Quote: Two methods help us with the fine-tuning of plant nutrition: leaf analysis and foliar fertilization.

Modern Guidelines on Fruit Tree Nutrition

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In the South Tyrolean fruit industry plant nutrition is considered a means to achieve the following primary objectives:

- high and regular yields
- good internal quality (storage potential, flavor, taste, firmness)
- external quality (fruit size, color, texture)
- little leaching

In order to achieve these objectives we make use of the following knowledge and techniques:

- knowledge of the nutrient losses through crop and soil
- nitrogen balance in the soils
- results of trials on fertilization
- soil, foliar and fruit analyses

The nutrient requirements of the crop are determined from the nutrient balance in the soil under our conditions. From fruit analyses and the mean production per hectare of 45 metric tons (MT)/ ha or 45 bins/acre we know the amount of nutrients taken up from the soil each year. This is an important parameter for us because our fertilizer program is based on it (Table 1).

If the nutrient supply in the soil is within the optimum range (class C) according to the soil analyses and our assessment, we recommend supplying an amount of nutrients which is slightly higher than that taken up by the crop (Table 2).

If there is a slight deficiency of these elements (class B), the nutrient supply is increased by 50%. On the contrary, if there is a slight surplus of nutrients in the soil (class D), the quantities are reduced by 50%. In case of a severe shortage, the fertilizer quantities are doubled. With a considerable surplus, a suspension of fertilization for several years is recommended.

In plant nutrition the health and the quality of the soil also play an important part. This applies especially to mobile elements like nitrogen, potassium and the trace element boron which tend to leach out.

In the South Tyrolean fruit growing region, approximately 80% of the acreage is on sandy loam soils or loamy sand of light to medium texture. The clay content varies between 8 and 15%. Soils

containing high amounts of clay are rare in our region. Near the rivers there are mainly sandy soils. In general our orchard soils are low in calcium, the pH ranges from 5.5-6.5.

Only about 20% of our orchards are situated on dolomite sediments. The calcium content and the pH value are accordingly higher (pH 7-8%). The South Tyrolean orchards are well supplied with humus (organic matter) because for decades it has been the practice to mulch the grass and all the organic parts of the trees, including leaves and the wood prunings. The humus content is within an optimum range of 3-5% and tends to increase.

The nitrogen level in the soils is generally well balanced, since the losses and the applications are in equilibrium in the long run. We adopted for our conditions the method developed by the German researcher F. Weller (Table 3). Of course, this balance is valid only for average soils with a humus content of approximately 3-4%. If on such soils nitrogen applications are suspended for some time, symptoms of N-deficiency such as small, yellow leaves, small fruits and stunted growth appear.

In soils rich in humus, e.g., in the lower elevations at the bottom of the valley, the N-balance is certainly positive. This means that the nitrogen supply through the breakdown of humus is higher than the losses through leaching and the crop. In such cases nitrogen fertilization is not advised. Practical proof of this is that there are quite a number of orchards where no nitrogen has been applied for many years with good crops and no deficiency symptoms.

On the other hand, the rare, very sandy soils which are low in humus have a negative N-balance, that is, their nitrogen requirements are higher than the natural supply. In this case it is often necessary to apply higher amounts of nitrogen than those which are used up by the crop.

Theories are quite useless unless they are confirmed by trials, practical experiences and observations. The Experiment Station Laimburg has carried out a trial on the application of increasing rates of fertilizers over a period of 17 years (Table 4). The results showed clearly that an increase in the application of nitrogen beyond the rates of 60 kg/ha N (53 lbs/acre N) does not lead to higher returns. This has contributed materially to a sound scientific back-up of the recommendations.

SOIL ANALYSIS

Soil analysis is essential for the orchardist and the adviser, since it supplies the basic data on the soil and its nutrient status. We test the soil for pH value, humus content, soil type and calcium level. Phosphorus, potassium and magnesium levels are determined in accordance with the German LUFA Research Laboratories.

Soil analyses are recommended for new plantings and young orchards. In the Integrated Production (IP) program it is mandatory to carry out a soil analysis within the first years. In bearing orchards a soil test is required every 5 years. Our two laboratories for soil analyses test approximately 3,000 soil samples every year for the fruit growers. The trend is increasing.

As a specialist in plant nutrition I assess hundreds of soil analyses every year and work out the fertilization requirements. In my experience in more than half the cases a significant reduction of fertilizer input can be recommended in comparison with the original fertilizer programs of the operations. This saves money, improves the internal and external quality of the fruits and safeguards

the soil and the water against toxic nitrates. The cost of US$40 per analysis is negligible in comparison with its advantages.

We did not have much use for the traditional leaf analyses which were usually performed in mid-summer. This is because

- results of the analyses arrived too late to allow major corrections through fertilization during the vegetative period
- leaf analyses can be utilized only to a certain extent for fertilizer programs in the following year
- growers were not ready to have leaf analyses made in the summer until shortly before harvest

EARLY LEAF ANALYSES

For these reasons we had been thinking of a new, earlier time of leaf analyses, soon after bloom. From 1993 onward the Research Station Laimburg launched an intensive program of leaf analyses carried out in many orchards in order to determine the nutrient level in the leaves in the course of the vegetative period. From these data the optimum range of nutrient levels was developed, starting from full bloom. Each element has its own typical curve, as is shown in the graphs (Figures 1, 2, 3).

This system allows us to make leaf analyses during the whole period of vegetative growth. The results are compared with the optimum values of the curve at the time of sampling. A result above the upper curve indicates a nutrient surplus, a result below the lower curve a nutrient deficit. However, the curves shown above are not intended to remain static; they are periodically adjusted with new findings.

Early leaf analysis has many advantages:

- At the time of the highest nutrient requirements (after bloom) it is important to determine a nutrient excess or deficiency.
- In spring the conditions are frequently unfavorable for nutrient take-up (frost, low soil temperature, waterlogging).
- An imbalance of the nutrient levels in the early vegetative period has negative effects on fruit set, bud formation and differentiation for next season and fruit quality.
- In case of a nutrient deficiency, a fast soluble mineral fertilizer or foliar fertilizer can be applied in time.

As we have had some problems with the availability of nutrients and trace elements, we have established a monitoring system of early leaf analyses in numerous trial orchards. With this system we can observe and analyze the characteristics of nutrient uptake during the season which are influenced by the meteorological conditions. On the basis of this we can work out our recommendations.

For example, in the cold spring of 1997, with frequent frosts, in numerous orchards the nitrogen concentration in the leaves was low after bloom. Through the frost irrigation much nitrogen was leached out and the low soil temperatures impeded the uptake of nitrogen. In this case we recommended foliar urea sprays because they are rapidly absorbed. Among the trace elements, manganese and boron seem to be very important for healthy development of the leaves. If our monitoring system should detect many cases of deficiencies of these two elements, we could immediately warn our orchardists to apply foliar manganese or boron sprays.

Our assessment of the traditional late leaf analyses in July/August follows the well-known international standards (Table 5).

EARLY FRUIT ANALYSIS

An additional method to target the nutrient supply, especially so as to improve internal fruit quality, is early fruit analysis. We have been using it since 1986 for a bitter pit prediction program. Also in this case we rely on a network of orchards with different varieties. For 12 years we have been taking fruit samples for analyses at the beginning of July, when the fruitlets have reached an average weight of 70 g. The calcium and potassium levels in the fruit supply useful information about the danger of bitter pit and other physiological diseases in the fall.

If the potassium/calcium ratio in the fruit projected forward to the fall remains under 30, there is no danger to the internal quality of the fruits. In this case we advise proceeding with the usual measures. As soon as the index rises above 30-35, we issue a warning. In the summer of 1998 the situation was extremely critical with a K/Ca ratio of 37. We never had reached such a dangerous value since the introduction of this method. In this situation the Advisory Service recommended a series of measures against bitter pit.

Measures recommended in case of an increased risk of bitter pit are:

- increased number of calcium applications
- summer pruning
- reduced irrigation
- ground cover under the trees

Before the 1998 harvest we noticed fruits with bitter pit symptoms on susceptible varieties like Jonagold or Braeburn and on trees bearing light crops. During storage, bitter pit damage increased further and reached an average of 8-10%. On Golden Delicious and Braeburn we recorded peaks of 30%. The bitter pit prediction model proved effective. However, if the conditions are very favorable for bitter pit incidence, even intensive calcium sprays can only reduce the damage, but they can work no miracles.

NITROGEN

Nitrogen affects all the important stages in the life and production cycle: e.g., shoot growth, yields and fruit quality. Therefore the handling of nitrogen fertilizers (rates, time, type of fertilizer) is a very delicate matter which requires a lot of experience, know-how and observation. The correct determination of the nitrogen requirements is rendered more complicated by some factors which are difficult to assess such as the amount of nitrogen leaching and the mineralization rate.

Under our soil and weather conditions the level of available nitrogen, N mineralized (N-min), is likely to be low in spring. Along with the soil temperature the N-min content rises, peaks in June/ July and remains very high until October. It is not until the soil cools down in the fall that the N-min values drop (Figure 4).

The nitrogen need of the trees shows a different curve. It reaches its peak in the spring (bloom until end of first stage of shoot growth) and flattens in the course of the summer until fall.

What can we do in practice in order to counterbalance these contrary developments in the soil and the trees?

1. In order to restock the nitrogen reserves after harvest, urea 30-40 kg/ha (26.7-35.7 lbs/acre) is sprayed. This is done especially in orchards with a heavy crop and a slight nitrogen deficiency.
2. If required, nitrogen is applied in pre-bloom.
3. If the nitrogen uptake is disturbed by low soil temperatures below 5°C (41°F) and frost, we recommend supportive urea sprays 5-7 kg/ha (4.3-6 lbs/acre) in the spring around bloom.
4. In the summer and before harvest the nitrogen and potassium supply frequently exceeds the requirements (due to the mineralization and breakdown of the grass mulch). If this becomes a problem (too vigorous growth, too large fruits, physiological disorders in the fruits) two measures are advisable: 1) a reduction of irrigation (by up to 50% of the evapotranspiration) and 2) a ground cover in the tree row.

In spite of all the information we possess on the nitrogen balance in fruit tree growing, the orchardists are still confronted with the basic question: How much available nitrogen is contained in the soil and how much should they apply in spring? Some years ago we introduced a valuable method, the N-min-analysis, which helps us answer these questions.

For the N-min-analysis we use a chilled soil sample to determine the available nitrogen (NO_3 + NH_4) in a 0-40 cm (0-16 inches) deep soil layer. The best time to do this is 2-3 weeks before bloom, prior to fertilization. Based on the N-min values we have worked out a nitrogen application program which has proven successful (Table 6).

This method allows a precise adjustment of N input at a critical time, that is, in spring before bloom. This analysis costs the orchardist only US$12.50. Lately we have also applied a colorimetrical field method, using the sticks (nitrate test) of the Merck Company. This seems to be an interesting and fast method.

From the data on the N losses through the crop, the N-balance in the orchard soils, the trials and the N-min examinations we can deduce that in a normal bearing orchard the trees require 30-50 kg/ha N (26.7-44.6 lbs/acre) every year before bloom. Sandy soils which are low in humus require more nitrogen (up to 80-100 kg/ha) (71.4-89 lbs/acre).

Very fertile soils with a deep subsoil frequently do not need an additional nitrogen application.

POTASSIUM

The key element potassium regulates water absorption, internal and external fruit quality, especially fruit size, taste and flavor and finally the incidence of physiological disorders. The uptake of potassium by the plant has a peculiarity which must be kept in mind when fertilizing.

The potassium level in the soil and, still more, the humidity of the soil influence the K-uptake very strongly. This renders correct potassium management in the orchard more difficult since numerous and well-distributed rainfalls in spring and summer may result in an undesirably high potassium uptake.

Potassium diffuses easily into the leaf and fruit tissue and excessive supply leads to leaf spots and leaf drop on Golden Delicious and Gala as well as to physiological disorders like bitter pit, internal breakdown and storage problems. Therefore we advise using potassium fertilizers with caution.

If the potassium level in the soil is within the optimum range, only the losses through the crop should be compensated, that is, 60-100 kg/ha K_2O (53-89 lbs/acre). For light crops the lower rate is advisable, for heavy crops the higher one. After the increased potassium uptake in the last years we now recommend splitting the potassium input. Before bloom only half the annual amount should be applied. If fruit set proves to be good or very good, the remainder should be applied.

CALCIUM

The key element calcium is decisive for the internal stability and health of the fruit. We know that in the South Tyrol the calcium level in the soil does not play a very important part. This element spreads very unevenly within the plant. The shoots and leaves have a high sink potential for calcium and easily absorb the calcium contained in the sap. The fruits absorb calcium, especially in the early stages, as long as they themselves assimilate. Later they absorb very little calcium.

We recommend calcium applications to the soil at regular intervals, in order to

- keep the pH value within the desired slightly acid range (pH 6-7)
- compensate the losses through leaching
- maintain the healthy soil texture, especially the stability of the crumbs and the soil aeration

With pH values ranging from pH 5.5-6.5 and a low calcium level we recommend an application of approximately 1,000-1,500 kg/ha (0.4-0.6 MT/acre) calcium carbonate, if necessary also dolomite, every two years.

MAGNESIUM, MANGANESE, BORON

Magnesium and manganese are the key elements for good leaf quality. Under our conditions even a slight deficit can result in poor leaf development in spring, leaves turn pale green while the veins remain dark green, leaf drop and thus a reduced photosynthesis.

An adequate magnesium concentration in the soil seems to be important. Therefore, even if the soil analysis indicates an optimum supply, we recommend an annual application of 20-30 kg/ha MgO (17.8-26.7 lbs/acre). Difficult soil conditions (cold soil, waterlogging, unfavorable pH) can reduce the magnesium and manganese uptake. In such cases we recommend foliar sprays with these two elements.

Our lightly textured sandy soils are often low in boron and therefore it is the most critical trace element in our fertilization programs. Boron is important to ensure

- adequate growth of the pollen tube which is crucial for a good pollination
- sufficient shoot growth
- suitable calcium deposit in the fruits
- smooth skin of the fruits

It is our primary aim in mineral nutrition to keep the tree healthy and to promote the nutrient uptake through the roots.

Starting from a very high fertilizer input we have now, after years of educational work, come very close to the actual nutrient rates required by a modern intensive planting. In spite of the reduced nutrient supply the yields are still increasing in our fruit growing area and the remarkable thing is that fruit quality also improves, especially taste and storage life. Of course, this practice sometimes takes us close to the lower limits, even with our fertile soils. Here we can easily slide into a slight nutrient deficiency. This situation obviously requires a good sense of the correct nutrient rates.

Two methods help us with the fine-tuning of plant nutrition: leaf analysis and foliar fertilization.

FOLIAR FERTILIZATION

Foliar fertilization is used for fine-tuning as

- a curative measure if deficiency symptoms occur
- a supplement to soil applications (if the uptake through the roots is impeded)
- a prevention of physiological disorders (leaf drop, bitter pit, etc.)
- a method to increase the reserves in the plants

We recommend the application of magnesium as magnesium sulfate (7-15 kg/ha = 6.2-13.4 lbs/acre) or as magnesium nitrate (4.5-6 kg/ha = 3.6-5.3 lbs/acre) in the following cases: 1) a magnesium deficiency (leaf symptoms or indicated by a leaf analysis) and 2) as preventive treatments on Golden Delicious and Gala if leaf spots or drop occur or if there is an accumulation of risk factors.

The new varieties Gala, Braeburn, Fuji and Pink Lady, but also Golden Delicious, are rather susceptible to magnesium and manganese deficiency and react with poor leaf development and spotted leaves. In these cases we recommend 2-3 treatments with manganese sulfate 3 kg/ha (2.7 lbs/acre) or Mantrac (Phosyn) 0.5 kg/ha (0.4 lbs/acre).

Boron fertilizers are readily absorbed by the leaves and transported to other parts of the plant. In order to ensure above all a good function of blossom organs, which is important for pollination, we recommend 2-3 boron applications (Borax 2.5 kg/ha = 2.2 lbs/acre or Solubor 1.5 kg/ha = 1.3 lbs/acre) from pre-bloom onwards. We usually mix boron with scab pesticides. Through these widely used treatments our light soils, which are low in boron by nature, receive annually a basic supply of this trace element.

Phosphorus and potassium are normally not applied as foliar sprays, iron and zinc only in exceptional cases.

FOLIAR CALCIUM

As a calcium fertilizer for preventing bitter pit and other physiological disorders, calcium chloride as a salt or in a soluble form has proven effective. Depending on the variety, the crop and the risk of bitter pit we recommend a range of calcium sprays (Table 7).

Factors to consider with calcium applications include:

- calcium chloride and, in case of a nitrogen deficit, calcium nitrate are the most effective foliar fertilizers
- begin sprays from 70 g fruit weight onwards; preharvest treatments are most effective
- calcium sprays can be delivered with fungicides, with low water volumes and through over-tree irrigation
- calcium chloride has no negative effect on the blush, fruit size and photosynthesis

If bitter pit pressure is very high, calcium applications alone can only diminish bitter pit incidence, not eliminate it.

FERTIGATION

Also in our fruit growing region drip irrigation systems are advancing, partially in combination with over-tree irrigation. This allows a fertilization technique known as fertigation. We know of the Dutch experiences with fertigation, where it resulted in increased growth, more flower buds and higher initial yields, especially in young orchards. In the trials carried out at the Research Station Laimburg, we also noticed somewhat increased growth and crops in the fertigation plots but not to such an extent as recorded in the Dutch experience. The fertigation plots showed a light increased tree growth in the first year (Figure 5).

However, it is not easy to discern how much of this is due to the regular irrigation and how much to the regular supply of soluble fertilizers. The cumulative yields over 5 years for Gala were also higher in the fertigation plots (Figure 6).

However, the increase in yields was not so high in comparison with the plots with broadcast application of different fertilizers as to justify the additional costs of drip irrigation since over-tree sprinklers are indispensable for frost irrigation. Our Advisory Service recommends drip irrigation only on elevated sites which are free of frost. In these sites this new technique is a practical method of distributing nutrients. The market offers a multitude of rather expensive soluble mixed fertilizers in various compositions. For economic reasons we prefer to use fertilizers containing only one or two elements, like calcium nitrate, urea, ammonium monophosphate, potassium nitrate, potassium sulfate and others.

CONCLUSIONS

Knowledge and modern analytical techniques help us find the right nutrient need for each orchard. Applying these techniques in the practice can improve fruit quality, save money and protect the environment.

Table 1. Nutrient needs of a crop of 45 MT/ha.

Nutrient	kg/ha	lbs/acre
N	15.7-22.5	14-20
P_2O_5	9.9	8.8
K_2O	54-72	48-64
CaO	3.3	3
MgO	3.6	3.2

Table 2. Suggested fertilizer rates with optimum soil nutrient level for a Golden Delicious crop of 45 MT/ha in South Tyrol, Italy.

Fertilizer	kg/ha	lbs/acre
P	10-20 kg P_2O_5/ha	8.9-17.8 lbs/acre
K	60-100 kg K_2O/ha	53-89 lbs/acre
Mg	20-30 kg MgO/ha	17.8-26.7 lbs/acre
B	0.5-0.7 kg B/ha	0.45-0.65 lbs/acre

Table 3. Example of an orchard nitrogen balance (based on F. Weller).

Input	lbs/acre	kg/ha	Loss	lbs/acre	kg/ha
Rainfall	17.8	20	gaseous loss	17.8	20
Biol. binding	17.8	20	leaching	17.8	20
Grass mulch	178	200	grass	178	200
Pruned wood	26.7	30	orchard uptake	26.7	30
Totals	241	270		241	270

Table 4. Cumulative crops 1972-1989 from N-fertilization trial at the Experiment Station Laimburg.

	Treatment		
Variety	Control	60 kg/ha N (53 lbs/acre)	120 kg/ha N (107 lbs/acre)
	Annual yield	Yield change	
Golden Delicious	45 t/ha	plus 4.2%	minus 0.1%
Rome Beauty	95 t/ha	plus 13.2%	plus 17%

Table 5. Optimal leaf nutrient levels based on summer analysis.

	%		ppm
N	2.3-2.6	B	30-50
P	0.16-0.26	Fe	40-100
K	1.1-1.6	Mn	40-100
Ca	1.2-2	Cu	5-12
Mg	0.18-0.36	Zn	20-50

Table 6. Nitrogen mineralization (N-min) values and appropriate nitrogen fertilization levels.

N-min		N-fertilization	
lbs/acre	kg/ha	lbs/acre	kg/ha N
<26.7	<30	26.7-44.6	30-50
26.7-44.6	30-50	0-26.7	0-30
>44.6	>50	0	0

Table 7. Number of foliar CA-treatments per season in South Tyrol.

	Fruit set	
Variety	Good	Weak (young trees)
Gala, Elstar, Idared	1-2	2-3
Golden Delicious, Fuji	2-3	4-5
Granny Smith, Red Delicious, Jonagold, Winesap	3-4	5-6
Braeburn	4-5	6-8

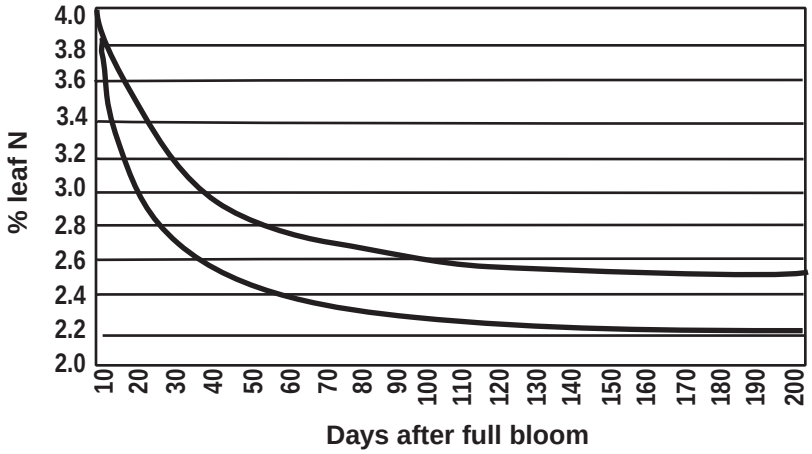

Figure 1. Range of optimal leaf nitrogen.

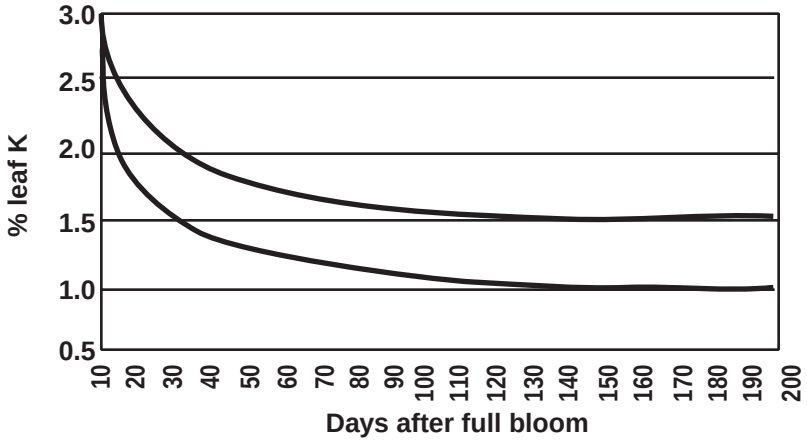

Figure 2. Range of optimal leaf potassium.

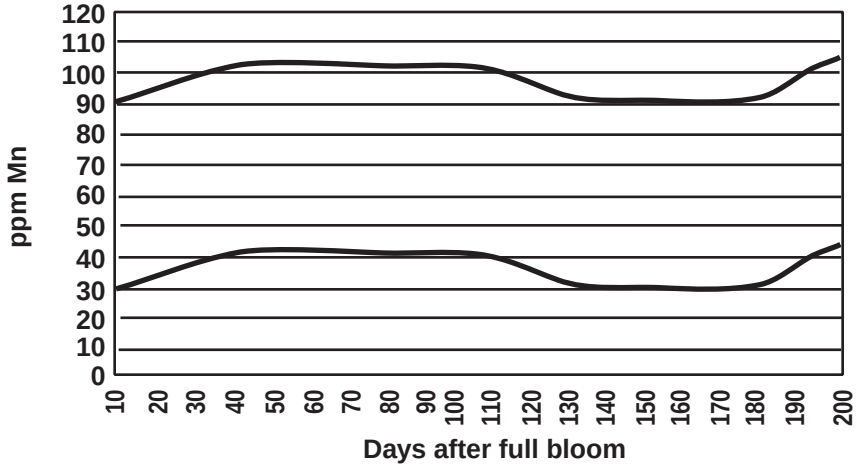

Figure 3. Range of optimal leaf manganese.

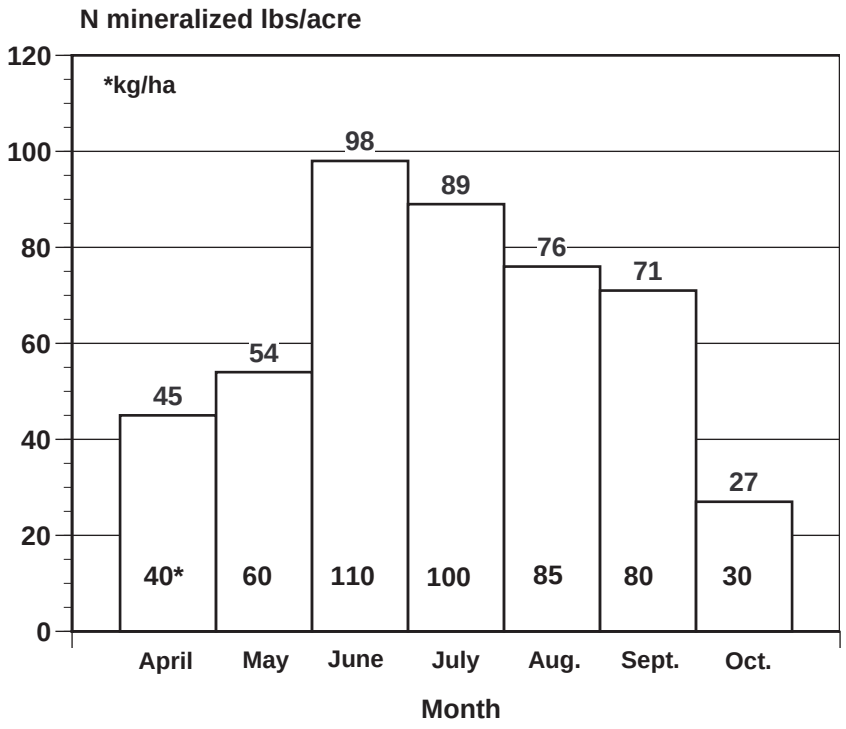

Figure 4. Mean values of N mineralized in orchard soils.

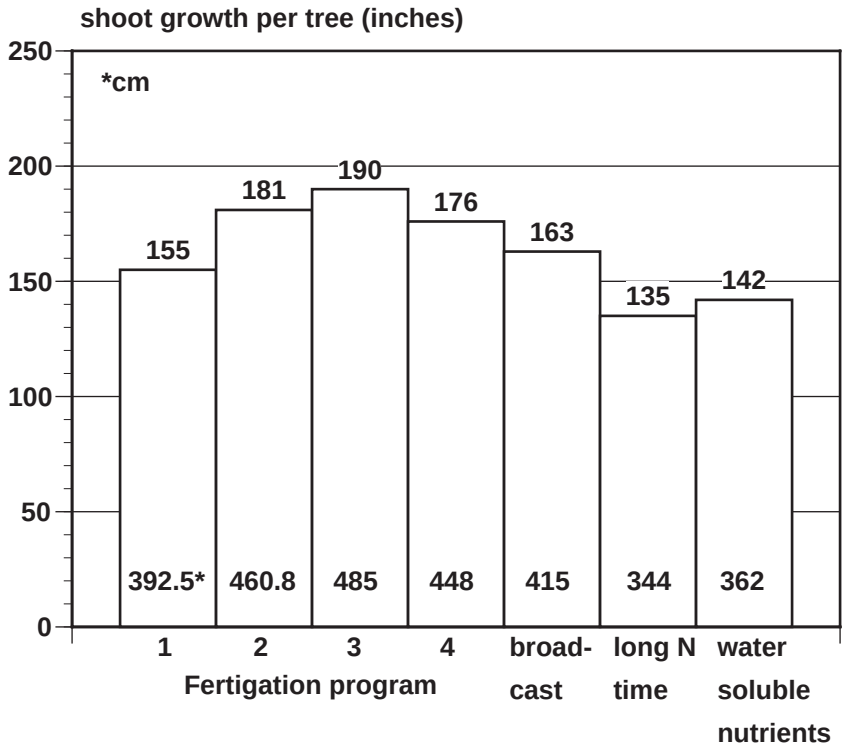

Figure 5. Tree growth in the 1st year in trees at the Research Station Laimburg in 1997 for different types of fertilization.

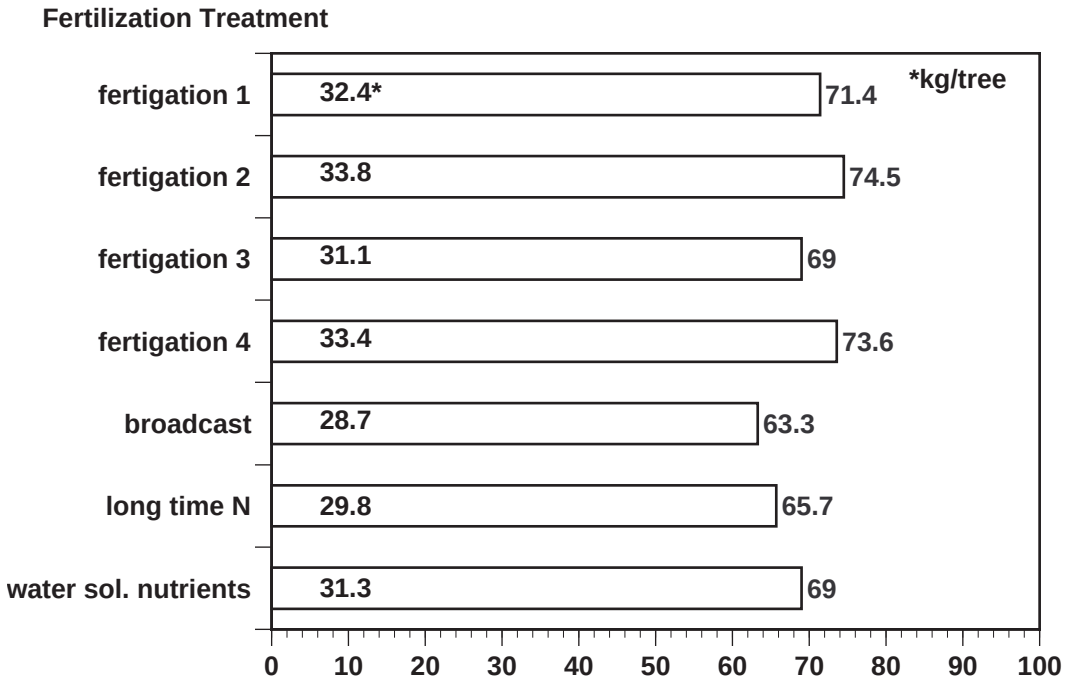

Figure 6. Cumulated crop yield (lbs/tree) to the 5th year in trials at Research Station Laimburg in 1997 for different types of fertilization on Gala.