the needs of certain phenological phases in the plant. In example start of root growth, flowering phase, or start of shoots growth, or phase of the yield formation, needs some of the stored nutrients in different amounts and different ratios. It could be said that this is regulated by the driven metabolic pathway. Generally, present hormones trigger the processes of certain biochemical syntheses and this will need some elemental support. Crucial is to note that each of these elements derive from these reserves stocked in wooden plant parts. However, this wooden tissue balances them, because this "swimming pool" should not be ever completely emptied. The loss of stored nutrients could be depicted as "water overflow above the firm edges of the pool". This means that stocked nutrients must be collected to a certain level in wooden tissues, where only the excess of their amount will allow this movement from reserves to the points of plant's growth or development of new tissues. In conclusion, the nutrient movement is governed by enough stored reserves, which support or block a new growth or building of new tissues.

In the meantime, the "pool" reserves are renewed via root adsorption, keeping an initial nutrient content at the level which enables plant's perennial life, especially in the periods which is not favourable for nutrient supply like droughts, flooding or simply the food shortage. As a result, investigations on perennial plants (Neilsen et al., 1997, Nachtigall and Dechen, 2006, Zanotelli et al., 2013, Tagliavini and Zanotelly, 2015) gave us reliable data that most of the nutrients are stored in root, stem and branches. With70% of stored nutrients these organs can be declared as "storage organs". This indication, however, could induce a misleading or misunderstanding about the total content of some element in different plant organs. This is typical for nitrogen as the most mobile and also most investigated element in plant tissues. Analyses can give us a presence of N in apple leaf between 2,10-3,07%, much higher than the content in roots (0,74-0,78%) and stem and branches (0,45-0,48%) as woody organs (Tagliavini and Zanotelly, 2015). By the calculation about the weight of the formed biomass has been done (d.m.), the total yield and stored N in woody organs are significantly higher, giving 19 kg/ha of total N in leaves and 36 kg/ha of N which is placed in wooden parts.

This role of stored nutrients induces a term of remobilization, which means their reabsorption from storage organs. This is a mechanism for retaining and conserving nutrients in perennial plants, when remobilization appears to be an important component of nutrient use and efficiency. This is especially exposed when it comprises a seasonal nutrient cycling. Therefore, remobilization appears periodically and usually is related to the season's changes. It is important to emphasize that early growth of apple, or growth of any part of perennial plant, are completely provided by the remobilization process. This practically means that there is no direct/instant effect of applied nutrients by fertilizers (mineral fertilizer) on apple growth, what is happening in fertilization of e.g. cereals. The adsorb nutrients in apple therefore should pass two steps after their uptake, where the first one is a deposition (storage organs) and, after, second one is internal redistribution. So, the real effects of fertilization will be shown after initial consumption of stored nutrients. Further nutrients uptake in later phase of running vegetation from fertilizer or from soil will support the further organs growth (leaves, buds' differentiation, fruit and shoot growth). This remobilization mechanism should be considered when planning a mineral fertilizer application for apple, because the nutrient should be in adequate quantity in organs when bud differentiation occurred. This specific growing phase of apple generally passed hidden, and it is totally separated from yield formation which is at this part of vegetation in focus of growers' interest.

4 Functions of minerals in apple nutrition

The functions of minerals in apple nutrition are numerous. Their role in plant tissues are based on deep physiological investigation. Most of them catalyse biochemical processes. They are generally coped as building material for tissues growth, except potassium which exists in plant tissues as free cation. Naturally, they significantly vary according to their content in tissues, ranging from their trace amounts up to the percentage participation in tissues. One thing is very important for these 17 macro and microelements what should never be forgotten or thrown away: they are of equal importance for the plant's growth. Also, for plant metabolism they do not have an alternative. Consequently, they must be present in demanding amounts in tissues to conduct a functional plant metabolism.

Nutrients affect the plant's growth, cell division, yield, yield quality, mineral composition, quantity and quality of syntheses of primary and secondary metabolites, disease resistance, etc., where the role of each nutrient are precisely described. However, nowadays, the present investigation related to nutrients tends to explore their mutual interaction on different complex parameters, like the nutrient effect on components of fruit coloration, nutrient effect on synthesis of different type of carbohydrates or vitamins, a synthesis of apple phytochemical and their health benefits, effects on nutrient antoxidative activity, or on nutrient rootstock/scion interaction etc. But the great number of them is still focused on nutrient effects on yield levels and fruit quality. These investigations are trying to find parameters for the practical use of nutrients to reach the two main goals in apple production: quantity and (market) quality. Up to now, it is obtained that whole complex of conducted investigation which confirms the positive role of nutrients in investigated biosynthesis.

Nitrogen: Nitrogen used by apple trees for growth can be derived from fertilizers, from soil, or it can be remobilized as N within the trees themselves as previously described. A mineralization of soil organic matter gives a certain amount of soil's N, but this is not a major contribution to the plant's N nutrition. This give the relatively respective amount of available N which depends primarily on a soil type, the degree and intensity of mineralization, but concerning that the orchards are not set up at the richest soil with organic matter, the content of such released nitrogen never exceed 20-25 kg N/ha per year (Rish et al., 2019). In practice, orchards are mainly supplied by N with liquid or granular mineral fertilizers, but if not, they will live only upon these reserves in soil and stored N in plant. In spring, with vegetation start, N is used from overwinter stored reserves in perennial, woody tissues by remobilization, so the growth of new roots, leaves, flowers and shoots is fully dependent on these reserves (Titus and Kang, 1982, Millard and Neilsen, 1989). Further, subsequent growth of apple trees during the summer, concerns a new accumulation of N by the roots, but this amount has been predominantly translocated in the leaves. This N stays in leaves before its withdrawal during senescence (Neilsen et al., 1997), and this withdrawal of N during autumn could also significantly enriched the "pool" of nitrogen for further remobilization. Also, during the autumn, up to the existing root activity before winter, N is also fulfilling woody tissues with N and after that, the adsorb N undergoes internal cycling (Ličina and Jakovljević, 1996).

Nitrogen is stored in perennial parts of apple trees over winter in roots as amino acids (Tromp, 1983), as proteins in the stem (Millard and Proe, 1991) and in bark (Titus and Kang 1982). In leaves, during the summer growth, N primarily participate in the building of Rubisco (Ribulose-1,5-bisphosphate carboxylase /oxygenase) (Titus and Kang 1982, Millard, 1996), the most present enzyme (40%) in leaves biomass (Teiz and Zeiger, 2010). Withdraw of N from leaves occurs during periods of senescence, when N present in leaves (N in amino acids) has been transferred in this form to woody parts. This N also makes a significant N- pool for subsequent remobilization and use for growth in the spring It is believed that 50% of the total N is in soluble form (amino acids), but Titus and Kang (1982) argued that proteins are the main storage form of N woody parts, with free amino acids of secondary importance. Parallel to this explanation, nitrogen cycling from leaves to woody parts must also be concerned as transfer of N from leave's compartments, what seems to be the key determination of such nitrogen allocation. This means that structural nitrogen, like N built up in a cell wall, contributes little to nitrogen resorption, because it has low degradability during leaf senescence, while metabolic nitrogen, like N from enzymes, is largely resorbed (Yasumura et al., 2006).

In apple physiology, nitrogen is the main constituent of proteins, amino acids, nucleic acids, chlorophyll, co-enzymes, phytohormones and secondary metabolites and therefore plays a major role in plant metabolic processes (Salisbory and Ross, 1992, Neilsen and Neilsen, 2003). Its requirements are higher than the requirement for any other nutrients. Nitrogen support's growth of new tissues formation, such as a developing leaves, shoots and fruits (Neilsen and Neilsen, 2003). It is well known that the deficiencies of N induce poor growth, low yield and leads to small fruits. Adequate supply of nitrogen should be during bud differentiation or otherwise its number will be significantly reduced. For better understanding, the nitrogen movement in trees if various tree parts are analysed. The Nitrogen content tends to be high in growing shoot tips, growing leaves and young fruits. However, high levels of nitrogen supply induce vigour growth, development of water shoots, induce fruit drop and increased physiological disorder in fruits (Hewitt and Smith, 1975, Faust, 1989). Excess of nitrogen also reduced fruit coloration and aggravate fruit maintenance over the time. So, concerning all aspect of N importance for plants nutrition, the availability of N to roots is therefore a decisive factor for apple growth.

Phosphorus: Requirement of phosphorus in apple growth is relatively small compared to other nutrients. Phosphorus stays as a key factor in compounds which provide energy transfer, also, phosphorus is a constituent of nucleic acids and, therefore, it is mostly required in plants during the stages of meristematic activity. This particularly concerns the start of growth caused by the seasonal changes or seedling's planting. A development of a new root system, flower formation, pollination and fruit setting are the periods when P plays a crucial role in plants. Therefore, the needs for phosphorus are generally exposed early in the season. Phosphorus deficiencies are harmful for the wide range of metabolic processes by delaying plant growth, causing poor root growth, and reducing a fruit size and quality of the yield (Marchner, 2002).

In plant supply with phosphorus, the main problem is its low content and its low mobility in soil. This is especially exposed for grown fruits, because apple root system is placed at deeper layers concerning surfaces one. However, by the use of fertigation system in orchards' nutrient supply, most of the problems of feeding fruits with phosphorous has been overcome. Phosphorous in nutrient solution can be applied to the root zone more often at different phenological phases to support growth of plants or to affect the development of some tissues like root tissues during elongation, flower tissues development and fruit setting. This fertilization technique completely erased the problem of phosphorus inactivation after its reservoir application during the soil preparation for orchards' planting. This has been usually conducted using huge amounts of phosphorus fertilizer which is subjected to the complex process of P immobilization in root's feeding layer. Accepted forms of phosphorus for plants are $H_2PO_4^-$ ion or $HPO4^{-2}$ ion, which is affected by soil's pH. The first one is available on acid soil, and second one on neutral and alkaline soils.

Potassium: Potassium is of a great importance for apple production. The present amount of this element in leaves and fruits are close to the level of nitrogen. In leaves, where the intensity of metabolic processes is the most exposed, potassium is the most abundant cation between others mineral nutrients (Neilsen and Neilsen, 2003). This element is responsible for photosynthesis, protein synthesis, enzyme activation (about 60 catalytic activities), osmoregulation, stomata movement and cell extension. Secondary metabolites are also very dependent on potassium level in cytoplasm. Its mobility and its fluctuation are driven by metabolic processes, where K transfer in plant is usually tied up to phloem and xylem vessels, but significant transport take place between cells (symplast pathway).

Apple uptake of potassium by roots usually depends on its quantity in soil, concerning that this element could be taken up opposite to the concentration gradient. In root tissue its concentration can exceed a hundred times of its soil's concentration, but still uptake occurred. The supply of potassium to apples trees primary depends on fertilizer application, considering that pH of soil solutions have no effect on its adsorption by plants. Otherwise the type and character of soil mostly affects its level in the ground and afterwards in plants. Its application is evidenced by increased fruit size, increased sugars and improved fruit colour (Rambola et al., 2000), thanks to its high osmotic potential which possess this free cation which is not tied up to any constituent compound in cytoplasm. Potassium application is particularly effective if it's happened during midstages of fruit development or, in soil rich in clay, at the end of growing season (Tagliavini and Marangoni, 2002). Its single use is usually avoided, because of potential adverse effect on Ca nutrition. Now, by using fertigation, K can be applied more often to the root zone and at the certain fruit developing stage.

Calcium: One of the major concerns for an apple grower is calcium, dispute that this element usually saturated soil's adsorptive complex to a large extent (60-80% CEC). In soil poorly provided with Ca, all problems related to the lack of Ca are about the bed fruit storage life: fruit quality is threatened by bitter pit, Jonatan spot or scald appearance. This is because calcium serves important functions within the plants, including the cellular behaviour and maintenance of cell division, cell integrity and membrane permeability (Mengel and Kirkby, 1982). However, one of the bad Ca futures is a low mobility in plants tissues, where no transfer between organs occurred. So, feeding apples with this element generally concern its foliar application on fruits during developing period. This is a direct care of the fruits and not leaves, and the goal of this measure is to make an increase of Ca concentration in outer fruit layer.

Magnesium: Magnesium is taken up by fruit trees in lower quantities then Ca. It is worth to know, that magnesium adsorption can be reduced by competing cations such as K, Ca or NH_4^+, especially when heavy K fertilizer use emphasize this antagonism in fruit production. Its role in plants is mostly associated with the chlorophyll formation, as an ion which possess a central place between four N terminated tetrapyrrole rings, but only 10-15%, or maximum 20% of its total content in plants belongs to this Mg fraction. The majority of Mg in tissues serves other not less important biochemical functions in plants, like enzymes activation involved in phosphorylation, activation of RUBISCO and protein synthesis (Mangel and Kirkby, 1982). In the concept of contemporary apple nutrition, Mg plays a significant role as regularly applied element through fertigation systems especially in orchards planted on soils with low clay content.

Sulphur: In apple trees, sulphur is required approximately at the same quantity as phosphorous. Like in the other plants, this macroelement is a structural part of sulphur-containing amino acids (cysteine, cystin and methionine), proteins and co-enzymes (Neilsen and Neilsen, 2003). In trees, sulphur also makes a wide range of stabile chemical complexes which provide metals binding to organic compounds, mostly with a catalytic enzyme character.

Iron: Apple growers very often fight against iron chlorosis, as a yellowing of young leaves caused by iron deficiency. In severe cases, the entire leaf turns yellow and it is common for an individual branch or one half of a tree to be chlorotic while the remainder of the tree appears normal. In some areas the entire orchards may be affected, while in others only the most susceptible plants show deficiency symptoms. These yellow leaves indicate a lack of chlorophyll and this reduction in chlorophyll content during the growing season can reduce plant growth and vigour. In addition, chlorotic plants are less productive, producing smaller fruits, while threatened orchards are without adequate yield. In severe cases if iron chlorosis persists over years, individual branches or the entire plant may die. The causes of iron chlorosis are complex and not completely clear, but everything about this deficiency is affected by reduced iron availability in soil. There is also some scientific indication that Fe problem also exists at the tissues level, where its Fe^{2++} physiological activities failed. Usually, iron chlorosis is related to the high pH of the soil (pH > 7.0) and soils poor aeration and excess of moisture (lime-induced chlorosis). Such soils typically have plenty of iron, but soil's high pH and carbonates causes chemical reactions that make the iron unavailable to plants. Such iron will be tied up indefinitely unless soil conditions change.

Iron is a one of the rare micronutrients with has multiple biochemical functions in plants. It is responsible for chlorophyll synthesis, and whole photosynthetic complex in leaves are built on this element. Also, huge number of catalytic reactions in plans relates to iron participation like a crucial process in plant cell: respiration, cell division, cell growth, etc. This gave a special attention to Fe in apple production, where some of the invented Fe fertilizers can successfully overcome the problem of its low availability in soil (Fe-chelates).

Manganese: Manganese in plant production belongs to three micronutrients which are responsible for yield size. Its participation in photosynthesis and nitrogen and carbohydrate metabolism seems to be crucial for this characterization. It is generally considered to be rather immobile in plants, but its increased concentration was dominantly observed in young growing tissues. The lack of Mn in leaves is easy to recognize, because specific "mosaic chlorosis" appears (intercostals parts are yellow, while leave nerves stay green). In Tyrol (Italy), as a well-known apple production area in the world, its foliar application sustains in practice for years.

Zinc: In tree plants, zinc is needed in small amounts, however, this microelement participates in huge number of enzymatic reactions. A special attention has been paid to its role in the production of the growing hormone auxin, which is responsible for the entire growth process. Proper cell division will terminate the shortening of internodes and formation of small leaves what is observed with zinc inadequate supply. The mobility of zinc in the tree depends on several factors. If the plants are with adequate Zn supply, zinc moves readily from old leaves to developing ones, otherwise, little zinc moves out of the old leaves if deficiency exists. Compare to the other fruits, e.g. stone fruits, apple is not so particularly sensitive to the zinc deficiency, but apple fertigation practice today frequently include this element in nutrition (Zn-chelates), while its foliar spraying in some apple growing regions became a routine.

Boron: Between micronutrients, boron trigs a great attention in plant nutrition concerning that it can be toxic. This is especially a big problem in orchards and vineyards planted in deserts. Due to the lack of the electrical charge of the B-acid molecule, B excess is easy to rinse with water, what start to be a practice from vegetation to the vegetation in some growing area. Only the application of this measure in such potentially B toxic regions provide fruit or grape production.

In plants, boron is needed for several metabolic processes, particularly in the activities of meristematic tissues. Cell division, supported by the uracil bases synthesis, makes the boron functions vital in the development of shoot's and tips tissues. It also plays a role in protein synthesis and metabolism of plant hormones, coupled with its capability to facilitate sugars transport, promote the importance of this non-metals for apple growth and yield quality. Its transport in plants has been relived as problem by its movement almost exclusively with the transpiration stream in the xylem. However, its mobility between organs usually is not exposed.

Copper: Despite that copper belongs to the element's which provides a high yield, a very small quantity of these elements is present in fruit trees. More than half of this copper in trees is in the chloroplasts, which participate in photosynthetic reactions. It is also found in other enzymes involved with protein and carbohydrate metabolism. Relocation of Cu in tissues is conditioned by its adequate supply. If the deficiency exists, it becomes immobile what is shown first at young leaves.

Molybdenum: Molybdenum is a component of two enzymes which deals with nitrogen metabolism, and their activities are more vital for annual plants, so its appearance and importance for apple production is minor or yet not define.

5 Foliar analyses – Leaf diagnosis

Nowadays, it is rare to meet visible symptoms of nutrient deficiency in commercial apple orchard. Naturally, it could occur at certain soil types, or, under certain soil conditions, but appropriate fertilizer recommendation must include real needs of the apple tree, even the possible lack of nutrients or their inactivation in soil. This is the only accepted approach by apple growers, where some of the deficiencies should be predicted.

For determination of nutrient's needs in apple productions, different kinds of tools are disposed. Beside visible symptoms of nutrient deficiency, a professional service can provide primary soil testing and leaf analysis. Generally, the whole modern apple production in the world is based on the use of these data. As a good example of good practice in soil monitoring and leaf diagnosis application is in Northern Italy (Tyrol), where 19.000 ha of apple orchards are coved by this standard control. The result obtained by thousands of leaves analysis provided the development of local standards for leaf analysis interpretation and strategy for low/adequate fertilizer input (Tagliavini and Marangoni, 2002). However, this small area is supplying up to the 50% of the national Italian apple market, 15% of the European and 2% of the global apple market (FAO, 2014).

A leaf tissue analysis is one of the most widespread tools to diagnose nutrient or nutritional status of plants. As a useful guide to supervise a nutritional program, it can help to recognize an uptake problem or to find the nutrient needs of apples. However, a complete diagnostic process includes additional tools such as soil testing, observation in the orchard, water quality testing and tracking use of fertilizer. As a method for obtaining data per se, leaf tissue nutritional analyses are worthless. The interpretation of obtained results is the main goal of this method and crucial for proper understanding a plant needs. These results may help to evaluate the presence of elements in leaves in adequate, deficient or excessive amounts (Marschner, 2002). Ability to make correct interpretation of laboratory tests needs either to compare the results against some standard, or, when you have visually identified nutritional problems in one's orchard, between samples. The last type of samples for analyses can be taken at any time during the season from healthy and problematic trees.

A leaf nutrient status monitoring usually is compared to some certified standards, which are created to be utilized as a reference for sufficient nutrient supply under different growing conditions. This usually means that these standards need a certain sampling procedure, because the nutrient concentration varies among fruit trees and changes over the seasons. With the aging of the leaf from spring to autumn, nitrogen, phosphorus and potassium concentrations decrease, while calcium increases, or, magnesium first increases and then decreases (Nachtigall and Dechen, 2006). Leaf samples collected much earlier tend to contain higher concentrations of elements such as nitrogen and potassium, and lower levels of calcium (Hoying at al., 2004). So, fully developed leaves should be sampled as entire leaves at mid-July (1-15 July) from the mid-shoots position in the most apple regions (Central and South Europe, while according to the delayed growing season in Norway, leaves collection should be done during August (Kvåle, 1995), what is, if compared to the main production areas, a significant delay. This was confirmed in another scientific research, where collecting of leaf samples was conducted in August in deferent apple growing regions in Norway. Fully-developed leaves have been taken from mid-extension shoots in 1-1,5 m height, where five leaves were collected per tree.

A general fact is that shoots bearing leaves for analyses must be from current year's growth. It should be collected about 50-100 leaves as at least four leaves form the periphery of each of 20-40 trees. Prepared leaves (washed and dried also according to the certain recommendation) are subjected to the analyses. Unfortunately, leaf sampling procedure or leaf preparing for analytical procedures, mostly are proposed by local community of apple growers or officially charged analytical institutions, which conduct soil and plant testing and propose fertilizer recommendations. Thus, all demands about sampling procedure should be obtained from these authorities.

Obtained results by analyses are compared to the leaf composition standards for apple which are available online for users all over the world. They gave a range of nutrient level as a deficient, low, normal, high, excess, or as a "desired levels", but something what should be emphasized that these standards have shown to be valid irrespective of cultivar, rootstock, training system or environmental conditions. However, the results of nutrient analysis cannot provide specific information on the appropriate fertilizer rate or timing on application. Besides, leaf analysis means a scan of nutrient content in a certain growing stage of plant, what trigs a question if some applied nutrient by fertilizers can make turnover within the leaves or at the level of whole plant. Therefore, only some of the nutrients should be traced over time in leaves, not all. Accordingly, leaf tissue analysis is particularly effective to evaluate nutritional status of apple with N and K, as mobile elements in tissues and easy applicable by fertilizer, while the evaluation of micronutrient's (manganese, copper, zinc, boron and iron) content in leaves, as a much better indicator of their availability in soil, can be used as diagnostic criteria or in correction purpose.

5.1 Leaf tissue analysis - Critical level of nutrients in apple leaves

Practically, leaf tissue analysis is normally used for one of two main reasons:

a) Diagnostic - to determine the reason for poor growth of trees or to define deficiency symptoms;

b) Monitoring - to assess the efficiency of current fertilizer management practices;

Consequently, a two-leaf sampling approach exists: one for diagnostic analyses and one for monitoring of the nutritional status of the orchard. The first one should be taken from areas displaying poor growth or from the area where deficiency symptoms appears. To ensure the real factors are the cause of deficiency, parallel sampling has to be done: one from "healthy" area and one from the area with "visible" deficiency problems on leaf or other tree' organs. The samples should be taken from each area showing slightly deficient symptoms.

If the monitoring of nutritional status has been conducted, samples are taken from an area which is representative. If monitoring is going to be conducted in future and the results should be compared between years, the sampling sites should be clearly defined, marked as a position at the site in the orchard (GPS locator).

When monitoring fruit's tree, the leaves from 20 to 25 typical apple trees should be sampled and marked as the reference one for future sampling. In leaf sampling, it should be kept in mind that they must be collected from shoots from current vegetation. These samples need to be from the same variety, rootstock, crop age and vigour, and as expected, from the orchard planted at the one soil type. A sampling procedure is a standard, or it could be recommended by the leaf analyses institution.

Like in soil, leaf tissue analyses are compared to a critical level of a nutrient in this organ, or, otherwise, between "good"and "bad" samples in a case of diagnostic criteria. The crucial is that the *results below the critical value indicate an insufficient level of nutrients for optimal apple growt*h. At this point, the plants may respond to added fertilizer or a foliar nutrient supply.

In literature, you can find a numerous examples of nutrients' critical level in leaves and they can vary between in a great extent. Table 1 gives example(s) of nutrient critical level of each nutrient as given lowest values, and, also, a range of its sufficient amount in apple leaves. A range between insufficient and maximal nutrient level could be defined as an optimal range of nutrient concentration in leaves.

The data from first column (Table 1) sublimes the results of leaf tissue analyses obtained over a long period from Norway's orchard and it could be used as a guide for proper evaluation of apple leaf diagnostic in this country. The next one presents the results from Sweden. They can serve for comparison with the Norwegian domestic results which has the most similar climatic and ecological conditions. The results from the third column have been proposed by Ohio State Extension Service (The Ohio State University) and they have been exploited in Benelux/German counties for years. Based on these results, apple growers from this region try to maintain the nutritional level in leaves according to the given ranges. As a result, they achieved desirable production of apple. The last column has been brought also from USA University Extension Service (Washington), and their results were checked over a long period. As it can be seen (Table 1), all presented leaves' nutrient content evaluations are similar, differing only in the maximum range of micronutrients (Fe, Zn).

Table 1. Nutrient critical and optimal concentration in apple leaves. (Norway, Sweden and two USA University Extension Services).

Elements	Norway[1]	Sweden[2]	Ohio State University[3] Cooperative Extension Service	Wash. State University[4] Extension Service
N **(%)**	2.0-2.5	2.3- 2,5 %	1.9-2.4	1.7-2 .5
P **(%)**	0.15-0.25	0,2 - 0,3 %	0.17-0.28	0.15-0.3
K **(%)**	1.2-1.6	1,3 - 1,5 %	1.2-1.8	1.2-1.9
Ca **(%)**	1.0-1.5	1,2 - 2,0 %	1.3-1.7	1.5-2.0
Mg **(%)**	0.2-0.3	0,2 - 0,3 %	0.24-0.36	0.25-0.35
Mn **(mg/kg)**	25-150	60 – 200	31-150	25-150
Fe **(mg/kg)**	40-400	> 60	35-150	60-120
B **(mg/kg)**	20-50	30 – 60	28-50	20-60
Cu **(mg/kg)**	5-20	8 – 20	5-10	5-12
Zn **(mg/kg)**	15-200	20 – 70	20-50	15-200
Mo**(mg/kg)**	-	-	0.5-1.5	-

[1] Source: Dyrkingsmanual: Gjødsling i frukthagar, Vangdal, 2017 (in Norwegian).
[2]Source: Fruktodling och efterskördbehandling, Tahir, 2014 (in Swedish).
[3]Source: Fertilizing Fruit Crops 1995 –Ohio Cooperative Extension Service. The Ohio State University;
[4]Source: Tree Fruit Soil Fertility and Plant Nutrition in Cropping Orchards in Central Washington 1980, WSU Extension;

However, it is important to know that nutrient concentration above the critical range may not be necessarily harmful to trees. This could be the result (or indication) of unique soil conditions or an effect ofother factor, like previous use of plant protection agents (with excess of micronutrients, mostly Cu and Zn). For an optimal growth of apple and full tree potential achievement, the nutrients should be kept in the middle of sufficiency zone.

Practical recommendation is that the nutrient level in leaves should be accepted mostly according to the *local* practical experience, especially for Norway, not only as “adequate range” or “optimal range” of some nutrient in leaves. This means that all other aspects of the obtained yield should be concerned, like apple quality, apple taste, its chemical composition, handling properties, plant’s disease resistance, etc., making leaf analyses as a very useful guide to achieve the high and good quality yield. Generally, leaf analyses should be conducted regularly (year by year) making a possibility to upgrade your critical approach to the obtained results.

5.2 How to “read” and how to use data from leaf mineral analyses

Nitrogen and Potassium- Concerning that use of fertigation, as currently very efficient way of supplying apple orchards with nutrients, the correction of inadequate N and K supply can be easily achieved. Applied liquid fertilizer can instantly cancel the possible lack of these two nutrients in trees. This improvement of nutritional status in trees by mid-season is possible (1-15. July), consequently in August in Norway, because the absorbed nutrients from soil are shared by nutrient’s primary stocking in woody parts and green growing organs. This means, that a part (or majority) of absorbed nutrients (N, K) will be directly transported to green parts and cause their increase. Considering that small amount of these elements (N and K) can be applied/absorbed by foliar fertilization, a commercial production practice usually does not consider this nutrient treatment of trees. Only the foliar K supply during the fruit ripening phase can be accepted as beneficial, thanks to K fast efficient and direct transfer into the fruits just after treatment, what promote its foliar use in practice.

Tracking of microelements (Mn, Zn, Cu, B, Fe) supply by leaf analysis has a bit diverge approach. In general, the leaf analytical results bring the data if trees have a sufficient or insufficient supply of each micronutrient. Afterwards, their mobility in soil and tissues and the effectiveness of their fertilizers (or the way of fertilization) to score adequate nutrient supply should be considered. This sounds like a limitation in the use of obtained analytical data, but it is the only possible way to correct how an inadequate or deficient level of these micronutrients in plants.

Phosporous- Previous remarks about leaf diagnostic include few elements. Phosphorous is one of them, as usually ranked at the second place in plant nutrition just after nitrogen. This is not because of minor importance for plant metabolism, quite opposite, its importance for plants is an outstanding category as it was previously discussed. It could be said that real reason is that P leaf analysis reflects only a status of this element in plants, whilst this P level mostly does not respond to the phosphorous fertilization. Instant correction of phosphorous in apple trees seems to be not possible and usually is a result of long-term fertilizer use.

Most recently, however, several conditions have been recognized when apples respond to P fertilization. These include times when apple root growth is limited due to the low P level in soil, or, when trees are newly planted, and P is needed for new root growth (Ličina et al., 2009). Responses to P application include intensive and fast growth of apple seedling after planting (Ličina et al., 2012) and accelerate flowering of newly planted trees (Raese, 2008, Bruneto et al., 2015). In the meantime, an increase of yield and increased of P concentrations in leaf are another complex category which could not be easily correlated (Nava et al., 2017). It seems that the reason for this is little knowledge about seasonal P requirements of apple trees. The peak demands of P could relate to springtime where intensive cell division and meristematic activities are predominant during the season. This is practically a time when the growth of trees can be seen, and later there is no need for phosphorous in apple growth.

Fertigation improved phosphorous supply of apple plants by enabling root contact with its solution at desired depth and by allowing mass flow P delivery in the root zone. This makes this fertilization practice superior according to the classic fertilizer (surface) broadcast application or foliar P fertilization, which is even not comparable with fertigation considering the applied P amount.

Fertigation becomes a standard recommendation for efficient supply of apple by phosphorous, considering that leaf analyses can only be the starting point for programming orchard's P needs for next vegetation. This program should be focused primary on the covering P consumption during the early growth in spring (root growth, shoots growth, flowering), which derives from woody parts. So, planned P amount by fertilizer use must be adequate and eligible to fulfil these depleted reserves, making a new P reservoir which can, or could, buffer all current P needs during vegetation.

Calcium- The interpretation of Ca leaf test seems to be very provocative. According to its dynamic in tissues, calcium content in leaves have steady, slow increase during the season with small decrease a few weeks before harvest (Vang-Peterson, 1980). After its uptake from soil, mostly in early season, Ca is built up in the cell wall and other organelles, what's make it immobile. This means, that Ca allocation in tissues is very slow and dependent on its continuous supply. As it was previously said, the main goal of Ca apple nutrition is building up good fruit quality, what is independent of its leaf's content. Accordingly, it seems that there is no practical need for Ca leaf diagnostic. This parameter can be used only as a warning for apple growers if Ca content is not complementary with the content of Mg in leaves. This means adequate/inadequate nutrition with some of these elements, where the low Ca content or narrow Ca/Mg ratio, means luck of calcium or its inadequate supply. The Ca/Mg ratio should never be 1, or close to 1, while higher Mg content is not accessible and can make disorder in plants.

Magnesium- Magnesium in leaves is mobile so lack in these tissues tends to develop deficiency symptoms first on older leaves, usually beginning around midseason. This is a very important fact, concerning that the results of leaves analyses are obtained at the same period. At this time, it can be seen a nutrient status of this element in apple, which is related to the tree growth and yield formation. Its content in leaves remains almost constant until the end of fruit maturation, so any disorder could be seen upon the analysis. To correct potential lack of Mg, a spray application will rectify its insufficient level more rapidly than its soil application. However, it is important to follow the magnesium sprays application with calcium one, to balance any Ca and Mg disorder.

Iron- In apple nutrition iron greatly dependents on balance between its solubility in soil and tree's demands. Although present in abundant in the most well-aerated soils, iron has a low biological activity, because it primary forms a highly insoluble compound causing iron chlorosis. This disadvantage affects the worldwide agriculture plant production, because 30% of global cultivated soils are on calcareous soils with low iron availability. This also happened in neutral and moreover in alkaline soils. Present in insoluble oxidized forms, iron is not a food for apple trees, and it should be transferred to its physiologically active form of Fe^{+2}. Fight against Fe chlorosis could be very difficult, and success can be very limited which appears temporary, but good thing is that this abiotic disease is not a major problem of the main apple regions. Iron deficiency can treat all areas or soils which contain lime, but soil's complex reactions which govern iron availability usually are tied up with excess of moisture, restrict air movement and cool soil temperatures. Due to this complex problem of iron chemistry in the soil, it seems that the use of deficiency-tolerant rootstock is an effective strategy to prevent Fe deficiency, concerning that all rootstocks are not sensitive to the lack of iron (Wang et al., 2018).

Leaf analytical data about iron content mostly are not sufficient for fertilizer recommendation or correction of Fe chlorosis. They could give Fe quantities which are not in accordance to the situation in orchard, meaning that a very low content of iron in leaves can be very helpful and able to remove all problems of iron deficiency, or, high Fe content in leaves could be inefficient when Fe chlorosis appears. The problem of this discrepancy is related to its physiological activity in leaves tissues, where a part of Fe is defined as a "physiological active" and a part of leaf's Fe is out of metabolic functions. A great number of Fe plant investigations claim that only Fe^{2++} expose functionality in leaves, while mostly present Fe^{+3} in leaves is needless (Mengel and Kirkby, 2001). However, this Fe^{3++} content in leaves could not be avoided because of chemical analysis, hence all obtained results from leaf diagnostic related to iron should be accepted with caution. For this reason, the excess of Fe found in the chlorotic tissues is now starting to be the topic of numerous investigations, emphasizing that Fe is more or less subjected to its metabolic miss-function in leaves, while Fe soil availability problems are of the second importance (López-Millán et al., 2013).

In practice, a lack of iron is visible during the early growth of young leaves, mainly in the first part of the vegetation, while lasting the Fe deficiency symptoms (yellowing of young leaves) greatly depends on whether conditions. In general, there is enough time react to and apply Fe fertilizer when Fe deficiency symptom appears, but the start of this treatment sometimes could be very late if the leaf analysis were awaited.

Manganese - In apple production in Tyrol (Austria), is controlled on regular basis via leaf analysis and belongs to the micronutrient which is included in apple nutritional programs. Appearance of its deficiency in early spring, especially under excessive moisture conditions, usually is not tolerated. By maintaining of Mn reserves in trees or its fertilizer use during currant vegetation, all problems about this micronutrient should be solved. Besides, Mn is considered as an element which regulates seize of fruit and yield height and this is an additional reason to keep its concentration in tissues at a desired level. Meanwhile, the open question stays about its use in apple nutrition; fertigation or foliar application, where both ways have a successful effect on increasing Mn content in leaves and whole plant. As a fact, the foliar application seems to be more economical under most growing conditions.

Boron and Zinc- Upon the leaf analyses, boron and zinc could be applied through fertigation systems, but effectiveness of this supply have received little systematic study despite their importance for maintaining consistent production in the orchards. Probably that great mobility of B in the soil, particularly in sandy soil (Neilsen et al., 1995), is not a source of problem at such, but Zn is considered less effective due to its strong adsorption by soil (Neilsen et al., 1988), especially on carbonate soils. Therefore, application of B and Zn through fertigation system should be replaced by foliar nutrition, where their foliar sprays have been stressed out as efficient instrument in correction of both deficiencies and maintaining their level in leaves (Neilsen et al., 2005).

Copper- Interpretation of leaf analyses related to the copper content deserves special attention, primary due to its low content and low mobility in plant tissues. Practically, there in no way that soil applied of Cu salts will show a positive change in Cu content in leaves or in other green organs of perennial plants. Somehow, this also appears to be the case with Cu foliar application in perennial plants, despite that only a small increase is needed (Hippler at al., 2018). This proves that this microelement must be stocked in a sufficient quantity in apple trees earlier as a reserve to be re-used and transferred to growing organs during vegetation. Otherwise, its single fertilizer improvement is nearly ineffective and need repeated actions, both as fertigation or foliar nutrition (2-5 times). At the same time, evaluation of copper leaf content is sometime provoked by additional Cu traces used in plant protection. This can mislead the interpretation, pointing that an increase of Cu in leaves exist, but the truth is that this detected Cu residues by chemical analysis couldn’t be removed (washed and rinsed) from cuticle or other epidermal parts. This Cu is without any physiological functionality or importance.

6 Foliar nutrition and its efficiency in apple production

A foliar nutrition is a specific approach of plant supply with mineral nutrients. It has been investigated for a long period and beginnings reach a period of past 19th century, when the first observation about positive effects of such applied nutrients was noticed. After this period (Gris, 1884., Mayer, 1874., Böhm, 1877), a crucial and basic role of plant leaf of light trapping and capturing CO_2 was enriched with some other functions, like gas exchange, moisture adsorbing or possible nutrients adsorption. Further investigations of leaf morphology and anatomy during past period pronounced leaf features which promoted this additional function of leaves related to the leaf cuticle character (Koch and Ensikat, 2008), leaf surface morphology and topography (Magarey et al., 2005), penetration of substances (Neinhuis et al., 2001., Koch and Ensikat, 2008), effects of stomata to a higher permeability (Schlegel and Schönherr, 2002., Schlegel et al., 2005), and a number of other similar or useful investigations which contribute/aggravate nutrient transfer in leaves (Table 3).

Table 2. Most common foliar-applied nutrients in European countries

Stage	Dose rate (kg/ha)	No. of applications	Remarks
Just before bud-break	5-10 [NPK (10-12%)-0-(40-45%)]	1	To improve bud quality and frost resistance
June – July	5-10 [NPK (10-12%)-0-(40-45%)]	3	For varieties sensitive to bitter-pit
June – August	5-10 [NPK (10-12%)-0-(40-45%)]	5-6	Other varieties
6 weeks after flowering	5-10 [NPK (10-12%) - (40-60%)-0)] and [NPK 0-(40-60%) - (30-40%)]	3-4	Till harvest
Post blossom	2.5-5 (10-15%)	3-4	Till harvest
After harvest	5-10 [NPK (10-12%) - (40-60%)-0)]	2	To build up reserves

However, we are still far away from full knowledge about the mechanisms of specific solution penetration which occurred during nutrient solution transfer through leaf cuticle. Given that the penetration of the cuticle is generally considered to be the rate-limiting step for foliar nutrition, several hypotheses about the penetration of nutrients via the cuticle have been raised. For instance, there is evidence, although still not extensive, that polar paths of diffusion across cuticles exist (Niemann et al., 2013). Ionic compounds use aqueous polar paths of diffusion, whereas lipophilic molecules diffuse along the lipophilic wax and cutin domains (Schreiber, 2005). The nature of these polar domains remains to be explained in more detail. Also, there is a need for some additional explanation about the resistance of leaf structure to this penetration (cuticle, intracuticular and epicuticular wax layer, leaf hairs, etc.), pores functionality (stomata conductance, cuticle pores resistance, size pore resistance, etc.) and all other parameter (environmental factors - humidity effect, physio-chemistry of foliar solution, droplet size, foliar adjuvant character, etc.) which enable or prevent nutrient entering process into the leaf tissues. At the same time, this penetration rates runs against a basic function of leaf surface barriers. This barrier was built up during plant evolution to prevent loss of water and pathogens' and insects' attacks. This is a crucial role of cuticle and other leaf protecting structures, where nutrient adsorption is something that has been discovered and can be used in practice.

As mentioned, plant leaf possesses a porosity which permits a solution transport, and it occurre as a passive process which is driven by concentration gradient. This transport is not a simple establishment of concentration equilibrium. It is truly achieved as impact of many biotic and abiotic factors as mentioned earlier. After all, a fact is that foliar treatment can increase a nutrient level in leaves, so the use of foliar fertilizer in agriculture is growing and expanding on all types of plant production. As a targeted and environmentally friendly treatment, with low nutrient input doses, the prediction of its high future use is optimistic.

Response to foliar nutrient sprays can be amazing when treatments are applied to deficient plants. Foliar nutrient spray studies have been developed on deficient plants treatments, so these treatments have been carried out until today to cure deficient trees or orchards and scored positive results. This is considered as a very fast and cheap method in curing these serious abiotic diseases. However, there is an increasing trend to apply foliar fertilizers in the absence of deficiency symptoms, at least as it refers to elements with little phloem mobility such as Ca, B, Fe, Mn or Zn. This supply is treated as complementary supply of these nutrients, while their use in plant nutrition it is not recognize as complete reliance on foliar sprays (Johnson et al., 2001). Such application is also valid for the situation when some of these elements peak in nutrient demand (Lester et al., 2006). It could be said that such foliar use of nutrients has a preventive character, what justified their foliar use as a helpful measure which can remove the worries of plant growers about the size and yield quality endangered by certain element deficiency.

A few facts about the foliar absorbed nutrients should be clarified. Firstly, a quantity of used nutrient in foliar fertilizer should be concerned, and this will be given trough foliar use of urea.Four treatments of foliar apply nitrogen in urea form as 0,1% solution (100 l/ha) means 211,6 g of nitrogen per ha (4 g x 46%). The treatments' N amount is shared between, 440 plants of orchard's trees per ha, meaning that each plant received 0,48 g of nitrogen, roughly about 0,5 g/tree of nitrogen. Concerning that proposed total biomass of a tree is more than 10 kg (d.m.), as an average weight about 20 kg per plant, a total content of N per tree (where 2-3% of N is in leaves, 0,1-0,3% N is in shoots, stem and root), gives about 60 g of nitrogen. Finally, the net application of foliar applied nitrogen is 0,5 g/tree, which represent only a 0,3-8% of total N content in the whole tree. This rises the question what the benefit of this treatment is, and, when applied, also as not fully adsorbed, how such a small amount of nitrogen can affect plant tissues.

This make sense only for micronutrients foliar application due their minor presence in plant tissues, but micronutrients application effect seems to be not clear. A similar confusing result in leaf analyses has been obtained after the use a single nutrient in foliar treatment, when its increase in leaf tissues overcome applied amount, especially in micronutrients. Results show covered and, usually underestimated, effect of foliar nutrition which denotes its simulative effect on plants growth, visible not only in leaf metabolism, but also in the metabolism of the whole plant. This is typical when a foliar treatment has been applied on plants in early growing stages, when applied amounts of nutrients are negligible, but they have a positive visual effect. This is another significant advantage of foliar nutrition use in practice, dispute its importance during nutrient's inactivation in soil.

Nowadays, in foliar nutrition new technological approaches includes nanotechnology, as it is believed a promising fertilization technology which can boost soil and foliar nutrition practice. Regarding nanotechnology, it is a multidisciplinary science and technology, which involves the manufacturing, processing and application of nanometre scale assemblies of atoms and molecules. It deals with materials which are classified as materials with at least one dimension less than 100 nm (Sekhon, 2014). The most important application of nanotechnology in agricultural production is in field of nano-fertilizers. This concept includes nutrient carriers of nano-dimensions, capable of binding nutrient ions due to their high surface area and steady and slowly release what correspond with crop demand (Subramanian et al., 2015). In nanofertilizers, nutrients can be encapsulated by nanomaterials, coated with a thin protective film, or delivered as emulsions or nanoparticles. The smaller size, the higher specific surface area and the reactivity of nanofertilizers may affect nutrient solubility, diffusion and hence availability to plants (Singh et al., 2016). Nanofertilizer technology is very innovative and primary is applied in field crop culture production, hence only a few reported literature data is available concerning fruit trees. In this context, Davarpanah et al. (2016) indicated that the foliar application of nano-Zn and nano-B fertilizers in pomegranate increased the leaf concentrations of both microelements, reflecting the improvements in tree nutrient status. Thus, more detailed and comprehensive work is needed in this promising area of research.

PRACTICAL ASPECTS:

Apple foliar nutrition comprised the application of macronutrients: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and micronutrients: zinc (Z), boron (B) and manganese (Mn). The most common macronutrients applied as foliar fertilizers are:

- **N** (as urea, ammonium nitrate and ammonium sulphate),
- **P** [as H_3PO_4, KH_2PO_4, $NH_4H_2PO_4$, $Ca(H_2PO_4)_2$ and phosphates],
- **K** (as K_2SO_4, KCl, KNO_3, K_2CO_3, KH_2PO_4),
- **Mg** (as $MgSO_4$, $MgCl_2$, $Mg(NO_3)]_2$,
- **Ca** (as $CaCl_2$, Ca-propionate, Ca-acetate).

Also, to the most commonly foliar-applied micronutrients belong to:

- **B** [as boric acid ($B(OH)_3$], borax ($Na_2B_4O_7$), Na-octoborate ($Na_2B_8O_{13}$), B-polyols,
- **Fe** [as $FeSO_4$, Fe(III)-chelates, Fe-complexes],
- **Mn** [as $MnSO_4$, Mn(II)-chelates],
- **Zn** [as $ZnSO_4$, Zn(II)-chelates, ZnO, Zn-organic complexes]

Source: Fernández et al., 2013.

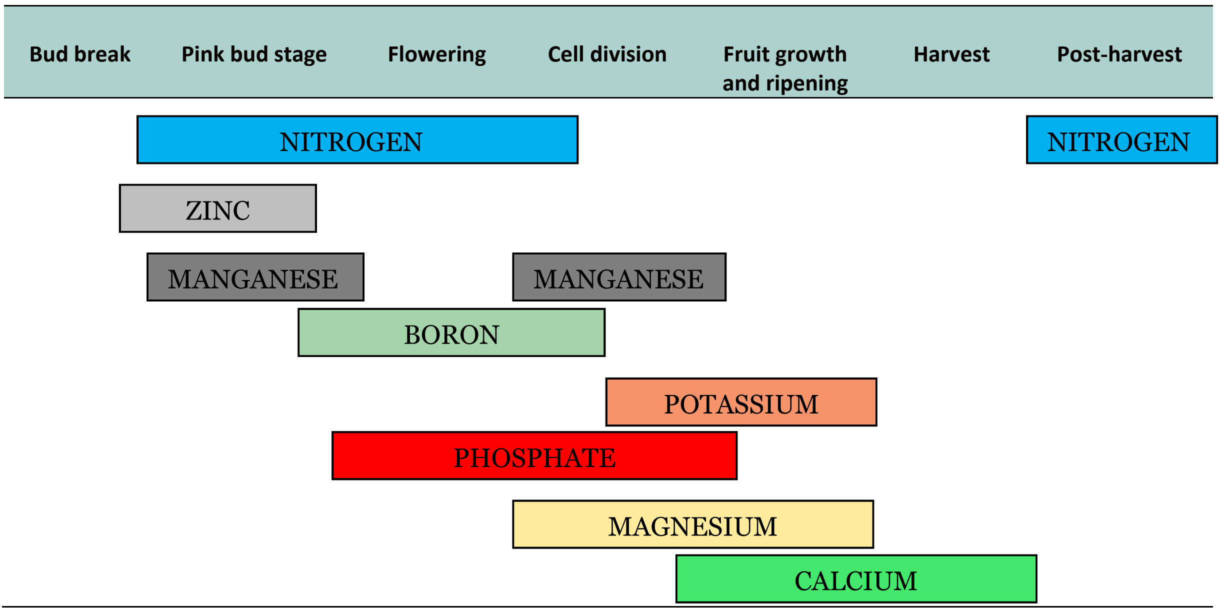
Foliar nutrients could be applied as *simple salts* or combined as *complex of salts*, but mostly they are applied as branded name of agrochemicals. Usually, the use of these agrochemicals is based on the recommendations of manufacturing companies, but independently, each farmer can prepare salt's solution and treat his plants in orchard. This means:

- Foliar solution should not be over-concentrated, otherwise it will cause burns at leaves. The range of concentration of applied salts or nutrient mixtures should be between 0,1% and 0,5% (as maximum);
- Foliar spraying (in Norway) should be done if daily temperatures don't exceed 22^{o}C or are being higher during the first hours after treatment;
- The dynamic of vegetation in Norway has been postponed for about 1-1.5 months if compared to the Central European countries. This is of importance in proper timing of foliar fertilization, because some application of nutrients should be adjusted to the certain growing phase;

The last notice derives from the previous discussion, where needs for foliar nutrients in apple production mainly exist for stimulating a certain metabolic process or for improvement of a certain yield quality (e.g. fruit coloration, fruit firmness etc.). These processes occur in defined period and this should not be missed, otherwise foliar nutrition is useless (Figure 2).

Despite the best option of foliar application of all proposed nutrients, apple growers can choose just one or two as mandatory requirement (Table 2). This is happening in the Tyrol apple growing region (Italy), where many growers have used only manganese and calcium sprays ($MnSO_4$, $CaCl_2$) for years. Additionally, soil foliar fertilization in apple production does not have to agree with soil fertilization. As discussed, comparing growing periods of apple in Norway with ones in Europe, significant delay exists, and this should be included in foliar nutrition planning. This means that post-harvest application of nitrogen in Norway is also remarkably postponed, where highly concentrated spray of urea (use 5% or total application of 10-15 kg/ha urea) should be applied few times, especially in years with heavy cropping. Such applied urea has a multiple purpose in fruit trees. First, it boosts the level of nitrogen in apple shoots by its migration from ageing leaves, and, as a result, this increase of nitrogen in shoots will support the growth of flower buds the next spring. Simultaneously, a large amount of applied urea accelerates leaf aging and induces a faster leaf fall due to the osmotic effect (Wojcik, 2006). This is of a great importance especially if fruits are grown in cool regions such as in Norway.

Table 3. Time of application of the different elements by foliar fertilization



Source: Wiedmer, 2019.

This is an excellent proposal for foliar nutrients application according to growing stage of apple trees. This could be done by using simple or complex salts or branded "foliar fertilizers" as commercial products.

Nowadays, the use of agrochemicals as "foliar fertilizers" in apple nutrition is dominant. Fertilizer companies offer numerous types of foliar products, varying in its chemical composition and efficiency. As was said, manufactures are proposing also a fertilizing plan which includes the use of their own products. Most of them have been tested in practice and valorised as positive and simulative in apple production. So, generally such recommendation should be fully accepted, having no significant professional remarks.

One of the leading worlds' fertilizer producers "Yara", as a domestic Norwegian company, also has their own products, offering a foliar fertilization plan. The proposed scheme is as follows:

Table 4. "Yara" - Apple crop nutrition-foliar program

Bud burst	*Pink bud*	*Start of flowering*	*Full flower*	*Petal fall*	*Fruit set*	*Fruit develop-ment*	*Harvest*	*Post harvest*
Zinctrac *700* 1 l/ha	*Bortrac* ***150*** **1 l/ha**	*Bortrac* ***150*** **1 l/ha**		*Seniphos* **10 l/ha 4 application**		*Seniphos* **10 l/ha 1-2 application**		*Zinctrac* ***700*** **1 l/ha**
Bud Bilder 5-10 l/ha				*Mantrac Pro* **1 l/ha**	*Bud Bilder* **5-10 l/ha**	*Stopit* **10-15 l/ha 10-14 intervals**		*Bud Bilder* **5-10 l/ha**
Ferleaf *100* 1 l/ha				*Ferleaf* ***100*** **1 l/ha**	*Magflo* ***300*** **4 l/ha**			*Bortrac* ***150*** **1 l/ha**

Source: "Yara" knowledge growth

As an explanation of Table 4, it's needed to be said that *Zintac* 700, *Bortrac* 150, *Seniphos, Bud Bilder, Mantrac Pro, Stopit, Ferleaf* and *Magflo* are commercial "Yara Vita" foliar fertilizers which contain 700 g Zn/l, 150 g B/l, (N 39 g/l, P_2O_5 310 g/l, Ca 40 g/l), (N 69 g/l, P_2O_5 50 g/l, MgO 240 g/l, B 30 g/l, Zn 100 g/l), Mn 500 g/l, $CaCO_3$ 224 g/l, Fe 100 g/l and MgO 500 g/l, respectively. According to the historical development of this company with its current position/reputation it possesses, it could be expected that all given recommendations are knowledge-based and previously tested. Consequently, it can be assumed that "Yara" company in Norway has a great impact on apple (and all others agricultural) producers as local fertilizer manufacturer and as an expert adviser. However, these recommendations have a relatively high costs, . In addition, the manipulative costs of soil/foliar fertilization are high, asmen engagement and machinery work is huge. This remark refers also to the other manufactures' recommendations and company products.

Similarly, to "Yara", the foliar products of other companies have been positively approved in apple growing practice. "Valagro" (Italian fertilizer company), is as another example of a company which proposed another useful/tested foliar treatments. Their foliar solutions could be performed in following phases:

- *Nitroammophoska* twice: at growing fruit and beginning of ripening
- *Boroplus* twice: at stages of beginning of flowering and growing fruit
- *Plantafol* four times: at stages of pink bud, beginning of flowering, growing fruits and beginning of ripening
- *Speedfol* four times: at green tip, full bloom, pink bud and beginning of flowering
- *Megafol* twice: at stages of before budding and growing fruits

The listed commercially named fertilizers of this company [*Nitroammophoska* ($NH_4H_2PO_4$ 20.0%, NH_4NO_3 20.0%, KCL 20.0%), *Boroplus* (boron 11.0%), *Plantafo*l [(total nitrogen 20.0% (nitrate–4, ammonia–2, urea-14), phosphoric acid 20.0%, soluble potassium 20.0%, B-0.02%, Fe* 0.01%, Mn*–0.05%, Cu*–0.005 (*– chelates in the form of EDTA)], *Speedfol* (amino acid 33.5%, MgO 2.7%, CaO 6.7%) and *Megafol* (amino acid 28.0%, total nitrogen 3.0%, amide 2.0%, organic C 9.0%, soluble potassium (K_2O) 8.0%)] has been applied as proposed, and obtained the results from testing showing the great improvement of apple yield and fruit quality in many aspects (Zargar et al., 2019).

A huge number of other additional experimental and practical results could be presented regarding the positive effects of foliar nutrition on apple growth or yield quality. However, this nutritional measure is not essential in every world's orchard. In Norway, as a non-leading country in apple production, it is starting to have attention similar to the other growing countries (Vangdal, 2017). Therefore, majority of professional recommendation today gives the need of Ca and Mg, but also, B, Zn, Mn in apple foliar nutrition. According to the Norwegian current practice, this recommendation includes next elements in foliar spraying.

Table 5. Apple foliar fertilization program proposed by fruit consultants in Norway

Period	Foliar application	Salts and products/ha
All applications except calcium	Monoammoniumfosfat	*MAP 3-5 kg*
Before blooming	Urea B foliar fertilizer Mangan Zink	*3-5 kg* *Solubor/Bortrac/Lebosal bor 1Kg/l* Lebosal Mangan 500/Mantrac 0.5-1 l Lebosal Zinc 700/Zintrac 0,5-1.0 l
Flowering– beginning of June	Mn^{+2} foliar fertilizer Mg^{+2} foliar fertilizer	250 ml *Mantrac* $MgSO_4$ 2-3 sprays after flowering Bittersalt 7 kg or Magtrac 3 l
Mid-June – early August (leaf diagnostic mid of August)	Ca^{+2} foliar fertilizer Mangan Zink Mg^{+2} foliar fertilizer	4-7 kg $CaCl_2$, (total 4-6 times) Lobosol Mangan, Mantrac 0.5 l *Zintrac* , Lebosol Zink 0,5 l Bittersalt 7 kg or Magtrac 3 l
Late August/before harvesting	Ca^{+2} foliar fertilizer K^{+} foliar fertilizer	2 sprays of *MKP mono- potassiumphosphate* (mono potassium phosphate) 2-3 weeks before harvesting to improve color and firmness. 5 kg
After harvest	Urea B foliar fertilizer Mg^{+2} foliar fertilizer Zink	1.5- 3% - for a few times *Solubor/Bortrac/Lebosal bor 1Kg/l* Magtrac 10 kg *Zintrac* , Lebosol Zink 0,5-1 l

Source: Norsk Landbruksrådgiving. Plantevernplan 2020 Frukt og bær

The physiological standpoint of foliar use of these elements in apple nutrition has been previously explained

7 Apple orchard location, soil physical and chemical properties

7.1 Climatic conditions

The cultivated apple has been grown in different world regions, framed by different climatic and other ecological conditions. This led to growth in different parts of the world, which results inuniqueness and specificity of ecological characterization of their growing regions. It is important to say, however, that apple is classified as a temperate fruit tree, meaning that this deciduous culture requires an extended cold period for bud development, buds break and flowering, and, moderate climate for fruit development and fruit ripening. It is desirable that evening and daily temperatures have a wide range, leading to better fruit quality. Apple growth is now distributed between northern and southern latitudes 30°- 50° at locations with satisfactory pomological growing conditions. This includes many different factors which are geographically conditioned, when orchards sometimes are elevated on height to avoid heat. Effect of elevation is present regardless of latitude and therefore plays a vital role when latitude is decreased. Also, adapting to the local climate condition means the use the north hill/slope sites to avoid spring frosts which usually restrict apple production in some areas.

Apple production in Norway is in the most suitable climatic regions, along fjord's side in western Norway and around lakes in Eastern Norway at 60° North. Due to the Gulf Stream, winter and blossom frost rarely occurs. Therefore, apples in Norway are grown in Southern, Eastern and Western Norway, in distinct regions with acceptable growing conditions. These regions include the counties of Vestfold & Telemark, Viken, Rogaland and Vestland.

The land used for apple production vary over the past period, having a fluctuation from 1,429 ha in 2010 to 1,455 ha in 2018, being the lowest in 2016 when 1,351 ha apple orchards have been cultivated. In last year's, the climate changes have led to higher summer temperatures and longer growing season (Tveito, Redalen and Engen-Skaugen, 2007), probably what would lead to the expansion of domestic apple production in future.

Locations of apple orchards in Norway perfectly illustrate the influence of natural factors on orchard location. Namely, Norway's apple regions are under considerable influence of nearness to large water surfaces (sea, lakes), because of its moderating effects on climate factors; reducution of spring frosts damages, increase temperatures during the extremely cold winter and as a consequence preventing winter injuries, increased precipitation during the vegetation and the influence on extreme temperature variations. Close planted land area is also influenced by large water basins, and usually it has been affected by water effect on soil formation during the formation of the soil.

The potential to be grown on different sites all over the world brings a wide diversity in orchards locations, consequently, the use of different soil types. It could be assumed that different soil types are formed on different geological substrate ("parent soil material" or "mother stone"), what could bring totally opposite soil properties. I appears that apples could be successfully grown on very young, not fully developed soils, which contains a huge mass of skeleton material, or, on the poor sandy soils, as very often in apple production. However, apples are grown mostly on developed soils which contain an organic matter and clay (secondary) minerals, but not infrequently, orchards are set up on the mixture of all soil types present at given location. As a result, all this different soil factors impose a unique approach or give some specific limitation in the techniques of apple growing. However, it should be kept in mind that the most critical factor in selecting an orchard site is temperature, while the other environmental factors, which include land use, are mostly adaptable and changeable. Means, during soil preparation, some soil properties may undergo significant changes, especially related to the nutrient content and physical properties. The initial soil preparation and current soil cultivation is a common practice for planting and growing orchards, what generally contribute to the spreading and production of this fruit species worldwide. Concerning soil, essential key factors is a fact that the apple trees should be supplied with enough water and enough nutrients, while this process happens in the root zone supplied with enough air. All other factors, like soil type, its mechanical properties, content of present nutrients and others, should be define as factors of secondary importance, which can be, or should be, corrected. However, such improper soil properties should not be neglected, but using certain melioration measures it should be corrected.

7.2 Soil depth of apple orchard soils

All apple orchards plantings are generally conditioned by the depth of the soil. This is of an importance to enable plants unrestricted root growth. The depth limitation growth is usually related to the vicinity of parent material, but a possible barrier to the root depth includes a seasonal or temporary water placement. Mostly common apple rootstocks penetrate the surface 0,8 m depth and this soil layer contains most of the formed root biomass. The 20-60 cm layer is the central zone for nutrient saturation and nutrient adsorption if we are talking about dwarf rootstocks. It could be expected that seedlings (tree developed from apples' seed) has much deeper root growth, but dealing with current growing practice, nowadays it is rare. All root branching and areal root spreading greatly depend on nutrient and especially water sources. Thus, if the dry period in fruit tree growth exists, it is appeared a deeper root growth, when penetration can reach 1-2 m, but occasionally, root growth of the certain apple trees exceeds few meters. In practice, it is also well-known that restriction in rooting volume reduce not only the root vigour, but also tree growth and fruit size, dispute a nutrient supply by fertilizer application and regular water supply. The intensive and deep root growth can be particularly important in coarse textured soils, which often have limited nutrient and water holding capacities.

7.3 Water content in apple orchard soils

Beside unsuitable climatic factors, it should be said that the extreme content of water in soil profile is one of the main limitations for apple growth. Nowadays, this occasionally happen as a result of wrong orchard projecting, but if so, this extreme negative soil condition must be corrected by amelioration measures. In addition, this limitation follows plant growth permanently during the whole season. The consequence of this is so called *asphyxia* (luck of oxygen) or *anaerobiosis,* which could be very harmful and negatively affects apple yield. Generally, the excess of water endangered the whole plant growth and apple organ's development. This overflow of water in the root zone can last for short periods with no harmful effects (7-10 days during winter, and 5-7 days when the vegetation starts) and this is generally related to the soil type and its physical properties. In such situation, metabolisms into the apple plants are disturbed. Due to the lack of oxygen, a few problems in plant tissues appear. This is a luck of terminal oxygen acceptor during the cell's respiration, then, disturbance in plant hormones syntheses (cytokines and gibberellins), and finally a syntheses of alcohol ethanol during the respiration process, which has extremely destructive and negative effect on plant tissues (Perata and Alpi, 1991). To recapitulate, the air supply of apple root zone must be permanent, with no interruption during the fruit's vegetation.

A bad drained soil can make some other outer preconditions which also could induce a negative impuls to apple metabolism. This can be exposed as an extreme sensitivity of apple trees to winter's low temeperatures, causing a splitting bark of the trunk. However, this is happening during moderately cold winter temperature, but not at the extreme one. Such a soaked tissues, caused by the excess of moisture and flodding, can lowered this important sensitivity threshold, what is mostly happening in young orchards. Well drained soils results in good aeration of soil profile, otherwise a poor aeration increased incidence of crown rot in apple trees (*Phytophthora cactorum*), what can be a serious treath to apple orchards and a possible clearing of the whole planted areas. Sometimes, the excess of water in the root zone can be induced by extreem iriggation, especially when controlled equipement (lysimeters) were not present during the watering, or, in the case of the compaction of clay fraction in deeper layer (20-40 cm), which practicaly make a barrier to water penetration and keep it mass in the root-zone profile.

7.4 Soil texture in apple orchards' soils

Sometimes soil texture, which refers to the participation of different soil mineral particles, is concerned as a one of the most importation soil factors, primarily due to the possibility of relatively easy change a nutrient and water status of the soil. Soil texture include clay (< 0,002 mm), silt (0,002-0,05 mm), sand (0,05-2 mm) and gravel (2-80 mm) fractions, where the predominance of some of them finally affects its physical and chemical properties. Mainly, soil's properties range from fine to course, and certain particle predomination of texture can be easy classified upon the soil texture USDA triangle classification (Fig.1). It could be said that apple trees prefer clay textured soils (clay loam, silty clay loams or sandy clay loams), but in practice very often orchards' can be found on soils with excess of clay, which impose special attention to proper and adequate irrigation, or, to the soils where the nutrients as ions and water as dipoles are not able to be kept and retain for plants. As a consequence,the estimation a soil texture, it should be assumed the influence of some soil properties on apple production. This includes water storage potential capacity, water transmission, aeration and nutrient exchange capacity. Into most of the orchards soils these individual soil texture particles are aggregated into larger units, creating a pore (macro and micro-pore) space throughout the soil profile, which is filled with air. This aeration in the soil profile of orchards' soils is more than desirable. Practically, intensive and constant cultivation in orchards is a measure used to preserve or to maintain and create new positive soil physical conditions.

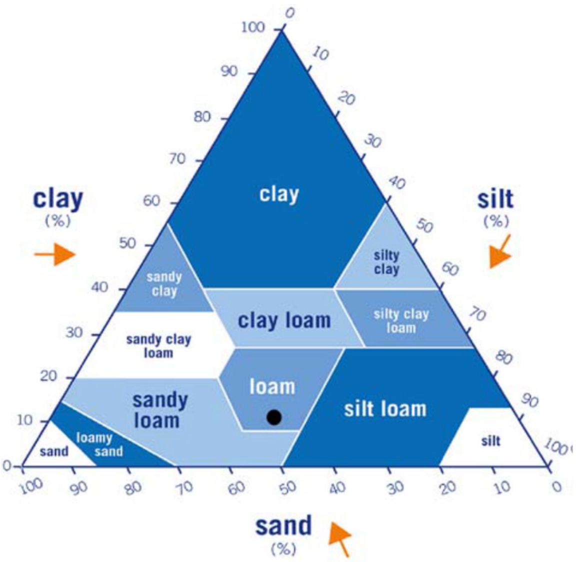


Figure 1. Soil's properties range from fine to course, and certain particle predomination of texture in the soil texture. USDA triangle classification

Each selected soil location for apple orchard demands a specific approach, and it could be said that basically every location on earth has a certain uniqueness which is not necessarily related to the variation in soil type. Soils as a growing media are closely linked to the local climate conditions and indirectly to the nutrient sources. Climate type is a main factor which runs the vegetation and the plant nutrient needs must be matched with the specific phenophase of plant's growth on the current location. Practically this means that dispute the soil type, the presence of some nutrients in excess can provoke a certain apple growing stage. This is happening with excess of phosphorus which causes an earlier flowering stage, as a result threatens the fruits with early spring frost. Also, the excess of potassium will promote earlier ripening of fruits, which stayed smaller, but with the earlier maturation phase which has a much smaller commercial value. This implies that the use of fertilizer should be additionally supervised and adapted to the local weather conditions. This is also another important factor which could distinguish plant's current needs and local soil-climate conditions. Besides the presence of storage nutrients, which additionally hardening evaluation process of fertilizer use in apple production, each location generally should be concern as a separate and independent, with specific nutrient demands.

7.5 Chemical properties of apple orchard soil

Soils can expose a great uniformity in morphological and physical characteristics, including colour, structure and drainage capability, but their chemical characteristic can make their properties extremely opposite. Such different soil's chemical characteristic are mostly the consequence of soil pedogenesis, therefore the knowledge about its properties are of a great importance, especially if soil is under exploitation. The major chemical properties affecting soils are: soil pH, salinity, cation exchange capacity (CEC), organic matter, and the C:N ratio (Carbon to Nitrogen).

7.6 pH of apple orchard soils

Between all chemical properties the soil pH has been attributed the biggest attention. This is not only in apple production, but in all other plant productions. VOften, soil pH is claimed as a main parameter of soil fertility. Basically, it is not the truth, but soil pH is one of the most indicative measurements of the general chemical status of soil. However, the soil pH should not be used for single or isolated soil fertility assessment. The fact is that pH value ranges from acidity to alkalinity (neutral = 7.0, acidic < 7.0, and alkaline is > 7.0), and affects the plants' growth. It could be generally stimulating for plant growth if pH range close to the neutral reaction, or, it can be very harmful if we are considering extremely low (pH 3,5-4,5) or extremely high (pH > 8,2) pH value. Determination of soil pH is usually done by measurement in mixture of water and soil, and obtained values concern *active acidity* (H^+ ions in soil solution), while measuring the pH in nKCl or $nCaCl_2$, where the adsorbed ions are replaced by K^+ or Ca^{2+}, where obtained values concern as a *potential acidity*. The last measurement gives lower acidity, indicating the adsorption ability of tested soil. Based on this fact, it could be seen that the difference between these two measurements at clay soils are more expressed compare to these two pH measurements on sandy soils. The following classification of pH (mixture of water and soil) can be used related to plant growth:

pH< 4,0 a strong acidity caused by the presence of excess H^+ and toxic Al^{+3}

pH< 5,5 a plant toxicity could be induced by the presence of exchangeable Al^{+3}

pH 5,5 to 6,5 slightly acid soil with no repercussion of plant growth

pH 6,5 to 7,5 optimal for the most cultures

pH 7,2 to 8,2 alkaline soils with predominance of calcium carbonate

pH > 8,2 alkaline soils with presence of excess of Na^+

Different plant species are with different responsibility to soil acidity, but according to the contemporary plant production, all types of plant production should be done on soils where pH is 5,5 at minimum. An optimal pH values for apple orchard soils supposed to be around 6,0 to 7,0, and this pH values should be accepted as a general extensive approach (Ferree and Warrington, 2003). However, great widespread of this culture over the globe, with apple orchards planted on existing local pH conditions, slightly modified the term "optimal" pH range to the "suitable" pH range. This is especially true for predominance of slight acid soils as the most frequently covered by apple orchards, although these soils could be easily turned into an "optimal" by lime application. Suitable pH is, however, related to the soil type and its chemical and physical properties, because most dangerous pH treats concerns possibilities for aluminium toxicity. Clay rich soils have higher aluminium content than sandy soils and higher pH is needed to avoid toxic effects of aluminium on the roots. So, Norwegian recommendations for pH in apple orchards is said to be 5,5-6,0 for sandy soils, 5,8-6,3 for silty soil and 6,0-6,5 for clay soil (Vangdal, 2017). Such soil pH evaluation for apple growth is mostly accepted, since apple is treated as plant which prefers a "slightly acidic soil". This is generally accepted and mainly presented in many fruit textbooks (Childers, 1954, König, 1976, Mišić, 1978, Atkinson et. al., 1980) and advised in extension service materials.

As a result, according to current agronomy practice, the low pH values (pH < 5,0) are not acceptable for plant production, with the tolerance to the demands of some plant species for low pH. Therefore, all acid soils should be subjected to pH neutralization. This soil pH neutralization is chemically a complex process, where the exchange reactions (desorption/adsorption) occurs between Ca^{+2} and H^+ ions of solid and liquid soil phase. This measure should be conducted in a manner that micronutrient availability is not minimized. Principally, this means that full neutralization is not necessary, because added lime to the acid soil in excess can block micronutrient availability for plants. This micro-deficiency (especially Mn deficiency) can have a serious harmful effect on yield formation for years, so soil pH melioration measure should be done very carefully. The goal in soil neutralization is to conduct so called "*controlled neutralization*" or "*moderate neutralization*", where only a portion of the soil acidity should be neutralized. This implies that total need of Ca^{+2} for pH-neutralization is divided in several portions and applied in year's interval - every three to five years.

In practice, the correction of soil pH is called liming. Lime materials are all chemical substances that increase the level of Ca and/or Mg in the soil and raise pH. Therefore, a large group of compounds that have an alkaline character does not belong to these materials (NaOH, $KHCO_3$, etc.). To this group of non-lime compounds belongs also a gypsum ($CaSO_4$), dispute it contains Ca in appreciable amounts. After hydrolysis in the soil, gypsum converts to a strong base [$Ca(OH)_2$] and a strong acid (H_2SO_4) which neutralize each other, resulting in a neutral soil effect.

After application, the liming reactions in soil begin with the neutralization of H^+ in soil solution by adding a base from lime material (usually OH^- or HCO_3^-). This well-known reaction where, for example, applied $CaCO_3$ behaves as follows:

$$CaCO_3 + 2H^+ = Ca^{+2} + CO_2 + H_2O$$

The fast reaction of $2H^+ + CO_3^- \rightarrow CO_2 + H_2O$ neutralizes H^+ soil solution. Exchangeable H^+ desorbs from CEC (Cation Exchange Capacity, see next Chapter) to buffer the decreasing H^+ solution. Two H^+ on the CEC are replaced by one Ca^{+2}. In this way, both soil pH and saturated bases (cations) increase. If sufficient $CaCO_3$ is available, H^+ will be converted to the H_2O. So, according to the weight relationship, as presented in equation, one mol of lime material neutralized two mol of H^+ because of that each lime material contain a Ca^{+2}. In practical farming the pH in soil solution will increase fast after liming and then after some time (days, weeks) reduced to the new pH level where a chemical equilibrium has established between soil solution and the surface of the soil particles. The long-term effect of liming is a rise in base saturation of the soil.

PRACTICAL ASPECTS:

a) Why to conduct the soil neutralization?

The question about the usefulness of liming in orchards with acid soil should never be asked. So, a simple answer for practice is that *liming should be absolutely carried out*, since this measure has no alternative. If this measure supports a soil conservation process, the goal of this ameliorative measure is not only to create an optimal pH conditions for apple growth. Therefore, desirable pH for optimal apple/plant growth is tightly associated with prevention of soil degradation caused by soil acidification. For that reason, this measure should be considered as a measure with the long-term effects. Practically, by adding lime and reaching desired pH of orchard soils, we retain good soil productivity, especially after years of exploitation. Therefore, the knowledge of the negative effects of low pH soil is very important, where proper soil pH management is aimed also to keep a soil's good structure and other properties of orchards' soil.

The use of lime in orchard soils has direct and indirect benefits which could be recognized in very short period (season or two). Direct benefits are related to making soil pH optimal conditions for plants growth, especially in elimination of Al^{+3} or Mn^{+2} toxicity treats. The pH may vary considerably both within and between orchards as figure 2 show as an example from Norwegians orchards. A population of present microorganisms with liming could be totally changed (*fungi→bacteria*), affecting completely different organic matter transformation pathways. Indirect benefits concern the increase of nutrient availability, like enrichment of Ca content to the plants or keeping availability of phosphorous in soil solution by elimination of its reaction with Al^{+3} and Fe^{+2}. The far more important indirect benefit of liming is improving a soil physical condition. By liming it could be improved the structure of fine-textured soils, because of increased soil organic matter contentment and enhanced flocculation of Ca-saturated clays. Therefore, the liming keeps good soil properties. Also, despite that liming is ameliorative measure, it is relatively cheap regarding the benefits it's provided.

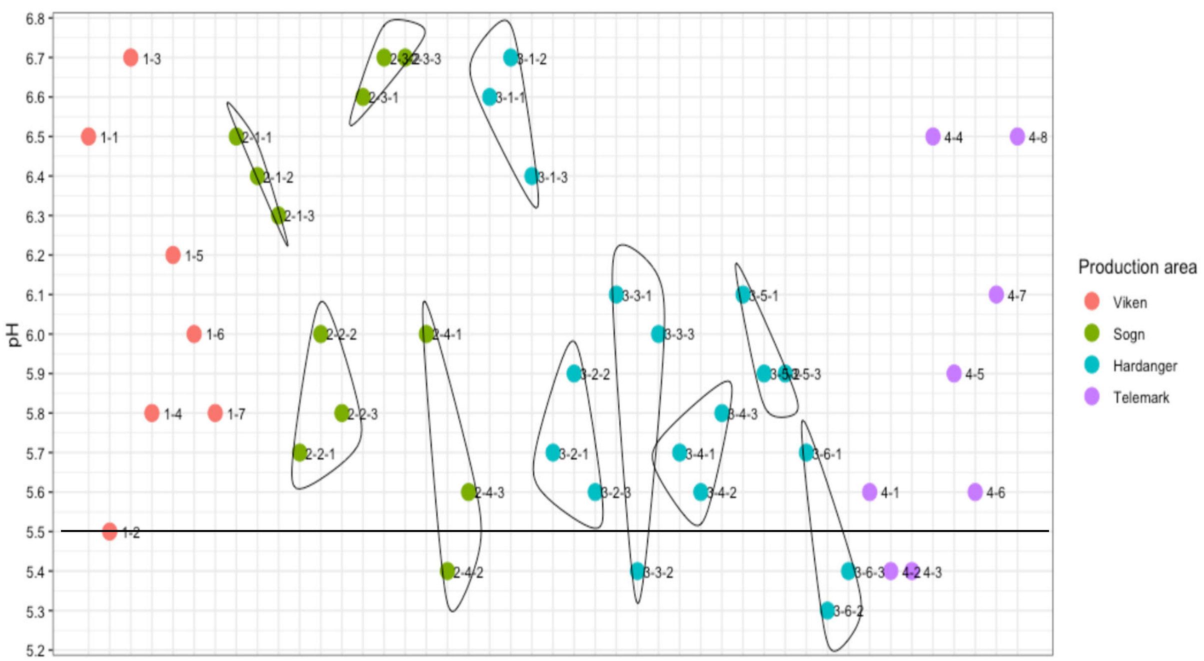


Figure 2. **Measured pH in different apple production areas in Norway. Encircled samples are soils from the same orchard. The values under pH 5.5 should be neutralized. Data after Paulsen (2019).**

b) In orchard soils exists a permanent acidification

It should be said that like other soils, orchard soils are subjected to a permanent acidification. Rainfall generally contributes to a soil's acidity, so soils formed under conditions of high annual rainfall are more acidic than are soils formed under more arid conditions. During the precipitation, basic elements such as calcium, magnesium, sodium and potassium held by soil colloids are replaced by hydrogen ions. Rainwater (H_2O) combines with carbon dioxide (CO_2) is forming a weak acid – carbonic acid (H_2CO_3), which ionizes, releasing hydrogen (H^+) and bicarbonate (HCO_3^-). Released hydrogen ions replace the calcium ions held by soil colloids, causing the soil to be more acidic. The displaced calcium (Ca^{+2}) ions combine with the bicarbonate ions forms calcium bicarbonate, which, being soluble, is leached from the soil. The net effect is constant increase of soil acidity.

Also, a soil acidification process is constantly happening during the nitrogen fertilization. In practice this means if greater is a nitrogen fertilization rate, the greater is a soil acidification. In this soil process, ammonium is converted to nitrate in the soil (nitrification), and H^+ ions are released. Now is well known that the amount of applied nitrogen in apple production is huge, and unless the plant directly absorbs the ammonium ions, it is mostly subjected to the nitrification process which promotes acidification. Beside fertilizers, this process is implied to all other nitrogen sources, like manures, legumes, organic debris and all other soil organic materials which undergo ammonification and nitrification process. Also, the nitrate provided by fertilizers or formed in soil can react with basic cations like calcium, magnesium and potassium and leach from the topsoil into the subsoil. As these bases are removed and replaced by H ions, soils become more acidic. Similar process of acidification has been happened by using sulphur originated from fertilizers or organic materials.

Even growing orchard plants also contribute to the permanent acidification, especially when Ca fertilizers are not applied to the soil. Fruits in nutrition take up more cations in proportion to anions. This causes H^+ ions to be released from plant roots to maintain the electrochemical balance within their tissues. As a result, this contributes to a net soil acidification. Also, subsoil acidity should not be neglected, meaning that the subsoil may be extremely acidic due to the acid character of soil parent material.

a) What kind of lime material to use?

The efficiency of each lime material could be evaluated by its comparison with pure calcium carbonate, because all these materials have a different neutralizing value. Calcium carbonate equivalent (CCE) represents the neutralizing value (NV) of the material compared to pure $CaCO_3$ (CCE=100%). The NV of used agricultural lime usually ranges between 86 (less effective than $CaCO_3$) to 135 (much more effective than $CaCO_3$). The application rates may need to be corrected of adjusted up or down depending on the type of lime material.

Between all liming materials, a pure $CaCO_3$ (mineral calcite) is the most common natural material and mostly common used lime in agriculture. It is available as ground limestone, or agricultural lime. It is the cheapest but least reactive form of lime. Calcite contains about 99% of $CaCO_3$, and generally has less than 1 to 6 percent magnesium. Its neutralizing value depends on its purity and fineness of grinding. In Norway shell sand is a quite commonly used as liming material for areas close to the cost. It is mostly $CaCO_3$, it is cheap and easily available but because of the course structure the liming effect is slow. If shell sand is used it must be washed free of salt to avoid negative effects on the growth.

Table 6. Properties of lime material

Lime material	Molecular Wt.	Equivalent Wt.	CCE	Ca Content
	g/mole	g/mole	g/mole	%
$CaCO_3$	100	50	100	40
$Ca(OH)_2$	74	36	135	54
CaO	56	28	179	71
$CaMg(CO_3)_2$	184	46	109	22 (13% Mg)
$CaSiCO_3$	116	58	86	46

In liming, calcium-magnesium carbonate (mineral dolomite) is also very often used (109 CCE), because of its favour Mg content. At this way, rinsed Mg during the acidification process is compensated and exposed to the plant nutrition. In this sense, this material is recommendable, especially if we are dealing with acid soil for apple production.

A CaO and $Ca(OH)_2$ in liming has a rare use. They are more reactive than calcium carbonate, but rather expensive for agricultural use. These lime materials present a quick-acting material. In practice, both materials are somewhat problematic to handle, but their CCE, especially $Ca(OH)_2$, are much higher than $CaCO_3$ (CCE 135%).

In practice, numerous Ca materials are used for liming. They derive directly from nature or been product of diverse sources, mostly being industrial by-products. This gives dissimilar results in liming, but this material should not be neglected especially if they contain organic matter. In other words, the best result in liming is achieved by the parallel use of lime material and organic matter (manure, etc.). However, there is one general demand for all kind of these materials that they should not bring potential polluters to the soil, like heavy metals.

b) What form of liming material should be used?

The effectiveness of agricultural limestone depends on the particle size distribution or *fineness*, because the reaction rate depends on the surface area in contact with the soil. Each material should be powdered into the smallest particle size, and, therefore, consequently the limestone material needed to be crushed. When crushed lime material is thoroughly incorporated into the soil, the reactions will increase with increasing fineness. It means that even if the CCE of lime is satisfactory, it will not neutralize soil acidity unless the limestone is finely ground. It is clear, however, that practice does not give a possibility to measure a particle size of lime, but general intention is to find material powered as much as possible.

c) How much lime to use?

Because of induced micro-deficiency in plants which could be the result of the use of excess of lime in soil neutralization process and which provoke a serious harmful effect on subsequent yield formation, this important soil pH melioration measure should be generally left to the soil specialists. After a needed soil analyses and number of chemical calculations in reaching the level of "*controlled neutralization*", they can propose an amount of lime which should be applied to the certain orchard. This is the best way to reach the sum of lime base (lime material) which should be applied. However, during the past years, when the liming benefits have been recognized, some other less scientific approaches got into the practice. Soil pH is greatly affected by its mechanical properties. Soils with different texture are very tolerant and flexible, and lime recommendation can affect a micro-nutrients availability.

Table 7. Suggested amount of lime (tonnes per ha)

Soil texture	Soil pH 4.0-4.5	Soil pH 4.6-5.0	Soil pH 5.0-5.5
Sands	4.0	2.5	1.5
Loams	5.5	3.25	2.0
Clay sand	9.5	6.25	3.5

Source: Thompson et al., 2011.

Table 7 presents the amounts of $CaCO_3$ which should be applied to acid soils with different acidity and physical properties. The recommended amounts should be applied in the ploughing depth as possible, what is much better than spreading lime material to the surface. Surface-applied lime reacts more slowly than lime that is mixed with the soil, and usually only affects pH in the upper 5-6 cm of soil. In contrary, deep ploughing of lime does not achieve desirable mixing in the upper 10 cm of soil.

The concept of lime application is to ensure relatively slow pH changes and to keep availability of micro-nutrient stable. This implies repeatability of this measure over the time. The most common "*controlled neutralization*" predicts lime application in a period of every *3 to 5 years,* what should be followed by pH control of treated soil.

Table 8. Amount of lime (crushed limestone, 45-50% limestone CaO) in tonnes per hectare needed to raise the pH of one unit (Sweden)

	Low humus <2%	Humus 2-6%	Humus rich
Sands	1	2-4	4-6
Loam	4	5-6	6-8
Medium clay	6	6-8	8-10
Extremely Clay	8	8	10-12

Source: Tahir, I. , 2014.

In Table 8, different concepts for liming has been proposed, and this includes a content of organic matter, practically, humus content. This is also "*controlled neutralization*", when relatively small amount of lime material has been proposed for use. The advantage of this method is that it comprises a humus content, which could participate in great amount in cool region.

A similar principal as the Swedish system has been used in Norwegian agriculture the last 40 years. Compare to the system in table 8, the system is more detailed on the effect of organic matter content in the soil. The buffer capacity is very dependent on the organic matter content and in Norwegian agriculture organic matter may vary from low to pure organic soil as peat soil. The amount of lime is given as CaO which makes it easier to use independent of type of lime material. The Norwegian liming recommendations are shown in table 6.

Table 9. The amount of CaO in kg per hectare to increase the pH in soil by 0.1 unit.

Soil type		% organic matter (OM)			
		0 - 3	**4 - 6**	**7 – 12**	**13 - 20**
Sand, silty sand	<5% clay	250	300	350	400
Silt	<5% clay	300	350	400	450
Sand, silty sand, silt	5 - 9% clay	350	400	450	500
Light clay	10 - 25% clay	400	450	500	600
Medium and heavy clay	>25% clay	400	500	550	650
Organic soil	21 - 40% OM	600			
Organic soil	41 - 75% OM	750			
Organic soil	>75% OM	900			

Source: Yara, 2018.

7.7 Cation exchange capacity in apple orchard soils

Cation exchange capacity (CEC) is defined as a degree to which a soil can absorb and exchange cations. It is affected by the negative charge at soil colloids. Upon the origin, its core could be inorganic and organic soil particles, and for this reason, CEC is highly dependent upon the soil texture and organic matter content. The function of such charged particles is to retain nutrient ions and water molecules in the soil profile, thus providing a nutrient reserve available to plant roots. Indirectly, this illustrates the importance of soil texture and organic matter content. The effective CEC vary with pH in soil because of the dissociation of organic acids are pH dependent. The potential CEC, however, is measured in a buffered solution normally at pH 7 and is independent of pH in the soil. Potential CEC is defined as the maximum CEC and if the pH is lower than 7 potential CEC is higher than effective CEC. The base saturation is calculated based on the potential CEC, i.e. the number of base cations in relation to the potential CEC. A base saturation of 60-70% is required for cultivated systems on acid soils.

In general, if the soil is with more clay or organic matter, the higher is CEC at a given pH. This implies the difference in sustaining an apple production on these two opposite substrates. Primarily, the critical is different supply of fruit trees with water and nutrients, where these two types of soils under the orchard should have different dynamic and applied quantities. The sandy soil has very small CEC, as a small capacity for retention of added water and nutrients, while the clay soil is with high CEC, which derives from very small charged particles (< 0,002 mm), thus the huge surface adsorbing area. This explains why the soil with such property possess ability to keep moisture for longer period, and it is the same for nutrients. In practice, it is obvious for fruit growers. So, the application of water and fertilizers should be adjusted to enable the production of apple on soils with different capability for holding water and ions. The plant roots also possess a cation exchange capacity, and this fact was mostly ignored. By excluding hydrogen ions from roots in outer solution, plants start to be an active component in ion exchange process which happens in the soil solution. Such “pumped” proton ions by membrane proteins, may replace nutrients adsorbed on the soil exchange complex. After that, nutrients (ions) are released into the soil solution and they can be taken by plants in contact with their adsorptive parts of root surfaces.

7.8 Soil organic matter in apple orchard soils

A simple definition of soil organic matter refers to a total content of organic substances in the soil. This includes a decomposed, chemically transformed, dissembled but not chemical transformed, or organic compounds which is chemically unchanged. It refers also to “fresh” organic residues or “living” soil organisms. So, the organic matter consists of soil biota (living organisms and roots), plant or animal fragments, and polysaccharides, proteins, amino acids, fats, lignin, waxes, resin, humus, and charcoal if the substances are chemically listed. Very often this important chemical soil component refers mostly to the humus, covering thus its humified or not fully humified fractions. However, humus is just a part of a soil total organic matter, concerning that a great part of organic compounds in soil undergo humification process.

Soil organic matter directly and indirectly provides nutrients to the trees, provides nutrients and energy for soil’s organisms (microorganisms and animals), improves structure and resilience of soil, supports soils’ buffering capacity for pH changes especially when chemicals (mineral fertilizer) are added, and directly or indirectly affects the supply of water and air to roots. Generally, it could be said that importance of this chemical substance in soil is unquestionable, having numerous positive effects on soil physical (improve a soil structures like porosity, looseness, absorptivity, etc.) and chemical properties (as a source of nutrients for plants and microorganisms), and the goal of each apple grower is to have an orchard with as much as possible organic matter. However, although organic matter is important in soil, apple growers usually don’t think much about it. They are much more occupied with managing their crops and trees, controlling pests and diseases, irrigating, managing labour, and doing other essential things. Another very present opinion, which most of the apple growers support, is that supplying organic matter to soil is too costly and practically very tough job, because organic fertilizer, especially in demanding quantities (tones/ha), are rare at the market. So, about soil organic matter, some things should be explained. Organic matter makes up only a small portion of the soil (maximum about five percent), but the impact of organic matter to the orchard soil are enormous and its application measure is with long-term assessment. If calculated, the soil prism of one ha (up to the 30 cm depth) weighted about 4.500.000 kg (100m x 100m x 0,3m x 1,5 g/cm^3), so usually the added amount of organic fertilizer (manure) is just a small quantity. So, when the farmer is trying to build up organic matter in the orchard by application f of a huge mass of 30.000 kg/ha of mineralized cattle manure (or 50.000 kg/ha before planting as melioration measure), in fact, he poorly contributes to its total content. This is only 0,7% of the soil mass, keeping in mind that all added mass of organic material will not be fully converted to the stabile humus. This converted amount of added organic fertilizer into the stabile and relatively resistant humus substances usually represents only a very small portion (1-3%). Meanwhile, the great majority of the world’s apple orchard soil are 1% and 2% humus (Childers, 1954), while the content of organic matter on sandy soils is negligible. The content of organic matter in soil is climatic related and it is normally higher in cold regions where the decomposition rate is low. In Norwegian orchards it is reported content of organic matter higher than 10% and normal content are in the range of 5-8% even on sandy soil (Paulsen, 2018). The next important question for apple growers is the nutrient efficiency of added organic fertilizer. The fact is that well mineralized (cattle manure - reduced to the 7% of d. m) manure has just a 0,5% N, 0,11% P and 0,4-0,5% K (Mangel and Kirkby, 1982), what is definitely not comparable with the content of this elements in mineral fertilizer (NPK, urea-46% N, ammonium nitrate-33% N, TPS-42-46%, etc.) if compared on weight basis. These numbers are comparable to newer Norwegian investigation on cattle manure used as fertilizer in agriculture. Measurements on cattle manure (7% of dry matter) in orchard districts has as an average of 0,4% N (50-60% in form of ammonium N), 0,06% P and 0,39% K (Daugstad et al., 2012). Organic fertilizers are used to improve soil physical properties (strong compaction, extreme porosity, soil stability, aggregate formation etc.), but in addition it can be an important source of nutrient supplier. If using 30.000 kg/ha of Norwegian cattle manure 120 kg N/ha, 18 kg P/ha and 117 kg K/ha is added.

However, besides not being supplied by manure, the origin of the soil’s organic matter in orchards is mainly associated to the plants root and soil living organisms. The amount of soil organic matter mostly depends on the amount and quality of the organic residues returned to soil. The great influence on this content makes soil texture, depth, soil density, soil pH, temperature, water content, aeration of soil, and consequently a microbial population. Organic matter is predominantly present in the surface layers, whereas the root and soil organisms has a constant activity. These two living factors enrich a root zone with *exudates* (organic excrements of roots and microorganisms), in a way that they continually feed other microorganisms. These vivid fractions of soil organic matter participate about the 5% of total soil organic content, where in addition to microorganisms in orchard's soils a "large" animal are included (e.g. earthworms). Inside the microbial or any alive tissues, present nutrients are not available to plants (this is called *immobilization*), but their availability has a high dynamic character. Namely, these structural nutrients belong to the most labile soil organic fraction, which plays very important role in nutrient cycling. Also, it should be known that nutrient amount in microbial tissues can be significant, so it could be found that under the conventional tillage system in orchard, nitrogen yearly can range between 58,4 and 67,5 kg/ha, while phosphorous between 22,0 and 37,3 kg/ha (Balota and Auler, 2011) in microbial tissues. Particularly of essential importance is that nutrients from the microbe cells are easy released, as much as five times faster than from decomposing soil plant cover residues (Paul and Clark, 1996). As a result, about 95 % of the soil organic matter is non-living and relatively stable and this material need decades for decomposition (Powlson et al., 1987; Sparling, 1997).

Other plant residues with much bigger biomass, such as leaves, and pruned shoots, plus organic mulch or manures added by the farmer, usually is a main support of the content of organic matter in orchards soil. The residues with low ratio carbon to nitrogen (less than 18:1), are decomposed quickly, having enough nitrogen to stimulate microbial activity, otherwise, organic residues with a high carbon to nitrogen ratio of more than 60:1 are decomposed very slowly. Simple sugars, simple proteins, and starch are easily decomposed, whereas hemicellulose, cellulose, fats, waxes, and resins are slowly decomposed. The delayed decay of lignin is even more exposed, but a stabile charcoal, which between all plant's origin residues, is considered as the most inert and the most resistant.

The intensity of mineralization is affected by soil character. Warmer soils, well drained and with better aeration, usually less dense, support more intensive organic matter mineralization, while deeper, compacted, particularly cold soils, also delayed this process. Consequently, in cooler climate soils often contain more organic matter than soils in drier and warmer climate. Similar is with wet soils, which make anaerobic condition which usually slow down a decomposing process and biological activity, so the percentage of organic matter stay high. Soil pH also affects the supply and decomposition of organic materials in soil.

Despite the all current problem in organic matter (manure) supply of apple orchards, its benefits should be summarized as chemical, biological and physical. Because of significant correlation between a percentage of organic matter in soil and soil fertility, a special attention has been paid today to soil organic matter in organic apple production. This way of apple production starts to be very trendy, and it needs exclusively organic fertilizers as a main source of nutrients for plants.

8 Introductions to the nutrient's availability in apple's orchard soil

Total amount of soil macro and micronutrients has a portion which is available for plants. Some general rule is that the total amounts of available nutrients are far beyond their quantities. Principally, a close correlation between a total amount of nutrients and their available fraction exist, but many soil factors affect this ratio. So, it could be expected that higher total content of certain element guarantees its certain available part for plants, but this portion is influenced by soil type, grown plant and environmental factors. This is well illustrated with iron content, which may possess a huge total content in soil's which range from 10.000-20.000 mg/kg, while its available fraction can reach just 1-25 mg/kg. Crucial is that even such a small amount of this micronutrient can satisfy plant's needs.

Nowadays a contemporary approach in plant production starts with soil analyses as the best tool for adjusting plant needs and fertilizer supply. Therefore, some scientific or, at least, professional modus operandi, must be included in the evaluation of obtained results. This is because that soil testing concerns routine soil analyses, where soils are subjected to the different chemical extractions in order to imitate or to simulate the forces which a root system possess in nutrients' (ion) adsorption. With the involvement of soil chemical analyses in practice, a calibration test is required, which deals with the crop's response to the proposed fertilizer recommendations. So, the selection of soil analyses (or their permanent application in soil testing), demands a certain knowledge about the soil properties, like a presence of organic matter, lime, alkalinity, acidity, etc. Otherwise, the obtain results cannot be adequately explained or can mislead. The interpretation of soil testing results is very complex and includes a broad knowledge about the soil, also, about the physiology of growing culture. So, soil testing cannot include all important factors which affect the process of nutrient adsorption, like a temporal and spatial dynamics of the soil nutrient supply or a plant's genetic specificity in nutrient demands. Because of nutrient availability dependence on various factors, the interpretation of soil tests deserves a considerable attention.

The most reliable data in soil testing is obtained from field plot fertilizer trials. However, this way of establishing nutritional status of soil (and evaluation of fertilizer needs) is highly time-consumptive work and includes a huge labour work. In the meantime, field trails are very expensive, giving the obtained results which should be applied only to one or other close location. At the same time, chemical soil analyses conducted in laboratories are adaptable for different soil conditions and they are cheap, fast and repeatable. Therefore, they are in a wide use. Soil chemical testing has been practiced in agriculture for years and been widely accepted in practice.

In soil testing different extraction procedure has been used. A wide range of extraction reagents exists, aimed to make a condition as similar as possible in rhizosphere zone during the nutrient adsorption. This implies the use of different types of weak extractants, like diluted acids, diluted salt solutions, different buffers, dilution of some complexing agents or just the use of water. Some modern concepts in nutrient extraction include even a synthetic permeable membrane which is made to imitate a root surface. This technique enables collection of nutrients from soil solution, and it could be said that this technique gives very reliable results. But, such estimation of plants nutrients' need is also time-consuming, expensive, and not so well-known, because the physiological foreknowledge is required.

All used extraction procedures are giving different results, particularly in estimation some poor mobile elements (P) or others with complex soil chemistry. As a rule, availability of anions is more complex question than cations in soil solution. Besides many good things they possess, soil chemical analysis are giving sometimes limited results, because they fail to provide information about soil structure, microbial activity or plant factor.

If nutrient possess a mobility in soil, it is a kind of guarantee that its availability is more exposed. This is closely related to so call "*mass follow*" which represents a water movement with dissolved nutrients through the soil profile. Mass flow represents horizontal, but also a vertical movement of soil solution. By this mass flow, trees are sufficiently supplied with some elements (like Ca and NO_3^-), whilst others (Mg) are also affected by this specific transport. Cations, like K, mainly supply plants via diffusion, and this, after their trees' adsorption, mostly led to their depletion zone from the root vicinity. The main supply of P as phosphate anions is also by diffusion. But contrary K the movement of P in mineral soil is very slow because of adsorption to Fe and Al components. As illustration, for phosphate it is reported a movement of only 0,13 mm/day while for nitrate and K the movement is about 3,0 and 0,9 mm/day in the same soil (Jungk, 1991). After depletion, however, diffusion contributes to a renewing a nutrients' reservoir with new quantities and water. This mobility of ions is defined as *diffusion coefficient*, while driving force for diffusion is a *concentration gradient*. In direct contact with soil solution, roots can simply intercept the water flow, and using some uptake mechanism, dissolved nutrients can be transferred through membrane into the tissues. The transpiration is main driving force which makes a constant supply of plants with water and indirectly with nutrients.

In orchard soils, these differences in concentration are mostly caused by the application of fertilizers. The added ions by fertilizers can make great imbalance between treated soil's zones and surround bulk soil. The existence of these two concentration zones builds up a great tension between different ion concentrations. So, diffusion is the main mechanism for the soil solution movement, where ions like a P and K as nutrients with low concentrations can reach the root surface. This process of balancing the water and soil solution ions is of a great importance for planted trees, especially when nutrient root's zone must be re-established.

Table 10. The classes of macro elements and Cu in Norwegian agriculture soil analyses

Class	1	2	3	4
Content	Low	Medium	High	Very high
P_{AL} **(mg/100g)**	0 – 4	5 – 7	8 – 14	>14
K_{AL} **(mg/100g)**	0 – 6	7 – 15	16 - 30	>30
K-HNO_3 **(mg/100g)**	< 30	30-79	80 - 119	>120
Mg_{AL} **(mg/100g)**	0 - 2	3 – 5	6 – 9	>10
Ca_{AL} **(mg/100g)**	<50	50 - 99	100 - 199	> 200
Cu_{EDTA} **(mg/kg)**	0 – 0.1	1.1 – 2.0	2.1 – 5.0	>5.0

Source: Krogstad, 1992.

All mentioned processes at soil-root interface are sometimes considerably more complex than explained, and a lot of internal (ion balance in tissues, electrical charge in root cells, tissues saturation, etc.), and external factors (water content, soil buffer capacity, organic matter and clay content, etc.) are involved in this mechanism of ion adsorption. In general, is worth to know about behaving of soil salutes, particularly if fertilization technique has been chosen according to the soil properties and type of fertilizers.

In order to collect as much as possible data about Norwegian orchard soils, results given in Table 9 and Table 10 present the classes used in soil analysis and the range of favourable macronutrients in fruit orchards (Kvåle, 1995; Vangdal, 2017).

Table 11. Optimal values of macronutrients content in soil analyses of Norwegian orchards

Nutrient	Units	Content
P_{AL}	mg/100g	8–12
K_{AL}	mg/100g	20–30
K-HNO_3	mg/100g	50–150
Mg_{AL}	mg/100g	10–20
Ca_{AL}	mg/100g	100–200

Source: Microelements: Kvåle, 1995., Vangdal, 2017.

Plant factor is another very important factor in proposing type of soil analyses and results anticipation. It could be expected that various type of cultures in agriculture production, differing extremely in habitus morphology and formed biomass, should have very different demands of soil analyses and fertilizer recommendation. However, the analyses of orchard soil seem to be much simpler, concerning that selection of the apple rootstock implies a quite unique demand for most of all used varieties. On the other hand, different soil factors, combined with a non-homogeneity of rootstocks physiology, make this question a bit more complex. So, apple-rootstock selectivity in nutrient adsorption and its different adsorbing potential has been in focus of the numerous investigations during the last decades. Based on them, a lot of things have been determined, like a rootstock sensitivity to Ca supply which directly promoted the resistance of fruits in storage systems and generally to fruit quality (Vang-Petersen, 1980., Bennewitz et al. 2011., Reig et al.2018). For that reasons, adequate apple nutrition is more than simple problem.

9 Nutrient management of apple orchards

A nutrient management programs for apple trees should be considered as nutrient supply throughout the season. Early season growth of root and canopy should be covered by large amounts of some elements, primarily nitrogen and phosphorous, while development, fruit growth and ripening require large amounts of potassium. In the meantime, the early trees growth in the spring should be happened with as little nitrogen as possible in organs, because of their very sensitive response to cold hardiness. So, the nitrogen status in plants should be characterized as very delicate, where the start of the season should be with its relatively high supply (in order to promote rapid leaf development, fruit setting and intensive fruit growth), afterwards, it should have a decline trend in tissues (in order to provide a good fruit ripening and proper wood maturation before winter).

Broadly speaking, nutrients in apple trees derive from tree sources (as was discussed in Chapter 5). The first one represents the internal plant's mineral deposit. The second one comprises nutrients adsorbed from soil, while the third one represents the nutrients adsorbed from fertilizers. This first package of nutrients in trees presents the plant reserve and they have been accumulated in trees' organs from the earlier growing seasons. This source of nutrients is readily available and used for trees initial growth during the spring. In fact, initial leaves and flowers development, also, early shoot growth and early fruit mass boost is mostly supported by this reserve. This second package of nutrients in trees includes nutrients obtained from mineralized soils' organic matter, or, by decomposed soil minerals, what is of minor importance. This source is changeable, and generally mostly depends on the local soil type and its organic reserves. If apple trees are not fertilized, this nutrient source primarily compensates a loss of nutrients stored in perennial organs used for new season's growth. The third nutrient portion in trees derives from mineral fertilizer and this is the most effective and powerful way in changing nutritional status of apple plants. Nutrients from all these sources can be used by plant to a greater or lesser extent, but it should be emphasized that the most effective way in nutrient enrichment of apple trees are the use of mineral fertilizers.

9.1 Fertigation in apple production

Such dynamic history of apple production also includes some breakthroughs in time as an novel thing. This is implied to fertigation. This is a measure where the soluble fertilizers are added through irrigation lines during watering. Chronologically, fertigation was an outcome of the localized irrigation. The advantage of fertigation is the possibility of regulating the doses and frequency of water and nutrient supply. This water and nutrient management comprise plant requirements determined by plant type, plant age, seasonal growing phase and soil weather conditions. This led the fertigation use all over the world on million hectares of cultivated land and different culture production. Nowadays, fertigation is still concerned as the best way of plant nutrition and plant water supply. A crucial thing of fertigation efficiency is less water waste and higher nutrient uptake by plants. T the whole system of fertigation has been developed in desert climate condition and shortage of water resources. For better understanding its efficiency, it should be stressed out that the use of "*drip irrigation*" ("trickle irrigation") made differences in surface and profile wetting compared to the sprinkle or other ways of irrigation. Here a smaller surface area is moisturized, shaped as very small circle where the water drops falls from irrigation tubes, making wet pyramidal cone under the dripping point in soil profile. This led to the smallest surface area exposed to evapo-transpiration as it is possible, also facilitating vertical water flow into the soil profile. Consequently, the water was not lost for wetting a large surface area and after not exposed to the surface soil drying, having better penetration in root zone at the same time. This is because that the initialized water flow by dripping derives from a very small and narrow surface point. However, this restricts a plant root system distribution mainly to the wetted zone, changing also considerably a fertilizing zone too. This modifies classical fertilization management, shifted a broadcast fertilizer application to the fertilizer addition into the irrigation water.

To fully understand the favourable effects of liquid fertilizer, primarily it could be accomplished by comparison of nutrients behave in soil after two type of fertilizer application: by liquid or by conventional (granular) mineral fertilizers. For effectiveness in plant nutrition, the key indicator understands a mobility of added ions by fertilizers. The conventional method of applying granular mineral (NPK) fertilizer implies its broadcast application, usually supported with some land treatment (tilling, disking or shallow ploughing), whereby nutrients are released from the granules over time into the soil solution. In this way, the nitrogen ions are relatively rapidly dissolved in soil solution, where especially nitrate ion has a great mobility by floating through the profile. This ultimately can lead to its leaching and loss. This nitrogen release from granules is followed by phosphorus and potassium ions, which are present at significantly higher concentrations in granules than in soil's liquid phase. They have a radial dilution from granules and their mobility is different and relatively slow. The potassium mobility in the soil profile is considerably lower than nitrogen's, resulting roughly in 20 cm of its vertical movement on the annual level. The phosphorus movement in mineral soil, however, is extremely low and it is reduced to its annual vertical migration of only 1-2 cm. Taking that into consideration, a phosphorous supply of apple trees are very often related to the use of "fertilizer deep placement", by the use of mechanical fertilizer row spreaders to carry out the input of granular fertilizer to the depth of 20-40 cm of soil profile. This represents a closer area to the root zone. So, the intensity and degree of release of nutrients from conventional fertilizers considerably depends on type and nature of mineral fertilizer. It can be expected that different manufactures produced a dissimilar technological product with similar, but not identical properties. Besides, nutrient release from granules largely depends on soil moisture, soil properties and intensity of chemical and microbiological processes that prevail in the soil. In addition to nutrients availability from mineral fertilizer, it should be also considering that literary all present soil chemical parameters (pH, oxidation-reduction process, CEC, DOC, etc.), has an influence on ions release from applied granules.

Based on current experience and practice, the application of liquid fertilizers has shown several advantages in agricultural production. Namely, it was found that the applied nutrients are immediately available for plants having a high degree of uptake, while the losses associated with their leaching or inactivation in the soil are reduced to minimum. One of the advantages of liquid fertilizers is great flexibility in timing of applications. Hence nutrient's demand in intensive orchard production systems is particularly variable, liquid fertilizers offers satisfaction of all specific demands appeared at each phenological phase during the fruits growth. So, the certain nutrient at elevated concentrations could be applied according to the plant's current needs (root development, start of vegetation, flower development, flowering stage, fruit setting, fruit growth, fruit ripening, etc.). This enables the use of liquid fertilizer at the time in quantities which will be fully employed in plant metabolism.

As a result, smaller amount of nutrients should be applied during season, but their effects on plant's growth and development is considerably much exposed. In this sense, a liquid fertilizer also brought some other advantages. This is mainly focused on the utilization of nutrients. Rather small amounts of added nutrients from conventional mineral fertilizers have been absorbed by plants. Cereal crops seem to be the most effective in this nutrients uptake, where in some "ideal" soil/whether condition the average rate of utilized nitrogen ranged about 50%, reaching up a 60% as a maximum. The rate of utilization of other two most applied elements (phosphorous, potassium) are much lower ranging about 20% and 40%, respectively (Mangel and Kirkby, 1982). In cereals this high nutrient adsorption probably appears because of their extremely huge root-soil contact area, which is not even comparable with small root surface of perennial plants. Therefore, the uses of liquid mineral fertilizers versus classic crude fertilizer increase a nitrogen uptake up to the 75-95%, phosphorus to 45%, and potassium at the average level of 85% of applied content (Kafkafi and Tarchitzky, 2011). This trend was caused by performed mobility of applied ions, associated with their progressive distribution of added liquid through the soil profile.

Table 12. Effectiveness in nutrients' adsorption from different way of mineral fertilizer application (broadcasted granular fertilizers, broadcasted granular fertilizers and irrigated, applied by fertigation).

	Soil application (broadcasted)	Drip irrigation (broadcasted and irrigated)	Fertigation
	%	%	%
Nitrogen	30-50	60	75-90
Phosphorus	20	30	45
Potassium	50	60	85

*Source: Kafkafi and Tarchitzky, 2011.

Except the mobile nitrate ions applied by classical broadcasting of NPK mineral fertilizers, a significant amount of nutrients remains on the soil surface. However, for the most common fruits, it is not a main adsorption zone for their roots, making surface soil zone primarily as a place of phosphorus and potassium accumulation. If such soil is irrigated, applied water has a positive impact on ions mobility, inducing their moderate spreading and distribution in soil profile which starts to be partially accessible to plants. At the same time, nutrients from liquid fertilizers are uniformly distributed along the wetting zone. The fertigation solution mainly saturates a whole soil volume where the fruit roots have been disseminated. As summary, it can be said that in the same cases, this is the only way of supplying root system with some low mobile elements (e.g. phosphorus) at the needed depth.

In addition to increased efficiency of these fertilizers, their limited use largely affects some ecological aspects. This is primarily linked to the possible risk of human environment contamination mainly due to the protection of soil and groundwater from over-fertilization. Excess of nitrogen fertilizers use impose a nitrate leaching, while intensive phosphorous application comprises a permanent accumulation of excess phosphate in the soil profile and water accumulations conditioning an algal proliferation, while large amounts of potassium ions from fertilizers in the soil maintain a high osmotic pressure of soil solution. This also could endanger plant health and yield quality, no matter of culture or crop production. Also, fertigation practice gives some other opportunities, like a simultaneous application of pesticides, growth substances, stimulators combined with nutrients and water. Last period is full of such innovations, where producer can choose between very selective and very precise effects of fertilizer or added substances in liquid solution.

9.2 Fertilization program for young apple trees

Before orchard planting, all ameliorative measures should be done as parts of implementation of the planting project. This includes deep ploughing, as a crucial measure of soil preparation and final surface tillage, which will regulate orchard soil as flat landscaped area. Other ameliorative measures, like liming, soil's organic matter enrichment, or conducting some drain measures, should be accomplish during the soil preparation according to the orchard projecting phase.

Immediately after planting, adequate water supply of new trees is essential. This is common for both terms of planting: spring or autumn. The purpose of watering the planted seedling is not only the increasing or adjusting humidity in root zone. The water has another function, to run out the air form the root-soil contact zone. Typically, as a part of common agro-technical measure is the use of fertilizers for supporting the growth of young plants. By this fertilization, young plants cover only the consumed/used nutrient reserves present in seedlings which has been spent for early growth. Dispute that this fertilization seems to be an additional encouragement of new growth, this fertilizer amount should be treated as a part of annual orchard feeding and nothing more. This is typical if apple planting is taking place in spring, while if it is happening in autumn, the regular nutrition is start early in the spring.

The planting process should be regarded as stress to plants. Despite that the initial apple growth is mainly supported by the nutrient reserves, the uptake of nutrients from the soil are often delayed due to root injuries. This originated from the seedlings taking out in nursery which is usually conducted by machine digging. Also, a loss of developed part of root system and the presence of damages on root surface makes an imbalance between upper tree growing parts and root system. Additionally, during planting, application of large amounts of solid fertilizers may cause damages to the root, so it must be placed away from the direct contact to trunk and roots veins. This makes the reasons why liquid fertilizers are preferred during plantings.

Real advantage of the use of liquid fertilizer in orchard planting is the mobility of applied nutrients in soil profile, since the applied granular fertilizers at the plant-whole surface practically stays inert. This means that nutrients from granular fertilizers (mostly N, P, K) need a time (and moisture) to be released. Phosphorous, for example, which is one of the most important elements for root development, cannot reach the root zone. After surface application it will remain at the soil surface, also, correspondingly, this is going to happened in certain extent with the other two elements - potassium and ammonium ions. However, compared to granular fertilizers, if these elements are applied as liquid fertilizer, these elements posses' mobility and they can satisfy the most of plants demands. The effectiveness of phosphorous from liquid fertilizer in young apple orchard was explained by Neilsen's investigation (Neilsen et al., 2008), where P-fertigated trees had a 20% increase in cumulative yield overall cultivars during the first five fruiting seasons.

As expected, the nutrients need of non-bearing apple orchards is less than bearing once. This means that level of nutrients will range according to the age of orchard. All recommendations should be applied according to the soil tests. In practice, feeding program for apple trees is usually coupled with recommendations made by fertilizer manufacturers. Such program for fertilization of non-bearing orchards are proposed by "Haifa Chemicals" (Table 13).

In the first year after planting (planted at the medium heavy soils) it is expected that nitrogen rate will be between 50-80 kg/ha (Table 9), in second year between 80-120 kg/ha, and in a third year, the rate of nitrogen should range between 120-150 kg/ha.

Table 13. The recommended average rates of nutrients (kg/ha) for non-bearing trees. Multiply K2O by 0,83 to convert to amount K.

Orchard age	N	K_2O
	kg/ha	kg/ha
1	50 – 80	50 - 70
2	80 – 120	70 - 120
3	120 – 150	120 - 145

Source: "Haifa Chemicals", Fertilization of apple trees: A recommendation for non-bearing Orchards- Lourens, 1999;

As it can be seen, a wide range of N and K has been given. It differs roughly in 1/3 of proposed minimal amount of these elements and practical suggestion is that the lowest value should be accepted. Then it will becloser to the given Herrera (2006) fertilizer recommendation for young apple orchards.

An exceptional approach in fertilization of apple by nitrogen has been given by Cheng and Schupp (2004), where young trees should be supplied at a rate of 17 to 30 g of N per tree by liquid fertilizers two weeks after bud brake. In the second year these authors proposed the application of 40 to 80 g of nitrogen per tree just before the new shoots begin their rapid growth. Additionally, by recognizing the nitrogen cycling in trees, they also gave a NDFF value (nitrogen derived from fertilizer) which represents the percentage contribution of fertilizer N to tissue N.

The given rates of the potassium average needs are as follows (Table 9): in the first year it is between 50-70 kg K_2O/ha, in the second this range is between 70-120 kg K_2O/ha, while in the third year, applied quantities of K should be between 120-145 kg K_2O/ha. Changing this nutrient application rates (N, K) over the first three seasons should be routinely carried out to promote rapid growth.

The question about the phosphorus application during the apple planting is quite complex. Because of its generally low level in soil, previously was suggested in some fruit growing textbooks (Bulatović, 1970, König, 1976, Veličković, 2002), that this element should be applied in huge quantities as a pre-planting measure. Such P input concerns the application of 500-900 kg/ha of pure phosphorous. This was called "*phosphatization*" and this measure was treated as ameliorative measure aimed to insure future sufficient supply of trees with this element. However, this measure was a complete fail because of constant phosphorous soil inactivation. Most of such applied P by fertilizers has been chemically or physic-chemically transformed into the unavailable/insoluble fixed forms (Ličina, 2012).

So, regarding P low mobility soil and its complex soil chemistry, its applied amount should be adjusted to the real plant's needs. In the literature it could be also found that early growth of apple tree is very dependent on soil's P reserves and its availability for plants (Atkinson et al.1980, Ferree and Warington, 2003), but the fact is that applied P amount during planting are much lower compared to the nitrogen and potassium needs. This quantity ranged from 10-20 kg/ha and this can be successfully covered by fertigation.

This was confirmed in some reports, when such a very low amount of applied phosphorus (6.5-12.5 kg/ha) gave quite satisfying results in young apple orchards regarding the plant growth and phosphorus content in leaves (Kangueehi et al., 2011). Phosphorous fertigation with its low quantity also increased early tree vigour of young apples, leaf and fruit P concentration (Neilsen et al., 1993). So, it is obvious that even a small quantity of added (liquid) phosphorous in root zone is efficient, probably due to its mobility or its direct contact to the root surface. Thus, fertigation definitely enhanced the efficiency of P in apple nutrition, allowing to "mass flow" to deliver a high P concentration directly to plants.

PRACTICAL ASPECTS:

It could be said that adequate *orchard planting* is the key factor of its future exploitation. All aspects should be included in this initial process: control of seedlings quality, adequate soil preparation, permanent water supply of orchard, plant protection knowledge and to master apple fruit-technology knowledge, etc. Planting an apple orchard needs a complex planning and true professionalism.

Fertilization during orchard planting - As it is known, planting of apple orchard is followed by watering of planted seedling as an essential practical procedure. Besides supplying plants with water and refreshing the outer root surface, water squeezes out the air from soil pores and makes a good, tiny adhesion surface coat, which is in charged to make as tight as possible contact between these two substantially different phases (soil and plant tissue).

However, watering, as a regular planting measure, could be also combined with fertilization. Simultaneous use of water and liquid fertilizers during planting has been already involved in practice (Ličina, 2012), and to this day it has been planted more than 500 ha of new orchards (and vineyards). The number of such perfectly rooted plants was excellent, close to 99%. If this procedure is simplified, it could be said that instead of watering of tree seedlings with poor water, after planning a solution of liquid fertilizers could be used. The consequence of such use of fertilizer during planting is that the root zone is easily enriched by nutrients, especially with phosphorous. Otherwise, P is generally immobile in soil profile and hardly could reach the root zone of 30-40 cm depth.

Practical application of liquid fertilizer during orchard plantings concerns:

- The use of so call "starter fertilizer" which implies the use NPK liquid fertilizers with increased level of phosphorous. Its NPK formulations can be: (10 : 50: 10) or, (11 : 44 : 11), or, (10 : 52 : 10) or (11 : 38: 3), or similar, what depends on the type of fertilizer product or fertilizer manufacturer;
- The use of adequate concentration of fertilizer solution for this watering/fertilization. The concentration range of such solution should be between 1,0 and 3,0%, but the most frequently 1,5% solution was used, having very good results. This concentration is for medium heavy soils, but for the heavier soils, applied concentration can reach 3% with no harmful effect to the root system;
- Just after tree planting, a solution is poured into the planting hole, moisturizing the whole mass of dig out and returned soil. This could be repeated after full soaking of applied solution with the same portion of prepared solution. For apple holes, about 3 – 5 l of this solution could be used in one watering, while the need for more water is compensated with an additional water quantity, but this happened very rare. This is a good fertilization procedure especially if the planted orchard is without installed fertigation system, otherwise, this starting fertilization should be conducted through irrigation system;

After planting, a regular orchard fertigation should be continued. The amounts of needed NPK for current vegetation, as well as for the next two are proposed in Table 14. The entire NPK quantity of these elements should be applied over the period of whole vegetations.

It is worth to notice, that the level of proposed level of nitrogen in the first year is lower compared to the previously reviewed data, because of the seedlings significant N reserves.

Table 14. The recommended average rates of nutrients (kg/ha) for non-bearing trees. Multiply P_2O_5 and K_2O by 0,44 and 0,83 respectively to convert to amount P and K.

Orchard age	N	P_2O_5	K_2O
Year	kg/ha	kg/ha	kg/ha
1	50	10-20	50
2	80	10-20	60
3	80	10-20	80

Source: Shear and Faust, 1980.

The second year is crucial for intensive growth of young trees, and this must be followed with increased amount of liquid fertilizers. Proposed amounts of all three elements include a significant increase of nitrogen (80 kg/ha vegetation), which is in charged to improve current trees growth, followed by P and K adequate supply. The third year after planting belongs to the standard fertilization regime.

Practically, according to the content of active substance in fertilizer (content of pure N, P, N), the certain amount of fertilizer must be diluted (concentration of 0,1 – 0,2%) and used for separate treatments by fertigation through system. A proposed amount should be divided for application into weekly amounts during whole vegetation, with at least three hours of irrigation per ha.

9.3 Fertilization program for bearing apple trees

As was said, fertilization program varies as a result of several factors: apple variety, rootstock type, expected yield, soil chemical and physical conditions and soil management. The presence of irrigation and possibility of adding nutrients to the irrigation water has also a great impact on fertilization programs, especially on amounts, type of fertilizer, timing and frequency of application. So, the recommended rates of the most important nutrients (N, P, K) can vary significantly, and it could be assumed that apple orchard in different parts of the world will be fed on different way. However, after years or apple cultivation, the use of fertilizers has been generally framed by nutrients rates because of practical or experimental testing. These frames are not strict for practice, and limits of fertilizer use can be easily changed, primarily influenced by nutrients stock in soils as a result of soil testing, but also by the variety demands, different rootstock activity, or by the orchard geographical location.

After soil testing and obtained results about nutrients availability in soil, a fertilization program is implemented. At the location with sandy loam-clay soil type, as one of the most widespread in northern apple growing countries, and predicted yield over the 45 t/ha, it could be proposed that nutrients demand in bearing orchards ranged for nitrogen between 75-100 kg/ha, for phosphorus between 30-50 kg/ha and for potassium between 150-200 kg/ha (Carroll and Robinson, 2006). It can be noticed that some precise adjustments could be done for all listed nutrients, but the key point is not to go beyond the pointed limits in a use of elements. A current situation in orchard will led growers to use a lower or to use higher quantities of N, P, K, and this should be done in accordance to the soil analyses which should be provided year by year.

Some of this recommendation has been accepted worldwide, while some of them have little variation, but some they have drastic changes. To gain some kind of objectivity in proposing doses of nutrients for own orchard, a comparison between different sources of recommendations could be very useful. In Europe the fertilizer recommendations were based upon the Netherlands experimental experiences from '60est, when 140kg N, 22kg P and 205 kg K were applied on hectare of apple orchard (Kipp, 1992). Later, recommended nitrogen application rates were increased to 200 kg/ha, but sometimes amounts as much as 300kg N/ha has been also applied. Recently, the reduction of N fertilizer us in Nederland mean the application of 100 kg/ha of N, minus the amount of available N from soil.

Similarly, in Italy, nitrogen application rates in orchards have been significantly reduced in last 15 years, before which excessive rates, often exceeding 200 kg/ha of N were used. Standard recommendation for fertilization now suggests less than 50 kg/ha of N for pome-fruits (plus base-dressing). Evidently, there is need to enhance the efficiency of N fertilizers, application technology and made a fine tune of N supply to avoid the occurrences of N deficiency symptoms (Tagliavini and Marangoni, 2002). Potassium supply of apple trees in Po Valley has been treated as efficient with about 100 kg/ha, what is much less than an average in other counties (Rombola et al., 2000).

In Canada, this recommendation of N application is between 88-176 kg/ha for young dwarf apple trees (Neilsen and Neilsen, 2002), while the recommended N and K amounts in Santa Catarina and Rio Grande do Sul States in Brasil are 50 and 100 kg/ha respectively, (Nava and Dechen, 2009). For South African apple orchards, however, there is another experimentally confirmed need of nitrogen, and this work reports that an annual requirement of apple trees is between 79 kg N/ha (minimum) and 115 kg N/ha (maximum) which enable a bearing of 45 t/ha of apple per year (Kangueehi et al, 2011).

In the meantime, the nutrients input in apple orchards in China (the biggest apple producer in the world) consist mainly of mineral fertilizers, where the N, P, K applications are often unbalanced. The recommended fertilization rate according to researchers and local extension services for major apple production areas of Shaanxi Province is 150-300 kg N/ha, 65-110 kg P/ha and 75-160 kg K/ha in form of mineral fertilizers and the use 30-60 t of organic fertilizer per hectare. This amount of organic fertilizers contains roughly 180-360 kg N/ha, 50-105 kg P/ha and 110-215 kg K/ha (as based on nutrient concentrations in different types of organic material) and needed to maintain annual yields between 15 and 30 t of apples per ha (Liu et al., 2002). Such high N application rate (between 400 and 600 kg/ha) in the major production area of this country is extremely high, even much higher than in other apple growing countries, however, as presented, the yield was not proportional to such high N input (Wang et al., 2016).

Magnesium is an element which has not been discussed in this proposed N, P, K fertilization, beside its great importance for apple production as was explained through its physiological functions. In some countries' regions, Mg application is concerned as regular (Italy, Spain), and its applied quantity range between 20-30 kg Mg/ha. Generally, its application has been done to improve the quality of yield, and not to affect the yield increase. In an apple orchard at Ora (Bolzano-Italy) magnesium fertilization (30 kg/ha) made the fruit firm and with less soluble solids at harvest. After storage, the fruits also contained more soluble solids and were more acid than in N and K treatments (Noé et al., 1995). Therefore, if apple orchard is planted on skeleton, sandy and non-clay soils, magnesium application is absolutely recommended. Other elements from the nutritional list for apple are selectively applied during the growing season mostly by foliar application.

9.4 Nutrient application before and during the vegetative season in apple orchards

Base-dressing is a measure which is still applied in apple orchards, despite it reminds us to the old practice when entire quantity of fertilizer for next vegetation has been applied. Nowadays, however, *base-dressing* means the input only of a portion of recommended amount of fertilizer. Generally, base-dressing concept is to supplement the soils reserves with NPK, and after, during the vegetation, to regulate current needs of plants by fertigation. If we are talking about the recommended values of 75-100 kg N/ha, 30-50 kg P_2O_5/ha and 150-200 kg K_2O/ha (Ohio Cooperative Extension Service), the base-dressing will take part of:

Table 15. Apple orchards' base-dressing. Multiply P_2O_5 and K_2O by 0,44 and 0,83 respectively to convert to amount P and K.

Element	Quantity
N	50 kg /ha
P_2O_5	30 kg /ha
K_2O	80 kg /ha

Source: Practical experience from Tyrol region, Benelux/German counties and the other apple growing regions where these elements has a medium level in soil

Generally, this part of the fertilization program should be conducted independently to soil analysis, while the specific trees needs should be supplemented during the vegetation by liquid fertilizer.

Apple growth during the season is followed by different consumption of nutrients. It is a consequence of happening different intensity and different metabolic processes in tissues and organs. It could be anticipated that each plant phenophase will demand some of elements in exactly defined amount to enable the occurrence of certain metabolic pathway or to activate some synthetic reactions. Therefore, plants provides nutrients in sufficient amounts. Otherwise, everything will be endangered, from cell division up to the total plant development. Therefore, fertigation has a possibility to make direct and very effective impact on plants, and this is realized by controlling the amounts of added fertilizer, timing of its application and by the possibility to be repeated. Thus, it could be said that some growing phase, like rooting, flowering, fruit setting, maturing, etc., will be instantly stimulated by the application of added elements given by liquid fertilizers.

To have the most efficient fertilization, the total seasonal application of each element should be split according to estimated monthly requirements in each phenological stage:

Dormancy;

Flower initiation;

Fruit set;

Fruit development and bud initiation;

Fruit development and vegetative development;

Beginning of harvest;

Post-harvest period.

This partition mostly coincided to the certain month which followed a vegetative growth, being different according to the climatic zone. For the Northern apple growing countries it is happening from the end of March till October, and often, a recommendation for fertilizer application are pertaining to certain months. Consequently, this schedule should be adjusted to the local weather condition or local climatic zone. For Norway, this means season delay for of about two months (April-October).

A portion of fertilizer should be divided according to the number of application and diluted in required amount of water. This gives the possibility that each phenological phase should be supported by certain amounts of elements. Means, a total proposed amount of N, P, K should be shared and adjusted to plant's needs during time.

Nitrogen – This NPK recommendation presents tested "adequate" supply of apple trees in the world. Therefore, if we are talking about the apple needs of **75**-100 kg N/ha, 30-**50** kg P_2O_5/ha and **150**-200 kg K_2O/ha), we must support:

- the first phase (dormancy) with 20 kg N/ha,
- the second one (flower initiation) with another 20 kg N/ha,
- then the third phase (fruit set) with 15 kg N/ha,
- the fourth phase (fruit development and bud initiation) with 12,5 kg N/ha,
- the fifth phase (fruit and vegetative development) need only 6,5 kg N/ha,
- the sixth phase (beginning of harvest) 0,0 kg N/ha is without N application,
- the seventh phase (post-harvest period) need about 10 kg N/ha, which will be stored in perennial organs for next vegetation.

Source: Experience from Tyrol orchards region and Benelux/German countries -"Haifa"-Lourens, 1999. - (Nitrogen was at the medium level in soil)

This fertilization program is giving a picture that less nitrogen is needed towards the end of season. As it can be seen, all intensive phenological phase is followed by appropriate sum of nitrogen which is responsible for increased metabolic activity in tissues. Rooting, flower development, leaves, shoots and fruit intensive growth, everything what was related to the intensive cell division and growth of tissue, was followed by high dose of nitrogen. Approaching to the end of vegetation, plant demands for this element diminished.

The applied amount of N can be maintained at this proposed level, but everything should be adjusted to the soil analyses especially if the amount of available N (NH_4^+ and NO_3^-) has estimated. This can give you useful information about the amount of N in kg per ha which exist in soil and which can be readily used by plants. The origin of this available nitrogen in soil could be from diverse sources, like a product of mineralization of soil organic matter, the residual part of previously applied mineral fertilizer, N from precipitation, N from decayed microorganisms, etc. It is very important that the amount of this present available nitrogen in soil should not be neglected, and usually it seriously contributes to nutrition of apple trees.

Concerning that soil test from laboratories in Norway does not give the quantity of available forms of nitrogen (NH_4^+ and NO_3^-) in soil's profile the adjustment of nitrogen recommendations should be done according to the local practice or to the current visual situation in orchard (shoots growth, plant's vigour, yield load, etc.). A method for plant available N in Norwegian soils are available and gives good correlation with plant uptake (Øien and Selmer-Olsen, 1980). The method is not routine method in agriculture because of need of deep sampling (0-60 cm), analysis of fresh samples or frozen samples (conserved samples) to ensure unchanged available N after sampling. Basically, some particularity of local Norway climatic conditions influenced the availability of nitrogen in soil (large organic deposits in soil, the degree of organic matter mineralization, annual precipitation level, soil low temperature, etc.), limiting the possibility to calculate the amount of available nitrogen for plants. In this sense, it is hard to clarify the real deposit of this element in soil and proposed a correct additional N fertilization. From the other side, in Mid-Europe region, the use of quantity of available nitrogen in soil (NH_4^+ and NO_3^-) is very popular and well accepted. This derives from the previously involved N_{min} method (Crook and Simpson,1971) created as a tool for lowering nitrogen doses in fertilization of some intensively fertilized cultures (e.g. sugar beet, wheat, corn, etc.). According to this method, the nitrogen dose was recommended upon the present reserve of available nitrogen (kg/ha of NH_4^+ and NO_3^-) in soil profile (0-60 cm), which was supplemented by minimal dose of N by mineral fertilizer. This method also worked well as orchards' N fertilization status, when the lowest amount of needed nitrogen should be added by N fertilizers.

Phosphorous - Phosphorous application should be also divided according to the growing phases of apple plants. This means that total need of this element during the vegetation should be shared and applied in certain periods. So, apple orchard trees should be supplied with different amounts of phosphorous. In:

- the first phase with 10 kg P_2O_5/ha,
- the second phase with 10 kg P_2O_5/ha,
- the third phase with 5 kg P_2O_5/ha,
- the fourth phase with 10 kg P_2O_5/ha,
- the fifth, sixth, and the seventh phase (post harvesting period) should be supplied only with 5 kg P_2O_5/ha each.

Source: Experience from Tyrol orchards region and Benelux/German countries
"Haifa"-Lourens, 1999.-(Phosphorous was at the low level in soil)

The highest demands of apple trees for phosphorus start in rooting phase. With the beginning of new vegetation roots starts to grow, then, a flower development, pollination and fruit set are very dependent on phosphorus content. Besides, all cell divisions and spring tissue growth are very energy dependent, what is also strongly connected to the phosphorus content in tissues.

Potassium - Similar calculation has been proposed for potassium:

- 15 kgK_2O/ha (dormancy),
- 15 kgK_2O/ha (flower initiation),
- 40 kgK_2O/ha (fruit set),
- 40 kgK_2O/ha (fruit development and bud initiation),
- 30 kgK_2O/ha (fruit development and vegetative development),

- 15-20 days before harvest and later (post-harvesting period), there is no need for potassium application.

Source: Experience from Tyrol orchards region and Benelux/German countries- "Haifa"-Lourens, 1999.-(Potassium was at the medium level in soil)

If compared with nitrogen, potassium possess a quite opposite dynamic in plant tissues. This element has the tendency to increase its concentration toward the final stages of vegetation. It means, the beginning of the vegetation plants can pass with smaller amount of this element in tissues, but fruit development, yield formation and sugar storage are the main trigger for increased accumulation of potassium. This question about the proper supply of apple plants with potassium took noticeable attention of apple producers. Nowadays, two main reasons drive this special approach to K adequate supply of apple: yield quantity and fruit quality (firmness, fruit size, coloration, sugar content, vitamin content, and acid content). Therefore, some of investigations are focused not only to the amount of applied potassium fertilizer, but also into its quality effects and timing of application (Nava and Dechen, 2011., Lu et al., 2015., Rather et al., 2019).

This great attention about the use of potassium in apple production made some variation in its use. That's how a guideline for splitting K application has been established. It gives a percentage of sharing of K_2O according to the growing stages: (1) leaf emergence, (2) flowering, (3) fruit-set, (4) fruit growth and (5) fruit maturation. Each of this stage share 15%, 20%, 25%, 25%, and 15% of recommended amounts of potassium (K_2O). This means if we tend to apply 150 kg/ha of K_2O in apple orchard, in the first growing stage (leaf emergence) it will be applied 23 kg/ha of K_2O, at second stage (flowering) 30 kg/ha of K_2O, at the third stage (fruit-set) 37 kg/ha of K_2O, at fourth stage (fruit growth) 37 kg/ha of K_2O, and at the fifth stage (fruit maturation) 23 kg/ha of K_2O. ("Haifa"- Lourens, 1999). Potassium application has increasing tendency towards fruit maturation, but general recommendation is that two weeks before harvest, potassium should not be applied.

However, it is important to know, if this listed exact amounts of fertilizers have not been used, another their proximate value could be easily calculated via calculating the proportional amounts. There is only one request in this calculation, that the ratios between quantities and ratios between different elements should be kept.

PRACTICAL ASPECTS:

In agriculture, fertilization is a measure which mostly increases soil fertility. Dispute of some possible limitations conditioned by the soil bad properties, soil fertility, broadly meaning, are generally based on its nutritional potential. So, the correction of present "soil potential" must be exceeded by the fertilizer use. Therefore, it can be said that a measure of base-dressing is crucial in maintaining the potential of soil fertility. The best approach in the estimation of fertilizer demands should be based on soil analyses. Therefore, it could be said that permanent control of soil fertility should stands as a common practice in apple growing.

Base-dressing is basis of orchard feeding, while fertigation is a measure which supplemented a nutrient soil reserve. For Norway growing practice, it should be suggested that the initial input of fertilizer should be low. There are a couple of reasons for such assumption. If this soil is treated as a soil for apple production, some of its performances greatly differ compared to the soils in other regions. It was evidenced that this soil is with large deposits of organic matter, under the influence of low temperatures, excess of moisture and limited aeration (Kvåle, 1995). This not favourable climatic condition probably provokes local apple growers for large nitrogen application in orchards, what induced typical N excess symptoms visible on trees in many Norway orchards (Kvåle, 1995). Therefore, for base-dressing a low dose of nitrogen should be accepted, counting on that this amount will be significantly increased by organic matter mineralization. In Norwegian soil mineralization of P is very low and normally we do not consider this P fraction. Available P came close to 100% from mineral fertilizers, manure or compost (inorganic P fractions) or from reserves of mineral P in soil. High degree of organic matter guaranteed the supply of apple trees will be generally adequate, while this added phosphorus will be its ready to use quantity for early growing stages when the outer temperature is low.

As seen in world's experience about the use of potassium in apple growing, general opinion is that successful apple growth, both in yield formation and fruit quality, are greatly dependent on potassium nutrition. The recommended high potassium uses in Northern countries (Denmark) gave a large increase of yield due to the fruit size increase. In Norway, this phenomenon was less visible because of the presence of high level of natural potassium in soil (Paulsen, 2019). According to Kvåle (1995), a previous potassium fertilisation and its excessive application caused magnesium deficiencies in many Norwegian orchards. However, it is about the region which possess a high precipitation what can induce a high K leakage (Kvåle, 1995), so, the recommended amount of potassium for base-dressing extended in a wide range, but the applied amount will be greatly dependent on present potassium status in soil (Table 16).

Table 16. Recommendation of base-dressing for apple orchards in Norway. Multiply P_2O_5 and K_2O by 0,44 and 0,83 respectively to convert to amount P and K.

N	P_2O_5	K_2O
kg/ha	kg/ha	kg/ha
30	10-20	60 - 100

Fertilization programs for established trees **-** The quantity of annual application of N, P, K are the basic decision in orchards' fertilization, and this greatly depends on soil supply and trees properties (cultivar type, trees vigour, yield load, rootstock variety, etc.). This amount should be adjusted to the local conditions, which according to the present ecological conditions in Norway, pose as a problem. It means that nutrient recommendations from leading apple growing countries are not simply transferable. For that reason, it could be said that in Norway a universal program for apple fertilization does not officially exist. All treatments and fertilization procedures were obtained from practice.

At present time, scientific (NIBIO) and professional institution ("Yara") paid more attention to this problem. They gave proposals which are related to the nutrition of local orchards (Table 6), which is adapted to the local weather condition.

Table 17. Recommended application of nitrogen, phosphorous and potassium to apple (trees in production) in kg/daa (kg/1000 m^2) and kg/ha (Norway)

	N		**P**		**K**	
	kg/daa	kg/ha	kg/daa	kg/ha	kg/daa	kg/ha
Yara	2–2.5	20-25	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

Source: Yara, 2018, NIBIO, 2018, Vangdal, 2017.

According to the conventional apple production and fertilizer use in Europe, all proposed amounts of nutrients are low. This listed recommendation of nutrients should be multiplied by 10, because they have been presented as nutrient amounts planned for the local surface unit (daa→decare = 1 000 m^2).

The proposed smaller amounts of nutrients should be connected to the smaller yield in Norway, where lower yield demands a lower fertilizer input. So, compared to any of words' apple production, local yield is considerably lower. However, to this lower apple yield contribute a lower number of trees per square unit, consequently which smaller requirement of nutrients. Also, a local soil's nutrient potential can approve such nutrient restriction input. Regarding Norway's apple growing regions, four of them are submitted to the soil testing through scientific project. Most of the orchards of these investigated areas are with high or, extremely high content of organic matter, as an excellent potential source of all nutrients, preferentially nitrogen (Paulsen, 2019). A couple of other benefits of its high presence in soils are also important for adequate plant nutrition. The high level of other two elements in soil (P, K) mainly derived from previous fertilization, what influence moderate needs for fertilizers.

According to the given growing conditions, probably a *NIBIO proposal has the best answer to the apple nutrient demands in Norway* (Table 13). Certainly, this proposal could be subjected to the correction, but basic-dressing and this current nutrient supply by fertigation probably can fully satisfy apple NPK needs.

Timing in fertilizer application – Previously was said for about at least two months delay of vegetation start in Norway, so time schedule of operations in orchards practically should be adapted to this situation. This includes fertilization practice. Basically, the growing phase (bud burst, flowering, etc.) should be the main indicator for implementation of some operation.

After base-dressing (autumn) orchards in Norway could be supplied during the vegetation according to professional proposal of "Yara Apple Program" schedule, as was foliar fertilization proposed. The good thing is that it could be relatively simple to handle this and do not need permanent care about the different dosages. Also, a predicted supply of phosphorous could be included in NPK formulations.

Table 18. Soil applied fertilizers in apple growing

NPK	Mouse ears	Pink bud (white buds)	Petal fall	Fruit Set	Fruit Let	Fruit filling to maturity	Post harvest
30% of total N				30% of total N			40% of total N
40% of total K2O				40% of total K2O			40% of total K2O
Fertigation with NPK fertilizers, where the mass of each element should be calculated from each fertilizer or NPK formulation							

Source: "Yara Apple Program"

If summarized, there are only two periods of nitrogen and potassium application during the growing period. After harvest, there is also one more as a soil input of these two elements. This is happening at the end of vegetation while the green mass of leaves still exists and works. So, it is important that this amount of nutrient is adsorbed and afterwards involved in metabolic process of tree. This will result in making nutrients' storage for the growth in next vegetation.

However, according to the given proposal for apple fertilization, a 40% of added N and K should be added to trees in this growing phase, but this is too much. Therefore, these amounts of fertilizer should be shared for their soil application in earlier growing phases, leaving only about 10 to maximum 15% of total nitrogen, or, 5-10% of potassium quantity. As was previously explained, it has a physiological explanation.

In Norwegian practice exists that nitrogen is applied about four weeks before bloom with the 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.

As comment for local potassium application, fertilisation might be reduced if soil reserves are high. On light, sandy soils, to potassium fertilisation should be paid a special attention, but generally the requirement of this element is larger than for nitrogen (Vangdal, 2017).

In practice, 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).

In regular practice, magnesium and calcium, like boron, zinc and manganese should be foliar applied as proposed in pervious Chapter.

9.5 Nutrient application by foliar nutrition

A pervious scheme of NPK application, presents only a part of regular (and practical) fertilization in apple orchards, because foliar feeding program was missed to be presented. As already said, this way of nutrition can make a significant influence on yield quantity, but primarily on yield quality. Therefore, great interest of producers have been grown about this nutritional approach, because this way of nutrient's application is relatively cheap and gives benefits which significantly overcome cost inputs. Already, these apple treatments achieved better producers' position on the market and enable better sales.

Through scientific research, a great number of foliar nutritional aspects has been investigated. In the focus of these investigations was not only the quality of apple, when some of non-visible benefits and side effects of this treatment were considered. This includes chemical changes in apple fruit where some secondary metabolites were investigated, then coloration pigments synthesis, synthesis of antioxidative substances, synthesis of vitamins, etc. (Štampar et al., 1999., Amiri et al., 2008., Murtic et al., 2012). Such great attention in foliar feeding resulted that this measure started to be a standard practice in the most of the worlds' apple growing countries.

Generally, along with regular input of nutrients through root system, foliar nutrition supports a metabolism of apples plants. Like a liquid fertilization use, a foliar application is also in accordance to phonological stages of apple plants. Therefore, the added nutrients instantly stimulated certain growing phase during the vegetation period.

All planed foliar treatments should be applied in concentration between minimum 0,1% up to the maximum 0,5%, and this must be done with adequate quantity of water. It is also important to say, that all proposed NPK fertilizer formulation are aimed just for foliar treatments, not for soil application. They possess the physic-chemical properties made by manufactures which improve its special characteristic. Apparently, these entire fertilizer characteristics are tuned to improve its efficacy during treatments by better attachment and adsorption by leaf surface. Foliar fertilizes possess some typical characteristic for this type of fertilizers like special adjuvant for better cuticle penetration, certain polarity, slat balance, etc. At the market today, you can find a lot of foliar fertilizers' producers which are competing for customer by using some technological advantages of manufactured products. But generally, they are offering products with single elements (as a single salt or this element in chelated form), or, foliar fertilizer with complex of NPK with different combinations of these elements. Concerning micronutrients, they can be applied as single, aimed for curing micronutrient's deficiencies, but mostly of them is mixture made in their different ratio combinations. Metals of micronutrients (Fe, Cu, Zn, Mn, Mo) are very often packed in chelated form, which has much more pronounced efficiency, having a better effect dispute that they contain a very small amount of nutrient (e.g. Fe EDTA of Fe EDDHA which range from 2% up to the maximum 6%).

If we assumed that the phonological stages are the same as was pointed out in timing the liquid fertilizer application [(1) dormancy; (2) flower initiation; (3) fruit set; (4) fruit development and bud initiation; (4) fruit development and vegetative development, (5) beginning of harvest (6) post-harvest period], the added nutrients have certain physiological response to plant metabolism. Accordingly, during the flower initiation (2) a foliar fertilization has to cover an instant need for phosphorus by NPK formulation like 10:50:10, 10:52:10, 12:40:12, or 11:45:11 (or similar). In this treatment, it is preferred that this formulation will include a mixture of microelements, prepared like a "cocktail". This growth phase is happening (in northern European counties) mostly during the March.

During the next growth phase (April), it is suggested to repeat the same NPK treatment combined with micronutrient. This will support a fruit set (3). Such foliar applied phosphorous (10:50:10, 10:52:10, 12:40:12, or 11:45:11, etc.) should support the energetic reactions, which has been intensified during this initial growth of each organ.

In May, a quite different NPK formulation is used. The growth of young fruits (fruit development and bud initiation (4), will be additionally supported by easy adsorbed nitrogen and potassium from the NPK formulation as 16:8:20, 20:5:30, 18:7:24, 17:9:29, (or similar). This NPK fertilizer should be also with microelements mixture. In this phase, immediate action of foliar adsorbed N and K is responsible for buds grow. Consequently, this foliar treatment supports the next year yield.

A fruit development and vegetative development (4), which is happening in June, will be assisted by foliar application of NPK formulation with increased level of potassium. In the meantime, nitrogen content is decreased, while phosphorous has a minor input. This means that type of NPK such as 12:2:44, 13:6:40, 10:5:30 (or similar) will be used, but instead of micronutrient, magnesium should be applied. This secondary element could be applied as singe component of fertilizer or mixed with NPK, ranging from 10 to 15% MgO. It has been given to plants to trig the photosynthesis, which will lead the fruit and vegetative growth during this period (Jun, July)

The next growing phase is happening in August as a phase when fruit maturation is occurred (5). Foliar fertilization will continue to supply the plants with potassium, so, the used fertilizers will be as previously mentioned (NPK 12:2:44, 13:6:40, 10:5:30 etc.). Growing process at this vegetative phase is not encouraged, in this period it is not desired, so, minimum nitrogen and phosphorus is needed. Added potassium has a role to improve colour of the fruit, to induce its better firmness by accumulation of sugars as important osmotic substances, as well as its sweetness, which will contribute to the better taste.

After the harvest (6) a foliar nutrition can be applied with different purposes. One is to enrich the leaves with nitrogen (possible use of urea-2-5%), which will be during senescence transferred in shoots and trunk, or, plant nutrition could be continued with increasing NPK (20:20:20, 18:18:18, 19:19:19 or similar) also counting on the mobilization process of nutrient from leaves into shoots and branches. Foliar feeding plants with magnesium or with the mixture of microelements are going to be applied according to the same purpose. The idea is to store these elements in green organ which will be at the end of vegetation transferred in perennial organs. Such stored nutrients are a kind of the nutrient guaranty for next season growth.

9.6 Fertigation of apple orchards

If liquid fertilizers can be applied through irrigation system to the plants roots, this process is called fertigation. This method demands special irrigation equipment, which mostly differ from the standard one used just for watering. The main difference is in a fertilizer injector, which posse's fertigation equipment as a head control unit of the system, placed before the filter. A different technique has been developed for application diluted fertilizer through irrigation system, but all of them are based on distribution of liquid fertilizer by water pressure. This delivery could be done by using Venturi pumps, or by injector pumps, which are mostly used in agricultural production, but there are some other systems, like by-pass flow tank or pressure-differential system or injection-pump system. Each of them has certain advantages and disadvantages, but usually they been chosen upon the ability to control the timing and to control the level of applied nutrients, with possibilities to be centralized and managed by sophisticated programs. These systems are, also, a labour saving and relatively cheap during the manipulation. The crucial is, however, that all of them have possibility to make a mixture of soluble fertilizer and possess an ability to distribute nutrients in exactly proposed amounts.

The activities of all fertilizer injector system enable to distribute dilute fertilizer to the plants in constant concentration. Generally, these concentrations are very low (0,1-0,2%), but solution is distributed through all fertigation lines on a constant rate, enabling thus feeding the plants during the whole growing period. Regarding the choice of fertilizer, apart from the used amount and type of fertilizer, some parameters need to be considered, such as its solubility, acidity effects, and compatibility, and finally the cost.

Concerning fertilizer solubility, the fertilizer stock solution (amount of fertilizer dissolved in small volume of water) should be always dissolved in a separate container and then poured into the suction tank. Used types of fertilizer should be highly soluble, with no insoluble particles or sediments, which might cause emitter clogging problems. Handling with solution should be with care, meaning, the fertilizer solution should be always shaken, well stirred, while the sludge from the bottom of the tank should be periodically removed. However, the degree of fertilizer solubility varies according to the producer, also, their physical properties greatly differ.

Nitrogen application implies the application of nitrate and ammonium ions. Nitrate form of N does not react with charged soil particles, and for that reason is not held in soil profile. It moves with other soluble salts toward the wetted front, while ammonium form of N (derived from ammonium or urea fertilizers) is not subjected to the immediate leaching, because it could be temporary fixed on exchange sites in the soil. Both forms of N are applied in relatively high amounts, especially if compared to the other nutrients. This make a possibility to induce some environmental consequences (e.g. nitrate pollution of groundwater), what should be always matter of concern. Potassium is less mobile than nitrate, and its distribution in the wetted soil volume is usually more uniform then other ions, due to interactions with soli-binding sites. Dripped K moves both laterally and downward, thus allowing more uniform spreading of this element in the wetting zone. According to its effect on the yield, now it is widely accepted that application of K by fertigation are the most effective and most efficient. Contrary to N and K, phosphorous is readily fixed in the most mineral soils, especially in acid soils reach Fe and Al and in calcareous soils. As was said, P in soil moves very little in depth, but thanks to cultivation, phosphorous could be found to the depth of tillage (10-30 cm). In apple orchard this has a practical consequence that cultivation below the canopy is not advisable, because of the tearing the part of the surface root system. This root part is responsible for adsorbing a low mobile nutrient in profile, such as phosphorous. If the efficiency of P fertigation is compared with surface P application, it is not comparable regarding a low P efficiency after surface soil application which is in order of 5-10%. It has been demonstrated the possibility that high rate of P fertilization increased the movement of P over normally expected due to the saturate reaction achieved (Papadopoulos, 2000). Therefore, continuous application of orthophosphate through irrigation water was shown to be superior compared to application of adequate P quantities as basic fertilization. Regarding the use of P fertilizers type, its solubility should be primary in focus, due to their inconsistent way of behaving in soil due to different manufactures.

The liquid fertilization, like some type of crude fertilizers does, produce soil acidity, or they can contribute to greater acidification. This is mostly related to the use of nitrogen fertilizer via nitrification process, what should be a bad consequence especially at acid soils. The key problem is the use of huge quantities of this nutrient, which can affect a serious problem in soils if its long-standing application exists. Phosphorous fertilizers affect the pH of the soil in the following ways: 1) *Direct acidification* of immediate action due to the low pH of P fertilizer after dissolving in the soil, and 2) *Indirect acidification* induced by urea hydrolysis as a component of P fertilizers. However, both acidification processes contribute to the higher mobility of present ions in soil, not only to Mg, Fe, Zn and micronutrients, but also the soil phosphorous which can be more adsorb by plants (Papadopoulos and Ristimaki, 2000).

A systematically monitoring and care should be conducted on such pH threatened soils by controlling pH at the beginning and at the end of growing season. Furthermore, a complete ionic analysis of the water is necessary, which also can contribute to the soil acidification.

The next thing of a great importance in fertigation application is awareness that this way of plant nutrition implies the use of great amount of diluted salts, and this can cause a soil *salinization*, as another big environmental problem.

10 Discussion about the results of the soil testing obtained from two laboratories

Two laboratories were engaged for soil nutrient testing in this project. The idea was to help farmers to collect the right data and provide them insight into soil fertility to obtain proper apple nutrition by using fertilizers. Also, the scope of this project was to obtain food safety products and to guide the producers how to conduct a production at the level which will preserve contemporary environmental demands. Soil analysis as a tool in fertilization planning has been used for decades in Norway fruit production using methods developed for Norwegian conditions. During the last years more and more soil samples from orchards are send to laboratories abroad, analysed using methods not commonly used in Norwegian agriculture. This is a challenge regarding interpretation of the results. To compare soil analysis methods two laboratories used by Norwegian fruit farmers took part in the testing. Both laboratories are EUROFINS company laboratories but testing according to different methods. EUROFINS is one of the leading laboratories in the agricultural sector which provide soil analyses and gives a case-specific advice, to help the managing of the production process. One of the laboratories is located in Wageningen. The Netherland is specialised on soil methods for fruit production used in Dutch farming. Some Norwegian fruit advisers are using the laboratory for Norwegian soils and the interpretation of results given by the laboratory. The second one is the EUROFINS laboratory in Jena, Germany. About 90% of yearly soil samples from Norwegian agriculture, including the majority of samples from orchards, are analysed at this laboratory according to traditional Norwegian soil methods. The interpretation of results are following advices given by NMBU (Norwegian Institute of Life Science) and NIBIO (Norwegian Institute of Bioeconomy Research - NIBIO) the two largest research institutions in Norway which deals with soil analyses for decades, both with great expertise in the field. Both the Norwegian institutions and EUFORINS Netherland treat soil fertility as highly decisive factor in plant production but using specific testing analyses. Different interpretational approach of obtained results, make quite diverse advises for apple fertilization. In this sense, the results obtained from this two testing are intriguing. Examples of analysis reports are given in Appendix (Appendix 1 and 2). In the following paragraphs the two laboratories are named NMBU/NIBIO and EUROFINS to separate methods and results.

At one site, NMBU/NIBIO's results from soil analyses are clear and widely recognized in the scientific world as "classic" one, usually obtained by single analytical well-known chemical procedure. In this sense, they are easily acceptable and could be subjected to further checking. NMBU/NIBIO's soil testing results provides available content of some tested element and it is used for proposing fertilizer recommendation. This estimated value of some available element in soil is quantitatively ranking according to the standards of applied method, therefore the fertilizer recommendations have these results. The analytical list of results contain a soil density (kg/l), pH, P-AL (mg/100g), K-AL mg/100g, Ca-AL mg/100g, Mg-AL mg/100g, Na-AL mg/100g, available Boron (mg/kg), available Cupper (mg/kg), available Zinc (mg/kg), available Iron (mg/kg), soil Alkalinity (mekv/100g), available Manganese (mg/kg), available Molybdenum (mg/kg), P-Olsen (mg/100g), solids (%), total Nitrogen (Kjeldahl-N) (%TS), TOC (%TS), C/N ratio. These analyses could be concern as a standard one, which can be very good starting point for fertilizer recommendations.

The NMBU/NIBIO report is not followed by an interpretation guide. However, the results are classified in the classes low, medium, high and very high related to soil supply of nutrients. The interpretations of results are performed by fruit advisers working together with the farmers.

Beside single concentration of tested elements, EUROFINS also give a calculation about the "total available stock" of some nutrient. Means, an estimated concentration of some element in soil has been calculated as portion of soil mass and it is given as its content in kg/ha. This represents the total pool of available elements for plant's growth. However, this is not a common practice in all apple growing counties. In Tyrol region (Trentino alto Adige region), as one of the leading European apple regions, soil testing reports contain only a concentration of some element. Also, similar reports are obtained from American University extension services and Australian soil testing institutions, and these analytical reports are also without a "total available stock" of elements in soil. In such reports, available content of some elements is compared with the guideline values (scale rated between low and high content), and then, a simple fertilizer recommendation was performed. This recommendation can be created as an amount of some element per square unit (ha, acre), or, calculated as an amount of nutrient per tree.

EUROFINS report includes all elements in Appendix 2, and as such they have been discussed. In this report for some elements it is specified a "soil element stock", as complete available reserve of detected nutrient in soil. Such wide analytical approach was probably done to clarify all aspects of soil's nutrient supply, nutrients availability and soil's nutrient potential to feed the plants. The above results are of a general nature, and they could serve for nutrition of all agricultural plants, not only for apple growth. In this sense, they are of importance and deserve a special attention for all soil users.

In EUROFINS soil testing report contains another very important aspect of soil fertility: Microbial biomass (mg C/kg), Bacterial biomass (mg C/kg) and Fungal biomass (mg C/kg). These investigated parameters illustrate an existence of living organisms in soil and reflects the nutritional status of the soils. These forms of microbial living biomass (bacterial and fungal) are pH dependent, and practically are directly affected by soil acidity. Naturally, all soil living organisms are closely related to the level of soil organic C, as a main support for their living, and this analytical data (organic C and inorganic C) also belongs to the soils' report. This well-known fact confirms a steady relationship between soils C and N content in soil.

The soil testing and interpretation results given by EUROFINS offers an approach presented as a pure computer program instruction. Moreover, it should be also said, that procedures of soil analyses in their labs are mostly done by functionally integrated analytical system, when tested soil extracts are submitted to subsequent flow-inn regents. Typical example of different types of soil's analyser is usually "Soil Auto Analyzer", as fully automated and independent analytical systems. Therefore, some of the obtained analytical data, such as Na, Si, Se content, are not in nutritional focus of apple plants, and, particularly, they do not have any practical or professional concern for apple growers. For this reason, it seems that such results have been marked just in order to present as many parameters as possible.

The EUROFINS soil testing report and fertilizer recommendations are presented as an intellectual product, dispute that it is probably based on the former serious scientific investigations or practical experience. This report contains two main indicators: "Results" and "Target value". The "Results" in EUROFINS report shows the results of soil chemical-physical analyses (kg/ha, g/ha, mg/kg, or %), while "Target value" is given as desired range of some nutrient level which should be in soil. Obtained recommendations, however, apparently hide an integral approach in soil-plants result's interpretation, meaning that they are only supported by the guideline limits. These guideline values of detected nutrients in soil are defined as low, rather low, good, rather high, and high,

Concerning that EUROFINS possess a great practice achieved from all over the world, nutrients' range given as a "Target value" must be the result of its experimental or practical experience (Appendix 2). However, the base of these values or standards is "hidden", being probably treated as company property or professional secret. Therefore, these data have no simple clue for easy understanding, or, there is no direct and clear relationship between obtained "Results" and aimed "Target value". Nevertheless, if the productive growth of apple is expected, the current soil nutrient status ("Result") must be harmonized with given apple demands according to the suggested range of desired nutrients ("Target value"). In other words, quantity of some element (kg/ha) in soil should be accomplish by fertilizer use without any additional explanation.

In EUROFINS results, the most frequent discussed macro elements (N, S, P, K, Ca, Mg) in apple nutrition are presented in “Results” as “Total N, S, P, K, Ca and Mg-soil stock”, while their available content in soil is given as “S, P, K, Ca and Mg - plant available” (except N). All this analyzed nutrients are presented as a part of soil mass (kg/ha). Parameter “soil stock” of some analyzed element is given after calculated nutrient content (kg/ha) in certain volume of the soil (kg of X element per ha). For this purpose, it must be known (or measured) a specific mass of investigated soil, what mostly ranged between 1,3-1,7 kg/l. Besides, the amounts of two elements (N, S) which should be “released” from organic complex or represent its available fraction in the soil, is named “N or S-supplying capacity”. Focusing on nitrogen, this “N-supplying capacity” probably includes two soil fractions of NH_4^+ and NO_3^- ions. The first one derives from soil solution and adsorptive complex as leftovers of previously applied N mineral fertilizers, whiles the second one concerns N ions which belong to the residues of organic matter mineralization. According to the results from one EUFOFINS report’s example, available amount of N is too high to be just a product of soil’s mineralization process, especially if it is considered that a relatively small amount of present organic matter (about 2%) in analyzed soil exist. Consequently, the majority of detected N ions derive from N mineral fertilizers. For sulphur, significantly smaller amount was defined as “S-supplying capacity”, showing that less available and less potential sulphur will be released to plants.

The group of all micronutrients (Fe, Zn, Mn, Cu, Co, B and Mo) in EUROFINS analyses is evaluated at the same way as macronutrient, whereby their content is defined in g/ha as “X (micronutrients)”-plant available amount and related also to a “Target value”.

The soil testing done by EUROFINS include some other soil parameters which are of the importance for fruit growth. First one is the pH of tested plots. This parameter can be used in controlling acidification process due to annual mineral fertilizer application. One of the most important soil factors is content of organic matter, derived from C-organic analyses. The C-content in EUROFINS soil report is not just an indication of the presence of organic matter, because reports could have a recommendation about the soil’s organic matter enrichment (kg/ha). In soil analyses, the soil physical properties are also estimated by determination of soil mechanical fractions (clay, silt, sand, or soil particle < 16 μm). This gives an indication about soil physical properties, and this can be indirectly used in the selection of soil tillage system or different mechanical equipement use. In analyses, the calcium carbonate content has been detected as a warning for apple growers about the possiblity of microelement’s deficiency appereance. Also, a CEC saturation (%) is part of EUROFINS soil testing, given as Ca, Mg, K, Na and H and Al-saturation. The obtained values are compared to a range of minimum and maximum given as a “Target value”. This parameter contributes to a better understanding of soil’s adsorption capacity, associated with its mechanical and organic fractions. However, it’s not clear if these „non nutrients’ analytical parameters“ of EUROFINS results are incorporated into the nutrients’ “target value”, because allphysic-chemical parameters can affect the nutrient availability in soil.

However, some remarks to the EUROFINS results could be done. Probably for apple growers it is not easy to reach some calculation based on the previously acquired experience in soil testing and fertilizer recommendations. In example, presented data about the total N stock are not so clear, because its current content in soil is pretty high (4340 kg N/ha). Also, a “Target value” of this element is high, between 3040-4250 kg N/ha. Practically this means that the total soil nitrogen is concerned. However, a total N includes over 90% of organic N, and this is only potentially available N for plants. Although the rate of organic matter mineralization is very important for plant nutrition, the intensity of this process is a matter of different soil factors and climatic condition. It could be measured only by simulation of this natural process in lab conditions, and after all, this result can give only a portion of available soil N, which can be released during the microbial activity over the vegetation period. In fact, this fraction is usually much smaller then quantity of NH_4^+ or NO_3^- originated from previously added mineral fertilizer. As said in previous discussion, this is generally the hugest available N soil fraction and practically serves as base of calculation of plant's N needs. Otherwise, the amount of the present total N stock in the soil is extremely high and can mislead the N requirement in orchards.

Generally, a matter of "Stock reserves" of some element is the major issue of EUROFINS reports. These stock reserves are confusing especially if this value is much lower than its available fraction, like in the case of potassium, or, on the contrary, in the case of phosphorus where its available fractions are practically negligible. In the case of micronutrients, the advantage is that you can do additional fertilizer application to satisfy plant needs.

One of the problems is related to the "Target value" of available Ca and Mg. The values of these two elements differ very little and their excepted range is relatively close (240-510 and 240-300 kg/ha), what disagree to the practice. This can give an indication that Mg in apple nutrition is more needed than Ca, which is expected to be related to soil type and soil properties. Such complex approach need some additional knowledge to accept trigged approach done by EUROFINS labs.

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Prøvenr.:	**542-2020-09270004**	Prøvetakingsdato :	
Prøvetype:		Mottaksdato:	27.08.2020
Prøvemerking:	A4	Rapporteringsdato:	02.11.2020

	Analyse	Resultat	Enhet	LOQ	MU	Metode
*	Volumvekt	0.98	kg/l	0.01		Kalkulering
a)	pH	6.6		3	0.3	ISO 10390: 2005-12
a)	P-AL	78	mg/100g lufttørket	0.2	6.2	DIN EN ISO 11885:2009-09, SS 028310:1995-12
a)	K-AL	13	mg/100g lufttørket	0.2	3.1	DIN EN ISO 11885:2009-09, SS 028310:1995-12
a)	Mg-AL	14	mg/100g lufttørket	0.4	2.4	DIN EN ISO 11885:2009-09, SS 028310:1995-12
a)	Ca-AL	620	mg/100g lufttørket	2.5	110	DIN EN ISO 11885:2009-09, SS 028310:1995-12
a)	Na-AL	7.9	mg/100g lufttørket	1.75	1.8	SS 028310:1995-12, DIN EN ISO 11885:2009-09
a)	Glødetap	9.8	% tv	0.1	0.3	EN 15935 (S33): 2012-11
a)	Syreløselig kalium	240	mg/100g lufttørket	10		DIN EN ISO 11885:2009-09
*	C/N forhold	10				Kalkulering
a)	Total nitrogen (mod. Kjeldahl)	0.47	% TS	0.03	0.02	DIN EN 13654-1: 2002-01
a)	Plantetilgjengelig bor	2.67	mg/kg	0.03		Internal Method (In-House)
a)	Plantetilgjengelig jern	320	mg/kg lufttørket			DIN EN ISO 11885:2009-09
a)	Plantetilgjengelig kobber	32	mg/kg lufttørket	0.2		DIN EN ISO 11885:2009-09
a)	Plantetilgjengelig mangan	2.5	mg/kg lufttørket	0.05		DIN EN ISO 11885:2009-09
a)	Plantetilgjengelig molybden	0.2	mg/kg lufttørket	0.01		DIN EN ISO 11885:2009-09
a)	Plantetilgjengelig sink	33	mg/kg lufttørket			DIN EN ISO 11885:2009-09
a)*	P-Olsen	15.0	mg/100 g tv	1.25	5.6	Internal Method (In-House)
a)*	Titrebar alkalitet	7.4	mekv/100g lufttørket			Internal Method (In-House)
a)	Tørrstoff	97.0	% (w/w)	0.1	1.0	EN 13040: 2008-01
a)	Totalt organisk karbon (TOC)	4.9	% TS	0.1		ISO 10694

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Prøvetype:		Mottaksdato:	27.08.2020
Prøvemerking:	A5	Rapporteringsdato:	02.11.2020

	Analyse	Resultat	Enhet	LOQ	MU	Metode
*	Volumvekt	0.98	kg/l	0.01		Kalkulering
a)	pH	5.9		3	0.3	ISO 10390: 2005-12
a)	P-AL	71	mg/100g lufttørket	0.2	5.7	DIN EN ISO 11885:2009-09, SS 028310:1995-12
a)	K-AL	16	mg/100g lufttørket	0.2	3.7	DIN EN ISO 11885:2009-09, SS 028310:1995-12
a)	Mg-AL	19	mg/100g lufttørket	0.4	3.1	DIN EN ISO 11885:2009-09, SS 028310:1995-12
a)	Ca-AL	370	mg/100g lufttørket	2.5	65	DIN EN ISO 11885:2009-09, SS 028310:1995-12
a)	Na-AL	14	mg/100g lufttørket	1.75	3.2	SS 028310:1995-12, DIN EN ISO 11885:2009-09
a)	Glødetap	8.7	% tv	0.1	0.3	EN 15935 (S33): 2012-11
a)	Syreløselig kalium	260	mg/100g lufttørket	10		DIN EN ISO 11885:2009-09
*	C/N forhold	11				Kalkulering
a)	Total nitrogen (mod. Kjeldahl)	0.39	% TS	0.03	0.02	DIN EN 13654-1: 2002-01
a)	Plantetilgjengelig bor	2.43	mg/kg	0.03		Internal Method (In-House)
a)	Plantetilgjengelig jern	280	mg/kg lufttørket			DIN EN ISO 11885:2009-09
a)	Plantetilgjengelig kobber	32	mg/kg lufttørket	0.2		DIN EN ISO 11885:2009-09

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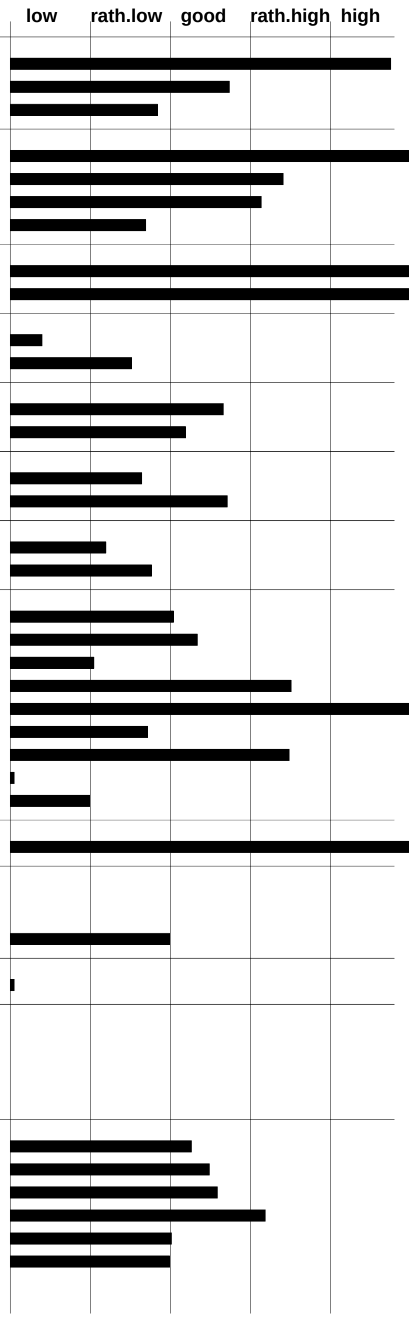
Noorwegen

Analyse	Investigation/ordernr:	Date sampling:	Date report:
	773509/005178523	21-09-2020	02-10-2020

Resultater		**Unit**	**Result**	**Target value**
	Total N stock	kg N/ha	6710	2590 - 3630
Chemical	C/N ratio		16	13 - 17
	N-supplying capacity	kg N/ha	85	95 - 145
	S-plant available	kg S/ha	100	20 - 30
	Total S stock	kg S/ha	1350	520 - 830
	C/S ratio		79	50 - 75
	S-supplying capacity	kg S/ha	17	20 - 30
	P-plant available	kg P/ha	18,9	6,7 - 9,3
	P-soil stock	kg P/ha	2760	395 - 510
	K-plant available	kg K/ha	225	390 - 490
	K-soil stock	kg K/ha	195	245 - 355
	Ca-plant available	kg Ca/ha	355	185 - 435
	Ca-soil stock	kg Ca/ha	4105	3715 - 5570
	Mg-plant available	kg Mg/ha	185	205 - 255
	Mg-soil stock	kg Mg/ha	315	155 - 380
	Na-plant available	kg Na/ha	50	90 - 130
	Na-soil stock	kg Na/ha	50	60 - 90
	Si-plant available	g Si/ha	18430	15550 - 67390
	Fe-plant available	g Fe/ha	8270	6480 - 11660
	Zn-plant available	g Zn/ha	670	1300 - 1940
	Mn-plant available	g Mn/ha	3780	2590 - 3370
	Cu-plant available	g Cu/ha	415	105 - 170
	Co-plant available	g Co/ha	10	10 - 20
	B-plant available	g B/ha	1205	260 - 390
	Mo-plant available	g Mo/ha	< 10	260 - 12960
	Se-plant available	g Se/ha	6,5	9,1 - 12
Physical	Acidity (pH)		6,7	5,4 - 5,7
	C-organic	%	4,1	
	Organic matter	%	9,2	
	C/OS-ratio		0,45	0,45 - 0,55
	Carbonate lime	%	< 0,2	2,0 - 3,0
	Clay (<2 µm)	%	3	
	Silt (2-50 µm)	%	26	
	Sand (>50 µm)	%	62	
	<16 µm	%	11	
	Clay-humus (CEC)	mmol+/kg	92	> 81
	CEC-saturation	%	100	> 95
	Ca-saturation	%	86	80 - 90
	Mg-saturation	%	11	6,0 - 10
	K-saturation	%	2,1	2,0 - 5,0
	Na-saturation	%	0,9	1,0 - 1,5
	H-saturation	%	< 0,1	< 1,0
	Al-saturation	%	< 0,1	< 1,0



Resultater		Unit	Result	Target value	low	rath.low	good	very good
	Soil crumbling	score	10,0	6,0 - 8,0				
	Soil slaking	score	8,8	6,0 - 8,0				
	Risk on wind erosion	score	7,9	6,0 - 8,0				

		Unit	Result	Target value	low	rath.low	good	rath.high	high
	Moisture retention cap.	mm	62						
Biological	Microbial biomass	mg C/kg	8	460 - 1380					
	Microbial activity	mg N/kg	113	60 - 80					
	Fungal/bacterial ratio		0,4	0,6 - 0,9					

Essential nutrients
Each crop requires nutrients. The essential nutrients that a crop needs most are nitrogen (N), sulphur (S), phosphate (P), potassium (K), calcium (Ca) and magnesium (Mg). The other essential nutrients are the micro nutrients iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), boron (B), molybdenum (Mo) and chloride (Cl). A crop require relatively low concentrations of these micro nutrients, however a deficit can cause loss of yield and/or quality in every crop.

A number of other nutrients (sodium, silicon, cobalt, selenium) can also be important to - amongst other factors - the yield, quality, resilience, sturdiness, fertility, palatability and (animal) health.

Elements can also compete with each other. For example, if the Mg status is "good" but the K status is "high", then an Mg deficiency can still occur. Therefore, the recommended dosages take these interactions into consideration.

Fertilisation recommendations and legislation
The fertilisation recommendations aim to achieve an agronomical optimum yield and crop quality. The recommendations do not take any legal restrictions into consideration.

Recommend.		Frequency	Crop	Application 2021	2022
in kg per ha per year	Nitrogen (N)		Apples new	80	80
			Apples existing	80	80
	Sulphate (SO_3)		Apples new	0	0
			Apples existing	0	0
	Phosphate (P_2O_5)		Apples new	0	0
			Apples existing	0	0
	Potassium (K_2O)		Apples new	0	0
			Apples existing	0	0
	Calcium (CaO)		Apples new	95	95
			Apples existing	95	95
	Magnesium (MgO)		Apples new	100	100
			Apples existing	100	100
			It is recommended to apply magnesium at the beginning of March.		
	Zinc (Zn)	per year	Apples new	0	
			Apples existing	0	
	Manganese (Mn)		No Manganese deficiency is to be expected.		
	Copper (Cu)	per year	Apples new	0	
			Apples existing	0	
	Boron (B)	per year	Apples new	0	
			Apples existing	0	
	Lime (nw)	once	Apples new	0	
			Apples existing	0	
	Effective org. matter	per year		4570	
Soil structure	Calcium (CaO)	once		0	
	Magnesium (MgO)	once		0	

Explanation

You can use the results and/or the recommendation from this fertilisation until the end of 2022 . Then you should have the field sampled again. That will give you a good insight into the fertility situation.

Sulphur:
Sulphur (S) is released by the degradation (mineralisation) of organic matter or manure. This mineralisation is performed by soil organisms. Soil organisms are not very active under colder conditions, which means not much S is released from the soil early in the spring. Therefore, it is sensible to fertilise with S for many early crops, even if the soil content is good or high (consult with your adviser).

Phosphate:
P-supplying capacity is 33 . The target in the range is 17 - 27
The P-buffering capacity indicates whether the P-soil stock is high enough to maintain the level of plant available P. When the buffering capacity (buffering power) is low, the plant available P will not remain on level during the growing season: it will decrease.

Calcium:
Depending on the state of the soil, the calcium recommendation is partly crop-based and partly soil-based.
The crop-based CaO fertilisation recommendation (directly below the potassium advice) is primarily intended to improve the quality of the crops.
The soil-based recommendation is intended to supplement the soil supply of calcium and will also have a positive effect on the soil structure (see CEC triangle). Please note: you may also be advised to give a dose of lime. You do not have to give several doses of calcium; you should subtract calcium from nitrogen, phosphate and lime fertilisers from the total.

Sodium:
Research suggests that sodium fertilization is not useful for this crop. No valuation and recommendation are therefore provided. Nevertheless, sodium is measured as it is part of the clay-humus complex (CEC-saturation).

Manganese:
The pH of the soil is taken into account in the valuation of manganese. Shortage in crops often leads to a reduction in quality and quantity of the yield. Shortages are visible first in th e youngest leafs. These become pale green, fold and become limp.

Soil life:
The biological soil fertility is measured by 3 characteristics, the microbial biomass, the microbial activity, and the fungal/bacterial ratio.
The acknowledgement of the measured results is based upon the amount of organic matter. There is not a recommendation given for the measured characteristics. On the basis of research projects there will be more information available.

Organic matter

Figure: Organic matter balance

Yearly breakdown rate (percentage) of the total organic matter content (%): 2,4

- Stock of organic matter which will remain after 1 year in the sampled layer if no (effective) organic matter is supplied.
- Total required supply of effective organic matter as a result of the degradation of the organic matter.
- Supply through crop residues (average within provided rotation scheme or crops).
- Remaining to be supplied through e.g. animal manure, green manures and/or compost.

Crop (residue)	Input of effective organic matter
Apples new	1250
Apples existing	1250

Average input/year	1250

250 kg effective organic matter has been assumed as supply from crop residues (50% coverage with grass). In case of full grass coverage you can take another 250 kg supply into account.

The quantity of effective organic matter which you have to supply to sustain the current organic matter content is high to such an extent that it is practically impossible to compensate it through the supply of crop residues, animal manure and compost. Taking current level of organic matter into account, this is usually hardly a problem.
For increasing the soil organic matter content by 0.1%: 2590 kg effective organic matter per hectare is needed.

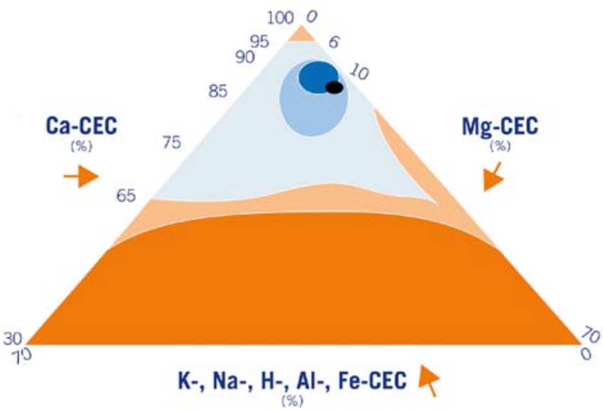
Figure: Quality of the organic matter

Organic matter consists primarily of C, N, P, S. If the organic matter contains relatively high amounts of N and/or S, this makes it attractive to soil organisms. Soil organisms happily eat this organic matter. N and S are released in the process and the amount of organic matter decreases slightly (dynamic organic matter). Organic matter can also contain a lot of C. This is generally less attractive to soil organisms (bacteria). As a result, the organic matter is not consumed as quickly by the soil organisms; making the organic matter more stable. Stable organic matter contributes - among other factors - to the workability of the soil and the looseness. Dynamic organic matter contributes primarily to the release of N and S and is therefore a source of these nutrients for the crop. The quality of the organic matter can be changed (gradually) by paying attention to the properties of soil improvers such as animal manure, compost and crop residues.

Physical

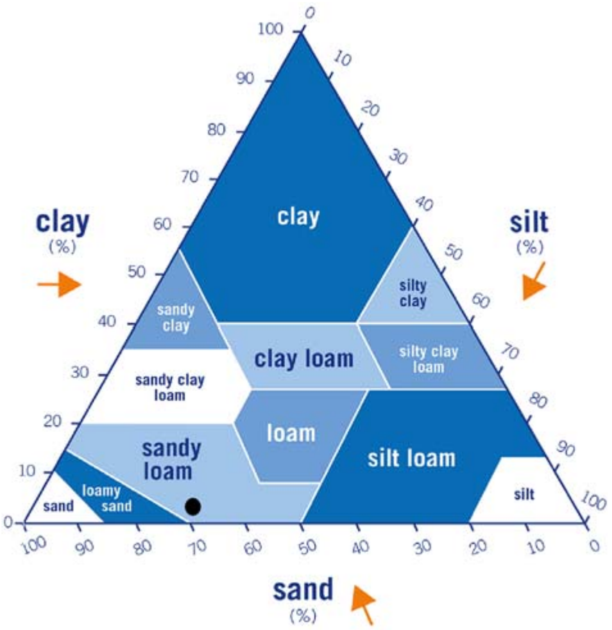
The assessment of soil structure is based on the Ca-CEC, K-CEC, and Mg-CEC ratio. Actual soil structure is - of course - not merely depending on ratio, but also on weather conditions, moisture condition of the soil, and the weight of the machinery.

Figure: Structure triangle



- optimal structure
- good structure
- moderate structure
- very moderate structure
- poor structure
- current structure

Physical **Figure: Texture triangle**

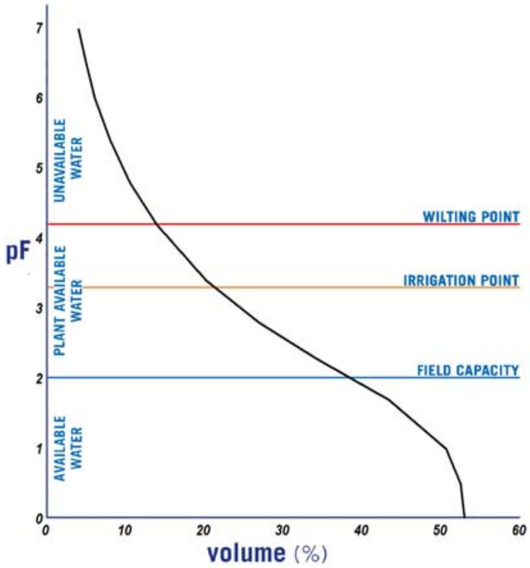


Besides clay, the silt and sand fractions are presented as well. Clay is smaller than 2 micrometer (µm), silt particles are 2-50 µm and sand particles are larger than 50 µm. The relative distribution of soil particles is used to estimate the risk of slaking. Slaking causes the soil pores to be clogged with smaller particles and degrades soil structure. The risk of slaking is greatest at 10-20% clay.

Median of the granular sand fraction (M50) = 115 µm.
M50 is a measure of the coarseness of sand. We use this when determining the water-binding capacity of the soil (pF/water-retaining ability).

Soil crumbling score is: good, however the evaluation of soil crumbling status is also depending on crop type.
Considering the results, the chance of soil slaking is small.

Figure: Water retention curve



The amount of plant available water in the sampled layer is 62 mm. This is the maximum amount you should irrigate. All excess irrigation will drain off the parcel or will sink to deeper layers.

Crops have difficulties to obtain water when the actual moisture level is below pF 3,3. When you are able to measure the moisture level, start with irrigation if the moisture content of the parcel is at 21,4 % and irrigate 44 mm.

The actual moisture level can be measured by using a soil moisture sensor, or collect soil from ten spots in the parcel. Measure the weight of the moist soil and the weight after 24 h drying. The difference between moist and dry soil is an indication of the moisture level of the parcel.

Contact & info

Soil layer:	0 - 25 cm
Sample was taken by:	Third party
Contact sample taking:	Han v/d Goor: 0888761010

After this report has been sent, the sample will be stored for another two weeks for you at Eurofins Agro, if the nature and test method of the sample so permit. Within that period you may complain and/or request additional tests.

09270081-Olavsh-1/101-112

Method		Result	Unit	Method	RvA
Results analyses	Total nitrogen stock	2590	mg N/kg	Em: NIRS (TSC®)	Q
	S-plant available	38,7	mg S/kg	Em: CCL3(PAE®)	
	Total sulphur stock	520	mg S/kg	Em: NIRS (TSC®)	Q
	P-plant available	7,3	mg P/kg	Em: CCL3(PAE®)	Q
	P-soil stock	244	mg P_2O_5/100 g	PAL1: Gw NEN 5793	Q
	K-plant available	86	mg K/kg	Em: CCL3(PAE®)	Q
	K-soil stock	1,9	mmol+/kg	Em: NIRS (TSC®)	
	Ca-plant available	1,7	mmol Ca/l	Em: NIRS (TSC®)	
	Ca-soil stock	94	mmol+/kg	Em: NIRS (TSC®)	
	Mg-plant available	72	mg Mg/kg	Em: CCL3(PAE®)	Q
	Mg-soil stock	10,0	mmol+/kg	Em: NIRS (TSC®)	
	Na-plant available	19	mg Na/kg	Em: CCL3(PAE®)	Q
	Na-soil stock	0,8	mmol+/kg	Em: NIRS (TSC®)	
	Si-plant available	7110	µg Si/kg	Em: CCL3(PAE®)	
	Fe-plant available	3190	µg Fe/kg	Em: CCL3(PAE®)	
	Zn-plant available	260	µg Zn/kg	Em: CCL3(PAE®)	
	Mn-plant available	1460	µg Mn/kg	Em: CCL3(PAE®)	Q
	Cu-plant available	160	µg Cu/kg	Em: CCL3(PAE®)	Q
	Co-plant available	4,1	µg Co/kg	Em: CCL3(PAE®)	Q
	B-plant available	464	µg B/kg	Em: CCL3(PAE®)	Q
	Mo-plant available	< 4	µg Mo/kg	Em: CCL3(PAE®)	
	Se-plant available	2,5	µg Se/kg	Em: CCL3(PAE®)	
	Acidity (pH)	6,7		Em:PHC3(Gw NEN ISO 10390)	Q
	C-organic	4,1	%	Em: NIRS (TSC®)	Q
	Organic matter	9,2	%	Em: NIRS (TSC®)	Q
	C-inorganic	0,03	%	Em: NIRS (TSC®)	
	Carbonate lime	< 0,2	%	Em: NIRS (TSC®)	
	Clay (<2 µm)	3	%	Em: NIRS (TSC®)	
	Silt (2-50 µm)	26	%	Em: NIRS (TSC®)	
	Sand (>50 µm)	62	%	Em: NIRS (TSC®)	
	Clay-humus (CEC)	92	mmol+/kg	Em: NIRS (TSC®)	
	Microbial biomass	8	mg C/kg	Em: NIRS (TSC®)	
	Microbial activity	113	mg N/kg	Em: NIRS (TSC®)	
	Fungal biomass	417	mg C/kg	Em: NIRS (TSC®)	
	Bacterial biomass	1141	mg C/kg	Em: NIRS (TSC®)	

The values stated on page 1 and 2 under 'Result' are calculated from the above mentioned analysis results.

Q Method accredited by RvA
Em: Method Eurofins Agro, Gw: Equivalent of, Cf: In conformity with
P-soil stock This analysis was performed in duplicate.

Results are reported in dry soil.
All procedures have been completed within the maximum shelf life between sampling and analysis.
The reported results only refer to the processed material on 23-09-2020

NIBIO - Norwegian Institute of Bioeconomy Research was established July 1 2015 as a merger between the Norwegian Institute for Agricultural and Environmental Research, the Norwegian Agricultural Economics Research Institute and Norwegian Forest and Landscape Institute.

The basis of bioeconomics is the utilisation and management of fresh photosynthesis, rather than a fossile economy based on preserved photosynthesis (oil). NIBIO is to become the leading national centre for development of knowledge in bioeconomics. The goal of the Institute is to contribute to food security, sustainable resource management, innovation and value creation through research and knowledge production within food, forestry and other biobased industries. The Institute will deliver research, managerial support and knowledge for use in national preparedness, as well as for businesses and the society at large.
NIBIO is owned by the Ministry of Agriculture and Food as an administrative agency with special authorization and its own board. The main office is located at Ås. The Institute has several regional divisions and a branch office in Oslo.

Cover photo: The apple cultivar 'Summerred' is one of the main commercial cultivars in Norway. Photo: Mekjell Meland