10. Pineapple

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10.1. Introduction

Pineapple is one of the tropical fruits in greatest demand on the international market, with world production in 2004 of 16.1 million mt. Of this total, Asia produces 51% (8.2 million mt), with Thailand (12%) and the Philippines (11%) the two most productive countries. America and Africa contribute 32% and 16% of world production, respectively, with Brazil (9%) and Nigeria (6%) also being major producers (FAO, 2006). A major part of world production is processed as canned products and juices, and about 25% goes to the fresh fruit market (Souza *et al*., 1999). In Brazil, pineapple is grown in most states and there has been a significant increase in production in recent years.

10.2. Climate, soil and plant

10.2.1. Climate

The pineapple, a tropical plant, grows best and produces better quality fruit at temperatures ranging from 22 to 32ºC and with a daily amplitude of 8 to 14ºC. In temperatures above 32ºC the plant grows less well and if associated with high solar radiation can burn the fruit during the maturation phase. Temperatures below 20ºC also result in diminished growth and favor the occurrence of premature flowering, which increases management problems and the loss of fruits (Bartholomew *et al.*, 2003). The plant is severely damaged by frost, but tolerates periods of low temperatures provided they are above 0ºC.

The plant grows best when annual exposure to the sun ranges from about 2,500 to 3,000 h, or 7 to 8 h of sunlight per day. There is a minimum demand of 1,200 to 1,500 h of sun. Shading affects the development of the plant, and this needs to be considered when choosing a site for its cultivation as a monocrop or in association with other crops (Reinhardt, 2001).

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Although cultivation at altitudes not exceeding 400 m is recommended, there are many production areas at higher altitudes. At higher altitudes, temperatures are lower and solar radiation less, and this in turn results in slower growth, a longer cycle and the production of smaller, more acidic fruit (Aubert *et al.*, 1973; Py *et al.*, 1987).

As pineapple is a short day plant (Van Overbeek, 1946; Gowing, 1961; Bartholomew *et al.*, 2003), natural flowering in the southern hemisphere occurs, for the most part, from June to August, when the days are shorter and night time temperatures are lower. Decreased sunlight due to clouds and water stress may sometimes trigger natural flower differentiation in other seasons, for example in autumn (April and May) and spring (October and November). Natural flowering occurs earlier in more developed plants and there are varietal differences, the cultivar 'Pérola' flowering earlier than 'Smooth Cayenne'.

Pineapple has a lower water requirement than the vast majority of cultivated plants. It has a series of morphological and physical characteristics typical of xerophile plants. It has the capacity to store water in the hypoderm of the leaves, to collect water efficiently, including dew, in its trough-shaped leaves, and to considerably reduce water loss (reduced transpiration) by several mechanisms.

Despite these adaptations to dry conditions, the greatest yields and the best quality fruits are obtained when the crop is well supplied with water. Well-distributed rainfall of 1,200 to 1,500 mm annually is adequate for the crop. In regions of prolonged drought, irrigation has often become indispensable. The pineapple's demand for water varies from 1.3 to 5.0 mm/day, depending on its state of development and on soil moisture. A commercial pineapple crop generally requires a quantity of water equivalent to a monthly precipitation of 60 to 150 mm (Almeida, 2001).

Relative air humidity averaging 70% or higher is optimal, but the plant can tolerate moderate variations. Periods of very low relative humidity (less than 50%) can cause fruit-splitting and cracking during the maturation phase. The low physical profile of the plant and the high planting densities used, reduce the crop's susceptibility to damage caused by strong winds. Hail can cause damage, but generally less than in other crops, because of the high fiber content and strength of the leaves.

10.2.2. Soil

Pineapple is very sensitive to saturation of the soil with water, which affects its growth and production. Consequently, good drainage and concomitant good aeration are basic requirements because they favor root development and reduce the risk of plant loss from fungal pathogens of the genus *Phytophthora*. The water table should be not less than 80 – 90 cm from the soil surface.

It is considered that an effective soil depth of between 80 and 100 cm will be adequate for growing pineapple because the roots tend to be concentrated in the top 15 to 20 cm of soil. However, within the effective soil depth, soil texture changes and/or abrupt increases in soil density inhibit root growth and prevent the roots growing deeper (Pinon, 1978; Py *et al*., 1987).

Soils of an intermediate texture (15-35% clay and more than 15% sand), without obstacles to the free drainage of excess water, are recommended most for this crop. Soils with a sandy texture (up to 15% clay and more than 70% sand), which generally have no drainage problems, are also recommended, but almost always, the incorporation of organic residues and manures is needed to increase their water-holding capacity and the retention of nutrients.

Clayey soils (more than 35% clay) that have good drainage, like many Oxisols, may also be recommended for pineapple plantations. On the other hand, silt soils (less than 35% clay and 15% sand) should be avoided. The large silt content causes undesirable soil structure characteristics, which affect aeration and drainage, and may negatively influence plant establishment and development (Pinon, 1978).

Land that is flat or has a slope not exceeding 5% is preferred because, in addition to facilitating mechanized cultural practices, the soil is less susceptible to erosion. Erosion can be a serious problem because the pineapple has a shallow root system and for a large part of the crop cycle there is little or no vegetative covering on the soil. Preventing soil erosion justifies considerable attention on the part of the grower. The utilization of more sloping land requires the adoption of conservation practices, like planting along contour lines.

Pineapple is well adapted to growing on acidic soils, a pH of 4.5 to 5.5 is recommended with slight variations depending on the variety grown (Bartholomew and Kadzimin, 1977; Pinon, 1978; Py *et al*., 1987). The plant tolerates a high exchangeable aluminum and manganese content in the soil, a condition favored on highly acidic soils. (Souza *et al*., 1986; Malézieux and Bartholomew, 2003).

An adequate ratio of exchangeable Ca/Mg should be close to 1.0 and even lower (Boyer, 1978). This means that the Mg content should be at least the same as that of Ca if not larger. This ratio is smaller than that recommended for other tropical species.

For many tropical and subtropical crops the optimal values for the ratio of exchangeable K/Mg in the soil are between 0.25 and 0.33 (Boyer, 1978). Py *et al*. (1987) stated that the ratio should not be greater than 1.0 i.e. K larger than Mg, because of the antagonism between these nutrients in root uptake. A decrease in the concentrations of Ca and Mg was observed in the 'D' leaf of cultivar 'Pérola' when given increasing amounts of K, indicating competition for uptake by these nutrients (Souza *et al*., 2002).

10.2.3. Plant

The pineapple (*Ananas comosus* L., Merrill) is a tropical plant, a monocotyledon and a herbaceous perennial, of the family Bromeliaceae, with about 50 genera and 2,000 known species. In addition to the fruit as a food, many species are grown for their leaf fibre from which bagging material is produced, and other species are grown as ornamentals (Collins, 1960; Cunha and Cabral, 1999).

The plant has a short, thick stem around which grow narrow, rigid trough-shaped leaves, and from which auxiliary roots develop. The root system is superficial and fibrous and generally grows no deeper than 30 cm and is rarely more than 60 cm from the soil surface. Adult plants of the commercial varieties measure 0.80 m to 1.20 m in height and 1.00 to 1.50 m in diameter (Kraus, 1948a; Coppens d'Eeckenbrugge and Leal, 2003).

The leaves are classified, according to their shape and their position on the plant, as A, B, C, D, E, F, from the oldest on the outside, to the youngest towards the centre (Fig. 10.1) (Krauss, 1948b, Py *et al*., 1987). The 'D' leaf, the youngest amongst the adult leaves and the most physiologically active, is used to evaluate the growth and nutritional state of the plant. It is the tallest leaf and grows at 45º to the soil surface and it presents its lower borders perpendicular to the base. The D leaf can be easily separated from the plant.

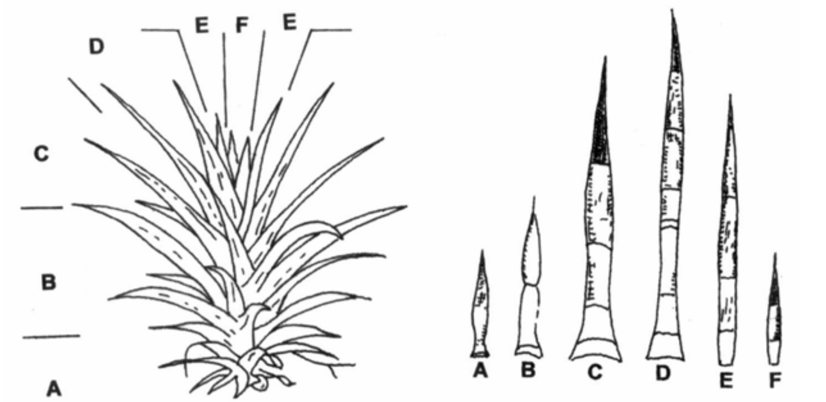

Fig. 10.1. Distribution of the pineapple plant leaves, according to age (A - oldest; F – youngest). (Py, 1969; Malavolta, 1982).

Inserted into the stem is the peduncle which supports the flowers and, later on, the sorosis type fruit (Okimoto, 1948). Plantlets develop from auxiliary buds located in the stem (suckers) and the peduncle (slips), which are most used as planting material (Reinhardt, 1998).

Pineapples can be grown once (a single cycle) or in one or more additional ratoon cycles. The cycles vary in duration, depending on the climatic conditions, the vigour of the plant material and the management of the cultivar. For example, and typical of pineapple cultivation worldwide, in the Brazilian Tropical Region, the first cycle lasts 14 to 18 months, whereas the ratoon cycles are shorter, often lasting only about 12 to 14 months (Reinhardt, 2000).

10.3. Soil and culture management

10.3.1. Soil preparation and liming

Careful preparation of the soil is important to guarantee good root development especially into the deeper soil layers. In virgin land, it is necessary to remove the vegetation by means of logging, removal of shrubs and branches, slashing and burning, followed by plowing and harrowing the soil in both directions to a minimum depth of 30 cm. In areas that have already been cultivated and there is no vegetation to remove it is only necessary to cultivate the soil as already described. Where pineapple has been grown previously it is essential to remove all crop residues, preferably by incorporating them into the soil, after partial decomposition. This helps to improve the physical and biological condition of the soil, because more than 50 mt/ha biomass will be incorporated into the soil.

Despite the recognition that pineapple is well adapted to growing on acidic soils, there are situations in which liming is necessary, principally when soil calcium and magnesium levels are low. Soil should be analysed to decide if it is necessary to apply limestone. The amount of lime applied should be such as to raise the soil to pH 4.5 to 5.5. Higher values can limit the availability of micro-nutrients (zinc, copper, iron and manganese) and favor the development of harmful microorganisms, like fungi of the genus *Phytophthora*, especially under wet conditions. If lime is required it should be applied 30 to 90 days prior to planting and incorporated by the plowing and/or harrowing used for soil preparation. It is preferable to use calcareous dolomite, because of the pineapple's requirement for magnesium.

10.3.2. Planting and weed control

The pineapple is planted into pits or shallow furrows to a depth not greater than one third the length of the plant, taking care to not let soil fall into the "eye" (leaf rosette) of the plant. Planting should be done in squares, the distance between plants depending on their type and size, to facilitate subsequent management (Cunha, 1999).

Planting densities vary according to the cultivar, product destination, level of mechanization, use of irrigation and other factors. High planting densities favor greater productivity, lower densities generally permit the production of a higher percentage of large fruits, which get higher prices in the market for fresh fruits. In Brazil the plant densities vary, in general, from 25 to 50 thousand/ha. Densities from 30 to 40 thousand/ha are more common, aiming to maintain a balance between fruit size and productivity. In other countries, where the "Smooth Cayenne" variety or its hybrids are grown, the densities can reach 86,000 plants/ha (Hepton, 2003), especially when the fruit is destined for canned fruit slices.

The plantation can be set up in a single or double row system. In Brazil the following spacings predominant: a) simple rows: 1.00 x 0.30 m (33,333 plants/ha), 0.90 x 0.30 m (37,030 plants/ha) and 0.80 x 0.30 m (41,660 plants/ha); b) double rows: 1.20 x 0.50 x 0.40 m (29,411 plants/ha), 1.00 x 0.40 x 0.40 m (35,714 plants/ha), 1.00 x 0.40 x 0.35 m (40,816 plants/ha), 1.00 x 0.40 x 0.30 (47,619 plants/ha) (Reinhardt, 2001).

For crops without irrigation, planting is usually at the end of the dry season and the beginning of the rainy season. Depending on the availability of planting material and local knowledge, planting can be done at other periods so that fruit production occurs when market conditions are more favorable. Irrigation makes it possible to plant and produce fruit during the whole year.

Because pineapple grows slowly and has a superficial root system, weed competition is very harmful especially when it occurs between planting and flower differentiation during the first five to six months after planting. In this period, the crop should be kept clean, but in the fruit formation phase the presence of weeds has practically no negative effect on production (Reinhardt and Cunha, 1984). Weed control is done in various ways, the most common ones being manual weeding and application of herbicides. Depending on climatic conditions and soil fertility, it may be necessary to weed manually up to twelve times during the crop cycle. During the initial establishment of the crop, it is possible to cut the weeds using cultivators pulled by animals. Another alternative, still little employed, is soil surface mulching. Depending on what is available on the farm or in the region, the dry straw of maize, beans and grasses, as well as pineapple plant residues and leaves, should be uniformly distributed over the soil surface, especially along the plant rows. In countries with high labor costs mechanical methods are used as is covering the soil between the rows with black polyethylene film (Reinhardt *et al.*, 1981). Weed control with herbicides is a good alternative to reduce the demand on manual labor, especially on large plantations and in rainy periods when weeds grow rapidly.

The most used herbicides belong to the uracil group (diuron, bromacil) while the triazines (ametryn, simazyn, atrazyn), are recommended for pre-emergence or early post-emergence application (Broadley *et al.*, 1993; Reinhardt, 2000).

10.3.3. Irrigation

Irrigation systems are usually drip and jets, and overhead sprinkle irrigation. Drip irrigation is used where the availability of water is limited, the cost of manual labor is high and cultivation techniques are advanced. In Hawaii, the drip irrigation system is commonly used along with polyethylene film to cover the soil along the planted rows in order to reduce evaporation. This system is generally characterized by high cost, because the density of plants requires a drip line for each double row of plants (Almeida, 2001).

Jet sprayers have the same efficiency and offers better opportunities for adaption to the crop than does drip irrigation, however it requires elevation of the emitter assembly to increase the effective area sprayed. As for drip irrigation, filtration of the water is not necessary.

Overhead spray irrigation is perhaps the best system considering the cup shape and the leaf arrangement on the plant. This facilitates the collection of water and its absorption is increased by the presence of external roots in the axil of the leaves. The systems most used are conventional spray, lateral row self-propelled, with linear (lateral boom) or radial movement (central pivot), self-propelled sprayers (with or without traction cables) and direct mounting (Almeida and Reinhardt, 1999).

In managing irrigation, especially in estimating the number and frequency of applications, it is necessary to consider the decrease in the effective rooting depth of the soil. In addition, it is important to use crop coefficients that reflect the various stages in the plant's growth. Initially growth is slow with a small ground cover and a coefficient of 0.4 to 0.6 should be used. This followed by a period of accelerated growth until about 70 to 80% of the ground surface is covered and the coefficients increase until they reach 1.0 to 1.2. With the maintenance of the ground cover and water demand until the start of the fruit's maturation phase, coefficients of 1.0 to 1.2 are used. Finally, in the final fruit maturation phase the water supply is reduced (decreasing coefficients from 1.0/1.2 to 0.4/0.6) with the aim of accumulating solutes and the quality of the fruit (Almeida and Reinhardt, 1999; Almeida, 2001).

10.3.4. Control of flowering

Flowering and harvest can be anticipated and coordinated by the application of growth regulators. Harvest should be planned to occur at the best time for selling and to avoid the concentration of on-farm operations (Cunha and Reinhardt, 1999).

Flowering can be induced by a number of compounds, the most common are calcium carbide and 2-chloroethylphosphonic acid (ethephon). Calcium carbide can be applied in granular or liquid form. As granules, 0.5 to 1.0 g/plant are put into the center of the leaf rosette during a wet or rainy period. In the presence of water, acetylene is produced from the calcium carbide and this initiates flowering. The liquid form can be used in dry season, the calcium carbide is diluted in water (4 to 5 g/L), in a tightly closed container, applying about 50 ml of solution to the center of each leaf rosette (Reinhardt *et al.*, 2001).

Ethephon is a liquid that releases the gas ethylene, the primary hormone responsible for flower differentiation in the pineapple. Ethephon can be applied in the center of the rosette or sprayed over the whole plant, using 50 ml/plant of a solution prepared with 0.5 to 2 ml/L water of the commercial product Ethrel (24% active ingredient) or a similar product. The increase in the pH of the solution, which is very low (3.0 to 3.5), due to the addition of calcium hydroxide (0.35 g/L), increases the release of ethylene. A 1 to 2% aqueous solution of urea stimulates the penetration of ethylene into the plant's tissues (Cunha, 1999).

The floral induction treatment is more effective if done at night or during cooler periods of the day (e.g. early morning or the end of the afternoon), preferably on cloudy days. This is because at these times the leaf stomata are open, increasing the absorption of the chemical.

Floral induction should only be performed on strong and well-developed plants, capable of producing fruits of appropriate size for sale and/or plantlets for use in new plantings. Fruit weight is directly related to plant vigor at the time of floral differentiation, although it also depends on the climatic conditions during its development. In the 'Pérola' variety, it is recommended to induce flowering in plants that have 'D' leaves with a minimum fresh weight of 80 g and a minimum length of 1.0 m, in order to get fruits weighing more than 1.5 kg (Reinhardt *et al.*, 1987).

10.4. Mineral nutrition

10.4.1. Uptake and export of nutrients

The pineapple has a large demand for plant nutrients and the amounts required often exceed those which the majority of cultivated soils can supply. For this reason, fertilization is almost mandatory where the fruit is destined for sale. Table 10.1 summarizes data from diverse authors concerning the quantity of macro-nutrients extracted from the soil by the pineapple plant.

The data in Table 10.1 indicate the following decreasing order of uptake. For macro-nutrients: K>N>Ca>Mg>S>P. The amounts, per hectare, are on average, 178 kg N, 21 kg P (48 kg P_2O_5) and 445 kg K (536 kg K_2O), with an average extraction ratio of 1.0:0.12:2.5, for N:P:K and 1.0:0.27:3.0, for $N:P_2O_5:K_2O$.

Table 10.1. Extraction of macro-nutrients by the pineapple crop (kg/ha, according to various authors).

Source	N	P	K	Ca	Mg	S
	------------------------- kg/ha -------------------------					
Stewart, Thomas & Horner	67	8	198			
Kraus	350	53	939	175		
Follett-Smith & Bourne	107	38	346	81	45	
Boname	83	12	363			
Cowie	123	15	256			
Choudhury	308	30	730			
Menon & Pandalai	139	20	243			
Menon & Pandalai	110	13	229			
Menon & Pandalai	74	30	325			
Hiroce *et al*.	355	32	509	236	115	40
França	106	10	243			
França	60	8	151			
Paula *et al*.	315	14	1,257	252	157	17
Paula *et al*.	300	14	444	161	33	35

Source: Teiwes and Gruneberg, 1963; França, 1976; Hiroce, 1982; Paula *et al*., 1985.

Table 10.2 summarizes some data referring to the extraction/accumulation of micro-nutrients by pineapple, which indicates the following decreasing order of uptake: Mn>Fe>Zn>B>Cu>Mo.

Nutrient off take is mainly in the fruits. Py *et al*. (1987) estimated the following quantities of nutrients are removed per tonne of fruit: 0.75 to 0.80 kg N, 0.15 kg P_2O_5, 2.00 to 2.60 kg K_2O, 0.15 to 0.20 kg CaO and 0.13 to 0.18 kg MgO. Based on these numbers, a harvest of 40 tons of fruit/ha results in the following export of nutrients per ha: 30 to 32 kg N, 6 kg P_2O_5/ha, 80 to 104 kg K_2O, 6 to 8 kg CaO and 5.2 to 7.2 MgO kg.

Table 10.2. Accumulation of micro-nutrients by the pineapple plant (g/ha, according to various authors).

Source	Zn	Cu	B	Fe	Mn	Mo	Observations
	----------------------- g/ha -----------------------						
Hiroce *et al.* (1977)	404	191	311	5,095	2,456	5	50,000 plants/ha, cv. S.Cayenne
Paula *et al*. (1985)	337	169	267	4,020	7,308		50,000 plants, cv. Pérola
Paula *et al*. (1985)	225	197	–	4,793	6,351		50,000 plants, cv. S. Cayenne

Nutrients are also exported in propagating material (crowns, slips and suckers) destined for planting in another area, and, less frequently, in plant residues removed from the field and used for other purposes like animal feeding.

10.4.2. Functions and importance of macro-nutrients

Nitrogen (N): Nitrogen, is required second after potassium by pineapple. Nitrogen mostly determines the productivity of the plant. The absence of N in either organic or mineral form, almost always results in compromised development and/or productivity of the plant, with the appearance of typical symptoms of N deficiency.

Deficiency symptoms (Plate 10.1) are characterized by greenish-yellow to yellow foliage, small and narrow leaves, a weak plant with slow growth, small and colorful fruit with a small crown and the absence of plantlets. Such symptoms are common on soils poor in organic matter, without fertilization and under hot and sunny conditions (Py *et al*., 1987).

In respect of fruit quality, studies conducted in several countries have shown reductions in juice acidity as the amount of N applied increases. Teisson *et al.* (1979), besides referring to the reduction of juice acidity with increases in N supply, also observed a decrease in juice ascorbic acid, and as a result an increase in internal darkening of the fruit. This symptom is often seen in long cycle crops.

Increasing levels of N can result either in a reduction of the Brix value or no significant changes in fruit sugar content. An excess of N also contributes to a reduction in fruit pulp firmness and an increase in translucency and, in hot periods, can also increase the risk of the appearance of a symptom known as "jaune" (ripening of the pulp, while the skin of the fruit remains green), according to Py *et al*. (1987).

The most common sources for N for the pineapple crop are urea and ammonium sulfate. Other sources of N, such as potassium nitrate and ammonium nitrate, as well as organic fertilizers (animal manure, plant cakes, compost and others) can also be used depending on their economic viability.

Phosphorus (P): Although there is a relatively small demand for P (the macro-nutrient accumulated in the smallest quantity) increases in productivity have been observed, in Brazil as well as in other countries (Malaysia, Guadeloupe and India, for example). This is certainly due to the low availability of P in most soils growing this crop.

According to Py *et al*. (1987), the symptoms of P deficiency include dark, bluish-green foliage, which is more pronounced in the presence of excess N, and leaves that completely dry out at the tips, starting from the older ones. The old leaves have dry, brownish-red tips and brown transverse striations and the borders of these leaves turn yellow from the tips. Plants suffering from P deficiency also have more erect, long and narrow leaves and roots with longer, more colored and less ramified hairs; the fruit is small and reddish in color. Such symptoms rarely occur, but they may appear more or less temporarily, especially in periods of drought, in poor soils or where the deeper soil horizons were exposed during soil preparation.

Malézieux and Bartholomew (2003) pointed out that P deficiency causes a reduction in the growth of all parts of the plant. They called attention to the fact that visual deficiency symptoms are often not seen and are not very specific, and hence could be mistaken for symptoms resulting from damage to the root system caused by water deficiency, nematodes or pests. Little importance has been given to P nutrition in relation to the quality characteristics of the fruit.

The main sources of P are fertilizers soluble in water, such as triple superphosphate (TSP), monoammonium phosphate (MAP), diammonium phosphate (DAP) and single superphosphate (SSP). The latter contains also sulfur (10-12% S). Magnesium thermophosphates (17% P_2O_5) have also been used as sources of P and magnesium (9% Mg).

Potassium (K): Potassium, the nutrient that accumulates in the largest amount in the plant, also influences productivity, although to a lesser extent than that of N. The large demand for K often results in the symptoms of K deficiency, especially in soils with low K availability.

Such deficiency symptoms (Plate 10.2) are mainly characterized by leaves with small yellow spots, which increase in size, multiply and coalesce around the leaf borders, which dry out. The plant has a more erect stature, a weak fruit peduncle, small fruit with low acidity and less aroma. These symptoms are common except in soils rich in K. The symptoms are favored by unbalanced fertilization, especially with N, strong solar irradiation, intensive soil lixivation and soils with high pH, rich in Ca and Mg (Py *et al*., 1987).

Potassium has a significant effect on fruit quality. Experimental studies have shown that increasing the amount of K increases the acidity of the pulp and/or sugar content, improves aroma, increases peduncle diameter (contributing to reduced fruit drop) and improves pulp firmness. Teisson *et al*. (1979) ascribed the benefit of increasing amounts of K to an increase in ascorbic acid in the fruit pulp and, in consequence contributing to a reduction of internal fruit darkening.

Potassium can be applied as KCl, potassium sulfate (K_2SO_4), potassium and magnesium bisulfate (20% K_2O) and potassium nitrate (44% KNO_3).

Calcium (Ca): Py *et al*. (1987) described the following symptoms of Ca deficiency in the pineapple plant: very small, short, narrow and breakable leaves and very short internode spacing. In a controlled environment Ca deficiency led to the death of the apex, with the development of lateral shoots, which have similar symptoms. Calcium deficiency occurs rarely, except in very poor soils.

Calcareous rocks are the most common sources of calcium. When raising soil pH is not required, agricultural gypsum (17 to 20% Ca) as well as single superphosphate (18 to 20% Ca) are good options. Calcium nitrate (17 to 20% Ca) can also be considered, when applied in liquid form (Souza, 2004).

Magnesium (Mg): Plants with Mg deficiency have yellow old leaves, except where shaded by younger leaves when they stay green (Plate 10.3); yellow spots which turn brown in a controlled environment; drying of older leaves, which have not finished growing before the deficiency appears; fruits without acidity, low in sugar content and without any flavor. Such deficiencies are very common on soils low in Mg, especially when intensely fertilized with K under conditions of high solar irradiation (Py *et al*., 1987).

Calcareous dolomites are, in principle, the source of Mg for the pineapple crop. When deficiency symptoms appear after the application of calcareous materials, or after the establishment of the crop, magnesium sulfate is an alternative for supplying Mg. This product can be applied in solid or liquid (spray) form, but its compatibility with other minerals should be verified, if mixtures are used. For foliar sprays the concentration of magnesium sulfate in the solutions can vary between 0.5% and 2.5%. Magnesium thermophosphates (around 9% Mg), used as a source of P also supply Mg.

Sulfur (S): Py *et al*. (1987) described the following symptoms associated with a deficiency of sulfur: pale yellow to gold colored foliage; pinkish leaf borders, especially on older leaves; normal plant stature; very small fruit. However, both Py *et al*. (1987), as well as Malézieux and Bartholomew (2003) considered the occurrence of such symptoms very rare in pineapples. Sulfur supply is normally done by fertilizers that are at the same time sources of some of the primary macro-nutrients, like ammonium sulfate (23 to 24% S), potassium sulfate (17 to 18% S) and single superphosphate (10 to 12% S). In selecting which fertilizer to use, it is important to be certain of the amount of S they contain. This is especially so where the crop is intensely cultivated and on soils poor in organic matter, in order to prevent possible S deficiency.

10.4.3. Functions and importance of micro-nutrients

According to Su (1975), the micro-nutrients that are most important for pineapples in many parts of the world, are iron (Fe), zinc (Zn), copper (Cu) and boron (B).

Normally, soils with little organic matter and available nutrients that have been exhausted by intensive cropping, or those with high pH (above 6.5) are likely to be also short of micro-nutrients and they require special attention in relation to micro-nutrients.

Py *et al.* (1987) described the following symptoms of micro-nutrient deficiency for pineapple.

Boron (B): A number of symptoms in different situations are attributed to boron. These include: orange and yellow discoloration, which becomes brown on only one side of the leaf; minimum leaf growth to two thirds of its normal length and with dry tips; a tendency for the leaf to curl, especially when grown hydroponically (Ivory Coast); chlorosis of the young leaves with reddening of the dead borders at the apex, especially when grown hydroponically (Malaysia); fruits with multiple crowns (Hawaii, Martinique); formation of a dead suberized tissue between fruitlets, at times accompanied by very small, spherical fruits (Australia, Martinique). These symptoms often appear on soils with a high pH, and when due to drought there is little B in the soil solution.

Copper (Cu): Light green narrow leaves with wavy borders, a pronounced U shape in cross-section and a small number of tricomes; leaf tips curved downward; old leaves with purple-red coloration at the fold; short roots with reduced hairs; stunted plant. These symptoms are relatively common, but their descriptions are often imprecise (Plate 10.4).

Iron (Fe): Development of chlorosis, starting in young leaves; the leaves are generally flaccid, wide, and yellow with a green 'web' of conductor veins. The old leaves are dry and when sprayed with large amounts of iron the leaves have green transverse lines. The fruit is red with a chlorotic crown. Symptoms can appear when large quantities of nitrate have been added. Iron deficiency can occur under a range of conditions, for example, on soil with high pH, soils rich in manganese (Mn/Fe = 2), compacted soils, areas of termite infestation and attack by pests both of which rapidly decrease root activity, drought, as well as other factors (Plate 10.5).

Manganese (Mn): The symptoms are not very well defined; the damaged leaves are marbled with light green areas, especially where the veins are situated, surrounding areas with a darker green color. Manganese deficiency is rare, but may occur on soils rich in Ca and with a high pH.

Molybdenum (Mo): Deficiency is likely in soils with pH <4, but there are few descriptions of the symptoms associated with Mo deficiency (Py *et al*., 1987; Malézieux and Bartholomew, 2003). An excess of nitrate in the fruit can affect the quality of canned pineapple products (Chairidchai, 2000; Chongpraditnun *et al*., 2000). As molybdenum is a component of the enzyme nitrate reductase, these authors studied the influence of applying Mo on the concentration of nitrate in the fruit. The concentration of Mo in the 'D' leaf was associated with a decrease in the nitrate in the fruit.

Zinc (Zn): In young plants, the center of the leaf rosette is closed, the young leaves are rigid, cracked and sometimes curved ("crook-neck"). In old plants, the basal leaves contain irregular veins, with the appearance of marble, and orange-yellow discoloration on the leaf borders and the tips are dry. Frequent attacks of the pest *Diaspis* result in these characteristic symptoms. Zinc deficiency tends to be rare, except in soils with high pH, due to excessive limestone applications, or where Ca and P have been poorly incorporated.

In conclusion, the following applications of micro-nutrients, in kg/ha, are recommended where deficiencies are seen. 1 to 5 kg Fe; 1 to 6 kg Zn; 1 to 10 kg Cu; 1 to 2.5 kg Mn; and 0.3 to 2 kg B. These micro-nutrients can be applied as solutions of their salts, e.g. $FeSO_4,7H_2O$ (20% Fe), $ZnSO_4.7H_2O$ (22% Zn), $CuSO_4.5H_2O$ (24% Cu), copper oxychlorate (35 to 50% Cu), $MnSO_4,4H_2O$ (25% Mn) and borax (11.3% B). These micro-nutrients can also be applied to the soil as solids, often as oxides and frits (synthesized silicates) of the respective elements. In the case of metallic micro-nutrients there is also the option of using their respective chelates, which can be applied as solids or liquids.

10.4.4. Evaluation of the nutritional status of the plant

The nutritional status of the plant can be done by analysis of the 'D' leaf (Fig. 10.1), as it is considered the one which best represents the nutritional state of the plant (see the section "The plant and its life cycle"). The "D" leaf is identified by gathering all the leaves in the hands to form a vertical "bundle" in the center of the plant. The "D" leaves are the longest ones. Leaf sampling can be done at any point in the vegetative cycle, i.e. from the fourth month after planting until the induction of flowering, at intervals of two to four months between samplings, although within ± 15 days of floral induction has been adopted as the best time for leaf sampling.

When sampling a commercial crop it is recommended to take at least 25 leaves, from each area of uniform crop, collecting one leaf per plant. The leaves should be pre-dried in the shade in a well-ventilated area before being cut into smaller pieces to send to the laboratory. For the analyses, the intermediate third of the non-chlorophyll portion (white) of the basal zone (Hawaiian technique) or the whole leaf (French technique) can be used. Table 10.3 summarizes information from different authors/institutions on the interpretation of the results of leaf analysis.

Table 10.3. Adequate concentrations of nutrients in the 'D' leaf of the pineapple plant, according to different authors/institutions.

Source	Dalldorf and Langenegger	IRFA	Pinon	Malavolta	Malavolta
Sample	--------------------- Whole "D" leaf ---------------------				Third middle part of the basal white portion of "D" leaf at 5 months
Timing	At the emergence of flowering	At the moment of flower induction	Along the cycle	At 4 months	
Nutrient					
Macro-nutrient	----------------------------------- g/kg -----------------------------------				
N	15-17	>12	13-15	15-17	20-22
P	±1.0	>0.8	1.3	2.3-2.5	2.1-2.3
K	22-30	>28	35	39-57	25-27
Ca	8 to 12	>1.0	1.4	5-7	3.5-4.0
Mg	±3.0	>1.8	1.8-2.5	1.8-2.0	4.0-4.5
Micro-nutrient	---------------------------------- mg/kg ----------------------------------				
Zn	±10			17-39	
Cu	±8			5-17	9-12
Mn	50-200			90-100	
Fe	100-200			600-1,000	
B	30				

Sources: Pinon, 1981; Malavolta, 1982; Lacoeuilhe, 1984.

10.5. Fertilization

The large nutrient demand of the pineapple means that fertilization is a common practice. Besides the nutritional requirements of the plant and the capacity of the soil to supply nutrients, specific recommendations for each area or producing region should take into account the following factors, which vary from region to region. These factors include the level of technology adopted and implemented, the destination and the value of the product and the cost of fertilizers. In spite of the variations that can occur because of these factors, in many pineapple producing countries, including Brazil, the recommendations per plant vary, in the majority of situations, from 6 to 10 g N, 1 to 4 g P_2O_5 and 4 to 15 g K_2O. However, decisions about the amount of each nutrient to apply that do not consider data from soil and/or plant analyses, could lead to gross errors that affect productivity, fruit quality and, consequently, economic returns. Souza *et al.* (2001) gave recommendations for an irrigated pineapple crop, based on results of soil analyses (Table 10.4).

Table 10.4. Fertilizer recommendations for an irrigated pineapple crop in semi-arid regions, results based on soil analysis.

	N	Soil phosphorus Mehlich (mg P/dm^3)			Soil potassium Mehlich (mg K/dm^3)			
		<5	6-10	11-15	<30	31-60	61-90	91-120
	kg/ha	------- P_2O_5 (kg/ha) ------			------------ K_2O (kg/ha) -------------			
After planting								
1st to 2nd month	60	120	80	40	90	75	60	45
4th to 5th month	80	-	-	-	120	100	80	60
6th to 7th month	90	-	-	-	135	110	90	75
8th to 9th month	90	-	-	-	135	115	90	60

Complementary information:

Planting densities: The recommended doses in the table presume there are planting densities of around 40,000 plants/ha (cv. Pérola). For densities of around 50,000 plants/ha, recommended for the cv. Smooth Cayenne, the doses should be increased by 25%.

Phosphate fertilization: If convenient for the producer, this could be done at the time of planting, in the pits or ridges.

Liquid fertilization: Having the option of fertilizing through liquids, to supply nitrogen and potassium, should be promoted a larger partitioning of the fertilizers (monthly or bi-weekly intervals). Liquid fertilization is also recommended for supplemental applications of magnesium and of micro-nutrients.

Induction of flowering: Ninth or tenth month after planting.

Source: Souza *et al.*, 2001.

10.5.1. Method of fertilizer application

Fertilizers can be applied either as solids or liquids. Applied as solids, fertilizers can be applied into the planting pits or furrows (the option most used for organic phosphate applications) or as a side dressing, the fertilizer being directed to the bases of the oldest leaves (the option most used for N and K fertilizers, but also used for water-soluble P fertilizers).

Application of solid fertilizers is done by hand, using simple tools like spoons. Irrespective of the method of application used, fertilizers should not be allowed to fall into the upper youngest leaves or into the "eye" of the plant, because of the damage they may cause. After the applying fertilizers to the soil surface, they should be covered with soil from the space between rows. This practice helps reduce the loss of nutrients and in fixing the plant in the soil.

Liquid fertilizers are applied to the leaves as a foliar spray. The architecture of the plant and the morphological and anatomical characteristics of its leaves favors foliar absorption of nutrients. This method of application, which is widely adopted by some producers, is frequently used to apply N, P, Mg and micro-nutrients, it is rarely used for the application of P. Foliar application is done using spray booms attached to backpacks or tractor mounted tanks.

Spraying should not be done in the hottest hours of the day to prevent leaf burning and excessive run-off and accumulation of solutions in the leaf axes should be avoided. Generally, the concentration of fertilizers in the solution should not exceed 10%, and in large plantations it is normal to spray at night. Another precaution that should be taken, when applying several fertilizers by foliar spray, is to verify the compatibility of the products being used.

Fertigation can be successful when used with overhead spray irrigation or with high frequency localized irrigation. Nitrogen is most often applied with irrigation, followed by K. Calcium, Mg, S and micro-nutrients may also be applied by fertigation. Fertigation with P is not common; P fertilizers are usually applied only once as a solid before planting. They are put in the planting pits or furrows, or as a soil cover, within 30 to 60 days after planting. There is, however, an option for applying P with the irrigation water, using diammonium phosphate (DAP, 45% P_2O_5), monoammonium phosphate (MAP, 48% P_2O_5) and phosphoric acid (40 or 52% P_2O_5).

Souza and Almeida (2002) presented two alternatives for applying N and K by fertigation. Either they can be applied at increasing amounts of N and K at equal intervals of time or in equal amounts of N and K at decreasing intervals of time. In these alternatives the total amount to be applied is given in 16 applications.

10.5.2. Timing of fertilization

Fertilization should be done during the vegetative phase of the plant's life cycle, i.e. from the planting until the induction of flowering. This is the period in which the plant uses the applied nutrients most efficiently. For crops grown without irrigation and when solid fertilizers are used, the timing of the application should take into account the distribution of the regional rains such that the application coincides with good soil moisture.

In general, applying nutrients during the reproductive phase of the plant is not recommended because there is usually little positive effect. However, there are special situations, as in the case of a malnourished plant at flower initiation, when the application of nutrients can result in positive effects on the weight and/or quality of the fruit. In these circumstances liquid fertilizers should be used until 60 days after induction of flowering.

10.6. References

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