Some relationships between soil and nutrient requirements and nutrient supply of pepper (*Capsicum annuum* L.) with respect to types grown in Hungary

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Summary: Exports and local marketability of both pepper protected cultivation and open field pepper production depend on whether we succeed in the near future achieving developments capable of bringing about significant improvement of yield and quality, as well as enhanced yield security. Results from experiments and surveys carried out on farms involved in production suggest that nutrient management is one of the factors whose development could considerably improve the marketability of pepper. Technological improvements in the field of nutrient supply are also urged by the more and more demanding environmental regulations, so it is inevitable to introduce a balanced system of nutrient supply system for pepper as well. The article is a collection and summary of the relevant results of 30-year experimental work in Hungary.

Key words: pepper, paprika, nutrient requirements, soil requirements, reasonable nutrient management, yield security, yield quality

Introduction

Bell pepper in today's sense is said to become common in Hungary around the end of the 19th century, the first growers were Bulgarian horticulturists settled in the southern part of the country. While the open air growing area of bell pepper had risen to approximately 10–12 thousand hectares by the end of the 1970s, in the early 1990s, a sharp decline began and now the total growing area is just over 4 thousand hectares. Hungary is situated on the north-east border of the open field production of bell pepper, therefore cultivation involves risks and as a matter of fact, market requirements can really be met only by cultivation under covered structures, i.e. forcing. Growing area of the latter has shown an increase over the last 10–15 years, constituting more than 50% of the total forcing area assigned to vegetables (2200–2300 ha). Currently, it is the fresh vegetable exported in the largest quantity, with annually figures exceeding 40 thousand tons (*Balázs et al.*, 2003).

Spice pepper production has a longer history, being a home spice for almost 300 years, a commercial article in Hungary for 160 years and an export good for 100 years. Its excellent flavour, aroma and pigment content are due to the rich and rapidly warming soils, as well as to the favourable climatic conditions. Its growing area has suffered a sharp decline as compared to that of the 70s exceeding 12–13 thousand hectares, and for the last years has not surpassed 6–7 thousand hectares including small gardens and small farms producing for home consumption. Annually, 50–60 thousand tons of fresh fruit, i.e. 8–10 thousand tons of pepper powder is produced, half of which goes for exports (*Hungarian Fruit and Vegetable Board*, 2003).

Pepper, regarded as a *Hungaricum*, will only be able to keep its inland and export markets if we manage to achieve considerable improvements in yield security and yield levels by means of developing an up to date production technology, which requires the nutrient management, relying on the nutrient and soil requirements of bell pepper, to be founded on a new basis and to be modernised. Related to this subject, a number of new research results and developments have come to light during the last decades, which have been introduced into production partially only.

Nutrient requirements of pepper

Nutrient requirements and nutrient uptake of the Hungarian pepper varieties were first closely studied on a scientific basis by *Horváth & Bujk* (1934), though pepper growers had already acquired a lot of experience in manuring as a crop of high nutrient demand. This attribute being interpreted broadly, is less associated with the amount of chemical elements built in the fruits and foliage, but refers to nutrient supply in general and soil conditions, expressing that pepper should be grown on nutrient rich soils having a good structure, because poor soil conditions diminish yields more drastically than in other vegetable crops (*Terbe*, 2003).

Chemical composition of the plant organs of bell pepper

Herbaceous plants, depending on age and environmental conditions, are composed of 80% water and approximately 20% dry matter. Although chemical composition of pepper, like that of other plants, changes slightly with the cultivation conditions and variety, in general, it is stated that nearly 30% of the dry matter is crude fibre, 12% protein, almost 50% N-free extracts, 4% fat and 6% ash. The ash contains mainly potassium, 42% referred to the whole plant, 24% oxygen, 5% phosphorous and calcium, 4% sulphur and a significant amount, 7%, chlorine and silicon. The so-called micro-elements constitute approximately 1% (*Loch et al.*, 1993).

Fruits contain substantially more water, 87–93%, but the rate of the single chemical compounds are also different from those of vegetative parts: 0.7–1.5% protein, 0.2–0.6% fat, 0.5–0.7% ash (*Lásztity*, 1990).

Experiments and observations under open field and forcing conditions going on for several years have shown that nutrient levels in the different organs of the optimally developing pepper plant are different for the three main macro elements. For phosphorous and potassium the lowest values were registered in the roots, the nutrient levels of the foliage for all three elements could be considered high as compared to the other organs (*Terbe*, 1985/a). The roots and the stems showed substantially the same average values in the experiments *(Table 1)*.

Nutrient composition of the plant organs of bell pepper, as influenced by the different environmental conditions first and mainly as a result of different nutrient supplies, vary significantly. N, P and K levels registered in the different organs were considerably influenced by the actual nutrient levels of the soil, though to varying degrees for the individual parts. The lowest fluctuation was registered in the fruit. As for the nutrients, it was the N content of the fruit that ranged between the narrowest limits (28%) and the K content that showed the highest differences (50%) (Somos et al., 1975/a). The results of the experiments indicate that even if the plants are markedly deficient in nutrients, the fruits are supplied adequately and more or less constantly with nutrients. Therefore, fruit nutrient contents should not be relied on in assessing the nutrient content of the plant or that of the soil, while they constitute the basis for estimating the amounts of nutrients removed from the soil by the fruits.

Nutrient contents of the foliage, as opposed to the fruits, respond sensitively to the single soil characteristics. Variations in the heaviness of soil texture, with identical nutrient levels, showed differences of varying degrees in experiments using growing pots *(Table 2)*. As the nutrient- and water-absorption capacity of the soil increased the nutrient content of the foliage diminished proportionally (*Somos et al.*, 1975/a).

The nutrient content of the foliage reflected very well the nutrient level of the root medium in the experiments for the investigation of deficiency symptoms on peat, perlit, washed sand and gravel. In the lower leaves the values registered for the three main macro elements were characteristic of the composition of the nutrient solution, while the younger leaves exhibited more even and higher nutrient contents. As regards microelements, results showed a greater deviation, the nutrient content of the younger leaves giving better indication on the nutrient level of the root medium in these treatments (*Terbe*, 1977/a). While nutrient levels in the fruits provide useful values for calculating nutrient requirements, the nutrient content of the leaves provides information on the actual nutrient supply of the bell pepper plant (*Terbe*, 1993/a).

Table 1 Nutrient contents in the different organs of pepper during fruit development
(Variety: Cecei édes)

Plant organ	Extremes of nutrient content mg/g dry matter as			Average nutrient content % of dry matter		
	N	P	K	N	P	K
Root	18.3 –34.2	2.2 –4.2	9.9 –26.9	2.4	0.25	1.4
Stem	7.7 –29.3	1.4 –3.7	10.8 –45.2	2.0	0.25	1.6
Leaf	16.9 –46.0	2.0 –7.3	26.2 –59.2	3.0	0.40	4.1
Fruit	23.3 –29.9	4.2 –5.6	19.0 –31.8	2.7	0.50	2.5

(Terbe, 1985)

Table 2 Influence of the root medium on the foliar nutrient content of spice pepper
(Variety: Kalocsai E-15)

Root medium	Nutrient content of pepper leaves (mg/g dry matter)		
	N	P	K
Gravel	38.6	5.1	37.5
Sand	30.8	3.5	29.3
Loam	25.6	2.8	8.7

(Terbe 1985)

Table 3 Nutrient uptake of bell pepper in function of yields

Yields kg/m^2	Total green weight kg/m^2	N	P	K	Ca	Mg
		kg/m^2				
4	5.8	15	3.9	19.3	14.0	2.5
5	6.9	18	4.3	22.9	16.8	3.0
6	8.0	21	5.0	27.7	19.6	3.5
7	9.1	24	5.7	32.5	22.4	4.1
8	10.2	28	6.4	38.5	25.2	4.8

(Geissler, 1985)

Specific nutrient requirements of bell pepper

Since 1978, fertiliser advice for the field crops, and since 1981, that for the vegetables have been planned, in Hungary. It has been based on the specific nutrient requirements of the yield, i.e. from the amount of the nutrients removed from the soil by the main and the byproducts (*Buzás*, 2004). The defect of the system is the complete ignorance of the fact that specific nutrient requirements, even if in a lesser degree than the nutrient composition of the foliage, are influenced by environmental factors and mainly by the volume of yield (*Terbe*, 2002/a).

Geissler et al. (1985) demonstrated that in blocky varieties the relative amount of nutrients removed by the fruits picked diminished with increasing yields. The decrease of the relative amounts is related to the reduction of dry matter content associated with the higher yields and with the decrease in the relative mass of foliage necessary for producing the respective yield *(Table 3)*. Probably, besides the different methods for the calculation of by-products, the different yield levels constitute one of the reasons for the considerable variation in specific nutrient values in the literature *(Table 4)*.

Considering the data from the home literature and calculations, as well as research results, fertiliser recommendations for bell pepper and spice pepper, all utilise the specific nutrient requirement figures listed in *Table 5*. (*Terbe*, 1999/a):

For the reasons already mentioned above, an improved fertiliser advising system calculated on the basis of yield-related specific nutrient requirements is being worked out relative to the major vegetable crops, such as bell pepper, under the coordination of the Vegetable and Mushroom Growing Department of the Budapest University of Economic Sciences and Public Administration and the Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences.

Investigations also have been aimed to reveal the influence of particular pesticides and herbicides on the nutrient composition of bell pepper. In experiments using growing pots, clear differences were shown as a result of the pesticides applied through the roots and leaves, where the pesticides caused the most concentration increases in zinc and manganese among the nutrients in the leaves (*Pankotai & Terbe*, 1987).

Dynamics of nutrient uptake in bell pepper plants

Nutrient requirements change not only with the variety, yield and environmental factors, but they are also influenced very much by the age of the plant. Regarding phosphorous, after germination and during flowering, plants accumulate a relatively great quantity compared to plant weight (*Mécs*, 1974; *Debreczeni*, 1979). Early phosphorous accumulation of pepper, i.e. increased phosphorous uptake, compared to plant foliage weight in seedling age, has been confirmed by several researchers (*Buda* et al., 1993; *Tóth* et al., 2002; *Glits* et al., 2000). In production, the practice does not pay enough attention to the increased phosphorous demand and does not take into account the factors interfering with phosphorous uptake in seedling age, e.g. low soil temperature (*Terbe*, 1978) and the particularly great phosphorous absorption capacity of peat (*Terbe*, 1979), with the consequence that latent phosphorous deficiencies, as well as acute ones, are very frequent in young plants (*Terbe*, 2001).

The dynamics of nitrogen uptake has a different pattern, being the most intensive in the period of growing foliage and at the beginning of fruit development (*Somos*, 1981). Potassium uptake, generally, follows the pattern of nitrogen uptake, but sharply declines at the end of the growing period (*Loch* et al., 1993). Some minor peaks in potassium uptake are caused by the intensive growth of lateral shoots (*Slezák* et al., 2002/a). The dynamics of nutrient uptake resulting on the one hand from the natural growth of the plant and on the other hand, from the cultivation technology applied, have practical importance in preparing fertilisation schedules and selecting nutrient ratios (*Szöri* et al., 2002/a).

Table 4 Specific nutrient requirements of bell pepper in function of variety and yield (based on the data from the literature)

Yield t/ha	N	P_2O_5	K_2O
	kg/t		
Below 10	6.0 –12.6	4.0 –6.8	4.8 –17.7
Blocky types above 50	2.4 – 4.6	0.5 –0.9	3.4 – 6.1
Conical varieties above 50	2.4 – 3.5	0.4 –0.8	3.3 – 4.8

(Terbe 2004)

Table 5 Specific nutrient requirements of pepper

Types	Nutrients	kg/t
bell pepper	nitrogen (N)	2.4 kg/t
	phosphorous (P_2O_5)	0.9 kg/t
	potassium (K_2O)	3.5 kg/t
spice pepper	nitrogen (N)	4.8 kg
	phosphorous (P_2O_5)	1.6 kg/t
	potassium (K_2O)	6.5 kg/t

(Náhlik, 1981)

Nutrient deficiency symptoms on bell pepper

Signs of defective growth resulting from different nutrient deficiencies are very often encountered among the physiological diseases shown by bell peppers both under forcing and open field conditions. In the majority of the cases, especially under forcing conditions, these phenomena are not to be ascribed to low nutrient supply, but are the effect of the factors interfering with nutrient uptake (*Terbe* in *Patócs*, 1989).

Nitrogen deficiency is often encountered in production, occurring even in soil-less culture, the most intensive form of forcing. The first symptoms are manifested in the chlorosis of the lower leaves and the reduced growth rate of shoots *(Fig 1)*. As a result of continued deficiency, bell pepper fruits will become elongated and their walls remain thin, the chlorosis will spread from lower leaves to middle and then to younger ones while necrotic spots will appear on older leaves (*Terbe* 2002/b). The plant is characterised by a so-called erect posture, with leaf stems running almost parallel to the shoot. Nitrogen content in the leaves of the plants with signs of N deficiency diminishes to less than 1.7–2.0%. The roots of the plants suffering from nitrogen deficiency are thin, showing less branching and having an elongated form. Excessive nitrogen application, if coupled with sufficient moisture, results in strong foliage and the formation of thick stems. The plant itself will start flowering later with poor fruit set (*Tsonev & Chal'kova*, 1972). The fruits will be small having forms less characteristic of the variety and show increased susceptibility to disease (*Tarjányi*, 1978).

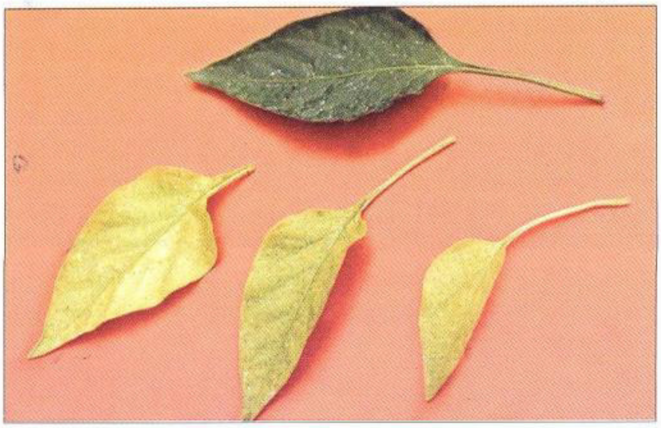

Fig. 1 N-deficiency on pepper leaf. On the top: leaf supplied with sufficient N

According to *Slezák* et al. (2002/b), excessive nitrogen application under water shortage reveals the characteristic symptoms of salt damage (thin stem, dark green leaves, brown roots).

Phosphorous deficiency, generally, occurs in the first part of the growing season during transplant growing on peat or next to planting to the field (*Blancard,* 1992; *Terbe,* 2001). Affected pepper plants are severely retarded in growth developing a thin stem and a remarkably weak root system (*Terbe,* 1997/b). Flowering is delayed and fruit set is poor *(Fig 2).* Brownish green or reddish green discolouration is observed on the backside of the first leaves. Later on, diseased leaves are shed, their phosphorous content does not reach 0.08–0.09% of dry matter (*Terbe,* 1978). The soils of the older plastic tunnels usually contain an adequate level of phosphorous; therefore symptoms of phosphorous deficiency are rarely encountered in peppers which have been planted out and took have roots (*Terbe,* 1993/b). Symptoms of excessive phosphorous application are unknown in the practice of growing, if an excessive fertilisation occurs the bell pepper plant will manifest it in the form of zinc and manganese deficiency, the antagonistic elements of phosphorous (*Terbe,* 1997/b).

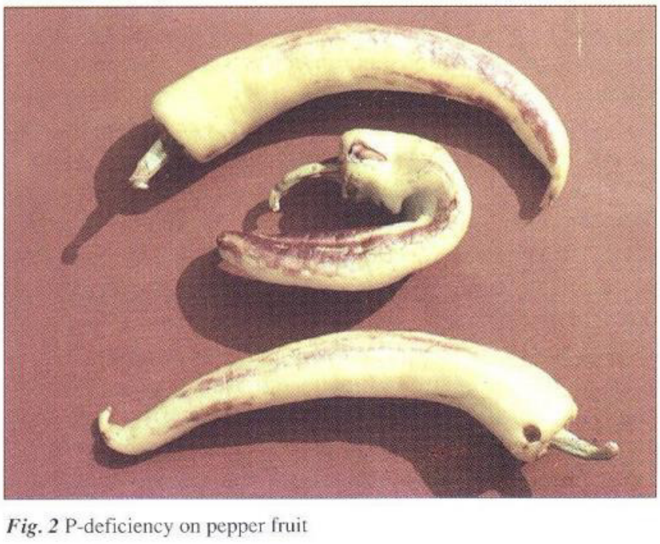

Fig. 2 P-deficiency on pepper fruit

Potassium deficiency, similarly to nitrogen deficiency, manifests by yellowing of the lower leaves. A substantial difference between the two deficiency symptoms is that while in the case of nitrogen the whole leaf will turn yellow (including the veins), in the case of potassium the main veins and the adjacent leaf tissue will remain dark green even when leaves are shed *(Fig 3).* The yellowing always begins at the tip of the leaf and proceeds proximally in the direction of the stem (*Miller*, 1961 & *Loch* et al., 1993). The development of acute symptoms are expected with less than 2.5–3.5% leaf potassium supply *(Table 6).*

Though potassium fertilisation has a yield increasing effect, optimal potassium supply has beneficial effects, mainly, on the plant compositional and physiological characteristics, as well as on yield security, which are as follows:

Increases yield security means, it

- improves the plant's tolerance to cold
- increases the resistance to diseases
- enhances drought tolerance

Fig. 3 Typical symptom of K-deficiency on leaf of pepper

Table 6 Foliar nutrient levels of deficiency affected bell pepper plants (nutrient percentage in relation to dry matter content)

Diseased plant	Nutrient content%
N deficient leaves	≤ 1.7 – 2
P deficient leaves	≤ 0.08 – 0.09
K deficient leaves	≤ 2.5 – 3.5
Ca deficient leaves	≤ 0.3 – 0.35
Mg deficient leaves	≤ 0.2 – 0.3

(Terbe, 1993/a)

Improves yield quality, it

- favours the formation of aroma, flavour and pigment compounds
- stimulates photosynthesis and enzyme reactions, therefore fruits will have higher sugar, protein and vitamin content
- improves the appearance and the marketability of the fruit by encouraging pigment production
- increases the dry matter content of the fruit
- increases the width of the cell walls, thus improving storability (*Terbe,* 1998/a).

Excessive nitrogen fertilisation may also create a latent deficiency of potassium, this danger being considerable in fertigated (irrigated with nutrient solution) pepper forcing. The increase of the ratio of potassium relative to nitrogen increased the dry matter and the vitamin C content of the fruit (*Slezák* et al. 2002/b; *Szűriné* et al. 2002/b; *Szepes* et al. 2002).

Sulphur deficiency occurs in the practice of growing only in soil-less cultivation, it is unknown in field production, even if pepper plants build relatively much sulphur in their bodies (4% of the ash fraction). This is explained by the fact that sulphur is present in many fertilisers as a secondary substance, and animal manure, which is well known to be used in great quantities for pepper, also contains considerable amounts. Bell pepper plants suffering from sulphur deficiency are not much back in growth respect to the healthy ones. Chlorosis, which is very similar to nitrogen deficiency, begins not on the lower leaves, but on the younger ones *(Fig 4)*. Erect leaf posture is also observable. In the case of a serious deficiency also some larger and dry spots will form on the leaves. The appearance of deficiency symptoms are expected under 0.15 mmol/kg concentration (in the leaf) (*Somos* et al. 1975/b).

The deficiency most frequently met in production is *calcium deficiency*. Usually, it is not the effect of low lime level in the soil, but the problem of the availability of calcium that accounts for the deficiency. As calcium is not a reusable nutrient, it cannot be metabolised within the plant, deficiency symptoms appear first on the younger leaves in the form of chlorosis. However, the characteristic symptom of calcium deficiency is not the chlorosis of the leaves, but the disorder develops, on bell pepper, but also on tomato and eggplant, mostly in the form of blossom end rot (*Blancard,* 1970; *Terbe & Szabó* 2003/a). In this case a dry sunken brown decay develops on the blossom end of the fruit, the size of the "ill" part is proportional to the severity of the deficiency *(Fig 5)*. The stalk-end part of the pericarp and the fruit is healthy. Susceptibility levels differ considerably among varieties, there are pepper varieties on which the symptoms of blossom end rot are practically unknown, while there are others which, due to the structure of their tissue, are very susceptible to the disease (*Reményi* et al. 2003; *Terbe & Szabó* 2003/b).

Fig. 4 Sulphur-deficiency symptoms on leaves of pepper plant

Terbe & Slezák (2002) attribute the development of calcium deficiency not to the low lime concentration in the soil, but to high soil mineral levels, high relative moisture content, low soil acidity and ion-antagonism (e.g. high potassium, ammonium and sodium concentration) which render Ca unavailable. Symptoms of calcium toxicity are unknown in the practice. High lime concentration in the soil is indicated through the deficiency symptoms of certain micronutrients, as high lime levels inhibit the uptake of boron, iron, manganese and in more serious cases some macro nutrients (*Blancard* et al. 1994; *Bergmann & Neubert,* 1976).

Iron deficiency constitutes a transition from macronutrients to micronutrients, from the point of its effects seems to be nearer to microelements. Generally, soils in

Fig. 5 Ca-deficiency on white pepper fruit

Fig. 6 Iron deficiency symptoms on young leaves of pepper plant

Hungary contain sufficient iron concentrations for plant growth and deficiency symptoms are caused by the poor availability of the nutrient, which is traced back to some soil defects (e.g. high pH, ion antagonism, poor aeration of soil, etc.). Deficiency is first manifested on young leaves and shoots *(Fig 6)*, then as time goes, it spreads over to the middle leaves. At the beginning, inter-veinal tissues start to discolour, and subsequently more light and white tissues begin to form on the newly developed shoots. As deficiency advances, not only the inter-veinal fields, but also the thin veins become discoloured (*Terbe*, 1985/b; *Buzás*, 1983). The most frequent reasons of iron deficiency in bell pepper production is a compact and poorly aerated soil structure, erroneous liming and over-irrigation. Healthy pepper plants show 120–220 ppm values in the young leaves, the development of deficiency symptoms are expected under 80 ppm iron concentration (*Terbe*, 1985/c).

Fig. 7 Magnesium deficiency symptoms on leaves of pepper plant

Symptoms of *magnesium deficiency* are more and more frequently observable in recent years in connection with bell pepper forcing with a plant support system. The deficiency of the nutrient results in an inter-veinal yellowing not on the lowest but always on the older leaves (*Terbe* et al., 1996). It is easily confounded with potassium deficiency since the chlorotic affects only the inter-veinal tissues, while leaf veins remain green *(Fig 7)*. It has a somewhat brighter yellow, more like reddish yellow colour than potassium deficiency and usually starts at the proximal end, as opposed to potassium deficiency that starts at the tip of the leaf. Magnesium deficiency is more and more frequently encountered in intensive bell pepper cultures, which is attributed to the fact that growers use not much magnesium fertiliser compared to nitrogen, phosphorous and potassium and soils are inadequately supplied with magnesium (*Terbe* & *Némethy*, 2003). The level of magnesium requirement per hectare, in the case of bell pepper, depending on yield levels, is near to the 30–70 kg/ha (*Terbe*, 1992).

Zinc is built in small amounts only into the pepper plant. Deficiency symptoms first develop on younger leaves. Leaves remain small and the inter-veinal tissues turn whitish-green. In the case of pepper, tiny necrotic spots are also observed on the leaves and stem. The tiny leaves make it relatively univocal, readily distinguished from the deficiency of manganese and iron (*Budai* et al., 1993). Development of the deficiency symptoms are expected under 0.3 mmol/kg concentration (in the leaf).

Manganese deficiency, similarly to iron deficiency, reveals itself first on the younger leaves in the form of inter-veinal chlorosis. The inter-veinal yellowing is then followed by the development of necrotic spots and symptoms gradually spread over to the middle leaves. Due to their similarity, it is very difficult to distinguish iron and manganese deficiency from one another. Occurrence of the disease is to be expected chiefly with high soil pH values or poor aeration of soils. Development of the deficiency symptoms are expected under 0.4–0.5 mmol/kg concentration (in the leaf). It is possible to encounter manganese toxicity in forcing, which is the consequence of the accumulation of condense water dripping from the metal structure or the result of manganese compounds freed during soil fumigation (*Terbe* 2002/b).

Boron deficiency is rarely encountered on bell pepper; it has been detected in soil-less culture and deficiency provocation trials, where as a result of the deficiency the leaves of the plant became rigid and fragile. Shoot tips of peppers suffering from boron deficiency die off, followed by a strong emergence of lateral shoots from the side of the leaves, and if the plant does not recover its boron balance also the lateral shoots will die off. Plants suffering from boron deficiency show poor fruit set, which have been observed also in other Solanaceous plants, such as tomato. It is very rare in production that the soil is deficient in boron; usually it is the high lime concentration in the soil and drought that inhibited absorption. Development of the deficiency symptoms are expected under 2.5–2.7 mmol/kg concentration (in the young leaf) (*Terbe*, 1984).

Molybdenum deficiency is rarely encountered on pepper in the practice of production. In contrast to other micronutrients, its occurrence is to be expected not on limy soils but on acid ones, causing inter-veinal chlorotic spots and in more serious cases also the yellowing of the thinner veins. Symptoms are always manifested first on the younger leaves (*Terbe*, 2002/b).

Copper deficiency is encountered only on rare occasions in the practice of production, which is explained by the fact that plants have very low copper requirements, 1–1.5 kg per hectare, while obtaining considerable amounts from the spraying of chemicals. Plants suffering from copper deficiency are characterised by wilting and leaf roll. Development of the deficiency symptoms are expected under 0.05–0.1 mmol/kg concentration (in the young leaf) (*Bergmann*, 1979).

Soil requirements of bell pepper

Looking for a favourable site for bell pepper production, the following major points and parameters should be considered: soil sickness, phytosanitary conditions, preceding crop, critical soil physical and biological parameters, climatic conditions, water supply and water quality, pollution effects, management of technical and human conditions.

Bell pepper is markedly sensitive to monocultural production. Generally, yield losses from soil sickness are still low in the second year, but yields of the third and subsequent years may suffer even up to 50% losses as compared to the previous year. The characteristic symptom of soil sickness in the case of the waxy variety group, especially in the case of the Cecei-type varieties, is the tiny size of fruits, which can also be induced by unfavourable soil nutrient conditions (*Terbe*, 1977) and viral infections (*Turi & Fodor*, 1975). According to the findings of *Tarjányi* (1964), in open field cultivation, average annual decreases were as high as 30% in monocultural production. It is known by every grower that the ignorance of phytosanitary prescriptions and the omission of plant hygienic regulations will increase the consequent damages. One of the most obvious ways for avoiding soil sickness is the use of crop rotation where bell pepper should not be planted to the same site before at least 4 years (*Somos*, 1981; *Terbe*, 1985/c).

The literature on the soil requirements of bell pepper is unanimous in underlining the high requirements of pepper in this aspect as compared to other vegetable species. A number of Hungarian authors, but foreign ones as well, prove that with every variety type, but especially in the case of those waxy varieties suitable for stuffed dishes, the best soils are sandy loams or loamy sands with high humus content (*Angeli*, 1955; *Terts*, 1966; *Koródi & Túri*, 1969; *Kovács & Zatykó* 1975; *Zatykó*, 1979). Sandy soils are also suitable for pepper, as are quick in warming up, especially in early open field cultivation and in forcing, however, they need heavy animal manure application in order to improve nutrient- and water-retention capacity (*Terbe*, 1997/c). Continuous irrigation and regular nutrient supply are essential in the case of sandy soils. Bell pepper does not tolerate compact and poorly aerated soils as well as those inclined to crusting and with thin topsoil or high ground water level (Somos, 1981).

The advisor's guide containing the fertilisation guidelines for field vegetables, which is still in vigour, recommends the following soil types for bell pepper production:

Habitat I – Chernozems (chernozemic brown forest soil, forest residual chernozem, leached chernozem, calcareous chernozem, chernozemic meadow soil, terrace chernozem, humus carbonate soil)

Habitat II – Brown forest soils (brown forest soil with clay illuviation, Ramann brown forest soil, brown soil with carbonate residues, slope alluvial soils)

Habitat III – Heavy meadow soils (alluvial meadow soils, solonetz meadow soils, boggy meadow soils, sandy meadow soils, pseudo gley brown forest soils)

Habitat IV – Loose soils (drift sand soils with more than 0.3 humus, humic sands, sandy brown forest soils, raw alluvial soils, humic alluvial soils)

(Pepper production on the soils belonging to the habitat group IV is recommended only under exceptional conditions with heavy application of animal manure and careful soil preparation)

Regarding the lime concentration of the soil, pepper does not differ from the other vegetables and the 1–5% concentration of carbonic acid lime is considered optimal both for forced and for open field bell pepper. If soils are poor in lime, occurrence of lime deficiency disease is expected, however, chlorotic symptoms may appear at lime concentrations above 5%, due to the antagonism of lime and the micronutrients (*Terbe*, 111/b). The readily available (water soluble) lime content is decisive from the aspect of the calcium supply of the plant. However, water soluble calcium is constituting, generally, only a very low percentage of total lime concentration of the soil (*Terbe*, 1998/b).

As far as the pH value of the soil is concerned, bell pepper seems to prefer the neutral or lightly acid soils (6.4–7 pH), supporting neither the alkaline (over 8 pH) nor the strongly acid (under 5.5 pH) soils (*Somos*, 1981; *Terbe*, 1996/a; *Drews*, 1971). In contrast to the other researchers, *Knott* (1973) considers those soils having higher acidity as being more favourable for pepper.

Slezák (2001) classified bell pepper as an explicitly salt sensitive plant; according to her findings, from this point of view it is akin to lettuce well known to be salt sensitive. She observed in the experiments that although germination of pepper did start in a more concentrated nutrient solution, but shortly after germination the young seedling died as assimilation started. Therefore, she defined the last day of germination given by the standards as the most suitable moment for stating salt sensitivity. Young seedlings tolerated significantly higher EC values on blotting paper under experimental conditions, which permitted the precise control of the concentration of the germinating solution *(Fig 8)*, than on soils with high humus contents under natural conditions, where they suffered damages already at lower EC values because of frequent and strong fluctuations of moisture concentration *(Fig. 9)* (*Slezák* et al., 2000).

Among bell pepper varieties, especially the waxy ones show a negative response to over fertilisation, to concentrated nutrient solutions, to secondary soil alkalinity and to irrigation water of poor quality with alkalinizing effect. Depending on organic matter content and soil heaviness, the EC value of the soil should not exceed 0.8–1.2 mS/cm under open field conditions and 1.7–2 mS/cm under protected cultivation. In the case of the waxy varieties, the lower values, in the case of Hungarian hot types the higher values should be taken into account (*Slezák* et al. 2003).

Even higher requirements should be prescribed for soil quality in protected cultivation in order to achieve higher yields. Higher nutrient level as well as better soil structure should be provided for the plant (*Terbe*, 1996).

The major soil structure indicators of soils for bell pepper forcing (*Terbe*, 1997/d):

air capacity	35–40 bulk volume%
water capacity	45–50 bulk volume%
pore capacity	75–85 bulk volume%
air permeability	at 10 cm meter depth 300–350 ml/sec at 20 cm depth 300–330 ml/sec at 30 cm depth 280–300 ml/sec
soil density (specific weight)	less than 7.8–0.8 kg/litre
soil resistance	at 10 cm meter depth<30 N/cm^2 at 20 cm depth <40 N/cm^2 at 3–35 cm depth <50 N/cm^2

Bell pepper reacts sensitively to chemical residues, consequently, abnormal development is encountered especially in the case of the waxy varieties. In many cases the plant itself is not destroyed, but indicates eventual residual soil disinfectants or herbicides through the distortion of leaves and the deformation of the fruits (*Terbe*, 2002/b).

Regarding soil nutrient levels, soils of open fields and those of greenhouses should be judged separately. In outdoor cultivation, the same figures and limits apply to bell pepper as to open field grown plants in general. Phosphorous and potassium levels are evaluated with the ammon lactate soil test method, nitrogen state is calculated from the humus value (*Náhlik*, 1981).

Based on foreign, especially Dutch experiences, soil nutrient supply is judged, both in seedling production and in forcing, on the basis of the water-dissolved nutrient concentration. *Zsoldos* et al. (1983), trying to find correlation between the lactate soluble phosphorous and potassium content of the soil and the water soluble nutrient content, concluded that the larger the water/soil ratio the closer the values for water approached those for AL. For example, approximately 60% of AL soluble nutrients are extracted with a 1:5 solution from the soils of raising seedlings and growing under plastic tunnels *(Fig 10)*. When the majority of the nutrients are present in water-soluble form, the easiest way to utilise plant nutrient supply is ensured principally from this source. In this aspect, intensive vegetable production is considered an extreme where, mainly, the water soluble fractions seem more advisable to be examined, in contrast to open field conditions where the lactate soluble nutrient amounts tend to correlate better.

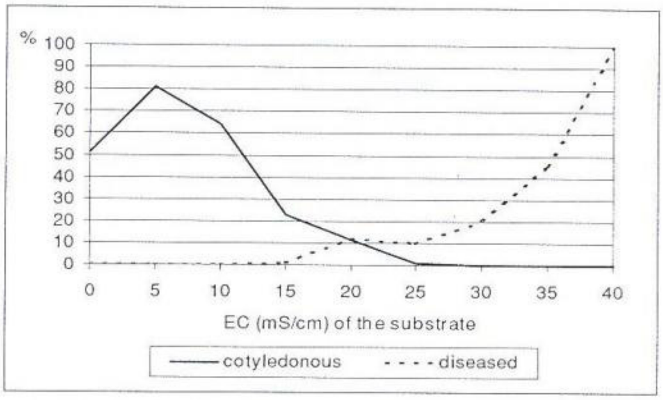

Fig. 8 Number of healthy cotyledonous and diseased plants germinated on wet sheet of laboratory paper with different value of EC. (Slezák)

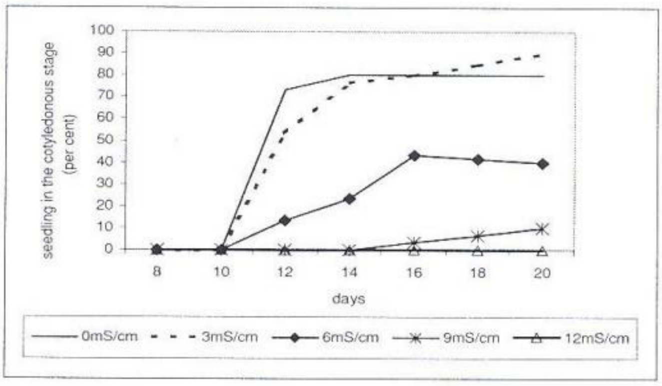

Fig. 9 Effect of EC value on germination of the paprika (Slezák)

There are two commonly used methods for the evaluation of soils under forcing, both of them starting out from water-dissolved nutrient amounts; in the first case the denominator is air-dry soil weight (mg/100g) and the soil is subjected to a 1:5 ratio extraction, the other provides a value relative to raw soil volume (mmol/l) and the soil is dissolved in water in a 1:2 proportion (*Budai* et al. 1993).

Some relationships between nutrient supply and yields

Concerning the soil requirements and fertilisation of bell pepper, a series of development stages (from sowing to pricking out, from pricking out to transplanting, the

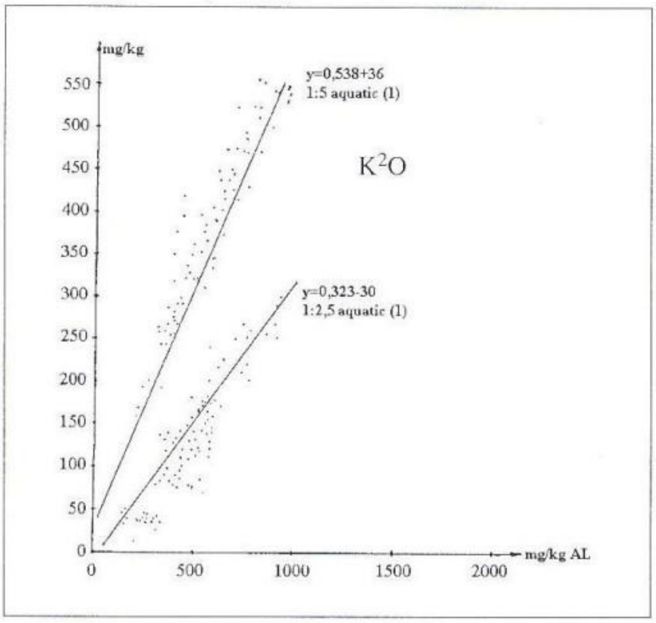

*Fig. 10.*Regression of the potassium of extracts of 1:2,5 and 1:5 soil: water ratios on the content determined by the AL 1, soil:water (aluminium lactate) method (Zsoldos et al. 1983). (Zsoldos)

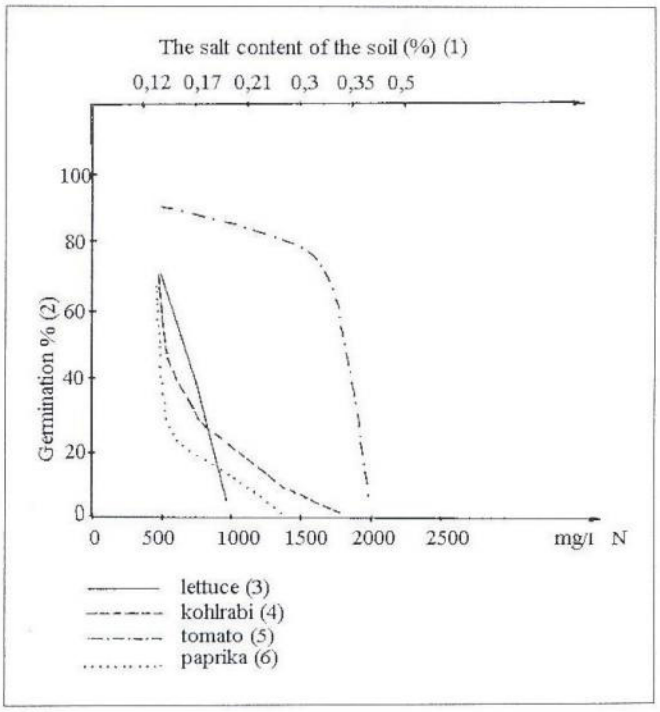

Fig. 11 Germination of seeds of some vegetable crops in sand-peat mixture (50–50 per cent) as a function of increasing nitrogen doses. (1), Per cent salt content of the soil; (2), Germination per cent; (3),Lettuce; (4), Kohlrabi; (5),Tomato; (6), Pepper. (Terbe)

phenological phases of production) must be distinguished as they differ in soil and nutrient requirements therefore having different fertilisation characteristics.

From its emergence until the appearance of the first foliage leaves, the plant feeds from the seed, i.e. from the endosperm, and nutrients applied into the soil have no influence on bell pepper development, on the contrary, as illustrated by *Fig 11,* they may reduce the speed of germination through the increased nutrient concentration, depending on the salt sensitivity of the plant (*Terbe,* 1979; *Terbe,* 1985/a). Therefore, prior to germination, no supplementary nutrient application is recommended, only after plant emergence when root activity begins (*Terbe,* 1977/c). In this stage, dilute nutrient solutions with high phosphorous content have beneficial effects on root development and thereby on the start of foliage development.

Estimation of sowing-soil quality depends substantially on two factors: what conditions are provided for germination and what is the risk of dumping off of seedlings in terms of plant hygiene. Therefore, seedling soils are recommended to comprise an 80:20% mixture of fen peat and rough fluvial sand containing no clay, without any nutrient enrichment (*Slezák* et al. 2002/c).

It is an important requirement for the media used from pricking out in raising transplants to planting out, i.e. the soils of the cubes and seedling trays, that, besides sterility and good structure, should abound in readily available nutrients while having a low EC (electric conductivity) value (*Kappel* et al., 2003). Farms meet this requirement with continuous (daily) fertigation, c.f. the case of using seedling trays, or with the application of slow-acting fertilisers (*Slezák* et al., 2003, *Tóth* et al., 2003). In experiments going on for several years and on the basis of the favourable experiences gained in production, the most suitable soil cube mixture has been found to be composed as follows:

80–90 bulk % high quality peat, preferably fen peat
10–20 bulk % rough sand containing no clay
3 kg lime powder
1.5 kg/m^3 complex fertiliser with retarded effect
3 kg/m^3 superphosphate fertiliser (20%)

Intensive experimental work was going on over the recent years to substitute peat in growing media (*Kappel* et al. 2003, *Slezák* et al. 2003), which are considered to be oligotrophic while having excellent structural characteristics. Their nutrient supply must be ensured with continuous fertigation.

Fertiliser requirements of open field grown bell pepper and spice pepper are determined on the basis of their specific nutrient demands. The calculation is based on nutrient balance, i.e. soil nutrient supply capacity and nutrients added to the soil in the form of manure and inorganic fertilisers should be in equilibrium with nutrient amounts utilised by the plant and nutrient losses (*Náhlik,* 1981).

The primary role of organic manure is to improve soil structure and physical characteristics, as a source of nutrients it plays a secondary role (*Terbe,* 1996/a). Under open field conditions, the application of 30–100 ton per hectare manure rates are considered reasonable, depending on soil conditions, financial possibilities of the farm and conditions of purchase, with the objective of improving water and nutrient absorption in light sands (habitat group IV) or that of soil loosening in soils belonging to habitat group III (meadow soils) (*Terbe,* 1996/b). In contrast to open field cultivation, farmers apply doses even as high as 10–30 kg/m^2 in forcing (*Terbe,* 1991).

Distribution of fertilisers recommended is influenced very much by soil quality (heaviness, nutrient level). In the case of open field grown bell pepper in a medium heavy soil with a medium level of nutrient supply, traditional fertilisers should be paced as listed in *Table 7* (*Terbe,* 1997/d; *Terbe,* 2004).

Under open field conditions if solid fertilisers are used, it seems reasonable to apply top dressings more frequently, but at smaller doses, to light soils having lower adsorption capacity, whereas top dressing may be accomplished in 2–3 parts to heavier soils. Regardless of the nutrient level of soils, it is not advisable to apply more than 50 kg/ha nitrogen (N) and 100 kg/ha potassium (K_2O), at once, because bell pepper is salt sensitive (*Terbe,* 1997/c; *Ombódi & Saigusa,* 2000).

Fertilisation of forced bell pepper, similarly to open field cultivation, is also based substantially on specific nutrient demands and nutrient balance calculations, which are adapted to the nutrient level of the soil. Since under forcing conditions more favourable circumstances are provided for bell pepper than in open fields and the safety of production is also significantly higher, thus yields are proportional with the growing period. Accordingly, in advisory work the length of the growing period is taken into consideration and nutrient amounts to be applied are given in proportion to time (*Budai* et al. 1993).

The use of nutrient solution in cultivation (intensive cultivation) makes it possible to change nutrient ratios that suit best to current nutrient requirements. Simultaneously with planting in order to promote rooting, it is advisable to soak transplants with high concentration phosphoric fertilisers (*Terbe & Tóth,* 2003). The N:P:K ratio should correspond initially to 2:1:3, 2:1:3 during flowering, 2:1:2 at the time of the first picking and 2:1:1 when harvesting fruits produced on the main stem. At the end of the growing period in summer time it is recommended to apply top dressings of a 2:1:0.5 composition or nitrogen alone (*Horinka,* 1997).

International findings have been confirmed by Hungarian experiments and observations in the farms. As a rule, 10–15 g/m^2 doses of compound fertiliser are applied every 5–7 days depending on the nutrient level of soil and the light conditions, in the form of nutrient solution, from planting out or from the first fruit set (on rich soils) until the end of the growing period, where the composition of the fertiliser should be in harmony with the phenological phase of the plant (*Glits* et al. 2000). The amount indicated is also applied more frequently, even at daily intervals. Depending on water quality, the ideal nutrient solution has a concentration of 0.1–0.3%, if needed, the water is to be acidified according to its hydrocarbon content (*Terbe,* 1991).

Table 7 Division of fertilisers on a medium nutrient level, medium heavy soil

Fertilisation	Fertilizer	%
base fertiliser	Nitrogen Phosphorous Potassium	– 80–90 50–60
starter fertiliser	Nitrogen Phosphorous Potassium	10–20 10–20 20–25
top dressing	Nitrogen Phosphorous Potassium	80–90 – 20–25

(Terbe, 1997/d)

It is essential in using nutrient solutions that water should be available in adequate quantity and quality. According to the investigations of Ráczné (2001), 40% of waters used for irrigation are inferior to the required level regarding quality parameters in the southern part of the Hungarian Great Plane. *Table 8* shows the value ranges of waters suitable for the fertigation of bell pepper.

The great majority of the soils of forcing houses showed alkaline reaction in contrast to the desired neutral or slightly acid pH, which is ascribed to the high hydrocarbon concentration of the waters (*Slezák* et al. 2001). Waters with high hydrocarbon concentration are recommended to be acidified for the purpose of fertigation, especially in the case of soil-less cultures.

Bell pepper, like other Solanaceous species, does not accumulate high amounts of nitrate in the fruit. Based on tests on farms and on experiments in soil-less cultivation, it is concluded that the level of nitrate registered in the fruit of bell pepper is far lower than the limit of meaning danger to human health even during the most critical winter period (*Table 9*). At the same time, investigations have

Table 8 Qualification of water for solution

Parameter total dissolved salts	Optimal 520	Sufficient 520–2000	Inadequate above 2000
EC mS/cm	below 0.5	0.5–1.5	above 1.5
Mn concentration mg/l	below 0.1	0.1–1.0	above 1.0
Fe concentration mg/l	below 0.1	0.1–1.0	above 1.0
Na mg equivalent /l	below 1.5	1.5–3.0	above 3.0
Cl mg equivalent/l	below 1.5	1.5–3	above 3.0
Hydrocarbonat mg equivalent/l	below 5.0	5.0–6.0	above 6.0

(cf. Ráczné, 2001)

Table 9 Nitrate concentrations in different paprika varieties (Soroksár)

Name of variety	NO_3-N, mg/kg	NO_3, mg/kg
Angeli emléke F_1	32	141
Fehérözön	36	159
Hatvani hajtató	36	159
HRF F_1	124	549
Hungarian Yellow Wax	27	119
Kovácsházi	36	159
Kosszarvú	34	150
Soroksári (R)	52	230
Tőrhüvely	28	124

(Zsoldos et al. 1983)

demonstrated that the nitrate concentration is higher in the waxy varieties than in the Hungarian hot types (*Zsoldos* et al. 1983).

Hungary is situated on the north-east border of the open field production of bell pepper, therefore cultivation involves risks as sudden temperature drops and increases, such as those in the recent years, and droughts may have unfavourable effects both on yield and fruit quality. Market requirements can really be met only by forced bell pepper, therefore its growing area has shown an increase for the last 10–15 years, constituting over 50 percent of the total forcing area assigned to vegetables (2200–2300 ha). As a consequence of more and more demanding regulations on environmental and food hygiene, so it seems likely that the rate of the soil-less pepper culture started in forcing, as well as the related research activities, will see a significant boom (*Szőriné* et al. 2002/a).

Conclusions

The nutrient requirements of bell pepper and those of spice pepper are identical in a number of aspects, but show several differences as well. Spice pepper, characterised by higher dry matter content and a lower yield potential, has specific nutrient requirements that are almost twice as large as those of waxy varieties. The divergence of the relevant data from the literature is ascribed, only partially, to variety characteristics; the significant differences in yield also contribute to it. While the balanced composition of nutrients in the fruit is an adequate starting point for the calculation of nutrient requirements, the nutrient content of the leaf, which is highly dependant on environmental conditions, provides information on the nutrient state of the plant.

The deficiency of the macro and micronutrients produces symptoms on bell pepper that are similar to those of other plant species and are indicative of the nutrient. Calcium is somewhat different causing a syndrome that is identical with that in tomato but considerably different from other vegetables. The waxy and cone-shaped local varieties are more sensitive to lime supply.

The increased salt sensitivity of bell pepper plants, especially of the waxy varieties, is easy to observe throughout the different phenological phases, which should be taken into consideration in the elaboration of the production technology (nutrient solution concentration, maximum nutrient dosage per treatment, quality of growing medium, nutrient content of the soil and EC).

It is in particular the green bell pepper that sets high demands to soil structure and this fact must be remembered in choosing the growing site, in nutrient supply, in designing the crop rotation and in soil tillage.

For the estimation of soil nutrient level if bell pepper is grown under intensive conditions, the analysis of water-dissolved nutrients provides more accurate information than the results of the ammonium lactate method that is utilised for open field conditions.

Nitrate values registered in bell pepper fruits are far under the level of endangering human health.

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