Nutritional recommendations for

STRAWBERRY

Haifa

Pioneering the Future

1. General information

1.1 History

Strawberries belong to the crop group of soft-fruits; they are the best of the berries. The delicate heart-shaped berry has always connoted purity, passion and healing. It has been used in stories, literature and paintings throughout the ages.

The first documented botanical illustration of a strawberry plant appeared as a figure in herbaries in 1454.

Strawberries were probably first grown in gardens in the 13th or 14th centuries, but for many years afterwards, especially in England, they differed little from the wild plants.

The American Indians were already eating strawberries when the colonists arrived. The crushed berries were mixed with cornmeal and baked into strawberry bread. After trying this bread, colonists developed their own version of the recipe and *strawberry shortcake* was created.

The English "strawberry" comes from the Anglo-Saxon "streoberie" not spelled in the modern fashion until 1538. The name strawberry probably comes from 'strayberry', for the runners cause young plants to stray from the parent.

All attempts to breed and improve the strawberry crop from European cultivars of the species *Fragaria vesca* failed until American varieties belonging to the species *F. virginiana* and *F. Chiloensis* were introduced to Europe in the 17th century. In 1780, the first strawberry hybrid "*Hudson*" was developed in the United States.

Almost all current commercial varieties worldwide belong to the species *Fragaria x ananassa Duch.,* and are octaploid (8n) in their genetic makeup, containing 56 chromosomes. This voluminous makeup gives the crop its high diversity and excellent potential to grow well and express its performance in a large variety of growth conditions, from (irrigated) deserts like South California and North Africa, through equatorial conditions as in Latin America and Central Africa, up to Alpine conditions in Scandinavia, Canada and Alaska.

Fragaria x ananassa, with large fruit (10 to 40 g), is by far the most important cultivated species, but other types of wild European strawberry are:

- The small-fruited Alpine strawberry, a form of Fragaria vesca. It is especially valuable as it has a much longer fruiting season and better flavored fruits.
- Fragaria chiloensis are also cultivated.

1.2 Nutritional and health values of the strawberry fruit

Table 1.1: The nutritive value of a serving (147 g) of edible strawberries.
Source: US Food and Drug Administration, 2009

Energy	45 cal	Vitamin A	45 IU
Protein	1.0 g	Vitamin C	94 mg
Fat	0.0 g	Niacin (Vitamin B3)	540 mcg
Carbohydrate	11 g	Folate	29.38 mcg
Dietary fiber	2.0 g	Manganese	540 mcg
Calcium	23.2 mg	Iron	0.6 mg
Magnesium	16.6 mg	Selenium	1.16 mg
Potassium	170 mg	Zinc	0.2 mg
Phosphorous	31.5 mg	Sodium	0 mg

The strawberry's high levels of potassium and magnesium help regulate blood pressure and help promote nutrient functions. The magnesium content also relaxes nerves and muscles and keeps blood circulating smoothly. Strawberries are richer in Vitamin C than citrus fruits. The very high content of Vitamin C supplies ~160% of the daily requirement (%DV) in one serving (147 g) of this fruit!

Strawberries are rich in niacin, belonging to the B-vitamin group. Niacin deficiency causes the pellagra disease. Niacin has been used for over 50 years to increase levels of HDL in the blood and has been found to modestly decrease the risk of cardiovascular events in humans.

Usage forms

Strawberries are marketed fresh and frozen. They are also processed for preserves, flavoring, concentrates and extracts.

1.3 Worldwide cultivation of strawberries

Table 1.2: Countries with the largest strawberry cultivation areas, down to 3,000 ha.
Source: FAO, 2012

Countries with over 3,000 ha of strawberry cultivation	Ha	Yield (MT / ha)
Poland	51,730	3.4
Russian Federation	26,000	6.3
USA	23,060	26.1
Germany	13,644	11.5
Turkey	11,679	25.7
Ukraine	8,100	7.1
Belarus	8,000	6.9
Serbia	7,603	4.3
Spain	7,000	39.3
Republic of Korea	6,500	35.7
Mexico	6,282	36.1
Japan	6,000	29.6
Italy	5,990	25.7
Egypt	5,245	45.5
United Kingdom	4,968	20.7
Finland	3,311	3.1
Canada	3,042	6.4
Morocco	3,035	46.3
World total	**243,907**	**17.9**

In several countries, for instance in Poland, which holds the world's record for largest growth hectarage, a large proportion of the crop is processed.

As seen above, most hectarage of strawberry production is concentrated in the northern hemisphere, but there is no agronomic reason to avoid increasing the growth areas in the southern hemisphere as well. Africa and Latin America are natural candidates for this expansion.

Table 1.3: Countries with the highest strawberry yield areas, down to the world mean figure
Source: FAO, 2012

Countries with strawberry yields over 20 MT / ha	Strawberry yield (MT / ha) in the country	Strawberry hectares in the country
Cyprus	57.5	32
USA	56.1	23,060
Kuwait	48.0	10
Morocco	46.3	3,035
Egypt	45.5	5,245
Spain	39.3	7,000
Israel	36.3	610
Mexico	36.1	6,282
Republic of Korea	35.7	6,500
Colombia	30.2	1,567
Belgium	29.7	1,100
Japan	29.6	6,000
Costa Rica	27.7	168
Malta	27.6	25
Netherlands	26.9	1,600
Chile	26.1	1,700
Italy	25.7	5,990
Turkey	25.7	11,679
Tunisia	24.1	340
Greece	21.8	380
Australia	21.2	1,383
United Kingdom	20.7	4,968
New Zealand	20.3	300
Guatemala	20.3	400
World total	**17.9**	**243,907**

1.4 Plant description and physiology

The strawberry plant is a typical hardy, perennial, rosette plant.

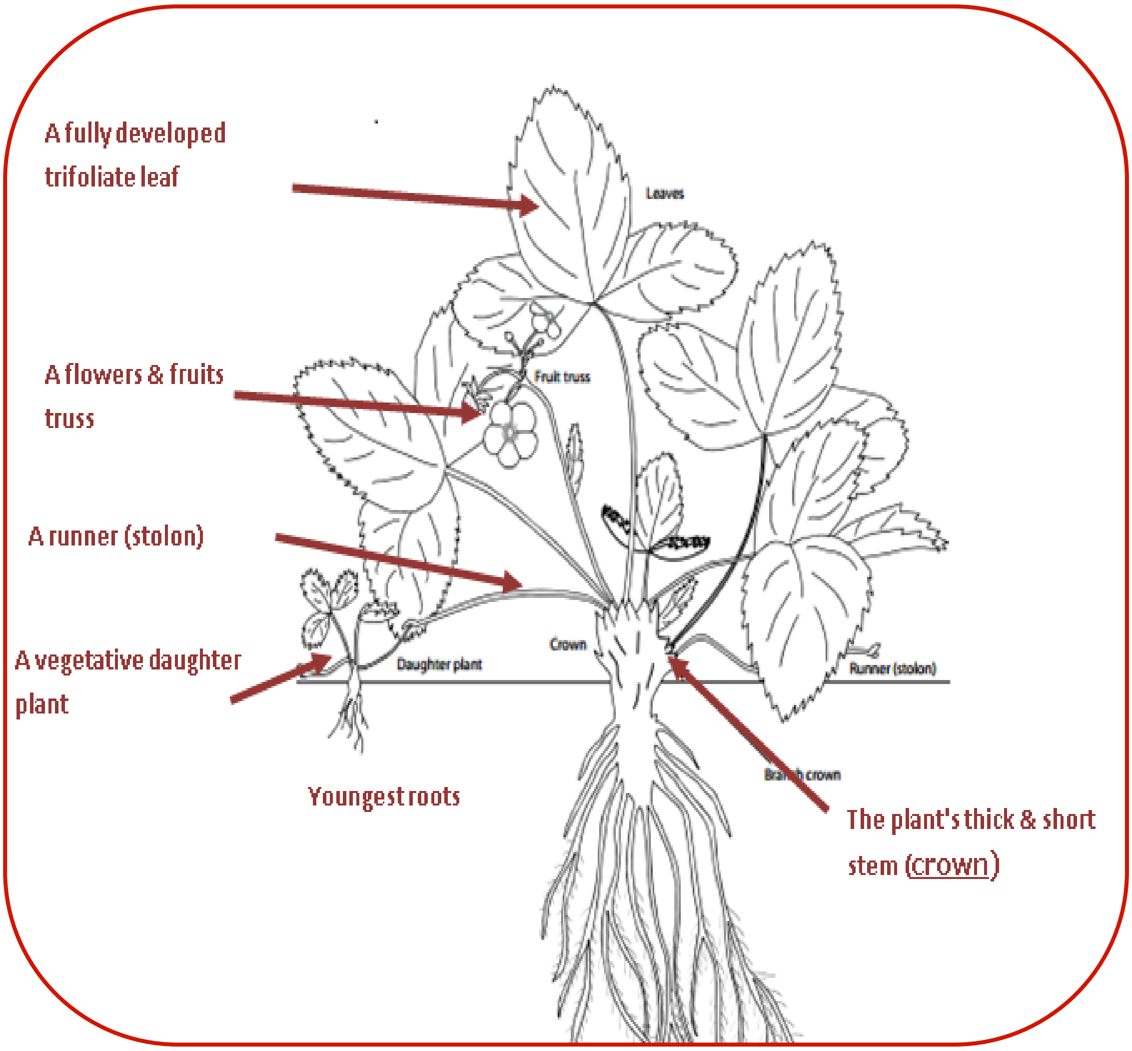


Figure 1.1: Schematic morphology of a strawberry plant
Source: Ellis et al, Ohio, 2006

1.4.1 Root system

The roots grow following a fixed pattern of three new roots emerging from each side of the base of every new leaf. Generally, there are 20 to 35 primary active roots. The root system is located mainly in the upper 20 cm layer of the soil. The root system is shallow, with 80% to 90% in the top 15 cm (6 inches) of clay. However, in well-drained, sandy loam soils they will be concentrated mainly at the 30 to 40 cm deep layer (see Figure 1.2). A primary root normally lives for one year and is replaced by newer roots as new leaves are formed at successively higher levels on the crown.

Fertility, water supply and aeration at soil depths greater than 15 cm are of major concern. Placing 2 to 3 cm (1 inch) of soil over the plant bed after harvest will enhance new root formation and make plants less vulnerable to cold and drought.

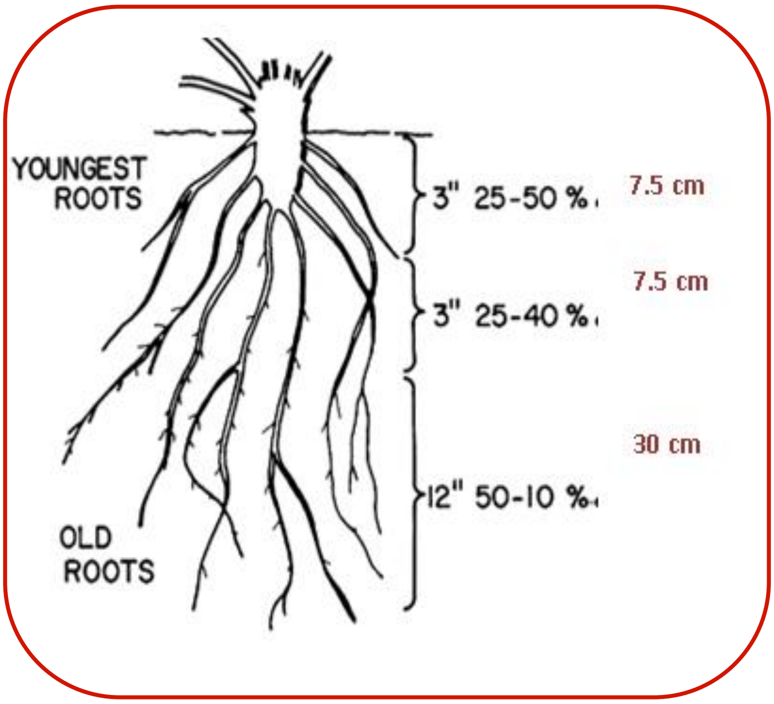


Figure 1.2: Root distribution of a mature strawberry plant, planted in well-drained, light soil
Source: Ellis et al, Ohio, 2006

1.4.2 Shoot system

The petiolate leaves and the inflorescence stalk originate from the short stem that is covered by brownish scales and called the plant's crown. Some axillary buds can develop into branches with long internodes called stolons, which produce a new leaf rosette and adventitious roots at the nodes. The stolons are used for propagation.

Figure 1.3: Typical strawberry trifoliate leaves

Strawberry leaves are arranged by a fixed spiral phyllotaxis, whereby every fifth leaf is situated exactly above the first one. This arrangement provides the highest light interception. Each year leaves and roots arise at higher points on the crown. Thus, the plant tends to grow out of the ground and develops poor root-soil contact with age. Strawberry leaves are among the richest species in stomata density. The lower surface of the average leaf has 300-400 stomata per square mm. In comparison, apple trees have only about 250 stomata/mm2. This means that on the one hand the strawberry plant can very efficiently absorb atmospheric CO2, but on the other hand, it is very susceptible to arid conditions.

Flowers and fruits are produced on a stalk that emerges from an axillary bud. Each flower is subtended by bracts and has five or more green sepals, five separate white petals, numerous stamens, and a domed receptacle (called a torus) that bears an indefinite number of pistils. In most cases the flowers appear hermaphroditic in structure, but function as either male or female.

Figure 1.4: A typical strawberry flower

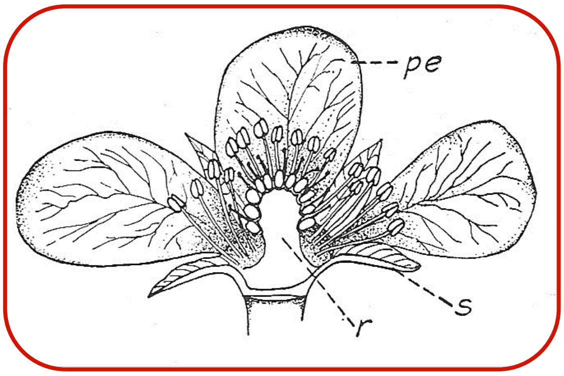


Figure 1.5: A strawberry flower

"**r**" points to the receptacle, which swells to become the edible part. The small ovoid structures on the surface of the receptacle are the carpels that each contain one embryonic seed, and will become the hard-walled true fruits as the seeds mature. S = sepals. Pe = Petals.

Source: Classic Botany Text, Hill, et al

The flower's pistil (ovary plus style and stigma) develops into a one-seeded, dry fruit, called an achene (see Figure 1.6). The achene is the hard structure found embedded on the fleshy receptacle, which becomes greatly enlarged. Therefore, this edible "fruit" is actually an aggregate fruit, in which the numerous achenes formed within a single flower are borne on a fleshy receptacle of that flower (see Figure 1.7).

Figure 1.6: Close-up photos of strawberry fruits, enhancing the view of the achenes in immature (left) and mature fruits (right)

Figure 1.7: Close-up photo of strawberry's thickened receptacle bearing the achenes on its surface

1.5 Fruit types

Depending on the plant’s genetic makeup, the fruits have considerably different shapes and sizes.
Source: http://strawberry.ifas.ufl.edu/breeding/varieties.htm

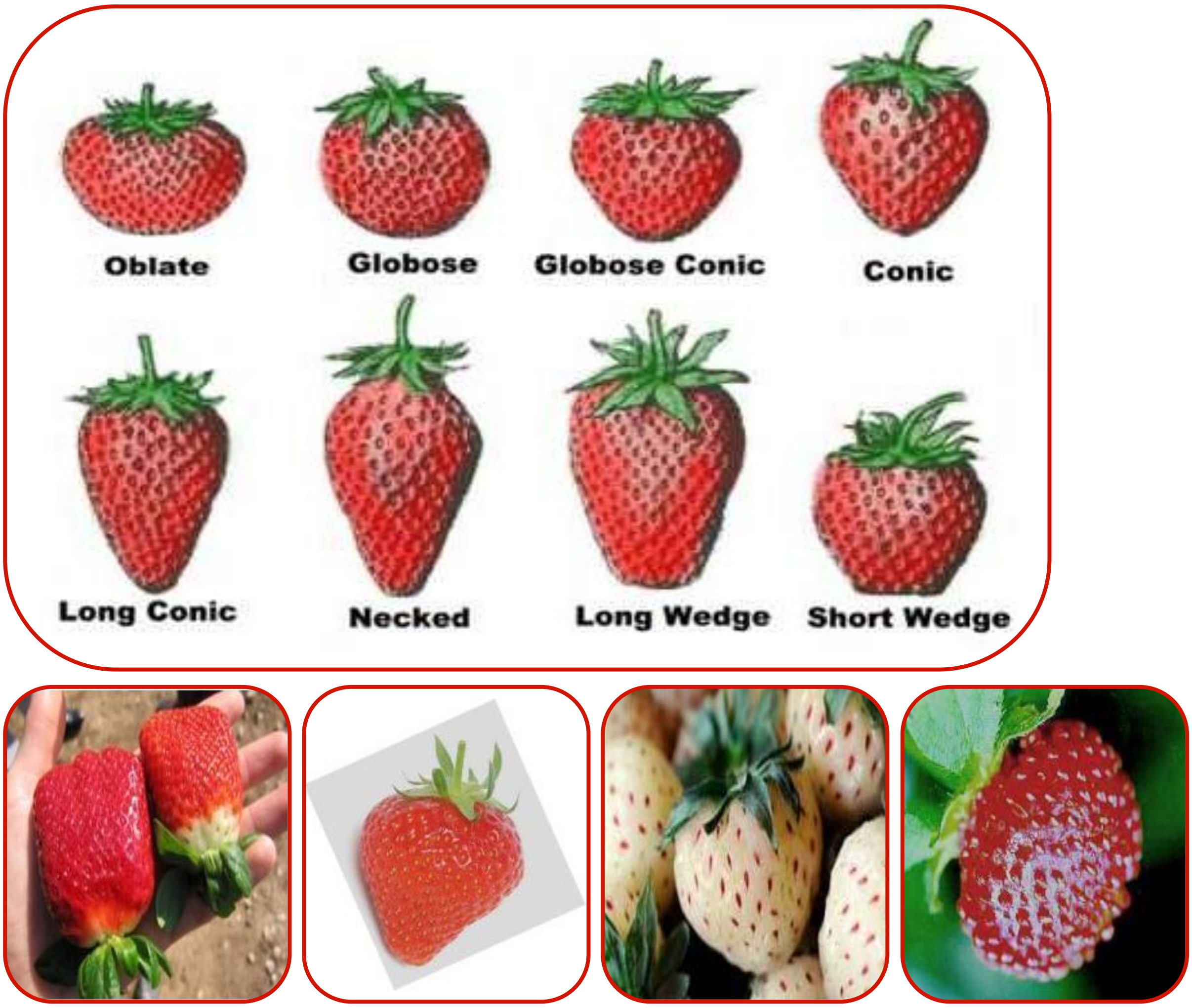


Figure 1.8: Several types of strawberry shapes and sizes

Strawberry fruits are delicate and require gentle handling to prevent bruising. With today's shipping technology, strawberries are available year round, but at a cost. Commercial growers have produced resilient hybrid berries known for their shipping quality.

1.6 Strawberry cultivars

Strawberries come in a wide assortment of commercially available cultivars. Differences between cultivars may include the ability to produce vigorous plants, degree of fertility, disease resistance (mainly to red stele and Verticillium root rots), fruit ripening date, berry freezing quality, firmness, berry size, color, shape, and flavor. Many cultivars have been developed at the University of California (Davis campus) by Driscoll Strawberry Associates Inc. (Watsonville, California), the US Department of Agriculture, Agriculture and Agri-Food Canada, and the UK's East Malling Research Station. Almost all of them are cultivars of *Fragaria × ananassa*. But some are *Fragaria vesca* and yet others are *Fragaria chiloensis*.

Cultivars can be separated into three plant types, based on their response to the number of hours of sunlight per day (photoperiod). These are June-bearers, ever-bearers, and day-neutrals. A relatively updated and exhaustive list of strawberry cultivars is available at http://strawberryplants.org/2010/05/strawberry-varieties

1.6.1 June-bearing strawberry varieties

Any list of strawberry varieties will probably contain mostly the June-bearing type. June-bearers are tremendously popular and common. They typically produce the largest strawberries, and do so over a period of two to three weeks, on average. Most June-bearing strawberry varieties produce a harvest around the month of June, hence the name. However, June-bearing strawberry varieties are further classified into Early Season, Midseason, and Late Season. By selecting strawberry plant varieties that produce during different parts of the season, one can prolong the harvest time and enjoy fresh strawberries over an extended period.

June-bearing strawberries are most often of the garden strawberry variety, *Fragaria x ananassa*. They are often planted using the matted row system.

For reference, each of the June-bearing strawberry types generally sets fruit for a total of 10 to 14 days. Early Season strawberry varieties usually begin fruiting in late spring. Early-Midseason strawberry varieties begin fruiting about five days after Early Season varieties. Midseason strawberry varieties begin producing approximately eight days after Early Season varieties. Late-Midseason strawberry varieties begin fruiting about 10 days after Early Season varieties, and Late Season strawberry varieties begin their berry production about 14 days after the Early Season varieties.

The June-bearing strawberry is a short-day plant, i.e., its apices will differentiate into flowers only when days have less than 12 hours of light. It's a popular type for commercial production in places like the Midwest USA, and will produce one crop each year. In the Mediterranean area, short day cultivars are planted in summer or autumn. Flowering occurs in winter and spring; harvest starts in spring.

Figure 1.9: *'Chandler,'* fruits, a short-day commercial cultivar grown in California

Following is a short (alphabetical) list of June-bearing strawberry varieties.

***Allstar*:** Berries are large, conical and light red to orange with a mild, sweet flavor. The plants are vigorous and make runners freely. This widely adapted variety has performed consistently well from the East to the central Midwest. It is highly resistant to red stele, with intermediate resistance to Verticillium wilt. It is very popular in Michigan.

***Cavendish*:** Very productive. Large, firm fruit with a good flavor, but with an uneven ripening habit. Plants are moderately vigorous. It is highly resistant to red stele and has some resistance to Verticillium wilt.

Chandler: Introduced by the University of California, this is a standard southern variety grown for wholesale markets in plasticulture. High yields have been experienced throughout the Carolinas and California. Not well suited for regions with harsh winters due to lack of winter hardiness. Chandler is also susceptible to anthracnose disease.

Darselect: (France) is a large fruited, high yielding variety. The berries are attractive and bright red with a long, conical shape. The flavor is very good. However, it tends to be soft. It is susceptible to powdery mildew, which can be a problem in areas with morning fog.

***Earliglow*:** An early berry of high quality. Its fruit is firm with excellent flavor and color. Yields may be low in New England. Fruit size tends to decrease as season progresses. Plants are vigorous runner producers. This is a good variety for beginner growers.It has good resistance to red stele and intermediate resistance to Verticillium wilt.

Elsanta: (Netherlands) is one of the most widely planted varieties in northern Europe. It has a high yield potential and its fruit is firm and aromatic. It is susceptible to red stele, anthracnose, and Verticillium wilt.

***Jewel*:** A glossy, attractive, medium-sized fruit with a firm texture and flavor. Good production and plants are vigorous with moderate winter hardiness. Care must be taken at renovation, to maintain a good plant stand. It is sensitive to Sinbar and susceptible to leaf spot, red stele, powdery mildew, black root rot, and Verticillium.

***Sparkle*:** The flavor is excellent, but the fruit is dark red and somewhat soft, and fruit size tends to decrease as season progresses. Plants are vigorous and produce many runners. This is one of the heirloom strawberry varieties and is an excellent choice for home gardeners and pick-your-own operations in northern climates.

***Wendy*:** A productive, medium-sized fruit with good flavor and color. Plants are vigorous and produce runners freely. It is moderately resistant to powdery mildew and susceptible to verticillium wilt. Plants do poorly in stressful conditions.

1.6.2 Ever-bearing strawberry varieties

Ever-bearing strawberry varieties are not really "ever-bearing." They generally produce two harvests per year: one in the spring and another in the late summer or fall. Under ideal conditions, it is possible for some ever-bearing strawberry varieties to produce three berry harvests. Most ever-bearing strawberry types are of the species *Fragaria vesca*. In general, ever-bearing strawberry varieties put out less runners (or no runners at all) than the June-bearing varieties, as most of the plant's productive energy is directed toward producing multiple strawberry harvests. Ever-bearing strawberry varieties are often planted using the hill system or in locations where space is limited.

Ever-bearers are long-day plants, i.e., their apices will differentiate into flowers only when days exceed 12 hours of light.

Traditional ever-bearing cultivars such as *Ogallala* and *Ozark Beauty* are not truly ever-bearing. They tend to produce a crop in the spring and a small crop in the fall, with little or no crop in between. *Ogallala* berries are medium sized and dark colored with a fair flavor. *Ozark Beauty* produces medium-sized, light-colored berries of average quality and has been extremely variable in its performance in Missouri.

1.6.3 Day-neutral strawberries

Day-neutral strawberry plants produce flower buds regardless of the hours of sunlight, approximately three months after planting. They will initiate flower buds during the entire growth season, assuming temperatures do not become too high. Day-neutral cultivars can potentially be harvested about every six weeks. It is generally accepted that day/night temperatures at or above 29^{0}C (85^{0}F) are the upper limit at which day-neutral strawberries will produce flowers.

The productivity and fruit quality of day-neutral strawberries are much better than the old "ever-bearing" types, such as *Ozark Beauty*, and should be used in place of them. Because of their unique growing habit, day-neutral strawberries must be treated differently than the June-bearing types. Day-neutral strawberries should be grown as annuals, plowed down the spring after planting and replanted every year. Beds can be carried over if plants are healthy and weed-free, but yields from day-neutral strawberries tend to decline dramatically in successive years.

Unlike June-bearing varieties, day-neutral strawberries will produce a good yield in the first year they are planted. They flower and set strawberries whenever the temperature is 2^{0}C to 29^{0}C (35^{0}F to 85^{0}F).

During milder years, they will still be producing fruit in October. The drawback to day-neutral strawberry plants is that they produce smaller strawberries than do the June-bearing and ever-bearing strawberry varieties. Their fruit is usually small to medium in size, rarely exceeding 2.5 cm (1 inch). Day-neutral strawberry varieties are often planted using the hill system, or in locations where space is limited.

The best day-neutral strawberry varieties for New England are *Seascape*, *Tribute*, and *Tristar*. *Tribute* tends to produce more fruit than *Tristar*, but it also produces more runners, which should be cut off. Both varieties have very good fruit quality.

Thus, day-neutral cultivars such as *Tribute* and *Tristar* generally produce a spring and fall crop in most of Missouri. *Tribute* plants produce moderate to high yields. Berries are large, have excellent firmness and very good flavor. The plants have good winter hardiness, are resistant to red stele and verticillium wilt and tolerant of the leaf diseases. *Tristar* plants produce moderate yields. Berries are medium to large and have excellent firmness and outstanding flavor.

The *Albion* strawberry plant (released by the University of California in 2004) is known for its large to very large fruit, which is mostly conical, very firm and red in color. Its flavor is very good for a day-neutral and is sweet and pleasant. It is a high yielding cultivar with robust runners and stalks. It is resistant to verticillium wilt and phytophthora crown rot, and has some resistance to anthracnose crown rot.

The *Aromas* strawberry plant (released by the University of California) has larger fruit and produces greater yields than *Selva* or *Seascape*. *Aromas* produces large quantities of late-season fruit. It also has a broader environmental tolerance and is more resistant to mildew than *Selva*, and is especially tolerant to spider mites. Its flavor is very good and fruit size and cull rate are superior to *Selva*.

Everest (developed in Great Britain) is a fairly new variety that has large, firm, bright red berries. It hardly produces runners and is only suited for plasticulture. Over-wintering can be a problem with this cultivar.

The *Hecker* strawberry plant (released by the University of California in 1979) has commercial potential for fruit stands and pick-your-own operations due to heavy production. It should perform well everywhere, including Alaska, as it is a day-neutral cultivar. Fruit is medium size with excellent flavor. It is similar to *Brighton*, but more cold-hardy.

The *Monterey* strawberry plant (released by the University of California in 2009) is a moderate day-neutral cultivar. It is a vigorous plant, and may require slightly more space than *Albion* with a similar production pattern. Its fruit is slightly larger than *Albion*, but less firm. It has an outstanding flavor and a good disease resistance profile, although it is susceptible to powdery mildew.

Portola is a cross between two advanced selections from California. The fruit, produced on long petioles, are orange-red in color and very shiny, almost plastic looking. The berries are larger in size than *Albion*. *Portola* is a vigorous plant and may require lower plant density than *Albion*. The cultivar is slightly resistant to powdery mildew, but is susceptible to leaf blight and botrytis fruit rot. Its yields are earlier and greater than other day-neutral varieties for first-year pickings. However, *Portola* is neither as flavourful, nor as sweet as *Albion*. It has a lower percentage of marketable berries, mostly due to botrytis and fruit rots.

The *Seascape* strawberry plant (released by the University of California in 1991) produces very large, firm fruit, which have a good color and flavor when picked ripe. It is a symmetrical, medium to long conical berry with a glossy finish. It is one of the most popular varieties with a general flexibility in planting dates and areas. *Seascape* is a very good choice for roadside and farmer's markets. This variety is highly tolerant of the virus diseases common in California; and is moderately susceptible to leaf rot.

2. Growing strawberries

2.1 Optimal conditions for field-grown strawberries

2.1.1 Microclimate

A favorable microclimate for strawberries is an area with full sun at least six hours per day, uniform temperature, rainfall and drainage, and good protection from wind.

If the site lacks a good microclimate, the grower must improve it, or choose another. A plot with a slightly sloped land facing south (northern hemisphere) provides good light exposure and air- and water-drainage.

2.1.2 Permanent shelterbelts

If the site lacks wind protection, shelterbelts should be planted to reduce wind velocity. Winds will dry fruit and plants during the growing season, desiccate plants during the dormant winter period, remove the winter snow cover in northern countries, and cause soil drifting during the plant establishment year. A properly planted and maintained shelterbelt can assist in obtaining a uniform blanket of snow to insulate plants from winter temperatures.

A number of ornamental plants are suitable for shelterbelts, and each has its advantages and disadvantages. Two species that have performed well in northern countries are Green Ash and Swedish Aspen. Ideally, the hedge should grow quickly, take up minimal amounts of land and produce a minimal amount of shade. Competition for fertilizer and moisture is also an important consideration. When selecting shelterbelt plants, avoid these characteristics:

- over-density of branches inhibiting snow infiltration
- wide spreading top
- high labor requirement for pruning
- limbs and branches susceptible to breakage from snow, ice and wind
- suckering roots
- high seedling production

2.1.3 Photoperiod

As mentioned earlier (in Chapter 1, paragraph 1.6.1) June-bearers will not produce flowers when the plants are continuously exposed to days shorter than 12 hours. Ever-bearers, however, will only flower when the plants are continuously exposed to days longer than 12 hours. It is necessary, therefore,. to plant the right cultivar in the appropriate season.

Photoperiods highly affect the growth and development of the strawberry plant. Long days (11 to 14 hours) encourage the production of stolons, longer petioles and larger leaf blades. Short days decrease plant metabolism and growth rhythm and they stop producing stolons, and produce less leaves with shorter petioles and smaller blades.

2.1.4 Temperature

Day-neutral strawberries will flower and set strawberries whenever the temperature is in the range of 20^{0}C to 29^{0}C (35^{0}F to 85^{0}F). 29^{0}C is considered the upper limit at which day-neutral strawberries will produce flowers. When temperatures descend gradually the plant can tolerate even temperatures as low as -6^{0}C (21^{0}F), but it will die when temperatures fall to -12^{0}C (10^{0}F).

When flowers are developing at sub-optimal temperatures they will develop in an irregular manner, with a much lower number of stamen, and those that are existent will produce markedly less pollen. When the temperature falls under 10^{0}C, the existent pollen will fail to germinate, so the productivity of these plants will be decimated in that season.

Because strawberries bloom very early in the spring, plantings should not be located in topographic frost pockets. Where cold air drainage is limited, the crop may be lost to late spring frosts, which can kill the flowers. Installation of frost control measures may need to be considered.

Descending temperatures are one of the stimuli (together with shortening day length) pushing the differentiation of the plant apices towards its reproductive phase (production of flowers), while ascending temperatures push the differentiation of the plant apices towards its vegetative phase (production of stolons).

2.1.5 Relative humidity (RH)

Development and spread of powdery mildew is favored by moderate to high relative humidity and temperatures of about 15^{0}C to 27^{0}C (60^{0}F to 80^{0}F). Unlike most other fungi that cause plant disease, powdery mildew does not require free water for spores to germinate and infect. In dry years, when most other diseases are not a problem, powdery mildew can represent a very serious danger.

Development of Angular leaf spot (bacterial blight) is favored by moderate to cool daytime temperatures around 20^{0}C (68^{0}F), a low night-time temperature (near or just below freezing), and high relative humidity. High RH also has a deleterious effect on the opening of the pollen sacs of the stamen. It is highly important, therefore, to enable good aeration of the plants growing in protected structures during the flowering season.

2.1.6 Soil type

Strawberry plants grow and produce satisfactorily in a wide range of soil types, from sandy to clay loams. The best soil for strawberry production is a deep, well drained sandy loam, well supplied with humus (over 2% organic matter). Heavy clay soils that are usually poorly drained encourage disease development and impede precisely timed field operations. Coarse textured sandy soils are often infertile and droughty, and require more frequent irrigation and greater attention to fertilization practices. Plants established in low-lying muck or organic soils are more vulnerable to frost injury.

Strawberries will respond positively to high organic matter content in the soil.

2.1.7 Soil pH and EC

If the soil pH is unknown, the grower should submit a soil test. Strawberries prefer slightly acidic soils with a pH of between 5.5 and 6.5. Too low pH values may require applications of ground limestone to increase the pH of more acid soils. Good vigor has also been obtained on soils with a pH slightly higher than neutral (7.5). Soil pH levels over 8 can adversely affect certain strawberry nutrients, especially the iron levels in certain cultivars. Yellowing in strawberries is also common where soil pH is high. The use of green manures and acidifying fertilizers can reduce the soil pH to some degree.

Optimal EC value is 1.5.
Source: Fennimore et al, UC Davis

2.1.8 Soil salinity and alkalinity

Strawberry plants are extremely sensitive to salinity, especially at the transplant stage. See the special paragraph devoted to this subject in Chapter 3, Special sensitivities of strawberries.

Highly alkaline soils can occur in bands or patches throughout a field. This can cause yellowing or chlorosis of the plants, a condition that can lead to significant yield losses or complete plant die-back.

2.1.9 Soil surface drainage

The surface drainage system must permit water to move away from the field quickly and completely. Water standing on the strawberry field for even a day or two will injure plants, especially during the intensive growth period.

2.1.10 Internal soil drainage

Poorly drained sites should be avoided. On sites with certain contours, such as dips, ridges and slopes, poor drainage can cause "yellowing" in strawberries. This condition can significantly reduce yields. On sites where drainage is a problem, the use of clay- or plastic-drainage tile could be considered. Raised beds, 20 cm (8 inches) high and 30 cm to 60 cm (2 to 3 feet) wide are recommended and should be maintained over the life of the planting. Application of perlite and working it into the soil will enhance good drainage.

2.1.11 Terrain slope

Strawberries should ideally be planted on slightly inclined slopes, especially if they face east or south-east (in the northern hemisphere).

Strawberries require cultivation, so avoid plantingthem on steep slopes. Plantings on 10% to15% slopes are likely to erode, with some plants being buried and others washed out of the soil. If sloping sites must be used, run rows across the slope or on the contour and use a wide row width.

2.1.12 Soil tilling

Soil tilling and nutrient availability can be improved by using green manure crops such as field peas, buckwheat, canola or rye. These crops can be rotated with the strawberry crop.

2.1.13 Quality of irrigation water

Irrigation is essential for high-yield strawberry production. Since strawberry plants are shallow rooted, permanent moisture is necessary to maximize production. An average of 300 mm to 450 mm (12 to 18 inches) of irrigation water is required over the growing season. Water applications may also be needed for spring frost control and for summer crop cooling when temperatures are above average. Water quality should be adhered to, regardless of the water application purpose.

Irrigation water with significant salt content, combined with poor soil structure, may also cause soil to develop unacceptable salinity levels.

As water quality crucially determines salinity severity, the following water characteristics are considered best for avoiding salinity injury to the plants.

Table 2.1: Most important parameters of irrigation water for strawberry fields

Parameter	Ideal level
pH	6.5 – 8.5
Electrical conductivity (EC_w)	< 1.0 dS / m
Total dissolved salts (TDS)	<450 mg / L
Sodium absorption ratio (SAR)	< 30
Chloride contents	< 130 mg / L
Boron contents	<0.7 mg / L
Nitrate contents	<5 mg / L
Bicarbonate contents	<1.5 meq / L

2.1.14 Previous and neighboring crops

Strawberries should not be planted in soils where strawberries, raspberries, vine crops, alfalfa, potatoes, tomatoes, peppers, eggplants, beans, carrot, okra or sod have been grown in any of the previous four years, unless the soil has been fumigated. Such sites are likely to contain disease and insect pests that may attack plants. The fungus diseases black root rot and verticillium wilt, which have attacked the above crops, build up in the soil. These diseases reduce the productivity of strawberry plants. Likewise, sites that are heavily infested with sedge, nutgrass, quackgrass, Johnson grass, and thistles should be avoided or treated prior to planting to destroy these chronic weeds. Fumigation should be considered if a long-term rotation that excludes the host crops is not feasible.

Sites surrounded by natural bush stands may contain native strawberry plants. These plants can harbor insects, diseases and viral pathogens that may infect cultivated strawberry stands. To maintain good sanitation, it may be necessary to kill native strawberry stands within 400 m (1,300 feet) of commercial strawberry fields.

2.2 Growth practices for field-grown strawberries

2.2.1 First year, field preparation

Day-neutral and June-bearing strawberries

Day neutral and June-bearing strawberries are easiest to manage on raised beds. The beds should be 15 cm (6 inches) high and 60 cm (24 inches) across on the top. The beds should be 120 cm (4 feet) apart at the center, leaving about 60 cm (2 feet) between beds for a walkway.

When grown on an annual basis, the center of the beds should be 120 cm (4 feet) apart in order to leave a 60 cm (2 foot) walkway between beds. The following spring / summer the plants will bear a heavy early crop followed by a smaller summer and fall crop.

An important part of field preparation before planting is the application of a base-dressing of fertilizer, which should be rich in phosphorus with an N-P-K ratio of 1-2-1 or 1-3-1, such as 5-10-5 or 8-24-8. It should be worked into the upper 8 cm to 20 cm (3 inches to 8 inches) of the soil. This issue is further elaborated upon in Chapter 4, Mineral nutrition of strawberries.

2.2.2 Planting

What

Use only certified disease-free plants from a reputable nursery. Plants should have large crowns with healthy, light-colored roots.

Figure 2.1: Strawberry plants ready for planting

When

Strawberries should be planted in the spring as soon as the soil is dry enough to be worked and prepared. Do not work the soil if it is wet; rather wait a few days until it dries. This is usually in March or April, allowing the plants to become well established before the hot weather arrives. Try to do the planting on a cloudy day or during the late afternoon.

How

Strawberries should be planted in holes large enough to slightly spread the roots out, and deep enough to bring the soil half way up the crown, making sure that the crown is above the soil level (do not cover the crown!) and that the uppermost roots are at least 7 mm (1/4 inch) below soil level. Pack the soil firmly around the plants and irrigate immediately after planting.

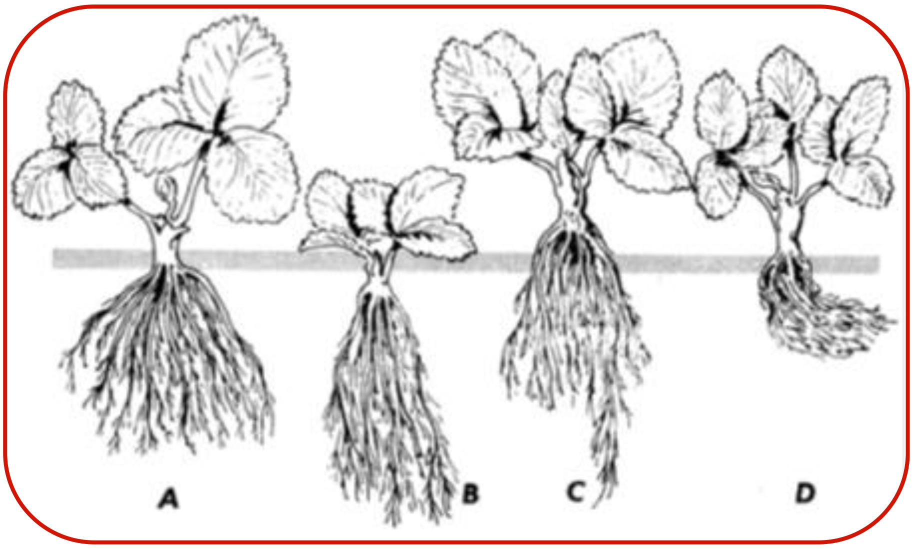


Figure 2.2: Proper planting method A, as compared to improper methods B, C and D for strawberry planting. At B the crown is too deep; at C the crown is too high; and at D the planting hole is too shallow, forcing the roots to bend and remain near the surface.
Source: Ellis et al, 2006

Water the plants slightly (5-10 mm) with a very diluted solution of water-soluble fertilizer, e.g., 0.2% (2 kg / m3) of 20-20-20 within a few hours after planting.

2.2.3 Plant arrangement

- Matted row system

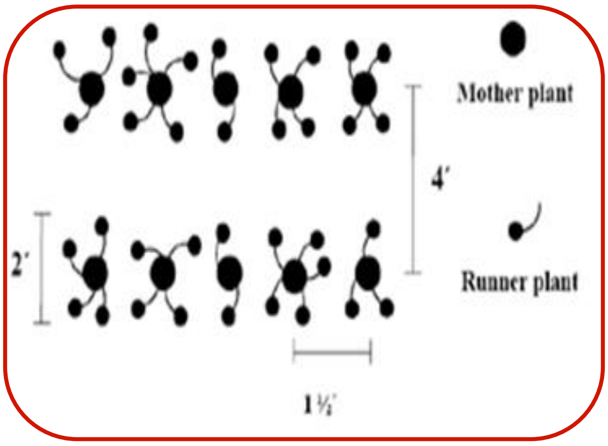
This is the best system for growing June-bearing cultivars. In the matted row system, all runners are allowed to grow and daughter plants are allowed to root freely to become a matted row, no wider than two feet. The strawberry plants should be set 45 cm to 75 cm (18 inches to 30 inches) apart, in rows 90 cm to 120 cm (3 feet to4 feet) apart.

Figure 2.3: Matted Row System. Straw mulching is seen in the aisles.
Source: http://www.poltersberryfarm.com/Strawberries.htm

2.2.4 Management of runners

As strawberries grow they will produce runners that will spread out and root to produce additional plants. Position the first runners with approximately 15 cm (6 inches) spacing between them. Only allow a few runners per plant,then remove additional runners to promote crown growth. The width of each row should be limited to 60 cm (24 inches) to maintain easy access in the planting. Runner plants that grow outside the 60 cm row width should be pinned back into the row to root or be removed if the plants become too crowded (less than 15 cm between plants). The runners can be positioned into the desired row width before they root and held in place with small stones, clumps of soil or old-fashioned hairpins (see Figure 2.4).

Soon after planting, the crowns will produce a few leaves, and flower buds will emerge. During the planting year, all flowers should be pinched off. This encourages runner growth and plant vigor to fill out the bed, leading to better yields the following year. Runner plants will begin to emerge from the crowns in the early summer. These should be used to fill out the rows.



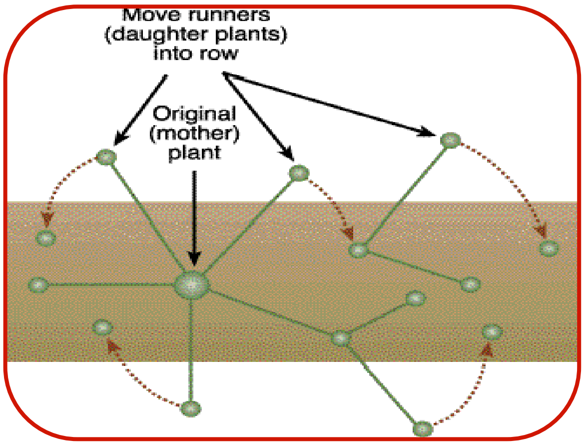


Figure 2.4: Runner positioning by active intervention
Source: http://www.poltersberryfarm.com/Strawberries.htm

- Spaced-row system

This system limits the number of daughter plants that grow from a mother plant. The mother plants are set 46 cm to 76 cm (18 inches to 30 inches) apart in rows 1 meter to 2 meters (3 feet to 7 feet) apart. The daughter plants are spaced to root no closer than 4 inches apart. All other runners are pulled or cut from the mother plants. Even though more care is needed under this system, advantages include higher yields, larger berries and fewer diseases.

- Hill system

This is the best system for growing day-neutral and everbearing strawberries as they do not send out many runners. In the hill system all the runners are removed so that only the original mother plant remains. Removing the runners causes the mother plant to develop more crowns and flower stalks. Multiple rows are arranged in groups of two, three or four plants with a 60 cm walkway between each group of rows. Plants are set about 30 cm (1 foot) apart in multiple rows. During the first two or three weeks of growth, the planting should be weeded; then the bed should be mulched.

Plant two rows of strawberries on each bed. The rows should be 30 cm (1 foot) apart, 15 cm (6 inches) from the left and right of the center of the bed. Plants within the row should be 20 cm to 25 cm (8 inches to 10 inches) apart. It is best to stagger the plants in the two rows on a bed such that a plant in one row corresponds to the space between plants in the other row.

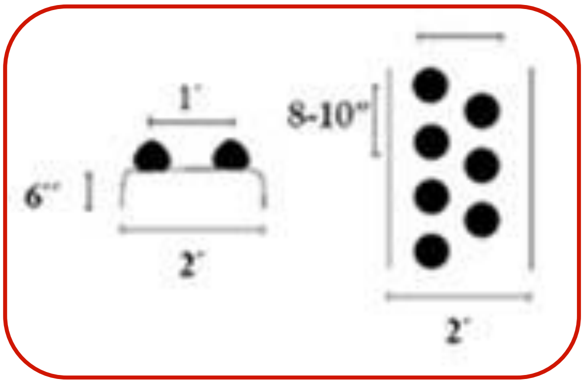


Figure 2.5: An established strawberry bed grown in a double row hill system.

2.2.5 Blossom removal

During the first growing season, remove flowers of June-bearing strawberries as soon as they appear. Removing the flowers promotes root and runner development, thereby insuring a large crop the following year.

For everbearing and day-neutral strawberries, remove the flowers until the end of June and then, after that date, allow the flowers to remain to set fruit for a summer / fall harvest.

2.2.6 Fertilization

After the first harvest, in the second season strawberries should be fertilized after renovation in July. Water the fertilizer in to get it down to the root zone. This application is made to keep the plants in a vigorous condition and to promote new growth and thus the development of more fruit buds. Do not over-fertilize because this will cause excessive vegetative growth, reduce yields, increase losses from frost and foliar disease, and result in winter injury. Read more about this issue in Chapter 4: Mineral nutrition of strawberries.

2.2.7 Cultivation

Cultivation is one of the most important practices in a new strawberry planting and it should be done frequently (once a week) for the first 6 to 8 weeks. Cultivation kills the weeds and loosens soil for better runner penetration. If necessary, herbicides can be an effective tool in controlling weeds in strawberries.

2.2.8 Mulching

Strawberries are very susceptible to frosts during their vegetative activity (as compared to their hibernation during cold winters). Such frosts may occur in the fall and in the spring. It is advocated, therefore, to mulch field-grown strawberries in the fall between mid-November and mid-December. Apply straw mulch after a few days of temperatures down to -6^{0}C (20^{0}F). Straw should be sifted loosely over the plants, just enough to cover them from view. After a week of settling, add additional straw up to a 7 cm to 10 cm (3 inch to 4 inch) deep layer over the rows. This mulch will protect the plants from cold temperatures that can kill the buds and injure roots and crowns. Where fall frosts are not likely, winter mulching is practiced to prevent damage to the roots caused by rapid freezing and thawing of the soil, and subsequent heaving of the plants out of the soil.

Mulches that have covered the plants during the winter months should be removed in the early spring, when the strawberry leaves show yellow, but should be left in the aisles to cover the blossoms in the spring when frost is predicted. Some of the mulch should be left around the plants to keep the fruit from soil contact and to conserve soil moisture.

Other benefits of mulching include help in controlling weeds and grass, protection from severe cold temperatures and help in keeping berries clean during harvest. Mulch the beds in the late fall, remove the mulch in the spring, and pinch blossoms for the first 4 to 6 weeks to improve later yields.

Many materials can be used for mulching. Straw is the most commonly used mulch. A typical straw mulching layer for winter protection will have about 9 tons / ha of wheat straw. But any loose material, which will provide cover without matting, can be used, such as pine needles or wood shavings. Do not use hay because it contains weed seeds that will start to grow among the strawberries the following spring. The mulch layer should be 15 cm to 20 cm (6 inches to 8 inches) deep over the plants.

If straw will be used, obtain straw shortly after wheat harvest. Loosen bales and soak in water. This, as well as subsequent rains, should germinate most of the grain before it is time to apply the straw.

Alternatively use aged sawdust. When sawdust is used, try to maintain a 2.5 cm (1 inch) mulch depth. No additional winter protection is needed.

"Floating" fabric row covers may also be placed over the plants to provide some winter and frost protection. These lightweight fabrics create a greenhouse effect that will make the plants bloom and fruit earlier in the spring and produce larger yields.

Row covers can be placed over the plants in the early fall or the early spring. Plants covered in the fall will have greater yield benefits from the covers, but additional mulch such as straw should be applied in mid-November for extra winter protection.

Figure 2.6: Strawberry flowers with frost damage (bottom), next to undamaged flowers (top).
Source: Ellis et.al, 2006

2.2.9 Plasticulture

The bulk of modern commercial production uses the plasticulture system. In this method, raised beds are formed each year, are fumigated, and are covered with large plastic sheets, under which the irrigation tubing is installed. The main advantages of this mulch are:

- A considerable increase in soil temperature of the active root zone of the plants. This enhances plant physiology and enables much earlier flowering and fruit bearing.
- Prevention against weed growth, thereby saving on herbicides and work.
- Protection of the beds from erosion by strong rainfall.

Plants are planted through holes punched in the covering. Runners are removed from the plants as they appear, to encourage the plants to put most of their energy into fruit development.

At the end of the harvest season, the plastic is removed and the plants are plowed into the ground.

Figure 2.7: Open-field grown strawberries on black plastic mulches

However, because this method requires a longer growing season to allow for establishment of the plants each year, and because of the increased costs in terms of forming and covering the mounds and purchasing plants each year, it is not always practical in all areas. In these cases the plants are not destroyed after harvest, but are kept from year to year, growing in rows or on raised beds. This system is most common in colder climates and where growers have less capital. It carries lower investment costs, and lower overall maintenance requirements. Yields are typically lower than in annual plasticulture.

2.2.10 Irrigation

On the one hand, strawberries are sensitive to periods of severe drought; dry soil can literally kill them or stop fruit production. On the other hand, they are sensitive to waterlogging that causes the roots to suffer oxygen deficiency, and is an optimal condition for soil-borne microbial- and fungal- diseases. Continuous optimal water status helps to get the highest yields of large berries. Strawberries should have a minimum of 25 mm (1 inch) of water per week. Up to 50 mm (2 inches) of water should be given weekly while the fruit is forming, from early bloom until the end of harvest. Watering should continue during dry periods in August and September. This later water helps reduce stress on the strawberry plants, which helps fruit bud formation in the following year.

Considerably higher rates are required during prolonged hot, dry periods. But, when it rains, a rain gauge should determine weekly rainfall. Irrigate to make up for rainfall deficiencies. Mulching helps keep the moisture level of the soil more consistent.

The irrigation system may also be used for frost protection, wherever this is valid. It should be turned on when the temperature drops to 0.5^{0}C (33^{0}F), and left to run until all the ice formed on the plants has completely melted. To take advantage of the irrigation system, several factors should be considered before installing an irrigation system:

- Water supply. Water may come from wells, ponds, lakes, and municipal lines. An irrigation pond would need to hold about 230 m3 / ha (150,000 gallons / acre) of water for plasticulture production to provide protection on three consecutive frost or freeze nights.
- Pumping capacity. A pumping capacity of as much as 5.1 mm / h (0.2 inches / hour) or 51 m3 / h is recommended for severe frost and freeze conditions.
- Pump. An electric pump is recommended for reliability if a reliable electric power service is available.
- Sprinkler type. Low-impact sprinklers are preferred. Special frost nozzles can be installed for some types of sprinklers, which will emit only enough water to protect the flowers and not flood the beds.
- Sprinkler spacing. A 12 meter x 12 meter (40 foot x 40 foot) triangular spacing will greatly improve the sprinkling distribution pattern under higher winds as compared to conventional 18 meter x 18 meter (60 foot x 60 foot) spacing. Sprinklers should be set up to provide complete coverage of the planting.

Figure 2.8: Mulching and laying drip line

Figure 2.9: Drip lines under plastic mulched four-row bed

Figure 2.10: Sprinkle-irrigated / fertigated strawberry field

2.2.11 Pollination

The strawberry is mostly self-pollinated and, under field conditions, self-pollination is satisfactorily supplemented with natural agents like wind, honeybees, and other insects. Based on studies of 11 cultivars, self-pollination accounts for 53% of fertile flowers, wind increases development to 67%, and insect pollination increases it to 91% (Source: Ellis et al, 2006). If wild bees are not plentiful, then honeybees can be used, but they are not strongly attracted to strawberries and may be attracted to competing flowers. Honeybee visits are limited to good weather. However, honeybees in sufficient numbers should be effective pollinators.

Pollination of all the pistils of a flower is necessary for maximum berry size. If few are fertilized, an irregularly shaped berry or “nubbin” of only one fifth the size of well-fertilized berries will develop.

Flowers pollinated at the most receptive time produced 13% to 58 % heavier fruit than those before or after the best time. The best time is 1 to 4 days after the flower is open. Generally, 2½ strong hives per hectare (= one per acre) is recommended. Bee hives should be placed in the sun on a dry surface (see Figure 2.11) Source: Ellis et al, 2006.

If a grower has a very large acreage of berries, few active beekeepers in the area and little or no natural shelter-belt areas, then it may be very good insurance to have honeybees brought into strawberry fields as the first flower opens. Growers will be in competition with apple growers in some regions, and beekeepers will prefer other crops to strawberries. For some cultivars, where primary flowers have been damaged, there may not be an economic advantage for bees. Also, certain insects can cause poor pollination. Therefore, frost control and insect control measures may need to be adequate before bees are considered.

Figure 2.11: Placement of beehives in the sun, on a dry surface to secure strawberry pollination
Source: Ellis et.al, 2006

2.2.12 Harvesting

Generally, berries ripen within 28 to 30 days (as few as 20 days under optimum conditions) after first bloom. The time between first bloom and full bloom can be 11 to 12 days. A great increase in the number of ripe fruit occurs over the first 4 to 6 days of harvest. Berries are harvested every other day under normal temperatures for about 6 to 7 pickings. Avoid picking the fruit when plants are wet. Keep harvested berries out of the sun and place them under refrigeration as soon as possible. Pick berries when they are fully colored for optimal size and flavor. Berries do not improve in quality after picking.

For hand harvest, it is wise to employ enough pickers to harvest the berries by noon, during the cool part of the day when pickers are most efficient. Harvested berries should be delivered and sold within 24 hours of harvest to reduce spoilage. About six pickers can harvest an acre of berries, or about 10,000 pounds, over the season.

The average picker can harvest 10 quarts (12 to 15 pounds) per hour over the entire season. Under excellent conditions, up to 175 quarts in a 10-hour day may be harvested by the average picker.

2.2.13 Second and third year care– mulch removal

Remove straw mulch in the spring as the weather begins to warm (before bloom). Check closely after each warm period (late February through March); if the plant foliage begins to show yellowing, remove the mulch. Rake mulch toward row aisles. This creates a clean walkway and will keep the fruit dry and clean. If a frost is predicted after the mulch has been removed, it may be raked back over the plants for the night to protect the flower buds.

Leave a light sprinkling of straw mulch on the plants; they will push through. If spring frosts threaten, rake the mulch back over the plants, but be sure to rake off the mulch during the day.

“Floating” fabric row covers can also be applied in the early spring. Leave the row covers on until the plants begin to bloom. This may occur two to three weeks earlier than plants without row covers, so be prepared to protect the flower buds from frost. Although the row covers will provide some frost protection, it is best to mulch or use irrigation over the row covers if a hard frost is predicted during early spring.

2.2.14 Harvest

Hand-pick berries daily if possible and pick all berries that are ripe. Toss out all moldy berries. This will help prevent rots from spreading. Grading and packing often takes place in the field, rather than in a processing facility. In large operations, strawberries are cleaned by means of water streams and shaking conveyor belts.

2.2.15 Renewing the planting

Renovation is an important part of strawberry care. Strawberry beds can usually be carried over for 3 to 5 years or more if the plants are vigorous, the bed is kept weed-free, and the planting is properly renewed or renovated every year. In order to insure good fruit production, June-bearing strawberries grown in the matted row system should be renovated every year right after harvest. As strawberry plants tend to get infected with leaf diseases, which may result in declining yields if not treated timely, plants infected with diseases should be removed.

The bed should be renovated shortly after the harvest is complete, usually late July. First, mow the old foliage with a mower, cutting off the leaves, about 3 cm (1.5 inches) above the crowns. Rake the leaves and, if disease-free, compost or incorporate into the soil. Then use a rototiller or spade to cut each plant row to a 15 cm (6 inch) width. (Runner plants from the 6 inch strip of "mother" plants will form a new matted row of plants.) To prevent overcrowding of plants and reduce the incidence of leaf diseases, thin plants to 5 to 7 plants per 30 cm x 30 cm (1 square foot). Next, spread a light, 1 cm to 2 cm (1/2 inch to 1 inch) layer of soil over the remaining plants, but do not bury the crowns.

Irrigate the planting well, wetting the soil to a depth of 15 cm (6 inches). During the rest of the growing season, irrigate to provide 25 mm (1 inch) of water per week, and continue to control weeds. During the summer, runner plants will emerge and should be placed to fill out the row to the desired 60 cm (2 foot) width, similar to the planting year.

Keep the planting healthy and vigorous throughout the season by controlling weeds, maintaining the proper plant density and row width, and watering regularly.

2.3 Optimal conditions and growth practices for protected strawberries

An ever-increasing hectarage of strawberries is produced under different protection conditions that range from low- and high-plastic tunnels, to plastic- and glass-greenhouses, equipped with the most modern production inputs, functioning during off seasons.

2.3.1 Protective structures

Temperatures below -0.5°C can cause severe damage to full blooms. Therefore, in Holland and Belgium, strawberries are grown in glasshouses during winter. In Spain, Italy, France, the UK and Germany, strawberries are grown in winter under polyethylene tunnels. In Israel, strawberries are cultivated under polyethylene tunnels and in greenhouses. When grown under protection the plants can be planted in soil or on in soilless containers of various types.

Figure2.12: Mini-tunnels, Israel

Figure2.13: A maxi-tunnel, Israel

2.3.2 Soil type

The best soil for strawberry production is deep, well drained sandy loam, well supplied with humus (over 2% organic matter). Heavy clay soils that are usually poorly drained, encourage disease development, and impede precisely timed field operations. Coarse textured sandy soils are often infertile and droughty, and require more frequent irrigation and greater attention to fertilization practices.

Strawberries will respond positively to high contents of organic matter in the soil, but application of fresh manure should be avoided.

2.3.3 The use of zeolytes

Zeolytes are negatively charged crystal alumina silicate, balanced by +1 to +2 valence cations. Zeolites also have high absorption level, water retaining and releasing, high cation exchange capacity (CEC) and high pH buffering capacity has been shown to be helpful for growing strawberries, for the following advantages:

- Holds minerals tight during complete cultivation, so few minerals are washed away
- Easy to use
- Good development of the leaf
- Good quality of the strawberry fruits

Source: Strawberrys, Loomans, 04.doc

Perlite / zeolite at 3:1 and 1:1 ratio (v/v) were found very efficient as soilless growth substrates, by Fotouhi Ghazvini et al, 2007

2.3.4 Soilless media

The ideal characteristics of growth media are summarized as follows:
Source: Chen & Inbar (1985)

- Physical characteristics
  - High water retention
  - High hydraulic conductivity to allow efficient drainage
  - High porosity to allow aeration
  - High air content even when water tension is low
  - Particle size distribution that allows the aforementioned characteristics
  - Low bulk density
  - Provide the plant with high physical anchoring
  - Stable volume, to minimize changes due to shrinking and compacting
- Chemical characteristics
  - High cation exchange capacity
  - Reasonable level of nutrients and ability to supply these to the plant
  - Buffer capacity to maintain stable pH level
  - Low soluble salt content
  - In the case of organic media it should have a low C/N ratio, with a very low decomposition rate

Some of these characteristics cannot be satisfied by all growth media types, so the actual growth medium is usually composed of two or more components that complement each other, optimizing the growth characteristics.

Several generally accepted compositions of soilless media for strawberries consist of various blends of peat-moss, rockwool, coconut fibers and perlite, such as:

- 60% peat + 40% coconut fibers
- 50% black peat + 50% medium peat
- 70% peat + 30% perlite

The most common type of soilless media used for strawberry cultivation is a peat grow-bag. Some growers use the cheapest peat bag available. However, this is false economy since strawberry roots are sensitive to waterlogging, and grow best in an open structured, free draining substrate. Strawberry plants grown in poor quality peat often turn yellow (particularly in the second crop), as a result of compost slumping and a lack of aeration, or waterlogging at the roots. Improved strawberry grow-bags feature free draining texture and will not slump, even after 9 to 12 months' use. The peat is augmented with 10% polystyrene or perlite, which further increases the aeration of the compost. With this mix, it is also possible to carry out a second planting in the same bag, and take a further two crops with only a small (10% to 12%) loss of yield.

Some growers use other soilless media. For example, in Scotland, several growers use 100% perlite successfully, whilst on the south coast of England growers use rockwool slabs.

2.3.5 Soilless pH and EC

When grown on soilless media, optimal pH value is around 5.7, and optimal EC values of the drip water in soilless cultivation systems are 1.5 to 1.7 dS / m. Hence, the optimal EC values of the drain in soilless cultivation systems are: 1.6 to 1.8 dS / m.
Source: Fruit & Veg Tech, issue of March, 2009, Abdal-Razak, Israel, 2004

Whatever media is chosen, it is best to raise the plants off the floor, ideally to a height of 120 cm to150 cm (4 feet to 5 feet). Where the load carrying capacity of the structure exceeds (10 kg / sq.m), metal gutters or a strained wire support system may be hung on chains from the roof. Alternatively, the support system may be mounted on steel poles or wooden posts driven into the floor. On a small scale, plants may also be grown on straw bales covered with plastic or wooden crates. However, as the crop gets closer to the floor, yields are lower and picking costs tend to increase.

Figure 2.14: Soilless cultivation of strawberries in the UK
Source: Atwood et al, 2005

2.3.6 Irrigation and nutrigation

Plants are best irrigated in protected cultivation with drip tapes or dripping systems. It is advisable for plants to receive nutrients with every irrigation session, with each plant receiving about 140 ml nutrient solution per day by multiple irrigation sessions, one to several minutes long, with ~90-minute intervals between the sessions.

2.3.7 Fertilization setup

Fertilizer solution should be discharged by 2 to 3 injectors (e.g., Dosatron), assembled in series. Two to three separate stock tanks should be used accordingly for fertilizer application.

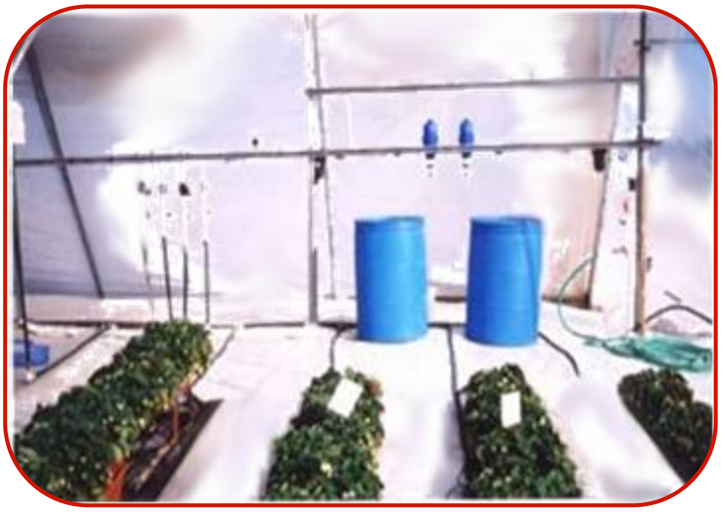


Figure 2.15: Dosatron injectors assembled in series inject fertilizer solutions from two separate stock tanks in greenhouse-grown strawberries.

Figure 2.16: The nutrigation control unit of the soilless cultivation plot in the UK
Source: Atwood et al, 2005

2.3.8 Pollination

Under greenhouse conditions, the activity of natural agents like wind, honeybees, and other insects is highly restricted by the protective structure. Bumblebees provide good pollination for strawberry plants and they perform much better than honeybees or hand pollination. Therefore, the use of bumble bees is absolutely essential to ensure good pollination. One beehive (e.g., Koppert Biological Systems Inc.) containing approximately 50 bumblebees is sufficient for pollinating about 4,000 strawberry plants (500 m^2 greenhouse area).

Figure 2.17: A bumblebee pollinating a strawberry flower

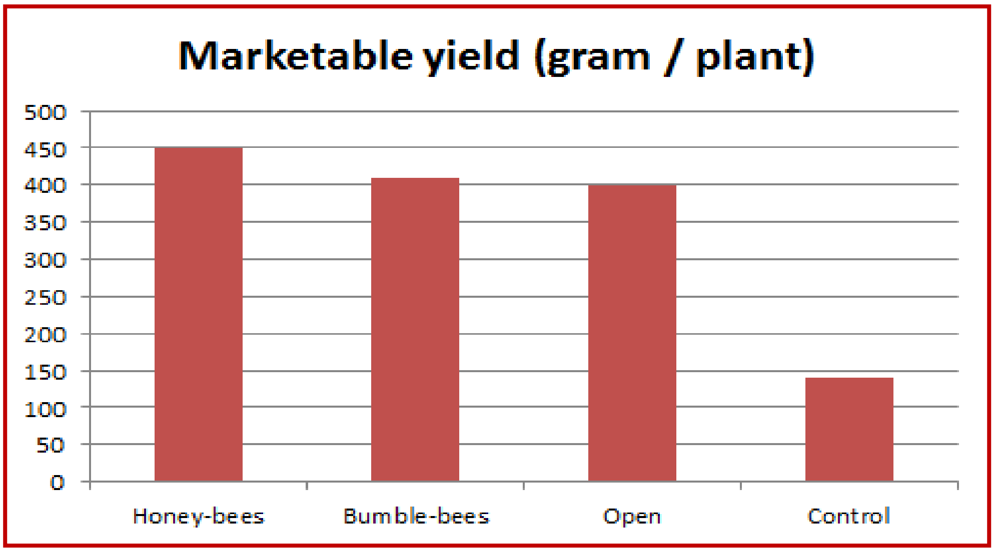


Figure 2.18: Evaluation of pollinators for high tunnel strawberry production

2.3.9 CO_2 enrichment in greenhouses

CO_2 enrichment of the greenhouse atmosphere markedly increases strawberry yield. Artificial CO_2 concentrations of 400 ppm to 900 ppm (as compared to natural concentrations of ~350 ppm), accompanied by increased light intensity, increased total yield by 8.7% to 31%, due to both higher individual fruit size, and increased number of fruits.

Fruit quality is enhanced too. Elevating the CO_2 concentration to 650 ppm and to 950 ppm resulted in higher fruit dry matter, fructose, glucose and total sugar contents, and low citric- and malic-acid contents. High CO_2 growing conditions significantly enhanced the fruit content of the following aroma compounds: ethyl hexanoate, ethyl butanoate, methyl hexanoate, methyl butanonate, hexyl acetate, hexylppm hexanoate, furaneol, linalool and methyl octanoate. Thus, the total amounts of these compounds were higher in berries grown in CO_2-enriched conditions than those grown in ambient conditions.
Sources: Lieten, Acta Hort., 1996; Wang & J. Bunce, in Science of Food and Agriculture, 2004

3. Special sensitivities of strawberries

3.1 Salinity

The strawberry is one of the most salt-sensitive crops cultivated by man. Salinity in the root zone radically decreases root development from the crown, water uptake, growth rate, and fruit yield. Salinity damage can be due to high concentrations of salts in the root zone, the accumulation of specific ions to toxic levels, or imbalances in ion ratios.

Symptoms of salt injury include dry and brown leaf margins, brittle leaves, stunted plant growth, and dead roots and plants. When salt toxicity is seen in localized areas in a field, it could be due to poor drainage. Symptoms can be seen throughout the field when salinity of the irrigation water is high. Excessive fertilization or application to wet foliage can also result in salt toxicity.

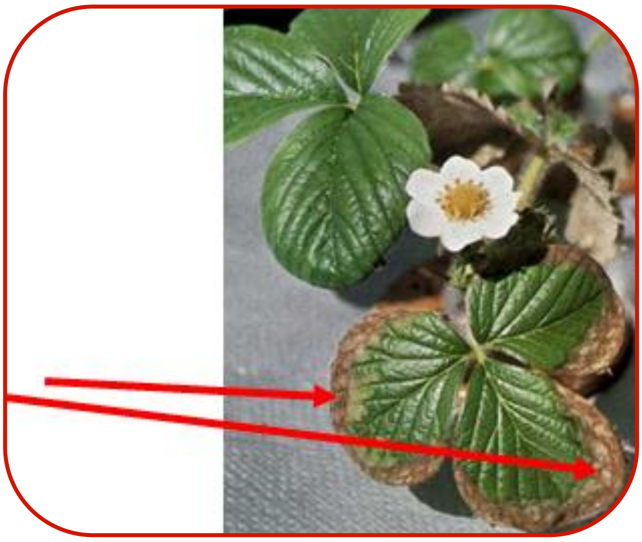


Figure 3.1: Salt injury symptoms in strawberry leaves: brown & brittle leaf margins
Source: Albert Ulrich, UC, 2009

3.1.1 General salinity

General salinity stress occurs when salts accumulate in the soil solution to a level where the strawberry plant can no longer extract ample water from the soil during growth. Salt-induced osmotic stress causes osmotic dehydration, which leads rapidly to a decrease in the water potential of cells and in cell volume (Levitt, 1980), and to a reduction in all vegetative and reproductive parameters, which finally is expressed by decimated yield. The amount of yield loss depends on the type and severity of salinity present, and the growth stage and length of time that the plant is exposed to the stress. Symptoms of salinity stress in strawberry plantings vary by variety, with the types and mixtures of salts involved, and as the severity of the problem increases. Mild salinity problems are frequently overlooked because plant size reduction and changes in plant color are uniform across the entire field. In general, however, advanced salinity initially causes a subtle change in foliar color, with plants becoming a darker bluish-green. As salinity stress increases, plant stunting becomes apparent and eventually leaves are burned at the tip and around the edges. Yield loss due to salinity problems is underway well before foliar symptoms become apparent.

As shown in Figure 3.2, yields decrease by 33%(!) for each EC unit increase in irrigation water salinity, above the threshold of 0.7 dS / m.

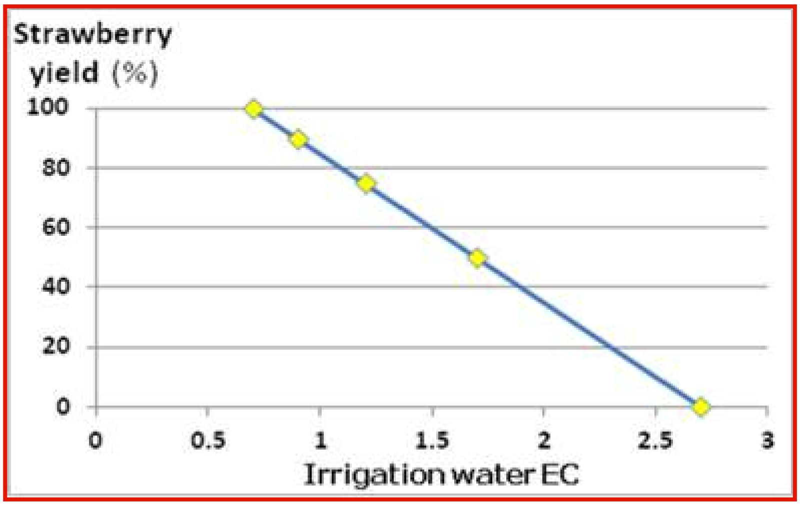


Figure 3.2: The effect of electrical conductivity (ECw) of irrigation water on strawberry yield, when soil was treated with less than 1% gypsum. Soil salinity extract (ECe) is generally 0.3 to 0.5 dS / m higher than the ECw.
Source: Wayne et al, 1991

The rate of potential yield loss due to increased salinity varies widely, depending on the strawberry variety, irrigation method, climate, soil conditions, and cultural practices. Where soils contain more than 1% gypsum, plants will tolerate about 2 dS / m higher soil salinity.

3.1.2 Chloride toxicity

If chloride ions (Cl^-) are present in excessive amounts in the soil solution they can be toxic to strawberry plants. This toxicity stems from impairment of leaf metabolism. The photosynthesis is reduced and carbohydrate production is limited, which in turn result in a lower strawberry fruit yield and quality loss. High Cl^- has been shown in numerous crops to induce nitrogen deficiencies due to reducing nitrate (NO_3^+) uptake.

The maximum permissible chloride level in the soil solution in most cases is 5 to 7 meq / L, and it varies somewhat by variety (see Figure 3.3). The highest allowable chloride level in irrigation water is 3 to 5 meq / L. Chloride higher than 0.5% in the dry matter of the plant indicates chloride toxicity.

A control plant, un-salinized

A plant treated with 10 mM calcium chloride ($CaCl_2$)

A plant treated with 10 mM sodium chloride (NaCl)

Figure 3.3: The effect of chloride on strawberry plants (cv. Selva)
Source: Khayyat et al, 2007

3.1.3 Sodium toxicity

If sodium ions (Na^+) are present in excessive amounts in the soil solution they can be toxic to strawberry plants. Excessive sodium ions stemming from high-sodium salts in the soil solution may compete with calcium ions for membrane-binding sites. This not only reduces Ca^{2+} uptake, but reduces Ca^{2+} transport and mobility to growing regions within the plant, which affects the quality of both vegetative and reproductive organs. Salinity can directly affect nutrient uptake. Similar effects take place in the context of potassium uptake. Potassium deficiencies have been shown to stem from excessive sodium in numerous vegetable crops.

The sodium adsorption ratio (SAR) of the soil rates the danger to plants, based on the levels of sodium, calcium, and magnesium ions in the soil solution. Tables 3.1 and 3.2, following, give the formula used to calculate SAR, and information for evaluation of the SAR. Sodium higher than 0.2% in the dry matter of the plant indicates sodium toxicity.

Strawberries (and other salinity-sensitive crops) irrigated with water rich in calcium, magnesium, and sulfate ions tolerate higher sodium levels than plants watered with lower concentrations of Ca, Mg and SO_4, even when they have same ECw. The reason for this is the counteracting effects of Ca and Mg on the sodium cations.

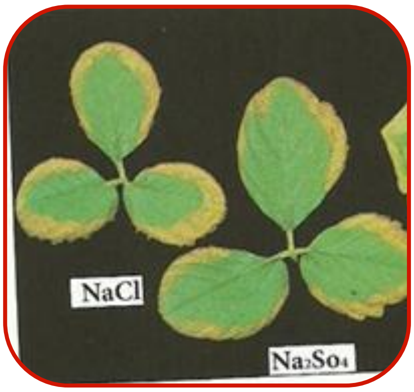


Figure 3.4: Sodium toxicity symptoms on strawberry leaves

3.1.4 Management of sodium- and chloride-toxicity in strawberries

As a result of the knowhow accumulated in many other crops grown under salinity conditions, it has been clearly shown for strawberries, too that the application of potassium fertilizers specifically combats excessive sodium in the soil solution. Similarly, the application of nitrate fertilizers specifically combats excessive chloride in the soil solution.

The study of Kaya et al, in Turkey, has established this effect very clearly on *Oso Grande* and *Camarosa* strawberries, in sand culture, as shown in Figure 3.5.

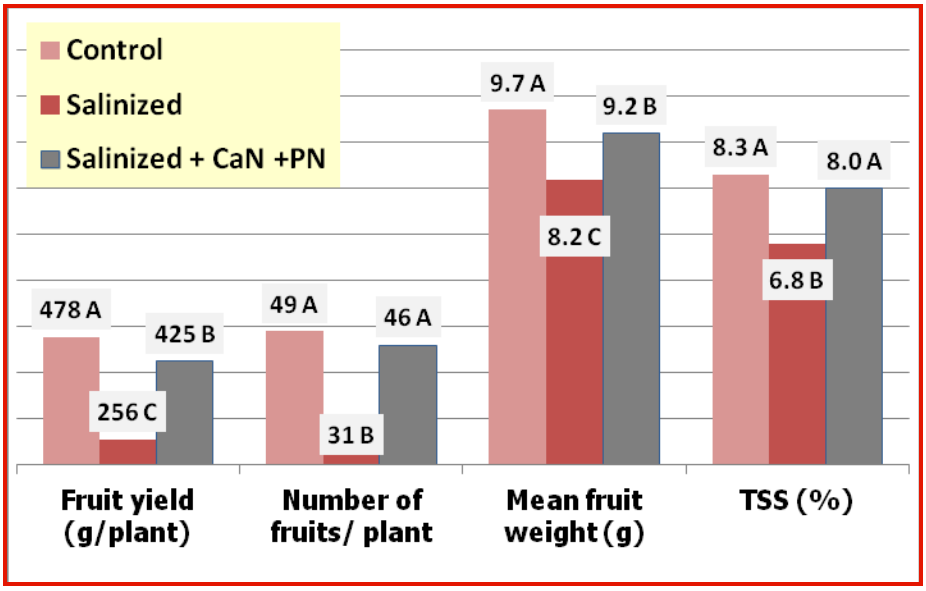


Figure 3.5: The effect of salinization and of counteracting it with potassium nitrate (PN) + calcium nitrate (CN), on most important fruit parameters of *Oso-grande* strawberries
Source: Kaya et al, 2003

Treatments were Control (nutrient solution alone), Salinized (nutrient solution + 35mM NaCl), and Salinized + 5mM CaN (calcium nitrate) + 5mM PN (potassium nitrate). The plants grown at high NaCl had markedly and statistically less dry matter, fruit yield, and chlorophyll content than those grown in normal nutrient solution for both cultivars. Both supplementary CaN and PN treatments significantly ameliorated the negative effects of salinity on plant growth and fruit yield. Moreover, in the cases of fruit numbers and TSS, the amelioration treatment revamped the plant performance to the rate of the control treatment with no significant difference between the two.

Sodium concentration in plant tissues increased in both cultivars in the NaCl treatment. Leaf concentrations of calcium, potassium, and nitrogen were much lower in plants grown at NaCl than those in the control treatment. Concentrations of these three nutrients were all significantly increased by both individual supplements, but were generally highest, in some cases very close to control values, in the salinized + CaN + PN treatment.

3.1.5 Boron toxicity

Boron is an essential nutrient for the plants. However, where present in excessive amounts, it is extremely toxic. It is present in irrigation water as un-ionized boric acid, expressed as boron element (B) in milligrams per liter. Boron concentrations lower than 0.7 mg / L will not affect plant performance. At concentrations of 0.7 to 3 meq / L, plant performance will be slightly affected, while at concentrations greater than 3 meq / L, plant performance will be severely affected. Boron tends to accumulate in the leaves until it becomes toxic to the leaf tissue and results in the death of the plant. In arid regions, boron is considered the most harmful element in irrigation water.

Studies and observations of various crops have shown that application of nitrates can defy the uptake of boron.

3.1.6 Water quality

The evaluation of the quality of irrigation water is based on laboratory tests. Laboratory determinations needed to properly evaluate irrigation water are listed in Table 3.1. The interpretation of laboratory irrigation water evaluations are based on the general rules in Table 3.2.

Salinity caused by irrigation water

Salinity problems in strawberry production are usually caused by salty irrigation water. To illustrate this claim let's quantify the problem.

Growers frequently apply 4,000 mm or more water per year to grow strawberries. This amount of water has a mass of 40,000 metric tons (MT). Let's assume that this water contains as little as 736 ppm total dissolved solids with EC=1.15 dS / m. Hence, the total amount of salts applied to one hectare equals 40,000 * 736ppm = 29.4 MT of salts each year!

Table 3.1: Salinity parameters and their values
Source: Wayne et al, 1991

	Symbol	Units	Usual range
Total salt content			
Electrical conductivity	ECw	dS/m	0 – 3
Total dissolved solids	TDS*	mg/L	0 – 2,000
Specific ions			
Calcium	Ca^{2+}	meq/L	0 – 20
Magnesium	Mg^{2+}	meq/L	0 – 5
Sodium	Na^{+}	meq/L	0 – 40
Carbonate	CO_3^{-}	meq/L	0 – 0.1
Bicarbonate	HCO_3^{-}	meq/L	0 – 10
Chloride	Cl^{-}	meq/L	0 – 30
Sulfate	SO_4^{2-}	meq/L	0 – 20
Nutrients			
Nitrate- nitrogen	NO_3-N	mg/L	0 – 10
Ammonium- nitrogen	NH_4-N	mg/L	0 – 5
Phosphate- phosphorus	PO_4-P	mg/L	0 – 2
Potassium	K^{+}	mg/L	0 – 2
Miscellaneous			
Boron	B	mg/L	0 – 2
Acidity	pH	1– 14	6.0 – 8.5
Sodium adsorption ratio**	SAR	n.a.	0 – 15

*Total dissolved salts (TDS) of the water is a parameter directly related to ECw as follows:

TDS (mg/L) = **ECw** (dS/m) **x 640**

Hence: The higher the ECw value of the water, it is more restrictive to strawberries.

**SAR is calculated by the values of Na, Ca, and Mg, expressed in meq/L by the following formula:

$$SAR = \frac{Na + meq/l}{\sqrt{\frac{(Ca^{++} meq/l) + Mg^{++} meq/l)}{2}}}$$

Table 3.2: Guidelines for interpretation of water analysis
Source: Wayne et al, 1991

Problem	Units	Restriction on water use		
		None	**Mild**	**Severe**
Salinity (affects plants ability to take up water)				
ECw	dS / m	<0.7	0.7 – 3.0	>3.0
TDS	mg / L	<450	450 – 2,000	>2,000
Infiltration (affects water penetration rate into soil)				
SAR = 0 – 3 and ECw=		<0.7	0.7 – 0.2	>0.2
SAR = 3 – 6 and ECw=		<1.2	1.2 – 0.3	<0.3
SAR = 6 – 12 and ECw=		<1.9	1.9 – 0.5	<0.5
SAR = 12 – 20 and ECw=		<2.9	2.9 – 1.3	<1.3
SAR = 12 – 40 and ECw=		<5.0	5.0 – 2.9	<2.9
Specific ion toxicity (affects the plants differentially)				
Sodium (Na^+)				
Surface/drip irrigation	SAR	<3	3 – 9	>9
Above canopy irrigation	meq / L	<3	>3	
Chloride (Cl^-)				
Surface/drip irrigation	meq / L	<4	4 – 10	>10
Above canopy irrigation	meq / L	<3	>3	
Boron (B)	mg / L	<0.7	0.7 – 3.0	>3
Other effects				
Nitrogen (NO_3-N)	mg / L	<5	5 – 30	>30
Bicarbonate (HCO_3)	me / L	<1.5	1.5 – 8.5	>8.5
pH Normal range	6.5 – 8.5			

3.1.7 General salinity management

Drainage

The proper preparation of soil and beds before planting is essential for successful strawberry production.

Adequate drainage is required to accomplish the leaching, which is necessary to remove excess salts from the root zone. Perched water tables, compaction layers, and stratified or layered soils can upset the attempts to do proper leaching. Deep (30 inch) subsoiling and chiseling temporarily alleviate these problems, but must be repeated regularly (every 1 to 4 years, depending on conditions).

Deep plowing, which mixes the soil more completely, can alleviate drainage problems for longer periods in many cases. Drainage canals and tile drain systems should be installed where high water tables inhibit drainage. Care should be taken to avoid forming hard pans.

The addition of organic amendments to heavy soils to increase drainage is helpful in some cases. However, care should be taken in selecting the types and sources of amendments since many organic amendments contain salts that can significantly increase the salt load of the soil. Applying manures or compost within a year of planting strawberries is not recommended. Cover- or green-manure crops should be incorporated into the soil early enough to be completely decomposed by the intended fumigation date.

High beds provide improved drainage. Increasing bed height may help to alleviate drainage problems. The strawberry plant has the ability to take water from any area within the root system where it can be most easily obtained.

Areas of the root zone which have lower salinity levels supply more water to meet plant needs than areas with higher salinity levels. It is essential to establish a large root system and an adequate wetted area.

Measuring water quality

Sampling the irrigation water 2 to 4 times a year is recommended if salinity is suspected. Every off-value from the parameters shown in Table 3.1 and Table 3.2 should be considered a potential risk to obtaining a good commercial strawberry yield.

Patterns of salinity buildup in the soil

Salts that contribute to salinity problems are readily soluble and move with water in the soil. Salt content of the root zone varies with depth and distance from the point in the soil where water is applied. Salinity near the application point of irrigation water is usually close to the salinity of the irrigation water. Each irrigation session pushes salts deeper into the root zone, where they accumulate until they are leached. With drip irrigation systems installed near the surface in homogeneous soils, water tends to make a deep heart shaped wetted area in the soil. Salinity is highest at the edges of the wetted area and lowest near the point of water application (i.e., nearest the drip line). The salinity gradient within the wetted area and at the bottom of the heart shape will depend on the amount and frequency of leaching.

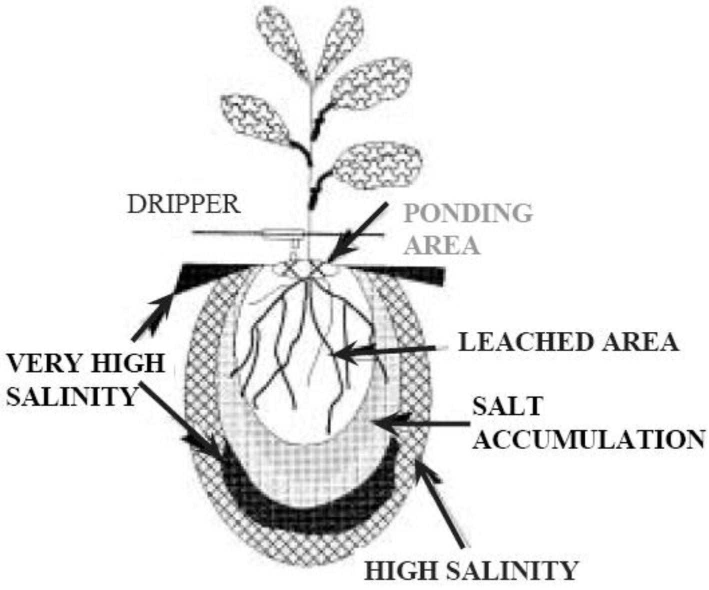


Figure 3.6: Soil, water and salt distribution in soil with a drip irrigation system
Source: Bravdo, 2007

Monitoring soil salinity during the season

Soil solution access tubes, which resemble tensiometers without a gauge, can be used to sample the soil solution during the season and monitor soil salinity. Salinity field testers are available to quickly process samples on the farm. Proper placement of the porous cup of the access tube in relation to the fertilizer band and drip irrigation line is critical in getting readings, which are a reasonable estimation of the average soil salinity of the root zone. Halfway between the plant row and the drip irrigation line and 20 cm (8 inches) below the surface, or at the same depth as the fertilizer band, appears to be one of the most favorable positions. Depending on cultural practices, however, other placements may be more desirable.

On four-row beds, two tubes should be placed to take samples both inside and outside the drip lines. An average of the two readings will give the best indication of an average salinity within the root zone. Samples should be taken midway between irrigation sessions. In other words, if irrigations are on a three-day rotation the samples should be taken a day and half after an irrigation session.

Leaching

Each irrigation session adds salts to the soil. The crop removes water from the soil to meet its needs but leaves most of the salts behind. This excess salt must be removed from the root zone before increasing to a level that affects yield. Salt is removed from the root zone by applying sufficient water so that a percentage of the total applied water percolates through and below the entire root zone, carrying with it some of the accumulated salts. The percentage of water applied above the amount necessary to meet evapotranspiration (ET) requirements is called the leaching fraction. Leaching requirements (LR) for drip-irrigated strawberry fields can be calculated using the following formula, if the irrigation-water salinity (ECw), soil salinity (ECe), and the estimated crop tolerance to soil salinity are known.

$$LR = \frac{ECw}{5 * ECe - ECw}$$

Example of estimating leaching requirement:

Given: total dissolved solids (TDS) of the irrigation water are 1000 ppm.
Hence, ECw= 1000/640 = 1.56.

If the required yield potential is 75%, then Figure 3.2 suggests that ECe should not exceed 1.8. Using the formula above will show that the leaching fraction is 21%, meaning that the leaching treatment should be done by applying at the specific irrigation session 21% above the normal rate.

$$LR = \frac{1.56}{5 * 1.8 - 1.56} = \frac{1.56}{7.44} = 21\%$$

The amount and frequency of irrigation should be calculated appropriately, to allow sufficient leaching while avoiding excessive soil moisture, which could cause other problems.

Drip irrigation technology in strawberry production with plastic mulch and frequent irrigations keeps the soil moist and very near to, or slightly above water holding capacity. Where salinity is a problem, irrigations should maintain a nearly continuous and slow downward movement of water and salts in order to maintain optimal salinity control. Monitoring the soil salinity throughout the season helps to maintain proper soil salinity levels and avoid salinity stress, which can easily go unobserved.

Leaching associated with the use of solid set sprinkler irrigation systems, before bed preparation or after transplanting and prior to putting plastic mulch over the beds, is an important part of establishing the planting. Sprinkler irrigation leaches salts away from the soil surface and the transplant crown, where salt can inhibit the adventitious root development necessary for the success of the planting. Rain water can be extremely helpful in decreasing salinity around plants during early growth if holes in the plastic are large enough to permit infiltration of the rain water around the plant.

The effect of fertilizers' salt index on salinity buildup

Nitrogen is the primary nutrient which needs to be supplied during strawberry production in most growing regions. Fertilizer placement is critical in strawberry plantings because of the crop’s sensitivity to salinity. Direct root contact with fertilizer applications will stunt or kill strawberry plants. Fertilizer formulations vary in their effect on soil salinity because various types of fertilizers, formulations, and blends have different solubility values. Most nitrogen and potassium fertilizers are very soluble and have high salt indexes (i.e., they dissolve rapidly and have an immediate impact on the salinity of the soil solution). Fertilizers with higher salt indices are more likely to cause general salinity problems, and to stunt or burn plants if placed close to the plant's root system at high rates. Most phosphate fertilizers are less soluble and have low salt indices. A fertilizer with a low salt index dissolves more slowly and is generally safer to place near plant roots. Low salt index materials have less of an immediate impact on general soil salinity.

Salt index numbers compare the solubility of fertilizers to highly soluble sodium nitrate, which has an index number of 100.

The index numbers of some fertilizer materials commonly used in strawberry production include ammonium nitrate = 104.7; urea = 75.4; potassium nitrate = 73.6; calcium nitrate = 52.5; and monoammonium phosphate = 34.2.

The salt index number is important for comparing fertilizers, but fails to take into account the difference in the nutrient analysis of various materials. For instance, urea contains 46% nitrogen by weight, ammonium nitrate contains 34% nitrogen, and calcium nitrate contains 15.5% nitrogen. Therefore, the partial salt index per unit of plant nutrient is a better measure of the material's impact on salinity, based on the number of units of nutrient that must be applied in a season. In other words, a material that has a high salt index and a high analysis will have less impact on the salinity of the soil solution than a water soluble material that has a low analysis. The low analysis material has other non-nutrient ions that also add to the salt load.

The partial salt index per unit of plant nutrient for ammonium nitrate = 2.99, calcium nitrate = 4.41, and urea = 1.62. Therefore, if a given amount of nitrogen is to be added to the soil and salinity is the only consideration, urea would be the best material because it would have the least impact on salinity.

Fertilizer placement for winter strawberry plantings

Controlled-release fertilizers (CRFs, resin-coated fertilizers) are often banded in a planting slot 15 cm to 20 cm (6 inches to 8 inches) deep (see Figure 3.8). The fertilizer band is covered with approximately 4 cm (1½ inches) of soil and transplants are placed directly above the fertilizer band. Direct contact of transplants with the fertilizer band should be carefully avoided. Supplemental applications of nitrogen as ammonium nitrate or urea are made through the drip irrigation system during the first three months of the season. Supplemental application rates and timing are based on climatic conditions and the observed needs of the plants. This placement of the fertilizer in a slot below the transplant, with the drip irrigation line above and between rows of plants, creates a gradient of salinity (salinity being lowest near the drip line and highest within or just below the fertilizer band). This gradient allows the strawberry roots to grow into areas of minimum salinity for optimal water uptake and also to selectively grow into fertilized soil of higher salinity, in which the plant can best take up needed nutrients. This appears to be the best method for applying fertilizers to strawberries in areas where water quality is low and salinity is a serious problem. Read more about the details and the advantages of this fertilization system in paragraph 6.2 of this publication: Controlled-release nutrition of strawberries.

Figure 3.7: CRF placement in deep slots during the preparation of the growing beds California, USA, 2004

Summer strawberry plantings

In summer plantings all of the lime, gypsum, phosphorous, and any potassium or minor elements that are to be applied, plus a portion of the total nitrogen, can be broadcast and incorporated into the soil that will make up the bed. Side dressing the nutrients in bands below and to the outside of the planting slots is also utilized in summer plantings. Additional nitrogen is often applied through the drip irrigation system during the growing season. If controlled / slow-release fertilizers are used, they are placed at the bottom of the planting slot below the roots, and covered with approximately 4 cm (1½ inches) of soil, to the side of the slot, or in the middle of the bed under the drip irrigation line (see Figure 3.8 below, and Figure 6.6 on page 101.

More fertilizer placement options are available to growers with summer plantings. The same concern should be exercised, however, for salinity control and monitoring of salinity levels to insure optimal yields.

4. Mineral nutrition of strawberries

4.1 Summary of main plant nutrient functions

Nutrient	Main functions
Nitrogen (N)	Building block of proteins (growth and yield).
Phosphorus (P)	Cellular division and formation of energetic structures.
Potassium (K)	Transport of sugars, stomata control, cofactor of many enzymes, reduces susceptibility to plant diseases.
Calcium (Ca)	A major building blocks in cell wall and reduces susceptibility to diseases.
Sulfur (S)	Synthesis of essential amino acids cystin and methionine.
Magnesium (Mg)	Central part of chlorophyll molecule.
Iron (Fe)	Chlorophyll synthesis.
Manganese (Mn)	Necessary in the photosynthesis process.
Boron (B)	Formation of cell wall. Germination and elongation of pollen tube. Participates in the metabolism and transport of sugars.
Zinc (Zn)	Auxins synthesis; enzymes activation.
Copper (Cu)	Influences in the metabolism of nitrogen and carbohydrates.
Molybdenum (Mo)	Component of nitrate-reductase and nitrogenase enzymes.

4.2 Tools for optimal nutrient management

The three tools for optimal nutrient management are:

1. Observation of plants and environmental conditions.
2. Soil and water analysis.
3. Leaf analysis.

4.2.1 Observation

Visual symptoms should be used as aids to interpreting soil and leaf analyses:

- Look for abnormal symptoms in foliage or growth.
- Look for significant variations in yield.
- Observation can locate nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, zinc, iron, manganese, copper and boron deficiencies.

4.2.2 Soil analysis

A soil test should be done one year before planting. Soil analysis is performed to assess the need for soil amendment, e.g., lime application to adjust low soil pH, and gypsum application to adjust Ca:Mg ratio or to reclaim alkaline soil. Samples should represent the effective rooting zone. A soil auger may be used to obtain samples. Generally, about 1 liter (1 quart) of soil per sample is adequate. Take 10 or more soil samples of a uniformly looking field of 2 ha (5 acres), and mix the samples. Take more samples for larger plots, or specifically from subplots that look different. Take the samples from the top 20 cm (8 inches). Send them to a soil testing laboratory that can provide recommendations for strawberries. Compare your soil test results with those in Table 4.1.

Table 4.1: Desirable ranges of pH, organic matter, and elements determined by soil test for strawberries

Parameter	Desirable values	
pH	5.3 – 6.5	
Organic matter	2% – 3%	
	Available	**Exchangeable**
Phosphorus	67 – 90 kg / ha ; (60-80 Lb / A)	
Potassium		315 – 360 kg / ha ; 280-320 Lb / A
Magnesium		280 kg / ha ; (250 Lb / A)
Boron	1.7 – 2.25 kg / ha ; (1.5-2.0 Lb / A)	
Zinc	11 – 13.5 kg / ha ; (10-12 Lb / A)	

Desirable ranges will vary with soil type (sand, silt, or clay), organic matter already present in the soil, and pH. Soil values may need to be amended in order to correct deficiencies or excesses that are identified.

A pH of around 6.5 is best for sandy textured soils, whereas for finer textured soils (e.g., loam) a pH closer to 5.3 is preferable. Soil pH has a strong influence on nutrient availability, and should be regularly monitored and corrected as needed. A low soil pH (acidic soil) will reduce the availability of nitrogen, phosphorus, potassium, magnesium, and molybdenum, while a high soil pH (alkaline soil) will reduce the availability of zinc, boron, iron, manganese, and copper.

Similar soil tests should be performed several times during the active growth and fruiting seasons. Separate samples should be taken from blocks that differ in age, cultivar type, vine performance, soil type, topography, and fertilizer history. When trying to diagnose a problem with crop growth and yield, samples should be collected from the rooting zones of the worst affected plants. In these circumstances, a second sample taken for comparative purposes from the rooting zones of normal plants may be useful.

4.2.3 Leaf analysis

Intensively grown strawberries require frequent and precise fertility management. Leaf analyses provide the best means of monitoring nutritional status (deficiencies or excesses) and correcting deficiencies that may occur. Leaf analyses not only ensure that yield and quality are optimized, but also protect against applying excess nutrients in the environment, and incurring unnecessary expenses.

The best way to decide how much fertilizer to apply is to collect leaf samples and have them tested for nutrient content. It is recommended to collect tissue samples at first bloom and to continue to do so every two weeks throughout flowering and fruiting.

Nutrient ranges for optimal production are well established. When nutrient levels are outside these ranges, decreases in quality will eventually occur. Tissue analysis can identify nutrient shortages early, before symptoms appear, thus giving growers time to adjust fertilization appropriately.

To collect a tissue sample from strawberry plants, select the most recently mature, trifoliate leaves. These are full-sized, green leaves and consist of a petiole (leaf stalk) with three leaflets. They leaves are usually located 3 to 5 leaves back from the growing point. Avoid collecting damaged leaves. Detach the petioles from the blades as they are collected, but submit them together as one sample.

Each sample should include leaf blades and petioles from 20 to 25 locations within a uniform area. For example, all of the plant material in a single sample should be of the same variety, growing on the same soil type, planted at the same time, and having the same management history. This will serve as a representative sample for that plot.

The most recent mature trifoliate leaf blade sampled at fruiting is the best indicator of the status of N-P-K concentrations in the plant, as well as the secondary elements Ca, Mg, and S, and the micronutrients Fe, Zn, Cu, and B.

The petiole from this same trifoliate leaf sampled throughout the season is the best indicator of the amount of nitrate-nitrogen not yet assimilated in the plant. Petiole analysis is more sensitive to changes in soil nitrate, and the analysis will also be affected by changes in temperature, solar radiation, and soil moisture. A concentration in the petioles in the range 3,000-10,000 ppm nitrate N (on a dry matter basis) indicates an optimal nutritional status.

When submitting leaf samples, an information sheet should be filled out, including fertilization history and environmental conditions. It is particularly important to provide the sampled variety name, as well as its growth stage. Growth stage refers to week of bloom and can be coded B1 through B12 (1^{st} to 12^{th} week of bloom).

Figure 4.1: Proper leaf blade and petiole sampling parts
Source: Clevelend, North Carolina, 2007. http://www.ncagr.gov/paffairs/release/2007/3-07sberry.htm

Leaf blade sampling

Sampling time:	During fruiting, preferably at first harvest
Plant part:	Leaf blades (excluding petioles)
Collect from:	Youngest mature leaves
Quantity per sample:	30-50 units
Comments:	Deficiencies are more likely to arise during fruiting, when substantial nutrient uptake is occurring.

Leaf petiole sampling

Sampling time:	Throughout the growth season
Plant part:	Petioles only
Collect from:	Youngest mature leaves
Quantity per sample:	~50

Nutrient concentration ranges for strawberries are listed in Table 4.2.

Table 4.2: Standard concentrations for foliar analysis of strawberries

Macro-nutrients	Deficient	Sub-optimal	Optimal	Above-optimal	Excess
			(%)		
Nitrogen	< 1.5	1.8	1.9 – 2.8	2.9	>4.0
Nitrate NO_3-N			<800 ppm		
Phosphorus	< 0.20	0.25	0.25 – 0.4	0.4-0.5	>0.5
Potassium	< 1.2	1.3 – 1.6	1.6 – 2.5	2.5 – 3.4	>3.5
Calcium	< 0.6	0.69	0.7 – 1.7	1.7 – 2.0	>2.0
Magnesium	< 0.25	0.29	0.3 – 0.49	0.5 – 0.8	>0.8
Sulfur	< 0.20	0.2 – 0.4	0.4 – 0.6	0.6 – 0.8	>0.8
Sodium			<0.10	> 0.10	
Chloride	-		-	> 0.50	
Micro-nutrients			**(ppm)**		
Manganese	< 40	49	50 – 200	200 – 350	>350
Iron	< 30	59	60 – 250	250	>350
Zinc	< 15	20	20 – 49	50 – 80	>80
Copper	< 5	6	7 – 19	20	>20
Boron	< 19	24	30 – 64	65 – 90	> 90
Molybdenum	< 0.5		> 0.5		

Sources: Strawberry fertiliser guide, Primefact 941, 2010. www.industry.nsw.gov.au and Ellis et al, Ohio, 2006.; Growing Strawberries, Abdel-Razak, 2004

4.3 Plant nutrients, deficiency symptoms, and application rates and methods

Nitrogen (N)

Nitrogen is the central component of all amino acids, which are the building blocks of all proteins and include, of course, all functional enzymes. Nitrogen is a highly important plant nutrient, which substantially affects quality and yield of strawberries. The plant quickly responds to every positive or negative change in its nitrogen status. Application of nitrogen fertilizers stimulates vegetative growth of leaves, petioles, and shoots. Heavy applications are not recommended because excessive vegetative growth will result in dense leaf canopy that will cover developing fruit, keeping it in a dark, cool and wet microclimate, and enhance the development of fruit rot diseases, such as gray mold. Excessive nitrogen causes fruit softening, which results in easily-damaged strawberries, delayed ripening, decreased yield, and increased powdery mildew and mite pressure.

Nitrogen deficiency is manifested (and consequently visualized more easily) in middle-aged leaves. The yellow strawberry plant leaves occur primarily at middle age, and not when the plant is young, when the new, still-green leaves emerge from the crown. The young leaves emerging from the crown exacerbate the deficient state of the middle-aged leaves by being a stronger sink for the nitrogen that would otherwise have been used in the older leaves. Due to the demand of metabolism and synthesis of the newly emerging foliage, nitrogen will be mobilized from the middle-aged leaves to the new ones. This leads to more severe color changes in the middle-aged leaves, depending on the overall severity of the nitrogen shortage.

Plants with mild N deficiency (N<2.0%) have smaller than usual chlorotic older leaves.

Slight nitrogen deficiency on a young leaf (right)
Source: Bolda , 2011;
http://ucanr.org/blogs/blogcore/postdetail.cfm?postnum=5404

Advanced nitrogen deficiency on young mature leaves
Source: Strawberry fertiliser guide, Primefact 941, 2010.
www.industry.nsw.gov.au

Figure 4.2: Slight (left) and advanced nitrogen deficiencies on plant leaves

More severe deficiencies cause shortening of the petioles, which turn red-purple and become brittle. The purple strawberry leaves are attributed to nitrogen and amino acid deficiency (see Figure 4.3). Sometimes, the calyx leaves also turn purple (see Figure 4.4). Nitrogen deficiency also reduces leaf area, root mass, and fruit size.

Frequently, older leaves also become reddish. This should not be confused with N deficiency.

Severe nitrogen deficiency on a single leaf

Severe nitrogen deficiency in the field

Figure 4.3: Leaves turn purple-red at advanced nitrogen deficiency

Figure 4.4: Nitrogen deficiency – red calyx
Source: Strawberry fertiliser guide, Primefact 941, 2010. www.industry.nsw.gov.au

Nitrogen application

The nitrogen available to plants in the soil occurs in two forms: nitrate (NO_3^{-}) and ammonium (NH_4^{+}). Nitrate is the preferred form for uptake by the plant. It is readily available for use and simple for the plant to metabolize, so nitrate share should be around 90% of the nitrogen applied. However, during colder seasons, the ammoniacal share of the nitrogen may be raised to 25% to 30% because nitrate absorption at these times is relatively inefficient. Prolonged usage of ammonium nitrogen should be accompanied by soil-pH measurements because it can lead to pH-drop, especially, in light soils with low amounts of calcium, which may, in turn, change the uptake rates of other nutrients. Manganese, for example, may reach toxic levels.

Typical nitrogen fertilizers used on strawberries include urea (46% N), ammonium nitrate (34% N), potassium nitrate (13% N), and calcium nitrate (15% N).

Animal manure may be used as a nitrogen carrier because it also contributes to soil fertility via its phosphorus, potassium, and micro-nutrient content. It also improves the physical structure of soil, as well as its hydraulic conductance. The use of animal manure is recommended only if it has been well composted. Although it may contain considerable concentrations of nitrogen at a relatively low price, the risk of microbial contamination by organisms such as salmonella and E. coli is too great for fresh produce. Hence, no fresh manure should be applied to the soil within 120 days before harvest.

In a matted row system, the majority of the nitrogen fertilizer should be applied during the summer months following harvest, when new leaf and shoot (runner) growth is needed to reestablish good planting vigor for the following year's crop.

During the planting year (assuming the general soil fertility is good), a strawberry planting should receive actual nitrogen at 22 to 45 kg / ha (20 to 40 pounds / acre) incorporated into the soil prior to planting.

Another 35 kg / ha (30 pounds / acre) should be applied in late June to early July.

A final 22 kg / ha (20 pounds / acre) can be applied in late August to early September. Each of these applications corresponds to periods of growth in the plants.

A 1:1 mixture of calcium nitrate Ca(NO3)2 and potassium nitrate (KNO3) with 14% N is the recommended source of nitrogen in new plantings because it is readily available, not volatile, and provides nitrogen, potassium, and calcium.

For established beds, only 11 to 22 kg / ha (10 to 20 pounds / acre) of actual nitrogen, if any, should be applied in the spring.

As part of the renovation process following harvest, 55 to 80 kg / ha (50 to 70 pounds / acre) of actual nitrogen should be applied to the planting, followed by 22 to 33 kg / ha (20 to 30 pounds / acre) in late August to early September.

Table 4.3: Nitrogen fertilizers and their usage indicators

Product	Analysis (%N)	Development stage for best results	Application rate (kg / 1,000 plants)	Comments
Urea	46	Early flowering onwards	0.4 to 0.5	Improves fruit size. Reduce at fruiting. Stop if fruit is soft.
Ammonium nitrate	34	As for urea	0.5 to 0.6	Improves fruit size. Stop if fruit is soft.
Ammonium sulfate	21 + 24% S	As for urea	0.9 to 1.0	Corrosive to mild steel.

If nitrogen is applied by nutrigation (through the irrigation system), which is typical in plasticulture systems, pre-plant nutrients should be incorporated into the soil, as recommended above.

In the planting year, actual nitrogen should be applied at 3.5 to 4.5 kg / ha / week (3 to 4 pounds / acre / week) from mid-May through early September.

In the fruiting years, apply approximately 11 kg / ha / week (10 pounds / acre / week) of actual nitrogen from mid-July through late August.

Table 4.4: Nitrogen application rates at annual strawberry plantations in Israel
Source: Abdal-Razak, Israel, 2004

Dates	Growth stage	Actual N application (kg / ha / day)
Oct. 1 – Nov. 20	Plant establishment and first vegetative growth	0.5 – 0.7
Nov. 21 – Dec. 20	1st wave of flowers and fruits	1.0 – 1.5
Dec. 21 – Jan. 20	Cold season, slow plant development	0.7 – 1.0
Jan. 21 – Feb. 28	2nd wave of flowers and fruits, marked vegetative and reproductive development	1.5 – 2.0
March 1 – March 31	3rd wave of flowers and fruits, peak vegetative & reproductive development	2.0 – 2.5
April 1 – end	3rd & 4th wave of flowers and fruits, peak vegetative & reproductive development. Plants use mainly stored organic nitrogen.	1.0 – 1.5

When the grower relies on nitrogen-fixing bacteria to supply part of the nitrogen portion, he should make sure that the soil molybdenum is sufficient, as nitrogen-fixing bacteria cannot fix atmospheric nitrogen to the soil without sufficiently available molybdenum.

Phosphorus (P)

Phosphorus is important in the plant's energy management (ADP-ATP) and it plays a role in fruit development. Available phosphorus is especially important during establishment of plantlets after transplanting, for new root formation.

Crude phosphorus is often present in adequate amounts for good strawberry growth, but most of it is not readily available to the plants because it is strongly tied up to both the mineral and organic fractions of the soil. As a result, it does not tend to move through the soil and is not easily leached. Availability is further reduced if the soil pH is too low (<5.5), or in the range of 8.0 to 8.5 (Figure 4.5), or if calcium, magnesium, or zinc are present at over-optimal amounts. Soil tests should read 20–30 ppm (Olsen method) for optimal phosphorus uptake. Strawberries do not have a very high phosphorus demand, but if it is not available at optimal rates it can be a limiting factor. Keeping the pH near 6.5 will aid in maintaining the optimal uptake of phosphorus. After planting, it is advisable to monitor phosphorus status by observing the canopy, leaf tissue analysis, and soil tests.

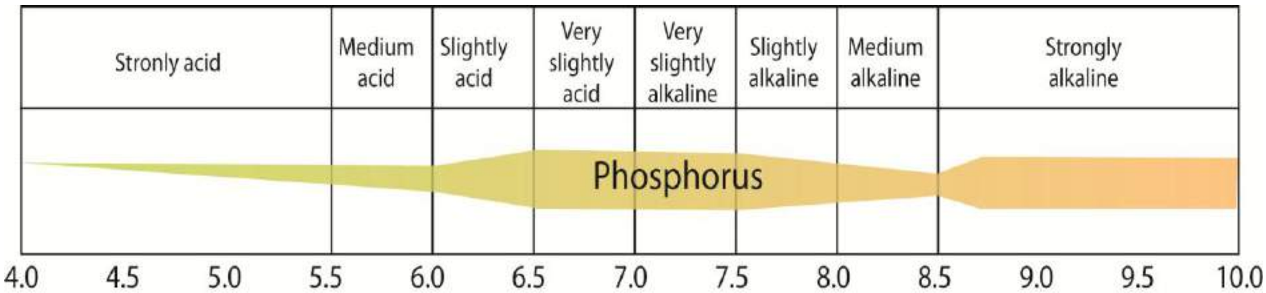


Figure 4.5: The availability of phosphorus to plant roots as a function of the pH of soil solution
Source: Illinois Agronomy Handbook, 1979-80

As a fertilizer, it becomes available to the plants slowly, and it should therefore be worked into the soil prior to planting to improve its uptake throughout the crop's life-cycle.

There is a strong antagonistic relationship between phosphorus and zinc: high phosphorus will invariably reduce zinc uptake, and excess zinc will have the same effect on phosphorus. The ideal phosphorus / zinc ratio is 10:1 respectively.
Source: http://www.nutri-tech.com.au/blog/2008/09/trace-element-essentials/

P deficiency

The first sign of phosphorus deficiency is a deep green appearance of plants and a reduction in leaf size. As the deficiency becomes more severe the upper surface of the leaves develops a dark, metallic gloss, while the underside becomes reddish purple (Figure 4.6). The fruit and fslowers tend to be smaller than normal and the roots are less abundant, stunted and darker. Leaf analysis showing P ≤0.2% in the leaves DM will ascertain this hypothesis.

Most phosphorus should be applied before planting and placed within the root zone. Applying superphosphate after laying plastic mulch in either the planting holes or in the walkways is not effective. Soluble phosphorus fertilizer can be applied by fertigation.

Upper surface of leaves develops a dark metallic gloss
Source: Strawberry fertiliser guide, Primefact 941, 2010. www.industry.nsw.gov.au

Severe phosphorus deficiency on a leaf, sometimes the underside becomes reddish purple
Cornell University, Department of Horticulture. 2011

Figure 4.6: Phosphorus deficiency symptoms on a strawberry leaf

Table 4.5: Phosphorus fertilizers and their usage indicators

Product	Analysis	Development stage for best results	Application rate (kg / 1,000 plants)	Comments
Triple super phosphate	46% P_2O_5 + 19% CaO	Pre-planting	2.5 – 3	Will supply P for several years.
Mono-ammonium phosphate (MAP)	61% P_2O_5 + 12% N	Early in season and after cutting back for second crop; or before cutting back if plants are kept for a second year.	1.0 - 1.2	Improves flower and fruit size, and root growth.
Mono potassium	32% P_2O_5 + 54% K_2O	Flowering and fruiting	0.6 – 0.7	Improves flower and fruit size, and root growth.

Haifa's specialty phosphate fertilizers

Haifa P™ Nutrigation grade phosphoric acid 0-61-0

Haifa MAP™ Nutrigation grade mono-ammonium phosphate 12-61-0

Haifa MKP™ Nutrigation grade mono-potassium phosphate 0-54-32

Potassium (K)

Potassium is the third macro-nutrient, (nutritive element required in relatively high amounts) by strawberries. It is an important component of strawberry plants and helps them acquire water by the roots and control water loss by transpiration. Potassium assists in sugar accumulation in the fruit, defies fungal and microbial diseases and insect damage, and plays an important part in tens of enzymatic reactions. Potassium may compete with magnesium for uptake by the roots and must, therefore, be maintained at an appropriate ratio (4:1, K:Mg) in the soil solution to prevent one of these nutrients from overriding the other, thereby creating a deficiency. Soil potassium is sufficient at 120 to 180 ppm.

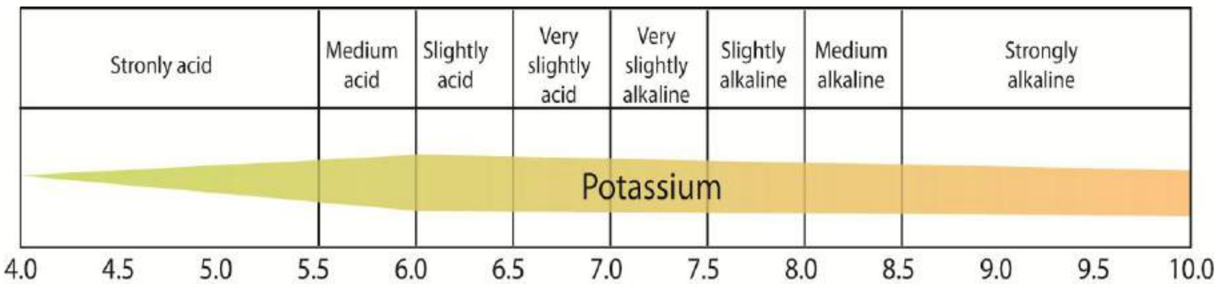


Figure 4.8: The availability of potassium to plant roots as a function of the pH of soil solution
Source: Illinoi s Agronomy Handbook, 1979-80

Potassium ion (K^+) is easily percolated from sandy soil, which is generally the best soil type for strawberries due to their high drainage capacity. It is highly recommended, therefore, to fertilize strawberry fields by continuous small applications of this nutrient throughout the growth season, e.g., by nutrigation. The recommended concentration in the soil solution should be around 1.5 meq / L (=60 ppm).

All major cations: calcium, magnesium, potassium, and sodium compete with each other on absorption by root cells. Therefore, they should be applied to the soil in a balanced manner. Over-liming, for example, can induce a magnesium deficiency, while oversupply of K+ can also reduce magnesium uptake, or can replace calcium in the plant, creating a myriad of problems, and vice-versa. Excessive sodium can replace potassium, producing another set of inherent problems.

The first symptoms of K deficiency (K <1.3%) appear on the upper leaf margins of the older (lower) leaves. The serration tips redden, the injury gradually progressing inwards between the veins until most of the leaf blade is affected.

Figure 4.9: Potassium deficiency on a strawberry leaf, showing increasing severity with age
Source: Strawberry Fertiliser Guide, Primefact 941, 2010. www.industry.nsw.gov.au

This is accompanied almost simultaneously by a symptom which appears to be unique to strawberries. The rachis (extension of the petiole to the central leaflet) darkens and dehydrates, sometimes a necrosis of this leaf region is evident. The blade area on either side of this tissue is similarly affected.

Figure 4.10: Potassium deficiency on a strawberry leaf, darkening and necrosis of leaflet basis and center
Source: Strawberry Deficiency Symptoms, 1980. Ulrich et al, Berkeley, California

Fruit quality is also affected by low potassium levels. The fruit can fail to develop full color, be pulpy in texture and lack flavor.

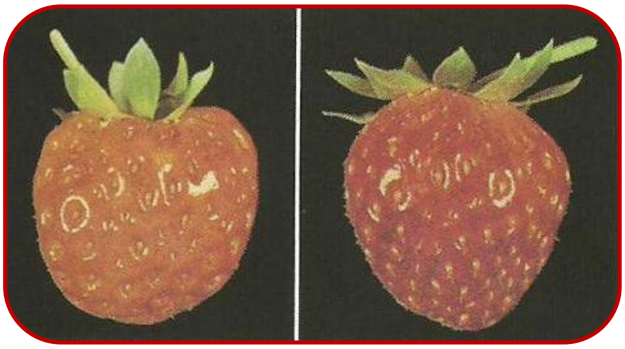


Figure 4.11: Potassium deficiency on a strawberry fruit. Right fruit is normal, while left fruit grew on a markedly K-deficient plant.
Source: Strawberry Deficiency Symptoms, 1980, Ulrich et al, Berkeley, California

Few runners are produced on K-deficient plants. Those that are produced tend to be short and thin.

The symptoms of potassium deficiency on the leaves can be easily confused with those of magnesium deficiency, see flowing, or with leaf scorch caused by salinity, wind, sun, or dry conditions.

Strawberry fields that are not set up for nutrigation (fertigation) need to be treated with low-solubility potassium fertilizer, such as potassium sulfate as a pre-plant dressing. Better-equipped fields, set up for nutrigation, should usecontinuous low rates of highly soluble potassium fertilizer. Potassium nitrate (13-0-46) is the best choice for this purpose as it contains a high amount of potassium and a marked, though not too high rate of nitrogen. Muriate of potash (KCl) must not be applied to strawberry fields due to its high content of toxic chloride. See Chapter 3, Special sensitivities.

Control

Apply potassium before planting and during early fruit development. A higher rate of potassium should be used in sandy soils and in high rainfall areas. Apply soluble potassium by fertigation after planting.

Table 4.6: Potassium fertilizers and usage indicators

Product	Analysis	Development stage for best results	Application rate (kg / 1,000 plants)	Comments
Potassium nitrate	13% N + 46% K_2O	Flowering Fruiting	0.7 – 0.8	Assists in maintaining fruit quality and flavor.
Potassium sulfate	50% K_2O + 16% S	Pre-planting Fruiting	0.7 – 0.8	As for potassium nitrate
Mono potassium phosphate (MKP)	54% K_2O + 32% P_2O_5	Flowering Fruiting	0.6 – 0.7	As for potassium nitrate

Haifa's potassium fertilizers for strawberries

Multi-K™ classic Crystalline potassium nitrate, 13-0-46, for side dressing

Multi-K™ GG Crystalline potassium nitrate, 13.5-0-46.2, for nutrigation and foliar feeding

Multi-K™ prills Prilled potassium nitrate, 13-0-46, for side- dressing

Multi™-K pHast Crystalline low-pH potassium nitrate, 13.5-0-46.2, for side dressing at high soil pH, or high water pH

Multi-npK™ Crystalline potassium nitrate, enriched with phosphorus, 13-3-43 for all uses.

Haifa MKP™ Technical grade MKP 0-52-34, for all uses

Calcium (Ca)

Calcium is a “secondary” nutrient as classified by strawberry plant requirement rates.

It has many functions in the plant. It is a structural part of the cell walls, by forming cross-links within the pectin polysaccharide matrix. With rapid plant growth, the structural integrity of stems that hold flowers and fruit, as well as the fruit firmness and shelf life, are strongly dependent on calcium availability. Calcium is also associated with the biosynthesis of proteins and seeds. It assists in root development and movement of carbohydrates within the plant. Calcium insufficiency may impede plant growth and, as its function in root growth is so important, plants may suffer from other nutrient deficiencies as a result of calcium deficiency.

Additionally, many fungi and bacteria invade and infect plant tissue by producing enzymes (e.g., polyglacturonase) that dissolve the middle lamella. Increasing tissue calcium content drastically lowers bacterial and fungal polyglacturonase activity.

Levels of calcium are usually adequate in the soil if the pH is in the appropriate range (6.0-6.2). Soils with a low pH may become calcium deficient. Soil test levels of 1,000 – 1,500 ppm are optimal. Calcium has rather low mobility in the soil and in the plant tissues, where it is mobilized almost exclusively by the transpiration stream.

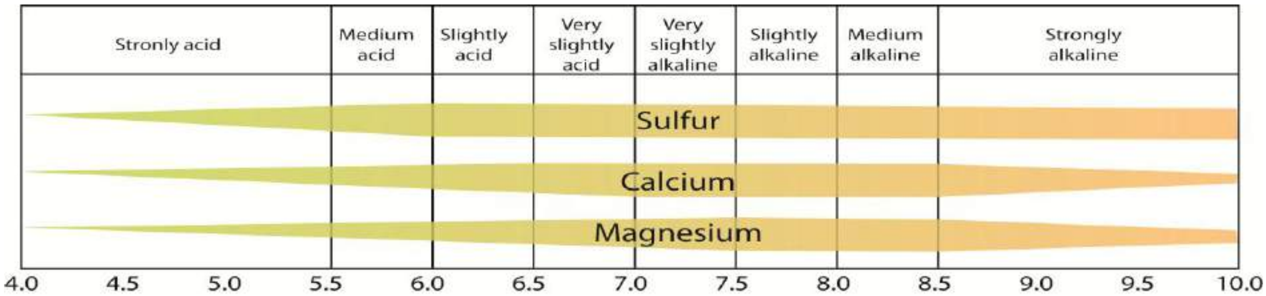


Figure 4.13: The availability of sulfur, calcium, and magnesium to plant roots as a function of the pH of soil solution
Source: Illinois Agronomy Handbook, 1979-80

Calcareous-, sodic-, slightly basic- and neutral soils generally contain a very high rate of soluble and plant-available calcium cations. In such soils, Ca^{2+} cations also travel freely with the movement of water, and reach plant roots by mass flow. Under these conditions, the amounts of Ca^{2+} reaching the roots are usually exceedingly higher (by a factor of several hundred) than the amount taken up by the roots, so fertilization with calcium of plants growing in such conditions is generally unnecessary.

Additionally, calcium cations are supplied to the plants by the calcium contained in the irrigation water. Representative values for calcium concentration in irrigation water are in the range of 25 to 200 g / m^3 (ppm). With irrigation dose of 5,000 m^3 / ha / year, calcium carried with the water to the irrigated plot ranges between 125 and 1,000 kg / ha / year. This is a sufficient rate for strawberries if all this water ends up in the plants' roots zone. But the grower should always make sure that these calculations are valid for his water sources.

Another source of calcium in the soil are phosphate fertilizers such as rock-phosphate (~46% CaO), single superphosphate (~28% CaO) or triple superphosphate (19% CaO), which are sometimes applied at large rates by base dressings, as rich sources of phosphorus. These fertilizers should be worked into the soil to improve uptake.

In acidic soils, however, application of soluble calcium salt, such as calcium nitrate, can be helpful in avoiding aluminum and manganese toxicity. Figure 4.14 shows the positive effect of nutrigation with calcium nitrate on soil pH at the end of the irrigation season, on the surface soil, where it exerted its effect on the soil lattice. It can be assumed that if the calcium were applied at higher rates the increase in pH could be detected at higher depths too.

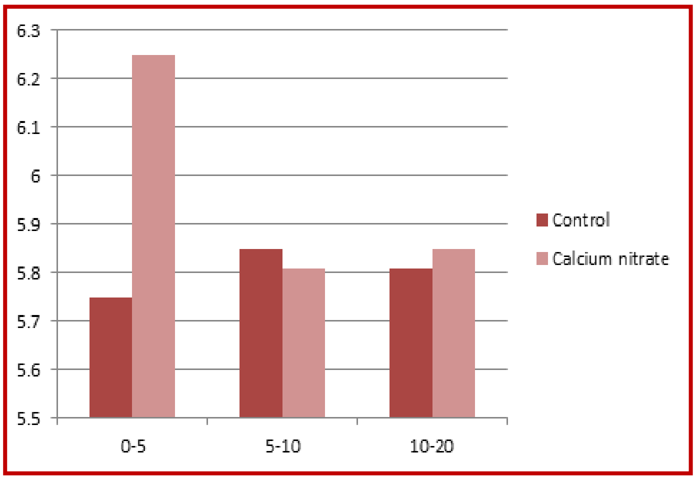


Figure 4.14: Effect of nutrigation with calcium nitrate on soil pH
Source: Haynes, 1990

Soilless cultivation is where calcium application by nutrigation is of highest importance because the inert growth medium cannot supply the necessary calcium. Here, again, calcium cations travel freely within the wetted zone and care should be taken not to leach them off the root zone.

When applying calcium by nutrigation (as well as by all other forms) special attention should be paid to apply it in a balanced way with other cations, such as ammonium, potassium, and magnesium because over-application of any of them will result in subdued uptake of the others, due to competition between the cations on the uptake site at the root level.

The calcium / magnesium ratio is of very high importance in fertility management, as soil structure, nutrient availability, and biological activity are all governed by the relative balance between these nutrients.

The calcium / boron ratio is very important because boron can be toxic in the absence of sufficient calcium. The synergy between these nutrients is delicate, so their deficiencies should ideally be addressed together.

Calcium deficiency

Calcium deficiencies can be the result of a soil fertility problem but are often caused by the plant's environment, and are associated with periods of rapid growth or soil moisture fluctuations. Young plantings and crops grown in the greenhouse, or on coarse textured, well drained soils and using trickle irrigation, may be subject to possible calcium deficiencies.

Calcium is taken up by the root tips and, once in the plant, is moved within the transpiration stream. It is transported to the most actively transpiring parts of the plant, such as the older leaves. Calcium is not redistributed in the plant, hence it does not move from older leaves to younger leaves like nitrogen. Fruits and young leaves transpire less water or none at all, and symptoms of calcium deficiency first appear in these tissues.

Symptoms include:

- During rapid leaf growth 'tip burn' symptoms may appear on immature leaves. See Figure 4.15. The tips of these leaves fail to expand fully and become black. The tip-burn may show also in folded emerging leaves.
- Leaf petioles may become necrotic and cause leaf collapse. See Figure 4.16.
- Expanded young leaves are cupped, puckered, or distorted, with blunt tips.
- Globs of syrupy liquid may be found on blade midribs.
- Fruit develops a dense cover of achenes (seeds) in patches or over the entire fruit; it may have a hard texture and acidic taste. See Figure 4.17.
- The roots become short, stubby, and dark.
-

Figure 4.15: Calcium deficiency typical tip-burn on leaves

Figure 4.16: Calcium deficiency on leaf petioles of greenhouse strawberry plants

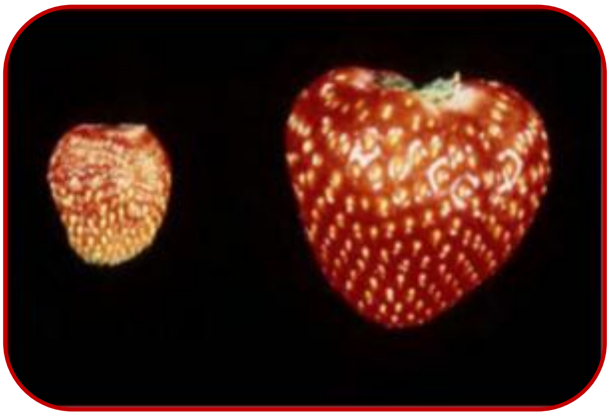


Figure 4.17: Calcium deficiency: small fruit with dense cover of seeds (left), versus normal fruit (right)
Source: Strawberry Fertiliser Guide, Primefact 941, 2010. www.industry.nsw.gov.au

Control

Adjust the soil pH. Apply calcium in the form of agricultural lime or dolomite before planting. Apply calcium nitrate by fertigation or as foliar spray at first sign of deficiency.

Table 4.7: Analysis of calcium nitrate and usage indicators

Product	Analysis	Development stage for best results	Application rate (kg / 1,000 plants)	Comments
Calcium nitrate	15.5% N + 26.5% Ca	Post-flowering and during fruit development	1.0 to 1.2	Improves fruit color and firmness. Do not mix with magnesium sulfate.

Calcium nitrate, CN, $Ca(NO_3)_2$ is the most important source of calcium in nutrigation. Once this fertilizer is applied, calcium cations and nitrate anions move in all soils and soilless systems in a similar manner. The plant roots will thus encounter both ion types in similar concentrations within the wetted zone, but it needs to be borne in mind that the nitrate anion is required by the plant at a 10-fold higher rate than the calcium. So the cation nutrition scheme should be balanced with appropriate rates of potassium and magnesium.

Haifa Cal GG Calcium nitrate

Haifa's calcium nitrate fertilizer for nutrigation is marketed under the brand name **Haifa Cal**™, and features the following parameters

Table 4.8: Haifa's Calcium nitrate (**Haifa Ca™l**) analysis

	Nutrition grade	Greenhouse grade
Total N	15.5%	15.5%
NO_3 – N	14.4%	14.4%
NH_4 – N	1.1%	1.1%
CaO	26.5%	26.5%
Ca	19.0%	19.0%
Insoluble matter	2,000 ppm	300 ppm

Apart from applying calcium nitrate when calcium deficiency symptoms are apparent, it is recommended to:

- Avoid great fluctuations in soil moisture. Therefore, using dripping irrigation and nutrigation is highly recommended.
- Adjust nitrogen or crop environment to discourage excessively rapid growth.

Calcium deficiency is often confused with:

- Herbicide injury (such as phenoxy- and dicamba- compounds and sulfur dioxide).
- Sucking insects e.g., aphids, leafhoppers, cyclamen mites, and plant bugs.

Magnesium (Mg)

Magnesium is always taken up by plant roots in the form of the divalent cation Mg^{2+}.

Magnesium has many functions in the plant. It is a central structural component of the green chlorophyll molecule, which is responsible for capturing light energy and using it to split the water molecule into its hydrogen and oxygen parts. It is required by a large number of enzymes involved in phosphate transfer. It is also involved in carbohydrate metabolism and movement of carbohydrates from leaves to upper parts; synthesis of nucleic acids. It is related to and stimulates P uptake and transport in addition to being an activator of several enzymes.

The commonly representative concentration of magnesium in plants is around 0.3% of dry weight, as compared with ~3% to 5% for N & K, and 0.5% for P & Ca. Strawberries are no exception to this rule, having 0.30% to 0.50% in dry matter as optimum concentration. Calcareous, slightly basic, and neutral clay soils generally contain a considerable rate of about 6% of magnesium cations in the composition of the clay mineral montmorillonite. While weathering, these soils slowly release the Mg^{2+} cations to the soil solution. In these soils, Mg^{2+} cations also travel freely with the water movement, and reach plant roots by mass flow. Under such conditions, the amounts of Mg^{2+} reaching the roots are usually exceedingly higher (by a factor of several hundred) than the amount taken up by the roots, so fertilization with magnesium of plants growing in these conditions is generally unnecessary. Silt or clay soils with a CEC greater than 10 meq / 100 g soil, are considered to have adequate magnesium if the magnesium share of this CEC is ~10%. Adequate magnesium levels in the soil solution are normally above 50 to 100 ppm.

Additionally, magnesium cations are supplied to the plants by the magnesium contained in the irrigation water. Representative values for magnesium concentration in irrigation water are in the range of 15 to 60 g / m^3 (ppm). With irrigation doses of 5,000 m^3 / ha / year, magnesium carried with the water to the irrigated plot ranges between 75 and 300 kg / ha / year. This is a sufficient rate for most crops if all the water ends up in the plants' roots zone. But the grower should always make sure that these calculations are valid for his water sources.

In acidic soils, however, application of soluble magnesium salts such as magnesium nitrate can be helpful in avoiding aluminum and manganese toxicity. Figure 4.14 above shows the positive effect of nutrigation with calcium nitrate on soil pH at the end of the irrigation season, on the surface soil, where it exerts its effect on soil lattice. Similar effect can be expected by applying magnesium nitrate.

Soil test levels of 120 to 180 ppm Mg should provide optimal growth for strawberries.

Soilless cultivation is where magnesium application by nutrigation is of highest importance because the inert growth medium cannot supply the necessary magnesium. Here, again, magnesium cations travel freely within the wetted zone and care should be taken not to leach them off the root zone.

When applying magnesium by nutrigation (as well as by all other forms) special attention should be paid to apply it in a balanced way with other cations, such as ammonium, potassium, and calcium because over-application of any of them will result in subdued uptake of the others, due to competition between the cations at the root level on the uptake site. Potassium can compete with magnesium for root uptake, and should therefore be kept at an appropriate balance (4:1, K:Mg) to prevent one from causing a deficiency in the other.

Availability of magnesium is reduced under low soil pH <5.5 (see Figure 4.13), and under heavy use of potassium fertilizers.

Symptoms of Mg deficiency (Mg <0.1%) in strawberry plants are:

- Tissue in the interveinal regions of older leaves starts with chlorosis, which turns into necrosis as the deficiency progresses.
- In some instances, a marginal scorch forming a halo pattern can be observed near the base of the serrations on the older leaves.

Marginal leaf scorch begins as yellowing and browning of the upper leaf margin, progressing towards the center of the leaf between the veins (see Figure 4.19). The basal part of the leaf and the short petiole remain green and turgid, unlike in potassium deficiency. Fruits from magnesium deficient plants appear normal, except that they are lighter in color and softer in texture.

Figure 4.19: Magnesium deficiency on strawberry leaves. Marginal scorch (left) and normal leaf (right)
Source: Strawberry Fertiliser Guide, Primefact 941, 2010. www.industry.nsw.gov.au

Control

Deficiencies in strawberry plants can be easily remedied. The most common source of magnesium for pre-planting application is dolomitic or "high-mag" lime, which, in addition to calcium, contains a significant percentage of magnesium. Apply dolomite several months before planting if soil test results indicate low levels of magnesium and low pH.

Magnesium nitrate and magnesium sulfate are soluble magnesium salts that can be applied directly to the soil, or through the irrigation system, and / or be applied to plants as a foliar spray. Magnesium nitrate ($Mg(NO3)2$; 11-0-0-16MgO) is a fertilizer with extremely high solubility. Its solubility is 8 to 9 folds higher than that of magnesium sulfate. Magnesium nitrate is also relatively rich in nitrate, which is the preferred form of nitrogen for strawberries.

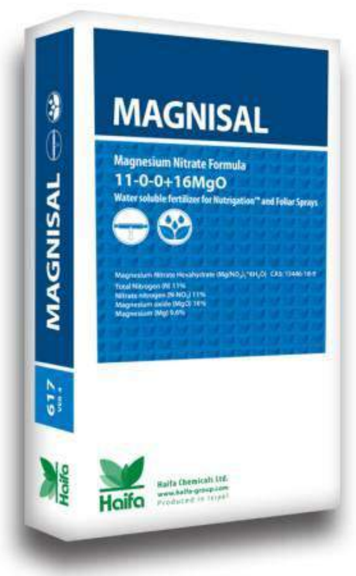
Table 4.9: Magnesium fertilizers and usage indicators

Product	Analysis	Development stage for best results	Application rate (kg / 1,000 plants)	Comments
Magnesium nitrate	11% N + 16% MgO	Pre-flowering	0.3 to 0.5	Improves fruit color and firmness.
Magnesium sulfate (*Epsom salt*)	16% MgO + 14% S	Pre-planting Pre-flowering	0.2 to 0.4	Improves fruit color and firmness. Do not mix with calcium nitrate.

A foliar spray of magnesium nitrate can also be used to give immediate relief, but it should be tested on a few plants first. Discontinue at the first sign of phytotoxicity.

Haifa produces and markets the most soluble magnesium product available, magnesium nitrate, under the brand name **Magnisal™**.

Following are the technical data of **Magnisal™**:



Analysis

MgO	16%
Mg	9.5%
N-NO3	11%
pH (0.1% solution)	5.56
EC (0.1% solution)	0.88 dS / m

Solubility				
0ºC	10ºC	20ºC	30ºC	40ºC
133	2,100	3,200	4,500	6,400

Magnesium sulfate heptahydrate (*Epsom Salt*, $MgSO_4$*7H_2O; 0-0-0+16.3MgO)

This is a natural occurring mineral with lower solubility. It also contains sulfur, which is a secondary plant nutrient and is hence required by plants at much lower rates. **Haifa** markets magnesium sulfate heptahydrate under the brand name **BitterMag™**.

Micronutrients

Micronutrients, also termed 'trace elements' are chemical elements present in the plants at 2-4 orders of magnitude less than, e.g., N and K. I.e., while common N and K concentration in dry weight of plants in around 3% to 5%, the common concentrations of micronutrients, is around 5 to 200 ppm.

The most important micro-nutrients in terms of strawberries are boron (B) and zinc (Zn). Others are iron, manganese, copper, and molybdenum.

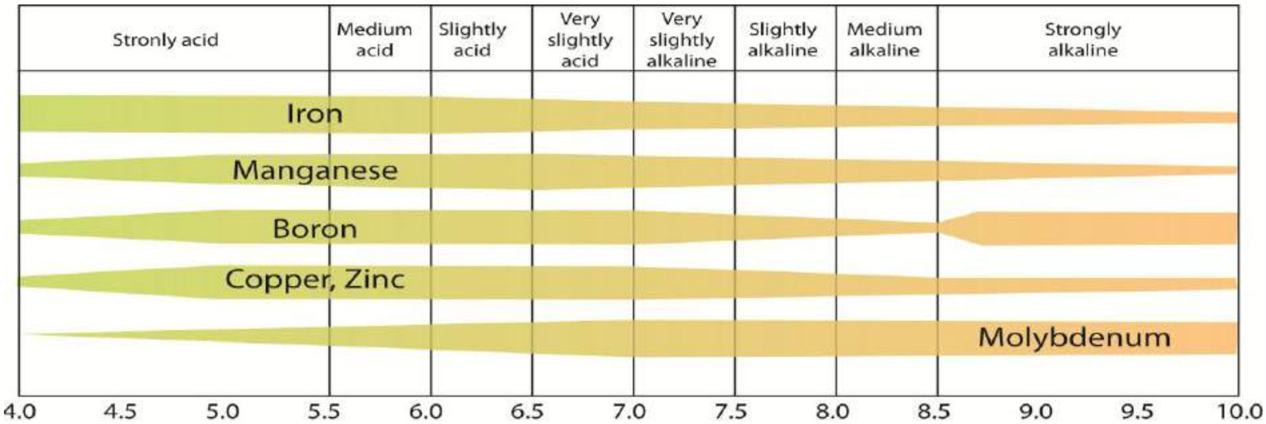


Figure 4.22: The availability of micronutrients to plant roots as a function of the pH of soil solution
Source: Illinois Agronomy Handbook, 1979-80

The cationic micronutrients, i.e., Fe, Zn, Cu, and Mn are highly vulnerable to clay particles in the soil. Therefore, if applied to the soil as inorganic soluble salts, e.g., sulfates, they will normally quickly be immobilized and rendered unavailable to plant roots. Moreover, micronutrients' availability to plant roots is highly pH-dependent. Figure 4.22 above shows that optimal availability of iron, manganese, boron, copper, and zinc takes place in the pH range of 5.0 to 7.5, while molybdenum is most available at pH> 6.5.

Boron (B)

Boron is associated with several of the functions of calcium. Boron improves calcium efficiency and vice-versa, but there is a downside to this system. If calcium levels are too low, boron can become excessive and toxic. Calcium and boron deficiencies should always be addressed together. Maintaining ideal boron availability for the full crop cycle can prove problematic because boron is the most soluble and leachable of trace elements, and maintaining good levels in wet conditions is a major challenge, especially in light soils. On the other hand, boron availability rapidly declines in dry conditions.

Apart from these soil problems, boron is not readily mobile within the plant. One ppm of boron is considered an ideal level in a soil solution but, as this level is very hard to maintain, well-timed foliar supplementation can be very productive, particularly when applied immediately before flowering.

The functions of boron in strawberry plants:

- It increases nitrogen availability to the plant.
- It is involved in the synthesis of cell wall components.
- Boron increases calcium metabolism and function efficiency within the plant.
- It has a central role in pollen-tube viability elongation and germination, hence in good seed set and normal fruit development and structure.
- Boron influences cell mitosis, development, and elongation.
- It plays a key role in the elongation growth of primary and lateral roots.
- Boron is important for fruit set.
- Boron helps in carrying sugars from the leaf to the seeds of the fruit.

Conditions associated with boron deficiencies:

- Leached, acidic soils.
- Calcareous or over-limed soils and soils with high pH.
- Light, sandy soils.
- Excessive usage of potassium and nitrogen.
- Drought conditions.
- Soils low in organic matter (humus is the boron storehouse).
- Boron performance can be negatively affected by low phosphate levels.

Younger boron-deficient strawberry leaves show puckering and tip-burn, followed by marginal yellowing and crinkling with reduced growth at the growing point. See Figure 4.23 below.

Figure 4.23: Boron deficiency on strawberry leaves
Source: Strawberry fertiliser guide, Primefact 941, 2010. www.industry.nsw.gov.au

Moderate deficiency of boron reduces the flower size (Figure 4.24) and decreases pollen production, resulting in small, 'bumpy' fruit of poor quality (Figure 4.25). Root growth can be stunted.

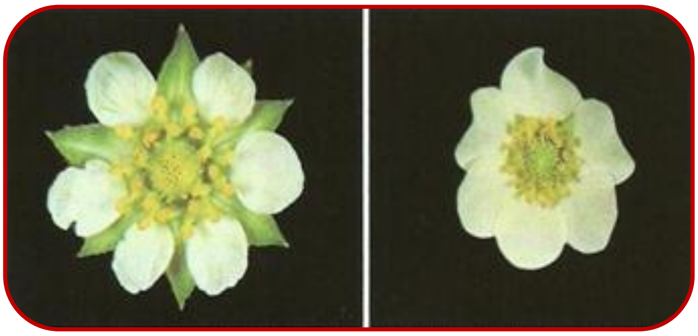


Figure 4.24: Boron deficiency on strawberry flowers, left - normal, right - B- deficient
Source: Strawberry fertiliser guide, Primefact 941, 2010. www.industry.nsw.gov.au

Figure 4.25: Boron deficiency on strawberry fruit
Source: Strawberry fertilizer guide, Primefact 941, 2010. www.industry.nsw.gov.au

Control

It must be borne in mind that excessive amounts of boron are toxic to the plant and should not be used excessively. The deviation from optimal concentrations of boron in the plant can risk its performance in both a deficiency or an excessive concentration, and the difference between the two is rather small, so care must be taken to make sure that the plant has enough, but never too much. No more than 500g / ha (1 pound / acre) of actual boron should be applied to a field in one year.

Preventing boron deficiency can be achieved by adding borax to the soil before planting. Taking care of a newly expressed boron deficiency in the field is done by applying a foliar spray, or fertigating with a soluble boron compound such as:

- Boric acid (H_3BO_3) with 17% B.
- Inkabor/Solubor (20.5% B).
- Ulexite: A calcium / borate product containing 14% boron, naturally fused with a calcium synergist.
- Stabilized boron humates: This product helps in the management of boron nutrition, mainly because complexing the boron by humates minimizes the leaching problem.

Borax is a series of salts of boric acid that differ in their hydration states (and therefore in their B content). It normally has 11% boron, with poor solubility, but it is useful in maintaining soil levels by pre-planting application.

Zinc (Zn)

The functions of zinc in soil and plant nutrition:

- Zinc activates many enzymes.
- Zinc has a critical role in the production of the auxin IAA, which regulates plant elongation and expansion as well as fruit development.
- It plays an important role in the formation and activity of chlorophyll.
- It is involved in protein synthesis.
- It is important for carbohydrate metabolism.
- Zinc plays a major role in the absorption of moisture. Plants with adequate zinc nutrition have enhanced drought-handling capacity.

The optimal level of zinc in strawberry leaf tissue is 25 to 45 ppm.

Common reasons for reduced zinc availability to strawberry plants:

- Zinc in the soil is more available to plants under low pH conditions. Therefore, reduced zinc availability to plants is very common in calcareous soils. Likewise, heavy applications of lime and / or phosphorus reduce the availability of zinc to the plants.
- Soils lacking mycorrhizal fungi.
- Light, sandy soils.
- High phosphorus levels – phosphate ties up zinc.
- Cold, wet soils.
- Soils featuring anaerobic decomposition, i.e., zinc bonds with sulfides produced in these conditions and becomes insoluble.

Zinc deficiency is easily distinguished on strawberry leaves by the discolored 'halo' that develops along the serrated margins of young, immature leaf blades. As the leaves continue to grow the blades become narrow at the base and eventually become elongated with severe deficiency. Yellowing and green-veining occurs. See Figure 4.26.

The fruit size may appear normal, but the number of fruit is reduced.

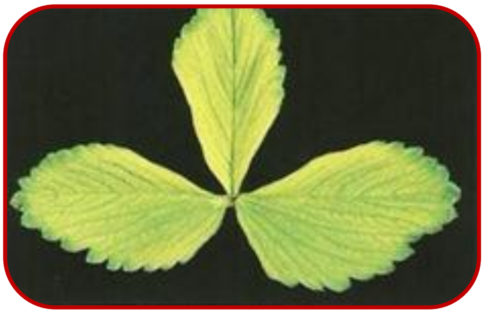


Figure 4.26: Manifestation of zinc deficiency by discoloration along the serrated margins of leaf blades, and chlorosis of interveinal area.
Source: Strawberry Fertiliser Guide, Primefact 941, 2010. www.industry.nsw.gov.au

Control

Zinc fertilizers

- Zinc oxide (ZnO) is a viable option to build soil levels and contains 80% zinc. However, it is usually a slow-release product that will only become available towards the end of the crop.
- Zinc sulphate heptahydrate ($ZnSO_4$*7H_2O) contains 23% zinc, while monohydrate ($ZnSO_4$*1H_2O) contains 35%. In terms of cost per unit of zinc, zinc sulphate monohydrate is usually the most economical choice. Add zinc sulfate ($ZnSO_4$) with 36% Zn to the fertilizer program and apply at planting to soils known to be low in zinc. It is typically applied as part of a fertilizer blend to the soil, or applied as a foliar spray to help achieve uniform distribution of a small amount of material over a relatively large area.
- The most efficient way to treat zinc deficiency is by Zn Chelate; 14% EDTA-Zn.

Chelates are generally highly water soluble. Chelates can be pre-dissolved and injected into the trickle irrigation system as liquid, for precise application commanded by the small amounts required. The chelating agent guards the micronutrient from immobilization as long as it is in the soil solution. But once it gets close to the acidic root surface it is released from the chelate complex, enters the plant and wanders around in it in the form of cation-organic acid, e.g., Zn-citrate.

Foliar spray. The application of zinc by fertigation or as a foliar spray can give immediate relief. However, the use of zinc sulfate as a foliar spray may damage young leaves, flowers, and fruit. Discontinue treatment at the first sign of phytotoxicity.

Haifa's products for controlling zinc deficiency

Haifa Micro Zn EDTA 15%, a stable, water-soluble and non dusting zinc EDTA chelate

Multi-K™ Zn crystalline potassium nitrate enriched with zinc

Multi-K™ ME 13-0-45+ME (crystalline)

Iron (Fe)

Iron is the most abundant element in the known universe, and yet the lack of plant-available iron can be a serious yield-limiter in almost every area of agriculture. Most soils contain 20 to 200 MT of iron per hectare, but very little of this reserve is plant available. Also, potential iron problems are magnified, as iron does not move easily within the plant. Ideal iron soil analysis ranges between 40 and 200 ppm, but levels exceeding these figures do not guarantee avoidance of Fe deficiency.

The functions of iron

- Iron is one of the essential elements required for biological nitrogen fixation.
- Adequate iron, in plant-available form, is essential for protein synthesis. non-haeme iron proteins.
- Fe is an indispensable oxygen-carrier for chlorophyll production.
- Iron is a constituent of cytochromes, it is involved in respiratory linked dehydrogenases.
- Iron is also involved in the reduction of nitrates and sulfates and in reduction processes by peroxidase and adolase.
- Fe increases leaf thickness, which, in turn, enhances nutrient flow, which eventually increases yield.
- Iron makes the leaf darker, with a greater capacity to absorb solar energy.

Conditions creating iron deficiencies

- Excessive phosphate applications or high phosphate levels in the soil.
- High manganese, copper, or molybdenum reduces iron uptake. Iron deficiency is bound to take place when manganese exceeds iron levels in the soil solution by two-fold or more. Therefore, iron should always be higher than manganese to avoid likely iron lockup.
- Cold, wet conditions limit iron uptake, particularly in the early growth stages.
- Excessive lime applications reduce iron availability.
- Inadequate soil aeration hinders Fe mobility.
- High soil pH (7.5 or higher, see Figure 4.22) and / or calcareous and poorly drained soils.
- Low organic matter, because organic matter serves as a chelating agent for Fe and other trace elements.

Iron deficiency is first expressed by yellowing of the leaf blade while veins retain their green color. As the deficiency becomes more severe, yellowing increases to the point of bleaching and the leaf blades turn brown. See Figure 4.28. Fruit size and quality are not greatly affected.

Figure 4.28: Iron deficiency symptoms on strawberry leaves. Green network of fine veins distinct in early stages, followed by interveinal yellowing and then severe chlorosis

Control

Check soil pH. If the pH level is high, cease liming and use pH-reducing fertilizers such as ammonium sulfate.

Apply Fe Chelates, e.g., Fe-EDTA (13% Fe), or Fe-DTPA (7% Fe), by fertigation or by foliar spray, when symptoms first appear. The type of chelating agent recommended depends mainly on the pH value of the soil or growth medium, and on the crop. If iron sulfate ($FeSO_4$), an inorganic soluble salt of iron, is applied to the soil, it will normally quickly be immobilized and rendered unavailable to plant roots.

Haifa's products for controlling iron deficiency

Haifa Micro™ Fe-EDDHA 6% water soluble chelate

Haifa Micro™ Fe-EDTA 13% water soluble chelate

Multi-K™ME crystalline potassium nitrate enriched with micro-nutrients

Foliar applied Fe chelates are most effective in correcting crop deficiencies in the growing season and are perhaps the best solution for strawberries grown on high-pH soils. Lowering the pH of clay-like soils to increase the availability of Fe does not make economic sense, and may even be nearly impossible.

Manganese (Mn)

Manganese is critically important in the reproductive stage of plant growth. The common requirement for soil-solution manganese is 30 to 100 ppm.

The functions of manganese

- It is involved in production of amino acids and proteins.
- Hastens the fruiting and ripening of crops.
- Accelerates and improves seed formation and germination, and the early establishment of the seedling.
- It is a critical enzyme activator for dehydrogenases, decarboxylases, kinases, oxidases, peroxidases, and non-specifically by other divalent cation-activated enzymes.
- Essential for carbohydrate and nitrogen metabolism.
- Manganese has important roles in chlorophyll formation and nitrate reduction.
- Required for chlorophyll production.
- Manganese is a vital component of photo-system II in the photosynthesis process. Hence, it's required for the assimilation of carbon dioxide in photosynthesis.
- Directly involved in plant uptake of iron.

Conditions creating manganese deficiencies

- Soil pH >8, or <4.5. See Figure 4.22.
- Soils with very high levels of organic matter.
- Light, sandy soils.
- Natural excessive calcium or overliming can tie up manganese, even moderate applications of lime will magnify a manganese deficiency.
- High phosphorus and iron can limit manganese uptake.
- An overuse of potassium and magnesium can reduce manganese uptake because of soil pH increases.
- When combined sodium and potassium base saturation percentages total over 10%, then manganese uptake will be limited, regardless of soil test results. This problem occurs most often in lighter soils.
- Cool, wet conditions.

The first sign of manganese deficiency is pale greening to yellowing of young leaves. As the deficiency progresses, the main veins remain dark green, while the interveinal areas become yellow, followed by scorching and upward turning of the leaf blade margins.

Scorch areas advance towards the centre of the leaf as broad rays extending across the veins. The fruit size can be reduced (see Figure 4.30). In many cases, the leaf blade develops a network of dense yellow dots (see Figure 4.31).

Manganese- deficient strawberry leaf
Somewhat faint interveinal chlorosis beginning at margins and progressing towards midrib

Manganese- deficient strawberry plant
Source: Strawberry fertiliser guide, Primefact 941, 2010. www.industry.nsw.gov.au

Figure 4.30: Manganese deficiency symptoms on strawberry leaves

Figure 4.31: Manganese deficiency symptoms on strawberry leaf – a network of dense yellow dots

Control

Manganese sulfate ($MnSO_4$) contains 31% manganese and can be used as a soil supplement or through fertigation when deficiencies are slight (i.e., 20 to30 ppm of Mn^{2+} in soil solution). It is generally not cost effective to build soil levels with manganese sulfate. In more seriously deficient soils the product of choice is Mn-EDTA (13% Mn) applied by fertigation or by foliar spray.

Foliar spray of manganese sulfate can give some relief but may be toxic, especially at flowering and at fruit-set.

Success in using Mn-EDTA for fertigation and foliar sprays is generally guaranteed.

Haifa's products for controlling zinc deficiency

Haifa Micro™ Mn-EDTA 13% water soluble chelate

Multi-K™ME crystalline potassium nitrate enriched with micro-nutrients

Manganese toxicity may take place when soil-pH drops during relatively short periods of time, as a result of continuous use of ammonium fertilizers.

Copper (Cu)

The ideal range of copper concentration in the soil solution is 5 to 10 ppm. Excessive copper can affect phosphate, zinc, and iron uptake. Where copper levels in soils exceed several hundred ppm, copper can become the yield limiting factor in many crops, including wheat, corn, cotton, pasture, canola, orchard crops, and vegetables, including onions, spinach, and brassicas.

The functions of copper

- Essential in many enzyme systems, particularly those associated with respiration (many oxidase enzymes). Copper is also a constituent of cytochrome oxidase and haeme in equal proportions. Anaerobic metabolism, and hormonal metabolism.
- Important for water movement within the plant.
- Copper is a key component in many proteins.
- Essential for chlorophyll formation and photosynthesis processes.
- Cu-proteins have a marked effect on the formation of lignin, and the composition of cell walls. Hence it is important for stems strength, flexibility, and elasticity.
- Vitally important for root metabolism.
- Helps prevent development of chlorosis, resetting, and die-back.
- Provides a natural fungicidal effect. This feature can be a problem where copper levels in the soil have become too high due to extensive human sprays (above 15 ppm), as this fungicidal quality becomes detrimental to beneficial fungi in the soil.

Conditions creating copper deficiencies

- Soil pH >8, or <4.5, see Figure 4.22.
- Light, sandy, coastal soils are invariably deficient.
- Peaty, high-organic matter soils tend to hold copper, strongly reducing plant availability.
- Excessive phosphate and nitrogen can limit copper availability.
- Over liming can create deficiencies.
- High zinc levels can reduce copper uptake.
- Drought conditions can intensify any copper problems.

Copper deficiency symptoms

Copper is relatively immobile within plants, so deficiency symptoms normally occur first on new growth, and youngest leaves are worst affected.

Copper-deficient strawberry leaves develop chlorotic to bleached blades, especially on their bases. Their veins remain green, but may sometimes become brownish-black. See Figure 4.33.

Figure 4.33: Copper deficiency symptoms on strawberry leaf

Control

When copper deficiency is encountered, copper sulfate, $CuSO_4$ (25% Cu) may be an efficient and inexpensive solution, and it is the best material to build soil levels. 20 kg/ha of copper sulfate is the maximum application rate for soil-grown strawberries, at any one time, as copper applications can affect soil-fungi. This figure should be reduced 20-fold in case of soilless grown strawberries.

$CuSO_4$ can also be used as a foliar feeding at 0.5%, to address deficiencies. It was proved that it is more effective than the more expensive hydroxides and oxychlorides.

The most effective way of correcting Cu deficiencies in strawberries is by applying copper chelates such as Cu-EDTH (14% Cu), by nutrigation (fertigation) or by foliar sprays.

Multi-K™ ME, is a product containing potassium nitrate plus a mixture of all micronutrients, for safe continuous maintenance of the plantation.

Haifa's products for controlling copper deficiency

Haifa Micro Cu-EDTA 14% water soluble chelate

Multi-K™ME crystalline potassium nitrate enriched with micro-nutrients

Molybdenum (Mo)

Molybdenum is the least abundant of all the recognized micro-nutrients in the soil. Molybdenum is the only trace element whose availability increases as pH rises.

The functions of molybdenum

- Essential for nitrogen fixation.
- Required for the synthesis and activity of the enzyme nitrate-reductase (reduces nitrates to ammonium in the plant).
- Involved in electron transport in plant metabolism.
- Linked to organically-bound phosphorus uptake in the plant.

Conditions associated with molybdenum deficiencies

- Acidic soils that are highly leached.
- Timber soils.
- Acidic, sandy soils.
- Soils that are high in other metal oxides.

Symptoms of deficiency

In strawberries, Mo deficiency looks very much like nitrogen deficiency (paleness and stunting). The leaf edges also tend to burn because of the accumulation of unused nitrates.

Control

When Molybdenum deficiency is encountered, molydbic acid monohydrate ($MoO_3 \cdot H_2O$ (59.6% Mo), or sodium molybdate dihydrate $Na_2MoO_4 \cdot 2H_2O$ (39.7% Mo), can be applied.

Haifa-Micro™ Comb is a stable, water-soluble and non-dusting balanced mixture of metal EDTA-chelates,. including molybdenum as follows:
7.1% Fe, 3.48% Mn, 1.02% Zn, 0.76% Cu, 0.485% Mo.

To sum up this chapter of nutritional disorders in strawberries, here is a short manual.

Table 4.10: Visual symptoms of nutritional disorders of strawberries
Source: Strawberry fertiliser guide, Primefact 941, 2010. www.industry.nsw.gov.au

Leaf symptoms	Possible causes
Uniform yellowing	Nitrogen or sulfur deficiency or poor soil drainage
Yellowing with veins remaining green	Zinc, manganese or iron deficiency
Yellowing of leaf base	Copper deficiency
Darkening of leaf base or center vein	Potassium deficiency
Dark green foliage	Phosphorus deficiency
Leaf scorch	Potassium or magnesium deficiency or salt toxicity
Growing points damaged with restricted growth	Calcium or boron deficiency
Brown-black veins	Copper or boron deficiency
Fruit symptoms	**Possible causes**
Poor pollination (bumpy fruit)	Boron deficiency, frost damage or high temperature during flowering
Hard seed	Calcium deficiency
Soft, poor color and flavor	Potassium deficiency

5. Fertilization recommendations for strawberries

5.1 Nutrients uptake and removal

The purpose of fertilizing any agricultural crop is to supply it with all the nutrients needed for the normal development of the plants. For this, naturally, one needs to know the amounts of nutrients that the plant needs, in order to:

- grow the vegetative mass,
- maintain plants' current activity, and
- build up the fruit mass that will eventually be removed from the field. In cases where the field serves multiple crops, growers indicate a minimal amount to be returned to the field, in order to compensate the field for the fertility that was used for the production of the exported fruit.

These crucial data are summarized in the following table.

Table 5.1: Uptake and removal of macro-nutrients by open-field or protected strawberry crop
Sources: La Malfa, 1992, and Haifa NutriNet

		N	P_2O_5	K_2O	CaO	MgO
Removal (kg/MT fruits)		6 – 10	2.5 – 4.0	10 – 15	3.7-4.9	1.1
Yield level	Uptake & removal by yield levels (kg/ha)					
8 MT/ha	Plants uptake	49	21	83	29	6
	Yield removal	15	5	26	9	2
	Total recommended application rate	59	68	108	15	6
16 MT/ha	Plants uptake	81	34	138	48	9
	Yield removal	30	10	51	18	3
	Total recommended application rate	97	83	179	24	9
25 MT/ha	Plants uptake	118	48	200	68	13
	Yield removal	47	15	80	27	5
	Total recommended application rate	142	100	260	34	13
30 MT/ha	Plants uptake	129	51	218	75	14
	Yield removal	57	18	96	33	6
	Total recommended application rate	155	104	283	38	14
35 MT/ha	Plants uptake	147	59	250	85	16
	Yield removal	66	21	112	38	7
	Total recommended application rate	176	113	325	43	16

Factors to be taken into account for efficient application:

- Strawberries' root system is rather shallow with ~70 % in the upper 7 cm (3") of the soil, and even shallower, just below the surface in mulched crops.
- The plant suffers from EC level higher than 2 dS/m and from brackish water and/ or soil.
- Floral bud differentiation, which determine the yield, occurs early and depends on the nutrient reserves of the plant
- Nutrient absorption is at its maximum during flowering.

5.2 Fertilization methods

Commercial cultivation of strawberries normally takes one of the following fertilization schemes:

- Base dressing + a few side dressings throughout the growth cycle of the crop. This method is common among growers who are not equipped with a nutrigation (fertigation) setup.
- Base dressing + many side-dressing sessions throughout the growth cycle of the crop. "Many" can take the form of once weekly, once daily, or even- many daily applications, carried out by nutrigation (fertigation).
- Usage of controlled release fertilizers. Special paragraph 6.2 of this publication is devoted to this advanced method.
- A combination of the above-mentioned methods, according to the grower's capability and preferences.
- Foliar feeding. This method serves normally as a complementary treatment to assist the application when encountering problems of soil uptake, and when fast correction results are needed.

5.2.1 Soil preparation and base dressing

Soil preparation should start 4–5 months before planting. So, for an autumn- planting of fresh runners, soil preparation that will include tilling, fumigation and weed control, should start by early summer.

Organic matter

As strawberries respond well to high organic matter in the soil, one or more of the following options is recommended:

- Well-composted animal manure such as poultry manure, applied at 8–10 MT/ha, several weeks before sowing of most green-manure crops.
- Sowing of green-manure crops, several months before planting. Green-manure crops like cowpeas, oats and forage sorghum can be grown for 2–4 months and incorporated into the soil before they mature. Sufficient time must be allowed for the crop to completely break down in the soil before fumigation and bed formation takes place.

Well-composted manure is advocated, while application of fresh manures such as fresh horse-, cow- or chicken- manure, just before planting, must be avoided, as these can burn and damage the delicate strawberry plants.

pH amendment

If the soil pH is below pH 6.0 apply either agricultural lime or dolomite at least 6 months before planting. Dolomite is best used if soil magnesium is low. The lower the pH value, the higher the rate of lime or dolomite that should be applied. The rate also depends on the planned life-span of the crop. About 5 MT/ha (2 ST/A) of ground limestone per expected year, will keep the soil at a relatively stable pH.

The lime or dolomite should be worked into the soil to a depth of 30 cm, which is the effective root region of strawberries.

Fertility

It is best to apply and incorporate all major nutrients into the soil, to ensure that young transplants will encounter a good mineral background for their establishment phase. It is preferable to apply the potassium and the phosphorus as low-solubility formulae such as potassium sulfate and triple-superphosphate, respectively, to support the plants throughout their growth cycle. The composition of this application may be as follows:

N	P_2O_5	K_2O	CaO	MgO
(kg / ha)				
150	150	240	120	60

Additionally, it is best to apply a small dose of N-P-K soluble fertilizer, a week or two before transplanting. Its N-P-K ratio should be 1-2-1 or 1-3-1, such as 5-10-5 or 8-24-8. It should be worked into the upper 8 cm to 20 cm (3 inches to 8 inches) of the soil, at a rate of 120 kg / ha (110 pounds / acre).

When soil zinc level is low, applications of zinc sulfate at 17 to 22 kg / ha (15 to 20 pounds / acre) prior to planting are recommended.

Table 5.2: Desirable pre-plant pH, organic matter, and soil fertility for strawberries

Soil parameter	Optimal values	
pH	5.8 to 6.5	
Organic matter	2% to 3%	
Phosphorus	67 – 90 (available kg / ha)	60 – 80 (available pounds / A)
Potassium	315 – 360 (exchangeable kg / ha)	280 to 320 (exchangeable pounds / A)
Magnesium	280 (exchangeable kg / ha)	250 (exchangeable pounds / A)
Zinc	11.2 – 13.5 (available kg / ha)	10 – 12 (available pounds / A)
Boron	1.7 – 2.25 (available kg / ha)	1.5 – 2.0 (available pounds / A)

5.2.2 Side dressings in open-fields

It is beneficial to apply fertilizers by multiple sessions during the life-cycle of a strawberry field, especially on lighter soils (that tend to leach nitrogen more easily than medium and heavier soil), as follows:

Table 5.3: Side / top dressings for open-field strawberries.\

Plant type	Timing	Product	Rate	
			Kg / ha	Pounds / Acre
All	Early spring, just before planting	8-24-8	120	110
All	Spring, 4 to 6 weeks after planting	20-20-20	80	70
All	Early August	20-20-20	60	54
Day-neutral and everbearing	After first harvest	20-20-20	60	54
June-bearing	Field renewal when plants are completely dry	20-20-20	60	54

Sufficient watering should be applied after each topdressing session to bring the fertilizer to the roots of the growing plants.

Hence, maximum annual application of 40 kg / ha of N for June-bearers and a maximum annual application of 80 kg / ha N for ever-bearers should be observed if applied as a base or top dressing.

Table 5.4: Recommendation for soil-solution composition of main nutrients, at peak demand, for field-grown strawberries in Israel

	Nitrogen	Phosphorus	Potassium
Application rate	1.5 to 2.5 kg / ha / day		
Soil solution	Nitrate-N: 20 to 30 ppm at all times	**P** kept at 20 to 30 ppm (Olsen)	**K** kept at 1 to 2 meq / liter

With a plant density of 35,000 plants / ha, and an expected yield of 35 to 40 MT / ha, the recommended rate of nutrients for outdoor grown strawberries are as follows:

N	P_2O_5	K_2O
(kg / ha)		
150 to 200	110 to 130	230 to 250

5.2.3 Nutrigation™ (fertigation) in open fields

This is an effective way to apply fertilizers to already established plants. The technique supplies soluble fertilizers to crops through the irrigation system, whether they are under the plastic mulch in the field, or in tunnels or greenhouses, using soil or soilless cultivation methods.

The use of compensated, no-leak drip irrigation allows for highly accurate application of both water and plant nutrients directly to the plants' root zone. This allows for precise feeding of the plants, according to their specific growth stage, and as a preparation for forecast stresses, or as a quick correction of plant nutrient imbalance during both the growing and fruiting stage of the plant.

To take advantage of this method, the fertilizers should be dissolved in high-quality irrigation water. Avoid using water with high carbonate levels (hard water), which may react with soluble fertilizers high in phosphate, sulfate, or calcium that can cause precipitation and block drippers.

A soluble fertilizer mix is best applied after plants are established and at different intervals, as detailed above. The nutrigation mix needs to change depending on crop need and seasonal conditions.

It is best to start injecting the dissolved fertilizer stock solution after about 20% of the irrigation water has been delivered, and complete the injection session after about 80% of the irrigation water has been delivered, to assist the movement of nutrients down into the roots zone.

Apply at least 0.5 to 1 liter of irrigation water per plant, depending on soil type. Some of the more common soluble fertilizers used in strawberries are shown in Table 5.5. Some can be in combination with others with no restriction, but care should be taken to never mix phosphate- or sulfatic fertilizers with calcium fertilizers in the same dissolving tank. Separating them between two dissolving tanks prevents the precipitation of calcium phosphate or calcium sulfate, in the tank or in the pipeline. Figure 5.1 describes a common method to safely prepare fertilizer combinations.

Table 5.5: Some common fertilizers used in nutrigation, their solubility, nutrient content, and soil reaction

Product	Analysis	Solubility (g / L) at 20°C	Reaction
Urea	46% N	1,070	Neutral
Ammonium nitrate	34% N	1,952	Acidic
Ammonium sulfate	21% N + 24% S	754	Acidic
Mono-ammonium phosphate (MAP)	12.5% N + 61% P2O5	370	Acidic
Phosphoric acid	61% P2O5	Already liquid	Very acidic
Mono-potassium phosphate (MKP)	52% P2O5 + 34% K2O	230	Acidic
Potassium nitrate	13% N + 46% K2O	320	Basic
Potassium sulfate	40% K2O + 16% S	110	Neutral
Calcium nitrate	15.5% N + 26% CaO	1,200	Basic
Magnesium nitrate	11% N + 16% MgO	2,250	Slightly acidic

Other soluble fertilizers include zinc sulfate, iron chelate, boric acid, manganese sulfate, and sodium molybdate. These trace elements are best applied if soil or leaf analysis indicates a need for them, or when plants show field deficiency symptoms.

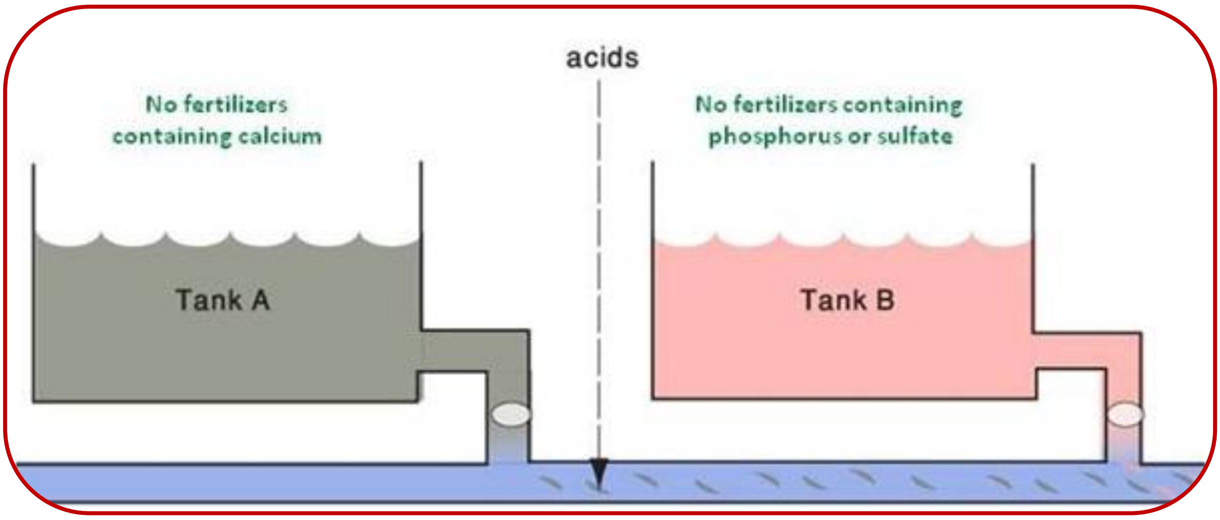


Figure 5.1: Recommended combinations of fertilizers to be dissolved in Tank A and Tank B for the preparation of stock solutions

When a heavy pre-plant fertilization is applied, such as:

- Nitrogen at 100 kg / ha
- Phosphorus at 100 kg / ha of P_2O_5
- Potassium at 200 kg / ha of K_2O

It is enough to leave for the side-dressing applications by nutrigation, a rate of 50 to 100 kg / ha of nitrogen + 50–100 kg / ha of K_2O.

It has been found that for the *'Chandler'* cultivar grown under plastic mulch on sandy soils, nitrogen at about 135 kg / ha is optimum for reduced vegetative growth and firmer fruit without compromising marketable yield.

The optimum N rate varies among soils, and may be even lower for heavier-textured soils. The recommended rate for K2O under these conditions is 135 kg / ha.

Table 5.6: Recommended N-P-K-Ca-Mg concentrations in nutrigation water during strawberries' main growth stages in the field
Source: Abdal-Razak, Israel, 2004

<table>
<tr><th rowspan="2">Dates</th><th rowspan="2">Growth stage</th><th>N</th><th>P</th><th>K</th><th>Ca</th><th>Mg</th></tr>
<tr><th colspan="5">(mg / L = ppm)</th></tr>
<tr><td>Oct. to Jan. 10</td><td>Establishment and vegetative growth</td><td>30 – 50</td><td rowspan="5">20 – 25</td><td>45 – 60</td><td>40 – 50</td><td rowspan="5">40 – 45</td></tr>
<tr><td>Jan. 11 to Jan. 15</td><td>1st wave fruit-set</td><td>70 – 85</td><td rowspan="3">60 – 80</td><td>70 – 90</td></tr>
<tr><td>Jan. 16 to Feb. 28</td><td>1st wave fruit growth</td><td>80 – 85</td><td>80 – 90</td></tr>
<tr><td>March 1 to Apr. 15</td><td>2nd – 3rd waves fruit-set & fruit growth</td><td>80 – 85</td><td>80 – 90</td></tr>
<tr><td>March 16 to end of May</td><td>4th wave fruit-set & fruit growth</td><td>55 – 60</td><td>55 – 60</td><td>70 – 80</td></tr>
</table>

As a result of the A/M application rates, the desirable N, P, and K levels in sampled soil solutions should be the following:

Nitrate-N: 20 to 30 ppm; P: 20 to 30 ppm (Olsen); K: 40 to 80 ppm.

5.2.4 Nutrigation™ (fertigation) in soilless culture

Table 5.7: Suggested nutrient composition for a two-stage growth cycle of cv. Elsanta*.
Source: Atwood et al, 2005, and Fennimore et al, UC Davis

Nutrient	**Starter** (mg/L)	**Fruiting** (mg/L)
NH_4-N	14	14
NO_3-N	100	120
P	46	46
K	175	250
Ca	140	125
Mg	20	30
Fe	1.5	1.5
Mn	0.8	0.8
Zn	0.5	0.5
B	0.15	0.15
Cu	0.05	0.15
Mo	0.05	0.05

* Cultivars like: *Diamante*, *Jubilee*, and *Everest* can tolerate somewhat higher nutrient concentrations

Nutrient irrigation-water conductivity

- Starter: 1.0 -1.6 dS / m, but increase rapidly on overwintered crops
- Fruiting: ~ 1.8 dS / m in normal conditions; 1.6 dS / m in hot / dry conditions; 2.0 dS / m in damp, overcast conditions.
- Ever-bearers can go over 2.0 dS / m
- Run-off should be up to 0.2 dS / m above the irrigation water

Table 5.8: Recommended macro- and secondary nutrient solution composition by growth phase in greenhouse soilless culture of strawberries in Israel
Source: Israeli Extension Service

Growth phase						
	Mg / L (ppm)					
Transplanting	55 – 60	20– 25	45 – 60	60 – 70	35 – 40	35
Anthesis** & 1st wave of fruits	70 – 85	20 – 25	70 – 90	100	45	50
2nd wave of fruits	80 – 85	25 – 30	80 – 90	100	45	55
3rd wave of fruits	80 – 85	25 – 30	80 – 90	100	45	55
4th wave of fruits	55 – 60	20 – 25	55 – 60	80	35	50

* The ratio Nitrate-N / ammonium N should be in the range of 7 to 11 throughout the growth cycle.

** Flower opening

Table 5.9: The micronutrient make up of the nutrigation solution

Fe	**B**	**Mn**	**Zn**	**Cu**	**Mo**
mg / L (ppm)					
2.8	0.6	0.4	0.2	0.1	0.03

Final irrigation water parameters

pH: ~ 6.0 to 6.2

EC: ~ 1.4 to 1.6 dS / m

Crops grown in soilless substrates and intensively nutrigated require regular monitoring of irrigation and nutrition. It is advisable to monitor the levels of feed being applied to the substrates as well as those draining through the system. Such monitoring should be used in conjunction with foliar analysis, to avoid excessive use of nutrient feeds and drainage of high concentration feeds into the soil beneath the bags, troughs, or other containers into which the crop has been planted.

Table 5.10: Liquid feed schemes for peat-bag and soil-grown strawberries in the UK.
Source: Strawberry Production Under Protection, supplies for small-holders,
https://www.suppliesforsmallholders.co.uk/strawberries-polytunnel-greenhouse-i-5.html

Crop stage	N	P_2O_5	K_2O	MgO	EC (dS / m)
	(mg / L)				
Bud break to flowering (peat)	120	100	200	25	1.6 – 1.8
Flowering to end of harvest (peat)	120	100	300	30	1.8 – 2.0
Soil grown	120	60	240	20	1.4 – 1.6

Table 5.11: Recommended nutrient composition of soilless-grown strawberries in Poland

Developmental phase	N	P_2O_5	K_2O	MgO
	(mg / L)			
Vigorous growth	120	66	150	25
Fruiting phase	100	50	200	30

Table 5.12: Recommended nutrient concentrations in the irrigation water of soilless-grown strawberries, in their fruiting phase, in South Korea

Parameter	Value	
NO_3	1.9 m mol/L	118 ppm
NH_4^+	0.1 m mol/L	2 ppm
P	0.40 m mol/L	12 ppm
K^+	0.7 m mol/L	27 ppm
Ca^{2+}	0.9 m mol/L	36 ppm
Mg^{2+}	0.6 m mol/L	15 ppm
SO_4^{2-}	0.5 m mol/L	48 ppm
HCO_3^-	<0.2 m mol/L	<12 ppm
Si^{4+}	0.30 m mol/L	8 ppm
Fe	5.8 µ mol/L	0.32 ppm
Mn	0.7 µ mol/L	0.04 ppm
Zn	0.3 µ mol/L	0.02 ppm
B	23 µ mol/L	0.25 ppm
Cu	<0.2 µ mol/L	<0.01 ppm
Mo	<0.2 µ mol/L	<0.02 ppm
Cl^-	<0.2 m mol/L	<7 ppm
Na^+	<0.8 m mol/L	<18 ppm
pH	5.6	
EC	0.5 dS/m	

Crops grown in soilless substrates and intensively nutrigated require regular monitoring of irrigation and nutrition. It is advisable to monitor the nutrient levels being applied to the substrates, as well as those draining through the system. Such monitoring should be used to determine the need for foliar feeding, to avoid excessive use of nutrient feeds and drainage of high concentration feeds into the soil beneath the bags, troughs, or other containers into which the crop has been planted.

5.2.5 Soluble compound fertilizers

Many fertilizer companies sell ready-to-use N-P-K blends in a variety of nutrient combinations and ratios that comply with the ratios needed by strawberry growers.

Compound fertilizers for nutrigation are generally composed of a mixture of solid products, mostly in crystalline form, containing any of the above mentioned N-P-K products, with or without soluble magnesium, and with or without micronutrients. They are generally physical blends, in which care has been taken to avoid interactions that would result in precipitation, caking, and to secure full solubility, free flow and high concentration of the nutrients. It is very important that no cheap components, such as potassium chloride, are included, to avoid salinity effects, as elaborated upon in Chapter 3, Salinity. It is the growers' responsibility to make sure they get high-quality components only.

Based on their N / P/ K ratios, there are several main families of products:

- The 1-1-1 group, such as 18-18-18; 19-19-19 and 20-20-20. The fertilizers belonging to this group are considered the formula for crop growth and vegetative development.
- The 2-1-1 group, such as 24-12-12 has a higher proportion of nitrogen, yet is easier to produce and the price per nutrient unit is somewhat lower.
- The "V" type fertilizers are formulae supplying the best nutrient ratios for flowering and fruit-set phenological growth stages. Characteristic examples for these NPKs are 2-1-2; 3-1-3 and 4-1-4, e.g., 20-9-20; 24-8-24.
- In situations of high potash requirements at the maturation stages of crops rich in sugar or oil, formulae of 10-5-35, or 16-8-24 are common.
- The "^" type fertilizers, e.g., 1-2-1 or 1-3-1, such as 15-30-15 or 10-30-10, are rich in phosphorus, and are used for the early stages of seed and transplant establishment, after planting.

Haifla produces and markets a large variety of N-P-K fertilizers complying with "**Nutrigation™ grade**" and "**Greenhouse grade**" standards. (The latter is more demanding in terms of purity, solubility, and reduced insoluble matter rates.) The products included in these groups are highly soluble, low in insoluble ingredients, practically free of deleterious ingredients, such as chloride, sodium, heavy metals, and perchlorates. Some of these products are enriched with magnesium, and some with organic compounds to satisfy specific requirements put forward by growers worldwide.

Haifa's compound products, specially developed for nutrigation of fruit trees and open-field vegetables, are grouped under the **Poly-Feed™ Drip** line.

Poly-Feed™ Drip formulae are enriched with magnesium and micronutrients. The wide range of products enable complete plant nutrition scheme, throughout the growth cycle.
Poly-Feed™ Drip is easily identified by the light-blue color of both the bag and the product.

The advantages of Poly-Feed™ Drip

- Fully water soluble.
- Made of high quality ingredients, exclusively.
- Consists of 100% plant nutrients.
- Virtually free of chloride, sodium and other detrimental elements for plants.
- Provides balanced, complete plant nutrition.
- Available in a wide range of formulae.

Micronutrients included in **Poly-Feed™ Drip**™ formulae: 1000 ppm iron (Fe), 500 ppm manganese (Mn), 200 ppm boron (B), 150 ppm zinc (Zn), 110 ppm copper (Cu), 70 ppm molybdenum (Mo).

Table 5.13: Haifa's **Poly-Feed™ Drip**: Fully soluble and chloride-free N-P-K compound fertilizers that supply all strawberry growers needs for nutrigation

Growth stage	$N:P_2O_5:K_2O$	Formula	$N-NH_2$ (%)	$N-NO_3$ (%)	$N-NH_4$ (%)	SO_3 (%)
Establishment	1-4-1	11-44-11	-	3	8	-
	1-3-1	13-36-13	-	3.7	9.3	-
	1-2-1	15-30-15	4.8	4.3	5.9	3.9
Vegetative development	1-1-1	19-19-19+1MgO	9.9	5.5	3.6	1.9
	1-1-1	20-20-20	10	6	4	-
	1-1-1	18-18-18+2MgO	9	5	4	3.9
	2-1-1	26-12-12+2MgO	20	3.5	2.5	3.9
	2-1-2	21-11-21+2MgO	13	6	2	3.9
Fruit set and fruit development	2-1-3	14-7-21+2MgO	-	6	8	25.2
	2-1-3	18-9-27+2MgO	8.6	7.6	1.8	3.9
	2-1-4	14-7-28+2MgO	-	8	6	16
	2-1-4	16-8-32+2MgO	5.5	9	1.5	3.5
	3-1-3	23-7-23+2MgO	15	6.5	1.5	1.9
	High K	12-5-40+2MgO	-	11	1	3.9

5.2.4 Foliar sprays

The purpose of foliar feeding is not to replace soil fertilization. Supplying a plant's major nutrient needs (nitrogen, phosphorus, and potassium) is most effective and economical via soil application. However, foliar application has proven to be an excellent method of supplying plant requirements for secondary nutrients (calcium, magnesium, sulfur) and micronutrients (zinc, manganese, iron, copper, boron, and molybdenum), while supplementing N-P-K needs for short and / or critical growth stage periods.

Strawberries respond to foliar nutrients with increased vegetative development and improved flower numbers, their fruit-set rate, and higher yields, as well as by higher flavor and sugar content. See Table 5.14 and Table 5.15. Treated berries are firmer, hold up better, and show increased resistance to fungus attacks in the field and post harvest.

Table 5.14: Main results obtained by foliar-fed Zn and Fe on "Chandler" strawberries
Source: Chaturvedi et al, 2005

Plant & fruit parameters	Control	$ZnSO_4$ (0.4%)	$FeSO_4$ (0.2%)
Plant height (cm)	15.5	18.9 (+22%)	18.3 (+18%)
Number of leaves/plant	19.2	24.9 (+30%)	23.2 (+21%)
Number of runners / plant	1.95	2.10 (+7.7%)	1.90 (-2.5%)
Number of flowers / plant	2.22	3.22 (+45%)	3.33 (+50%)
Number of fruit-set/plant	1.77	2.60 (+47%)	2.8 (+58%)
Number of fruits/plant	11.2	16.1 (+44%)	16.9 (+51%)
Plant fruit yield (g/plant)	86.4	133.9 (+55%)	140.5 (+63%)
Mean fruit mass (g/fruit)	6.85	7.85 (+15%)	7.98 (+16%)
Ascorbic acid (mg/ 100g pulp)	65.5	66.1 (+1%)	65.94 (+1%)
Fruit acidity	0.962	0.968 (+0.6%)	0.967 (+0.5%)
TSS contents (^{0}Brix)	8.70	9.32 (+7.1%)	9.42 (+8.3%)
Shelf life in ambient temp. (days)	2.45	2.71 (+11%)	2.71 (+11%)

Table 5.15: Results (expressed as % change over control) obtained by pre-harvest foliar-feeding with Ca and B on "Chandler" strawberries
Source: Singh, et al, 2007

Fruit parameters	Control	$CaCl_2$ (2kg/ha) + Boric acid (0.15 kg / ha)	Boric acid (0.15 kg / ha)
Incidence of fruit albinism	15.1 a	6.5 b (-57%)	14.8 a (-2%)
Incidence of fruit grey mold (%)	8.4 b	1.9 a (-78%)	8.1 b (-4%)
Incidence of fruit mal-formation	12.4 a	3.1 b (-75%)	3.4 b (-73%)
Marketable fruit yield (g/plant)	149.3 a	179.2 c (+20%)	161.3 b (+8%)
Fruits firmness after 5 shelf days	0.91 a	1.33 b (+46%)	1.01 a (+11%)
Ascorbic acid content (mg / 100g pulp)	39.1 a	45.0 b (+15%)	40.2 a (+3%)
TSS content (mg/ 100g pulp)	8.5 a	7.8 b (-8%)	8.2 a (-3%)
Acidity content	0.91 a	1.07 b (+18%)	0.95 a (+4%)

The initial application at the first sign of bloom is made to promote plant growth, early season fruiting and improved set.

A second application two weeks later helps to prolong plant vigor and fruiting, as a further aid to increasing total yield and quality.

Additional applications are recommended at 14- to 20-day intervals.

An application in the first half of September aids in the development of fruiting buds for the following spring.

Additionally, foliar feeding is intended to delay natural senescence processes shortly after the end of reproductive growth stages. Foliar feeding targets the growth stages where declining rates of photosynthesis and leveling off of root growth and nutrient absorption occur, in attempts to aid translocation of nutrients into seed, fruit, tuber, or vegetative production. Also, foliar feeding is an effective management tool to favorably influence pre-reproductive growth stages by compensating for environmentally induced stresses of adverse growing conditions and / or poor nutrient availability. Early foliar applications can make an already good crop better, either by stimulating more vigorous regrowth or maximizing the yield potential growth stage period.

Foliar fertilizer sprays can be used on established plants to quickly correct deficiencies identified by leaf analysis or by field symptoms. There are several commercial blends of complete foliar fertilizers suitable for strawberries. They contain a wide range of essential nutrients that are readily absorbed through the leaves. Plants under stress, for example during early fruit set and fruit development, can benefit from a foliar fertilizer spray program. Most foliar fertilizer sprays can be tank-mixed with pesticides; however, check the labels of both products before mixing.

Micronutrients should be applied according to need as determined by a tissue test, and should always be applied along with nitrogen in the solution. Combinations of certain nutrients may pose solution solubility problems, especially where nutrient solutions are combined with fungicides and pesticides. Potassium nitrate is compatible with most pesticides, exceptions being lime and sulfur. Magnesium sulfate is not compatible with arsenicals or copper sprays. Dormancy zinc sprays are not compatible with oil. Manganese solutions should not be mixed with phosphate, iron sulfate, or with nabam.

Buffering agents should be added to the foliar fertilizer solution to stabilize the pH of the solution (preferably between 5.0 and 6.0) and provide for quick and uniform coverage of the spray.

Biuret-free urea and compound nutrient sprays are commonly applied to large acreages of strawberries in the northern USA during the fruiting period to maintain fruit size. Here again, spraying is combined with the application of insecticides and fungicides. Sprays are performed during the late spring and early summer. The materials are added to the spray tank and applied along with insecticides and fungicides.

Table 5.16: Foliar spray program for maintaining highly fertile strawberry plants (nutrient-specific recommendations for addressing deficiency situations were suggested in Chapter 4).

Growth stages	N	P_2O_5	K_2O	Ca	Mg	Mn	B
	Application rate (kg / ha)						
	For annual fields						
First sign of bloom Two weeks later 2 to 3 weeks later	2.8 - 3.9	0.6 - 1.1	0.9 - 1.4	1.1 - 1.7	0.6 - 1.1	0.6 - 1.1	0.3
	For perennial fields						
Early spring at 15-20 cm new growth Early September (fall)	1.7 - 2.8	0.35 - 0.6	0.45 - 0.9				

6. Haifa nutrition recommendations

6.1 Mineral nutrition of strawberries with fully soluble fertilizers

Please note that the following recommendations should be used as guidelines only, as the real applications are dependent also on many local conditions that can have a crucial effect on the plantation performance, e.g., cultivar, planting season, individual growth stage durations, ambient temperature, soil fertility, mineral contents of irrigation water, etc.

6.1.1 Soil-grown strawberries with expected yield of 25 MT/ha

Soil type: sandy loam ; Irrigation method: above canopy sprinklers

Base dressing

Fertilizer	Rate (kg / ha)
Ammonium nitrate (34% N)	130
Superphosphate (25% P_2O_5)	400
Potassium sulfate (50% K_2O)	364
Dolomite (26% CaO)	131
Magnesium sulfate (16% MgO)	81

Side dressing

Growth stage	Days per growth stage	Fertilization during growth stage (kg / ha)	
		Ammonium nitrate	Multi-K+ME
Planting: October 15		---	---
Establishment, until November 15	30	85	65
Growth, until January 8	55	---	---
First flowering: January 8	5	---	---
First flowering: January 8	5	---	---
Growth of 1st fruit wave, until February 28	45	110	60
Growth of 2nd fruit wave, until April 5	36	---	---
Growth of 3rd fruit wave, until April 30	25	85	80
Growth of 4th fruit wave, until May 31	30	---	---
Total for season	226	280	205

Foliar feeding

None.

6.1.2 Soil grown strawberries with expected yield of 40 MT / ha

Soil type: sandy loam

Irrigation method: drip

Base dressing

Fertilizer	Rate (kg / ha)
Ammonium nitrate (34% N)	197
Superphosphate (25% P_2O_5)	308
Potassium sulfate (50% K_2O)	316
Dolomite (26% CaO)	162
Magnesium sulfate (16% MgO)	100

Side dressing by nutrigation

Growth stage	Days per growth stage	Fertilization during growth stage (kg / ha)				
		Ammonium nitrate	Haifa MAP™	Multi-K™ GG	Haifa Cal™ Nutrigation™ Grade	Magnisal™
Planting: Oct. 15						
Establishment, until Nov. 15	30	40	25	80	5	3
Growth, until Jan. 8	55	30	20	80	5	3
First flowering: Jan. 8	5	--	15	20	--	--
Growth of 1st fruit wave, until Feb. 28	45	35	10	110	10	7
Growth of 2nd fruit wave, until Apr. 10	41	35	5	130	10	7
Growth of 3rd fruit wave, until May 5	25	30	5	80	8	5
Growth of 4th fruit wave, until June 10	35	30	5	15	--	--
Total for season	236	200	85	515	38	25

Haifa MAP™: 12-61-0, fully soluble Mono-ammonium phosphate.

Multi-K™ GG: 13.5-0-46.2, fully soluble potassium nitrate.

Haifa Cal™ GG: 15.5-0-0+ 26.5 CaO, fully soluble calcium nitrate.

Magnisal™: 11-0-0+ 16 MgO, fully soluble magnesium nitrate.

Foliar feeding

In mid-November: Poly-Feed™ Foliar 21-21-21 with micronutrients

6.1.3 High-tunnel, soil grown strawberries with expected yield of 50 MT / ha

Soil type: sandy loam

Irrigation method: dripping

Base dressing

Fertilizer	Rate (kg / ha)
Ammonium nitrate (34% N)	233
Superphosphate (25% P_2O_5)	344
Potassium sulfate (50% K_2O)	376
Dolomite (26% CaO)	192
Magnesium sulfate (16% MgO)	119

Side dressing by nutrigation

Growth stage	Days per growth stage	Fertilization during growth stage (kg / ha)				
		Ammonium nitrate	Haifa MAP™	Multi-K™ GG	Haifa Cal™ Nutrigation™ Grade	Magnisal™
Planting: Oct. 15		47	29	95	6	6
Establishment, until Nov. 15	30	35	22	95	6	6
Growth, until Jan. 8	55		17	24		
First flowering: Jan. 8	5	42	11	131	12	12
Growth of 1st fruit wave, until Feb. 28	45	42	6	156	12	12
Growth of 2nd fruit wave, until Apr. 10	41	36	5	95	10	10
Growth of 3rd fruit wave, until May 5	25	35	5	19		
Growth of 4th fruit wave, until June 10	35	47	29	95	6	6
Total for season	236	237	95	615	46	31

Haifa MAP™: 12-61-0, fully soluble mono-ammonium phosphate.
Multi-K™ GG: 13.5-0-46.2, fully soluble potassium nitrate.
Haifa Cal™ GG: 15.5-0-0+ 26.5 CaO, fully soluble calcium nitrate.
Magnisal™: 11-0-0+ 16 MgO, fully soluble magnesium nitrate.

Foliar feeding

1. In mid-November: **Poly-Feed™ Foliar** 21-21-21, with micronutrients, at 0.5%
2. In February: **Poly-Feed™ Foliar** 16-7-30+2MgO, with micronutrients, at 0.5% to 1%

6.1.4 Green-house, soilless grown strawberries with expected yield of 60 MT / ha

Soil type: sandy loam

Irrigation method: dripping

Nutrigation

Growth stage	Days per growth stage	Fertilization during growth stage (kg / ha)				
		Ammonium nitrate	Haifa MAP™	Multi-K™ GG	Haifa Cal™ Nutrigation™ Grade	Magnisal™
Planting: Oct. 15		10	20	30	10	8
Establishment, until Nov. 15	30	40	45	80	20	15
Growth, until Jan. 8	55	40	37	150	50	40
First flowering: Jan. 8	5		5	15	10	5
Growth of 1st fruit wave, until Feb. 28	45	10	50	370	48	30
Growth of 2nd fruit wave, until Apr. 10	41	10	42	310	50	30
Growth of 3rd fruit wave, until May 5	25	16	27	140	45	20
Growth of 4th fruit wave, until June 10	35	25	30	55	36	21
Total for season	236	151	256	1,150	269	169

Haifa MAP™: 12-61-0, fully soluble mono-ammonium phosphate.

Multi-K™ GG: 13.5-0-46.2, fully soluble potassium nitrate.

Haifa Cal™ GG: 15.5-0-0+ 26.5 CaO, fully soluble calcium nitrate.

Magnisal™: 11-0-0+ 16 MgO, fully soluble magnesium nitrate.

Foliar feeding

1. In mid-November: **Poly-Feed™ Foliar** 21-21-21, with micronutrients, at 0.5%
2. In February : **Poly-Feed™ Foliar** 16-7-30+2MgO, with micronutrients, at 0.5-1%
3. In mid-March: **Poly-Feed™ Foliar** 16-7-30+2MgO, with micronutrients, at 0.5-1%

6.2 Controlled release nutrition of strawberries

6.2.1 Multicote™ Agri Controlled Release Fertilizers technology

Multicote™ Agri is a controlled-release fertilizer, designed to release available nutrients to the soil solution slowly and continuously over months. **Multicote™ Agri** is made of polymer-coated fertilizer granules. Following application, the granules start absorbing soil moisture that dissolves the granule cores that are made of a soluble fertilizer mini-granule. The dissolved nutrients then diffuse, slowly and continuously, into the root zone. The release rate depends upon, and is dictated solely by the soil temperature and the granule coating pore size. The release rate increases as temperature rises, which coincides with plant uptake rates as a function of temperature. Other factors, such as soil type, humidity, pH, and microbial activity do not affect the release rate. **Multicote™Agri** products also contain non-coated, readily available nutrients, for establishment and initial growth.

The advantages **Multicote™ Agri**:

- Nutrients are supplied in accordance with plant needs, for optimal development and best yields.
- Single application per season, which results in a drastic reduction of field labor and application costs, as well as considerably less soil compaction.
- Minimized losses through leaching, volatilization or fixation in the soil, without compromising on nutrient availability throughout the growth season.
- More efficient use of fertilizers without wastage enables reduced application rates.
- Ecologically superior (no soil or air pollution).

Multicote™ Agri release mechanism

Multicote™ Agri is based on polymer-coated fertilizer granules. During the production process, water-soluble nutrients are encapsulated in a polymeric shell. This shell prevents the immediate dissolution of the fertilizer when applied to the soil. The thickness of the shell determines the longevity of nutrient release. See Figure 6.1a.

Following application, soil moisture slowly penetrates through the coating. This moisture starts a gradual dissolution of the nutrients inside the granule. See Figure 6.1b.

The dissolved nutrients diffuse through the coating to the root zone, providing the plant with available nutrients in measured portions according to its growth needs. See Figure 6.1c.

The diffusion rate, which is the actual release rate, is dictated solely by the soil temperature. The release rate increases as temperature rises.

While nutrients are released to the root zone, further penetration of moisture dissolves more of the solid fertilizer. At a certain stage, the entire content of the granule is dissolved, ready for diffusion and release. Starting at this stage the release rate slows down. See Figure 6.1d.

After the release is complete, the empty shell ruptures and degrades, leaving no residues in the soil. See Figure 6.1e.

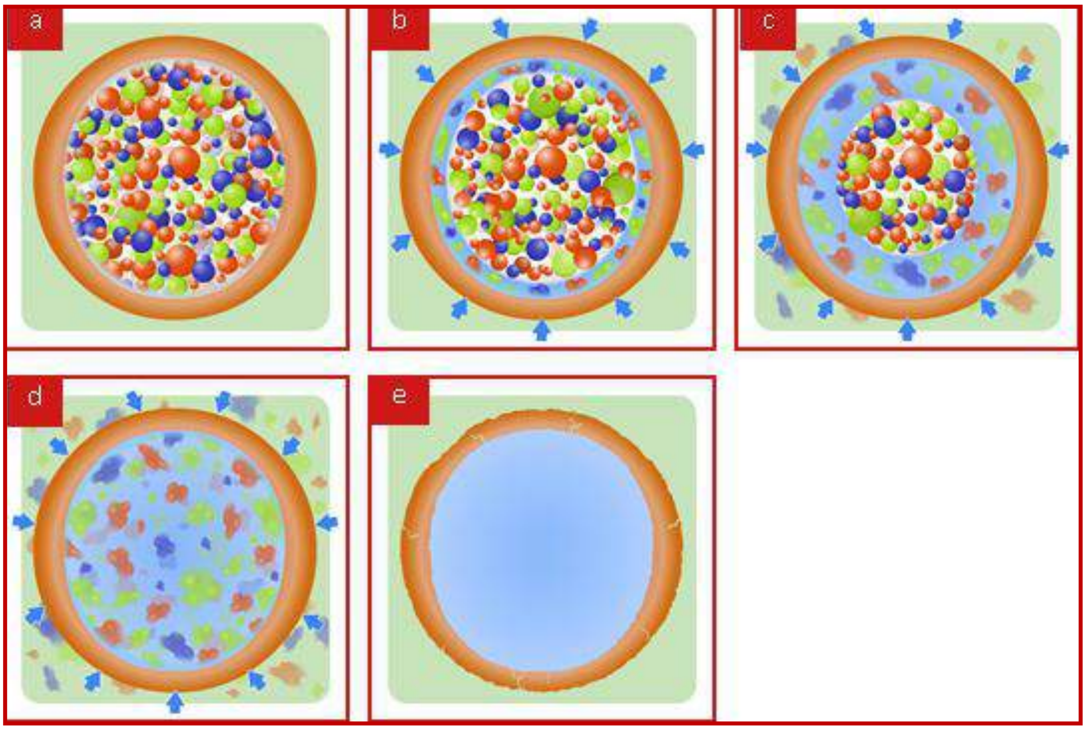


Figure 6.1: Multicote™Agri release mechanism

Multicote™ Agri for strawberries

Haifa offers worldwide strawberry growers **Multicote™ Agri** formulae specially tailored to suit local cultivars and growth conditions. **Multicote™ Agri** formulae for strawberries may consist of either 100% polymer coated fertilizer granules, or, for cost-saving reasons and / or to meet local specific plant nutrient requirements, it may partially contain also non-coated, readily available fertilizers.

The versatile controlled release characteristics of **Multicote™ Agri** give growers the power to apply a cost effective fertilizer, a suitable product for each strawberry growth area.

Multicote™ Agri minimizes nutrient loss, gives strawberries the right amount of nutrients, and helps strawberry growers maximize profitability.

The **Multicote™ Agri** granules are banded in a planting slot 15 cm to 20 cm (6 inches to 8 inches) deep. The total rate of fertilizer applied depends on the type of materials used and the residual nutrient levels in the soil.

Shortly after the granule application the strawberry roots identify the granules as a source of beneficial nutrients, and new, efficient roots are formed near the granules to take advantage of their contents. See Figures 6.2.

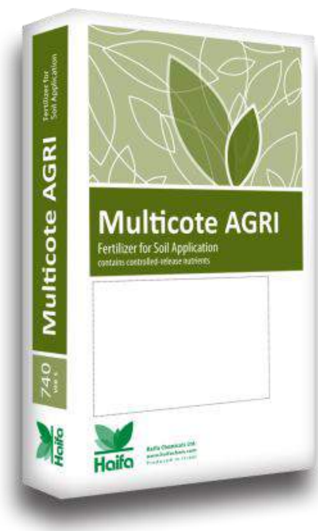



Figure 6.2: A strawberry plant dug out to demonstrate grain application location, and the dense net of newly formed roots around the **Multicote™ Agri** granules

6.2.2 Worldwide fertilization practices with Multicote™Agri

Israel

Soil type: light textured soil

Planting time: early to late fall

Growing method: mainly plasticulture; covered with mini- or high-tunnels

Fertilization

Recommended plant nutrients for 7 to 8 month growth period (kg / ha)

N	P_2O_5	K_2O	CaO	MgO
220 -250	120– 130	350– 370	200– 250	100– 120

Application rates of N & K throughout growth stages (kg / ha / week)

	Nov.	Dec.	Jan.	Feb.	March
N	7.5	11	7	11 – 14.5	11
K_2O	-	17.5	11	17.5 – 21	17.5

Pre-plant fertilization

Nitrogen, after transplanting is supplied with the first fertigation.

Phosphorus: Applying 500 to 1,000 kg / ha of triple superphosphate (46% P_2O_5).

Potassium: Applying 500 kg / ha of potassium chloride 60% K_2O.

Side / top-dressing with Multicote™ Agri:

The required plant nutrients are supplied by **Multicote™ Agri** (6 months) **17-8-27** or **Multicote™Agri Multicote™ Agri** (6 months) **15-5-30** (90%-50%-90%, respectively, polymer coated), at a rate of 800 to 1,000 kg / ha. This **Multicote™ Agri** application results in higher yield of better quality fruits.

There are three application methods:

1. Broadcasting on the bed, before planting, and incorporating with a rototiller.
2. Banding **Multicote™ Agri** between two planted rows, next to the irrigation line.
3. Broadcasting after plants are established, before mulching with plastic, and incorporating with a suitable cultivator. This method is the most popular type of application.

The normal yield of a field planted in mid-October and harvested until the end of May, is 70 to 75 MT / ha in mini-tunnels and 75 to 80 MT / ha in high tunnels. It is distributed between the months shown in Table 6.1.

Table 6.1: Average yield (MT / ha) during the growth period

	Nov.	Dec.	Jan.	Feb.	March	April	May	Total
Export quality	0	5	2	5	3	0	0	15
Local market	0	3	3	7	10	12	10	45
Total	0	8	5	12	13	12	10	60

South Africa

Soil type: Sandy, in some cases sandy-loam

Growing period: Planting in March / April (autumn), harvesting: June to December

Normal yield: 40 to 50 MT / ha

Growing method: Multi-span tunnels and open fields with mini-tunnels during the winter months. The objective is to grow a fair-sized plant, not overly vegetative, that continuously flowers and sets fruit. The fertigation solution is adjusted during the season using soil solution and leaf analysis, as well as visual observation. Irrigation is by means of single dripper line with a 35 cm dripper-spacing.

Fertilization

The seasonal plant nutrient application (kg / ha) is about:

N	P_2O_5	K_2O
200	100	300

Pre-plant applications:

- Lime and / or gypsum are applied prior to ridge formation; rate is based on soil analysis.
- **Multicote™ Agri (6) 17-8.5-26** (80-100-100% polymer coated) @ 1,100 kg / ha.

Post planting, calcium nitrate is applied throughout the season by fertigation at a rate of 40 ppm. Additional **Multi-K™** is applied at the final stages of the season to stretch the growing season and maintain fruit quality as long as possible. Whenever needed, **Multicote™ Agri** may contain also Mg and micronutrients.

Application method

The fertilizer is banded by a Monosem fertilizer applicator mounted on the ridger. A single band of fertilizer is placed between two rows of plants on each ridge. See Figure 6.3.

Figure 6.3: A 'Monosem' fertilizer applicator mounted on the ridger. **Multicote™ Agri** applied simultaneously with bed preparation

California, USA

Soil type: Sand / sandy-loam to loamy clay soil

Growing period: Winter: October to May; Summer: July to December

Growing method: Open field, plastic mulch

Fertilization of winter crop

Recommended plant nutrients for Southern California

The seasonal plant nutrient application (kg / ha) is about:

kg / ha			lbs / acres		
N	P_2O_5	K_2O	N	P_2O_5	K_2O
225	90	160	200	80	140

Normal yield: 67 MT / ha (30 ton / acre or 5,000 trays per acre)

Pre-plant: 15-15-15 or 16-20-0 at: 225 to 334 kg / ha (200 to 300 lb / acre), plus
Multicote™ Agri 22-8-13 at 900 to 1,100 kg / ha (800 to 1,000 lbs / acre), 100% polymer coated

Recommended plant nutrients for Northern California

kg / ha			lbs / acres		
N	P_2O_5	K_2O	N	P_2O_5	K_2O
110	45	70	100	40	60

Normal yield: 78 ton / ha (35 ton / acre or 5833 trays per acre)

Pre-plant: **Multicote™ Agri** 22-8-13 at 530 kg / ha (475 lbs / acre), 100% polymer coated

Application method

Multicote™ Agri is applied in a tight band by 'Clampco' shank (see Figure 6.4 to Figure 6.6) and placed precisely in the fertilizer slot, at least 4 cm (1.5 inches) off the transplant roots of two-row beds

Figure 6.4: 'Clampco' precision applicator provides free flow of **Multicote™ Agri**

Figure 6.5: A two-row 'Clampco' applicator, banding **Multicote™ Agri**

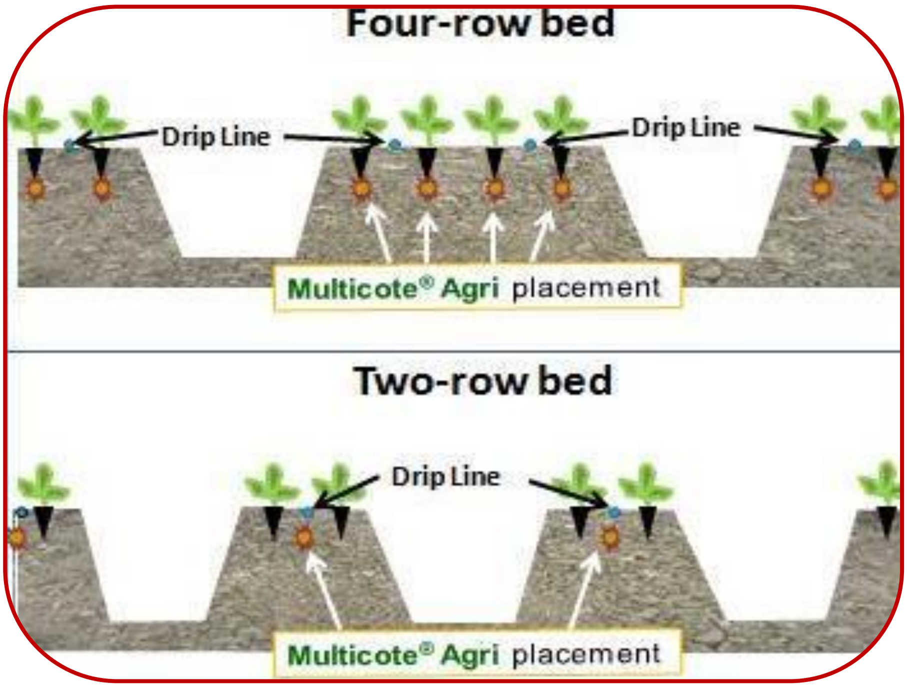


Figure 6.6: Two- or four-row bed planting and **Multicote™ Agri** placement patterns in California strawberry

Fertilization of a summer crop

Normal yield: 34 ton / ha (15 ton / acre)

Pre-plant fertilization is not practiced.

- CAN solution of 15% to 17% N is applied monthly at an application rate of 280 to 470 L / ha (30 to 50 gal / acre).
- White (technical grade, 75% P_2O_5) phosphoric acid is applied ~45 days after planting, at a rate of 470 L / ha (50 gal / acre).
- During the first two months after planting, a solution of 4-10-10+ME, made from ***Multi-K***™ is fertigated four times a month. Standard rates are 4 to 11 kg N / ha / application (3 to 10 lbs N / acre / application) or at a rate of 50 to 100 L / ha (5 to 10 gal / acre).
- At the end of the season, 2-18-18 analysis, for juice and freezer berries, may be applied.
- Liquid feed is also applied right after rain, depending on amount of rainfall.

Figure 6.7: Mulched strawberry in open-field in southern California

Mexico – Baja California

Soil type: Medium to light textured

Growing period: Transplanting - September to mid October, harvesting ends in May

Growing method: Similar to southern California; 2 or 4 rows / mulched bed

Fertilization

Base-dressing, similar to Californian practice. During bed preparation, **Multicote™ Agri** (6) 22-8-13 is applied at 800 to 1,200 kg / ha before transplanting.

Fruit quality

Highest fruit quality is harvested between December and February. Lower quality is harvested between March and June.

Central Mexico – Inland

Soil type: Medium to heavy textured

Growing method: Open field is practiced by 70% of the growers.

Growth period: Transplanting in August / September; harvesting ends in April / May.

Inundation: It is a common practice is to flood the field between growth seasons in order to control weeds and soil-borne diseases (see Figure 6.8). The flooding lasts between 1 and 3 months.

Figure 6.8: Flooded field

Soil preparation: Beds are prepared in May, sometimes with base-dressing incorporation. Some growers apply fertilizers only after transplanting in September.

Transplanting: In August and September, immediately after draining the flooded field.

Fertilization

N	P_2O_5	K_2O	CaO	MgO
kg / ha				
185	160	320	85	When needed

Application methods

1. Traditional method

Common N-P-K fertilizers, such as: 12-11-17, 15-15-15, etc., are applied in two sessions after transplanting.

The first application takes place 20 to 25 days after transplantation, and second application takes place 60 to 65 days after transplantation. However, part of the required plant nutrients are sometimes also applied as base-dressing.

2. Advanced method

Multicote™ Agri (8) 12-15-17 (30%-0%-30% polymer coated), at a rate of 500 kg / ha is applied in September / October, 20 to 25 days after transplanting, once only, either manually (Figure 6.9) or by a mechanical applicator (Figure 6.10). This application method eliminates the need to top-dress at a later stage.

Figure 6.9: Multicote™ Agri , manually applied

Figure 6.10: **Multicote™ Agri** , mechanically applied

Fertigation

During all growing stages, strawberries are fertigated with water-soluble fertilizers.

Harvesting

Harvest is done once every 3 days, up to 60 to 70 harvests during the crop cycle, until the end of May. The highest quality fruit is obtained during February to April.

Normal yield

45 to 55 MT / ha

Central Mexico – inland

Soil type: Medium to heavy textured

Growing method: Macro-tunnels are practiced by 30% of the growers

Field preparation: Starts in May, soil is base-dressed, and then beds are mulched with plastic.

Macro-tunnels

Tunnels are installed before the rainy season. In the past, it was common practice to flood the field (Figure 6.11) to control weeds and pests. Today, most growers use pesticides and herbicides for this purpose.

Figure 6.11: A flooded macro-tunnel

Figure 6.12: A macro-tunnel fertilized with ***Multicote™ Agri***

Growing period: Early August / September; end of the harvest March to mid-May

Transplantation: The transplanting process starts after draining the flooded field, in August.

Fertilization: After bed preparation and mulching, **Multicote™ Agri** (8) 15-15-15 (100%-0%-100% polymer coated) is applied at a rate of 400 kg / ha (Figure 6.10).

Normal yield: 65 to 75 MT / ha. Harvest is done once every 3 days, up to 60 to 70 harvests during the crop cycle, until the end of May.

Spain

Soil type: Sandy soil with high pH around 7 to 8

Growing period: Planting in April; end of harvest in October

Growing method: Open field, no mulch, irrigated by sprinklers

Fertilization

Recommended plant nutrients for the entire growth period (kg / ha):

N	P_2O_5	K_2O
140	60	50

Pre-plant fertilization

Multicote™ Agri (4) 15-15-15+1,2 MgO or **Multicote™ Agri** (4) 18-11-11+4 MgO, at 20 to 30 g / linear meter

Side-dressing: 11 weeks after planting, weekly fertigation sessions from June to September, with water-soluble fertilizer, such as: **Poly-Feed™** 22-0-10+3MgO + MAP

Figure 6.13: Transplanting and application of **Multicote™ Agri**

Figure 6.14: Initial growth stage of the field

Appendix I: Conversion tables

Table 1: Conversion coefficients between nutrient forms

From	To	Multiply by	From	To	Multiply by
P	P_2O_5	2.29	P_2O_5	P	0.44
P	PO_4	3.06	PO_4	P	0.32
H_3PO_4	H_2PO_4	0.9898	H_2PO_4	H_3PO_4	1.01
K	K_2O	1.20	K_20	K	0.83
Ca	CaO	1.40	CaO	Ca	0.71
Mg	MgO	1.66	MgO	Mg	0.60
S	SO_3	2.50	SO_3	S	0.40
S	SO_4	3.00	SO_4	S	0.33
N	NH_4	1.28	NH_4	N	0.82
N	NO_3	4.43	NO_3	N	0.22

Table 2: Conversion coefficients between nutrient concentration expressions

From	Correspondent element (mg)	1 mmol	Correspondent element (mg)	Weight of ion
NH_4^+	14 mg N	NH_4^+	14 mg N	18 mg NH_4^+
NO_3	14 mg N	NO_3	14 mg N	62 mg NO_3^-
H_2PO_4	31 mg P	H_2PO_4	31 mg P	71 mg P_2O_5
HPO_4^2	31 mg P	HPO_4^2	31 mg P	35,5 mg P_2O_5
HPO_4^{2-}	15.5 mg P	K^+	39 mg K	47 mg K_2O
K^+	39 mg K	Ca^{2+}	40 mg Ca	28 mg CaO
Ca^{2+}	20 mg Ca	Mg^{2+}	24 mg Mg	20 mg MgO
Mg^{2+}	12 mg Mg	SO_4^2	32 mg S	48 mg SO_4
SO_4^2	16 mg S	Na^+	23 mg Na	-
Na^+	23 mg Na	Cl	35.5 mg Cl	-

Fertilizer concentration calculations

A. Units used

ppm = parts per million

mM = milli molar

meq/l = milliequivalent per liter

B. Fertilizer concentrations

a. Parts per million (ppm)

The term states how many parts of solute there are in a million parts of the whole solution. Parts per million usually expresses concentrations on a mass basis, e.g., 1 gram in 1 metric ton of water (the mass of 1 cubic meter of water).

b. Milli-molar (mM)

One millimolar (mM) concentration refers to a solution containing one-thousandth of molecular weight (g) of the solute per liter of water. One molar (M) concentration equals 1,000 millimolar (mM) concentration.

c. Milliequivalent per liter (meq/L)

Milliequivalents per liter (meq / L concentrations are often used to show the strength of fertilizer ions (anion or cation) in a solution. Since one equivalent weight is the molecular weight divided by valence, one meq / L refers to the ionic concentration of a solution that contains one millimole / valence per liter of water.

The nutritional value of solid fertilizers

The nutritional value of solid fertilizers is generally expressed in a constant order and percentage of its constituents. For example, a fertilizer designated: **18-9-27+2MgO** contains:

18% of nitrogen + 9% of phosphorus oxide + 27% of potassium oxide + 2% of magnesium oxide.

Hence, 1 kg of this fertilizer will contain 180g of nitrogen + 90g of P_2O_5 + 270g of K_2O + 20g of MgO.

As in several parts of the world (e.g., South Africa and Australia) nutrients are expressed by their elemental form and not by their oxide form, one can easily transform the above data by using Conversion Table 1 above. Hence, the above mentioned fertilizer contains: 180g of nitrogen + 90g x 0.44 = 39.6g of elemental phosphorus + 270g x 0.83 = 224.1 of elemental potassium + 20g x 0.6 = 12g of elemental magnesium.

The nutritional value of liquid fertilizers

The nutritional value of liquid fertilizers is generally expressed in a constant order, which is equal to the one used for solid fertilizers, but the contents are indicated on a volume basis, accompanied by the specific gravity of the solution. For example, a fertilizer designated: **9-3-6** contains**:** 9% nitrogen + 3% phosphorus oxide + 6% potassium oxide.

If the manufacturer indicates that the specific gravity of this fertilizer solution is 1.18 kg / L, one liter of this fertilizer contains:

1,000 x 0.09 x 1.18 = 106.2 g of nitrogen +

1,000 x 0.03 x 1.18 = 35.4 g of P_2O_5 +

1,000 x 0.06 x 1.18 = 70.8 g of K_2O.

Table 3: Conversion coefficients between agronomic units

From	To	Multiply by	From	To	Multiply by
Acre	Hectare	0.405	Hectare	Acre	2.471
Kilogram	Pound	2.205	Pound	Kilogram	0.453
Gram	Ounce	0.035	Ounce	Gram	28.35
Short ton	Metric ton	0.907	Metric ton	Short ton	1.1
Gallon (US)	Liter	3.785	Liter	Gallon (US)	0.26
kg / ha	lb / acre	0.892	lb / acre	kg / ha	1.12
MT / ha	lb / acre	892	lb / acre	MT / ha	0.001

Appendix II: Haifa Specialty Fertilizers

Pioneering Solutions

Haifa develops and produces **Potassium Nitrate** products, **Soluble Fertilizers** for **Nutrigation**™ and foliar sprays, and **Controlled-Release Fertilizers**. Haifa's Agriculture Solutions maximize yields from given inputs of land, water, and plant nutrients for diverse farming practices. With innovative plant nutrition schemes and highly efficient application methods, Haifa's solutions provide balanced plant nutrition at precise dosing, composition, and placing. This ultimately delivers maximum efficiency, optimal plant development, and minimized losses to the environment.

Potassium nitrate

Haifa's potassium nitrate products represent a unique source of potassium due to their nutritional value and contribution to plant health and yields. Potassium nitrate has distinctive chemical and physical properties that are beneficial to the environment. Haifa offers a wide range of potassium nitrate products for **Nutrigation**™, foliar sprays, side-dressing and controlled-release fertilization. Haifa's potassium nitrate products are marketed under the **Multi-K**™ brand.

Multi-K™ products

Pure Multi-K™

Multi-K™ Classic Crystalline potassium nitrate (13-0-46)

Multi-K™ Prills Potassium nitrate prills (13-0-46)

Special Grades

Multi-K™ GG Greenhouse-grade potassium nitrate (13.5-0-46.2)

Multi-K™ pHast Low-pH potassium nitrate (13.5-0-46.2)

Multi-K™ Top Hydroponics-grade potassium nitrate (13.8-0-46.5)

Enriched products

Multi-npK™ Enriched with phosphate; crystalline or prills

Multi-K™ Mg Enriched with magnesium; crystalline or prills

Multi-K™ Zn Enriched with zinc; crystalline

Multi-K™ S Enriched with sulfate; crystalline

Multi-K™ B Enriched with boron; crystalline or prills

Multi-K™ ME Enriched with magnesium and micronutrients; crystalline

Nutrigation™

Nutrigation™ (Fertigation) delivers pure plant nutrients through the irrigation system, supplying essential nutrients precisely to the area of most intensive root activity. Haifa's well-balanced Nutrigation™ program provides the plants with their specific needs according to seasonal changes. Decades of experience in the production and application of specialty fertilizers for **Nutrigation™** have made Haifa a leading company in this field. Haifa keeps constantly up to date with contemporary scientific and agricultural research, in order to continuously broaden its product line to better meet the requirements of crops and cropping environments.

Haifa offers a wide range of water-soluble fertilizers for **Nutrigation**™. All products contain only pure plant nutrients and are free of sodium and chloride.

Multi-K™	Comprehensive range of plain and enriched potassium nitrate products
Poly-Feed™	Soluble NPK fertilizers enriched with secondary micro-nutrients
Haifa MAP	Mono-ammonium phosphate
Haifa MKP	Mono-potassium phosphate
Haifa Cal	Calcium nitrate
Magnisal™	Our original magnesium nitrate fertilizer
Haifa Micro	Chelated micronutrients
Haifa VitaPhos-K™	Precipitation-proof poly-phosphate for soilless Nutrigation™
Haifa ProteK	Systemic PK fertilizer

Foliar Feeding

Foliar Feeding provides fast, on-the-spot supplementary nutrition to ensure high, top quality yields and is an ideal feeding method under certain growth conditions in which absorption of nutrients from the soil is inefficient, or for use on short-term crops. Precision-timed foliar sprays are also a fast-acting and effective method for treating nutrient deficiencies. Foliar application of the correct nutrients in relatively low concentrations at critical stages in crop development contributes significantly to higher yields and improved quality. Haifa offers a selection of premium fertilizers for foliar application:

Haifa Bonus™ High-K foliar formulas enriched with special adjuvants for better absorption and prolonged action.

Poly-Feed™ Foliar NPK formulas enriched with micronutrients specially designed to enhance crop performance during specific growth stages.

Magnisal™, **Haifa MAP™**, **Haifa MKP™**, **Haifa Cal™** and **Haifa Micro**™ are also suitable for foliar application.

Controlled Release Nutrition

Multicote™, Haifa's range of controlled release fertilizers, includes products for agriculture, horticulture, ornamentals, and turf. Multicote™ products provide plants with balanced nutrition according to their growth needs throughout the growth cycle. **Multicote™** products enhance plant growth, improve nutrient use efficiency, save on labor and minimize environmental impact.

Single, pre-plant application controlled-release fertilizer can take care of the crop's nutritional requirements throughout the growth season. Controlled release fertilizers are designed to feed plants continuously, with maximal efficiency of nutrient uptake. Controlled release fertilizers save labor and application costs. Their application is independent of the irrigation system, and does not require sophisticated equipment.

Taking advantage of MulticoTech polymer coating technology, Haifa produces the **Multicote™** line of controlled release fertilizers.

Multicote™ Products

Multicote™ for nurseries and ornamentals; NPK formulae with release longevities of 4, 6, 8, 12 and 16 months

Multicote™ Agri / **Multigro™** for agriculture and horticulture

CoteN™ controlled-release urea for arable crops

Multicote™ Turf / **Multigreen™** for golf courses, sports fields, municipals and domestic lawns