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Macronutrient accumulation in green pepper (*Capsicum annuum* L.) as affected by different production technologies

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Summary: Based on the experiments, an assessment was made to determine for green pepper the amount of nutrients extracted by unit weight of fruit and plant parts not meant to be consumed (foliage, stem, root), i.e. the specific nutrient requirements of pepper. A further objective was to find out to what extent nutrient accumulation in individual plant organs was influenced by differences in production technology and soil conditions.

Key words: green pepper, specific nutrient requirements, nutrient content

Introduction

Over the past ten years considerable technological changes and developments have taken place in greenhouse cultivation and in intensive field production. Nutrient supply constituted an important element of them, the development and modernization of which permitted to improve the international competitiveness of vegetable farms by producing significant yield increments, by improving yield quality and by increasing yield stability in a considerable degree.

The drastic drop in fertilizer use that occurred in the middle 1980s was not typical to the vegetable farms applying intensive production technologies, as opposed to the farms engaged in field production, nevertheless a more rational fertilizer use began in this area. The former practice of overfertilization diminished significantly and there was an increased demand for fertilization advice based on soil analysis.

The so-called white stuffing types (e.g. Ciklon F_1, HRF F_1, Táltos) are produced on approximately 60% of the green pepper growing area in Hungary, it is followed by the tomato shaped pepper (e.g. Paradicsom alakú zöld Szentesi; Pritavit F_1; Kárpia F_1, Greygo) with 30% and the remaining 10% is shared by the other variety types.

As West-European and South-European countries had earlier opted for the introduction of the bigger fruited green peppers of blocky and lamuyo types into production, which types have environmental requirements that differ in several aspects from those peppers bred in Hungary and customarily consumed in the country which have a white fruit and a cone shape (stuffing type), therefore research results, production technologies and experiences should be adopted with certain reservations. *Somos* (1981) characterizes this difference as the cone shaped varieties of Hungarian breeders being more demanding in terms of environmental conditions and having a much more sensitive reaction to unfavorable environmental factors. This opinion seems to apply also for soil and nutrient requirements, which is confirmed both by the research carried out so far and by production experiences.

Plant nutrient requirements are substantially determined by the amount of nutrients accumulating in the product (crop) and in the by-product proportional to the former, specific nutrient requirements, which are usually described as nutrient amount per unit yield or less frequently per unit area. This is the basis for the assessment of nutrient requirements in vegetable production, both nationally and internationally. The value indicated this way also means the nutrient amount extracted or to be extracted by planned yields (*Debreczeni*, 1979).

In the case of pepper the nutrient amount extracted from the soil by the fruits, according to the data published by the authors, shows a rather great difference which can originate from the fact that the growing conditions, yields and the varieties, variety types tested were different (*Table 1*). If the data regarding the varieties grown in greenhouse and those with white fruits are separated it can be seen that the difference will be significantly reduced:

nitrogen (N):	2.4 – 4.6 kg/t
phosphorous (P_2O_5):	0.5 – 0.9 kg/t
potassium (K_2O):	3.4 – 6.1 kg/t

Table 1. Macronutrient amount accumulated by pepper plant according to data from national and international authors

Author	Yield level	Plant part (t/ha)	Nutrient uptake (kg/t)					Nutrient amount corrected to one ton fruit (kg)				
			N	P_2O_5	K_2O	CaO	MgO	N	P_2O_5	K_2O	CaO	MgO
Horváth and Bujk (1934)	9.0	fruit foliage	31.0 44.0	9.0 6.0	41.0 40.0			8.3	1.6	9.0		
Obermyer (1938)	10.0	whole plant	137.0	24.0	142.0			13.7	2.4	14.2		
Cochran and Olson (1941)	10.0	fruit foliage+stem	30.3 51.0	9.0 8.0	22.0 34.0	4.0 48.0	3.1 33.0	8.1	1.7	5.6	5.2	3.6
Hester and Sheldon (1949)	4.0	fruit levél+stem	6.0 18.0	10.0 17.0	6.0 13.0	8.0 18.0	1.0 20.0	6.0	6.8	4.8	6.5	5.2
Somos and Sovány (1963)	29.0	fruit+foliage+stem	133.8	15.2	182.6			4.6	0.5	6.1		
Terts (1966)	10.0	fruit	24.0	7.0	31.0			2.4	0.7	3.1		
Spaldon and Gromova (1967)	7.4	foliage+stem fruit	30.8 62.1	8.8 21.8	58.0 73.0			12.0	4.0	17.7		
Geissler (1970)	55.0	fruit+stem+foliage	220.0	27.0	260.0	130.0	22.0	4.0	0.5	4.9		
Kaufmann and Vorwerk (1971)	30.0	whole plant	85.5	11.1	98.1	33.0	11.0	2.8	0.4	3.3	1.1	0.4
Berényi (1973)	10.0	whole plant	78.6	15.2	81.1			7.9	1.5	8.1		
Pecsenyeva (1973)	55.0	fruit+foliage+stem	220.0	30.0	260.0	120.0	25.0	4.0	0.5	4.9		
Roorda van Eysinga (1973)	60.0	whole plant	141.6	47.4	232.2	22.5	18.4	2.4	0.8	3.9	0.4	0.3
Kovács and Zatykó (1975)	25.0	fruit+foliage+stem	225.0	31.0	294.0			9.0	1.2	11.7		
Hamar (1978)		fruit+foliage +stem						2.4	0.9	3.6		
Zatykó (1979)	10.0	fruit	24.0	9.0	34.0			2.4	0.9	3.4		
Náhlik (1981)		fruit+foliage+stem						2.4	0.9	3.5		
Geissler and Gohr (1983)	80.0	whole plant	280.0	6.4	385.3	252.3	48.1	3.5	0.8	4.8	3.7	0.6
Balázs (1994)	15.0	whole plant						2.4	0.9	3.4		
Horinka (1997)	15.0	whole plant						2.4	0.9	3.5		
Füleky (1999)	15.0	whole plant						2.4	0.9	3.5		
Agrolinz (2003)		whole plant						2.4	0.9	3.5		
Csathó (2004)		whole plant						2.4	0.9	3.5		
Péti Nitrokomplex (2004)		whole plant						2.4	1.0	3.5	1.8	0.3
Gyúrós (2005)	20.0	whole plant						2.4	0.9	3.4	a	

Table 2. Specific nutrient requirements of pepper plants as influenced by variety and yield level (based on literature data)

Yield level t/ha	N	P_2O_5 kg/t	K_2O
below 10	6.0–12.6	4.0–6.8	4.8–17.7
between 10 and 50	2.8–9.0	0.4–1.2	3.3.–11.7
above 50	2.4–4.6	0.4–0.9	3.3–6.1
Blocky varieties above 50	2.4–4.6	0.5–0.9	3.4–6.1
White varieties above 50	2.4–3.5	0.4–0.8	3.3–4.8

If in *Table 2* the values relative to green pepper as provided by the different authors are grouped on the basis of yield level the results obtained will show significantly lower variance.

Experiments and observations conducted for several years in the field and in the greenhouse indicate that nutrient demands of the individual organs of the optimally growing pepper plant are not met in a uniform manner as regards the three main macronutrients. For phosphorous and potassium the lowest level was detected in the roots, while the nutrient concentration of the leaves could be regarded as high in the case of all three elements (*Terbe*, 1985). In the experiments the root and the stem had almost the same average values (*Table 3*).

Bergman (1992) detected approximately the same average values in the period of picking in the leaves of pepper plants adequately supplied with nutrients:

nitrogen:	3.0–4.5%	boron:	40–80 ppm
phosphorus:	0.3–0.6%	molybdenum:	0.2–0.6 ppm
potassium:	4.0–5.4%	cupper:	8–15 ppm
calcium:	0.4–1.0%	manganese:	30–100 ppm
magnesium:	0.3–0.8%	zinc:	20–60 ppm

Table 3. Nutrient content of individual plant organs of green pepper during fruit development

Plant organ	Minimum and maximum values of nutrient concentration mg/g dry matter			Average nutrient concentration in the percentage 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 (2004) found in his experiments that the nutrient composition of the individual pepper plant organs, depending on the different environmental factors, but first and foremost due to the different nutrient supply, showed significant variation. N, P and K levels detected in the individual organs were affected by soil nutrient levels to a considerable extent but differing from plant organ to plant organ (*Slezák* et al., 2005). The smallest variation is detectable in the pepper fruit. Among the nutrients it is the fruit N content that has the smallest range of variation (28%) and potassium that shows the greatest difference (50%).

The nutrient content of the foliage, as opposed to that of the fruit, responds sensitively to the different characteristics. In experiments on plants growing in pots differences of varying degrees were observable with different soil textures and identical nutrient supply levels, depending on the individual nutrients. In parallel to the growing nutrient and water retention capacity of the soil the nutrient content of the pepper plant foliage decreased proportionally (*Terbe*, 1996, *Slezák* et al., 2003).

Material and method

The objective of the experiments set up for the investigation of the specific nutrient requirements of pepper was to determine for green pepper the amount of nutrients extracted by unit weight of fruit and plant parts not meant to be consumed (foliage, stem, root). A further objective was to find out to what extent nutrient accumulation in individual plant organs was influenced by differences in production technology and soil conditions.

The experiments were set up on sand well-supplied with organic material, on peat in container and under hydroponic conditions.

In the hydroponic treatment the root medium utilized consisted of 2–5 mm river gravels from the Danube. Fertigation was carried out twice a day with Volldünger (14:7:21+2) nutrient solution of 0.3% concentration, and the amount of the nutrient solution applied was 30–32 liter/day.

For the treatment consisting of the application of containers or growing pots we used chalky fen peat from Kecel, which was added a supplemental application of 3 kg/m^3 super phosphate (18%) fertilizer before filling the plastic containers. In the case of the trellised plants the amount of the medium was 5 liter per plant. Fertigation was carried out daily with Volldünger (14:7:21) nutrient solution of 0.3% concentration, and the amount of the nutrient solution applied per container was 0.3 liter/day.

In the case of the soil grown plants cultivation was carried out on sand added with a manure dose of 10 kg/m^2. In the course of fertigation, which in a similar manner to the case of the plants grown in hydroponics and with nutrient solution was carried out with Volldünger solution of 0.3% concentration, the objective was to keep the water soluble nitrogen, phosphorous and potassium concentrations between the following limits:

nitrogen (N):	10–20 mg/100 g
phosphorous (P_2O_5):	5–8 mg/100 g
potassium (K_2O):	20–30 mg/100 g

(These intervals correspond to a soil well supplied with nutrients in conformity with the results of the tests elaborated for Dutch greenhouse soils.)

Soil nutrient concentration was determined from an aqueous extract of a 1:5 mixture prepared by shaking. Nitrogen, phosphorous and potassium concentrations in the plant samples were measured from the stock solution after digestion according to the phosphorous analysis method described by *Krammer-Sarkadi*. Nitrogen was distilled from the stock solution in a *Wagner-Parnas* apparatus by using an alkaline solution and then trapped in boric acid. Phosphorous was determined according to the method of *Fischke-Szubarov*. Potassium was determined with a spectrophotometer.

The trials comprised two green pepper varieties used in greenhouse production: the variety DUNA F_1 is a pointed green hybrid and the variety HRF F_1 is a white fruited one for stuffing. Relative to growing methods a comparison was made between traditional cultivation applying no trellises (bush form) and the trellis system (with two stems).

The seedlings germinated from the seeds sown in January were planted out in each of the three years in the middle of April as plugs with 7.5×7.5 cm soil cubes into the unheated plastic tunnel and glasshouse, with a density of 4 plants per square meter in the case of the ones trained to two stems, while in the case of the seedlings produced by the traditional technology (bushy plants) 10 plants per square meter.

Results and discussion

The basis of the nutrient supply calculations of green pepper, similarly to field crops, is considered to be constituted by the amount of nutrients required to produce one unit of crop, i.e. the specific nutrient requirements. Though we are aware that the average nutrient contents of plants are not exactly identical with the nutrient amounts required to produce the maximum yields, still the nutrient content of the harvested yield can be regarded as a starting point/working basis for the elaboration of fertilization norms, for practical applications', says *Tolner* (1999) and continues: 'Data from experiments demonstrate that plant nutrient uptake, the nutrient content of the harvested yield is not a constant value, but is dependant on the genetic characteristics of the plant as well as on external environmental factors'.

In pepper production, as opposed to field crops, several production technologies are distinguished, with which yield weight and the ratio of the fresh weight and dry matter content of the individual plant organs may probably differ significantly (*Slezák*, 2001). As no results of measurements and calculations of such kind had been encountered in the literature in connection with the national varieties, we decided to be the first to measure the ratios between the weights of the different plant organs with plants grown trellised and untrellised on soil, in container and in hydroponics.

The method of pruning (trellised plants, bushy plants) had an approximately 10% influence on the proportion of fresh weight and dry matter content of the fruit compared to other plant organs (leaf, stem, root), which originated from the different yield levels. The bush form compared to the trellised plants showed a higher proportion of foliar weight, mainly because of the lower yield results. The difference between the growing media (soil, hydroponics, containers) was smaller in this aspect.

With the individual growing methods the proportion of the roots and that of the stems relative to the foliage and to the fruits showed a smaller difference in absolute value, but a considerable one in percentage.

Practically no difference was observable between the two varieties in terms of the distribution of fresh weight and dry matter content among the individual plant organs expressed as percentage (*Figures 1 and 2*).

Nutrient contents as calculated for the dry matter measured in the individual organs showed a significant difference. For nitrogen the highest values were detected in the leaf (the average was 40.8 mg/g for the variety HRF F_1 and 36.8 for the variety Duna F_1), this was followed by the fruit (32.2 mg/g and 30.5 mg/g, respectively), and significantly lower levels were found in the root and in the stem (average values: 19.8 and 19.16 mg/g, 15.5 and 15.7 mg/g). The greatest fluctuation in response to the different growing methods was detectable in the leaf and in the stem, occasionally exceeding 50%. Significantly less variation was found in the root. The fruit nitrogen content could be regarded as uniform and the deviation was not superior to 10-15% between the individual treatments. It can be concluded that no significant difference was detectable between the two varieties in terms of nutrient accumulation where the difference was not superior to 10 % in any of the organs.

For phosphorous the highest values were measured in the fruit (average value: 5.2 mg/g and 3.7 mg/g, respectively), this was followed by the leaf (average value: 4.2 and 3.7 mg/g), then by the root (2.6 mg/g and 2.7 mg/g) and by the

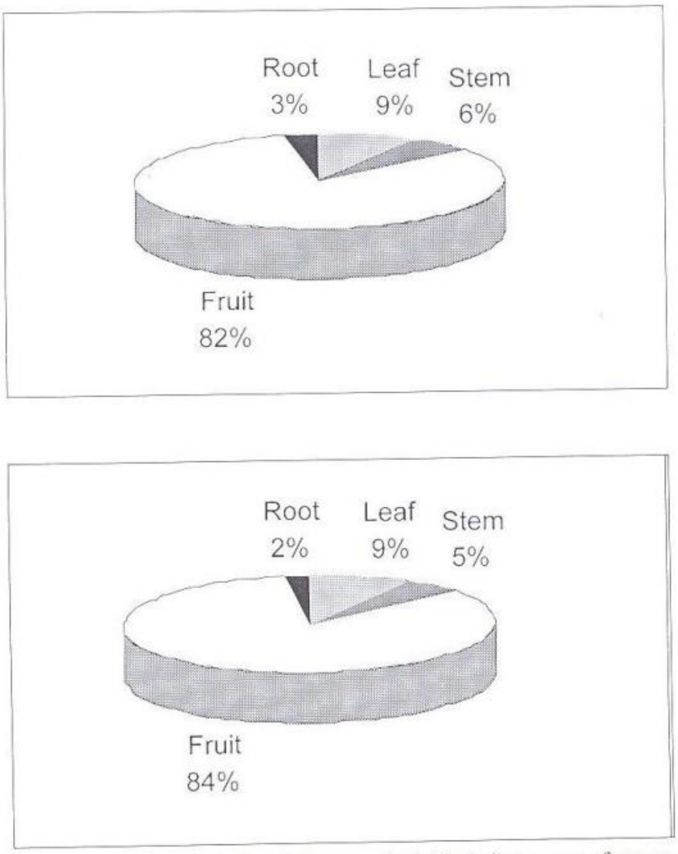

Fig. 1. Distribution of fresh weight among individual plant organs of pepper expressed as percentage (on the left the variety Duna F_1; on the right the variety HRF F_1)

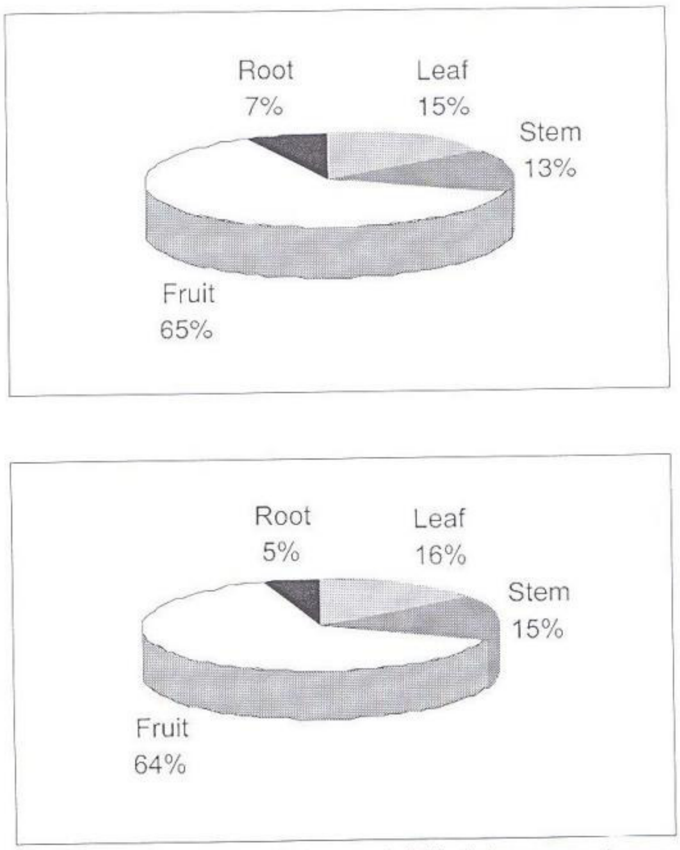

Fig. 2. Distribution of dry weight among individual plant organs of pepper expressed as percentage in the average of 3 years (on the left the variety Duna F_1, on the right the HRF F_1 variety)

Table 4 Distribution of nitrogen, phosphorous and potassium among individual plant organs of pepper as associated different growing technologies

	HRF F_1			DUNA F_1		
	N%	P%	K%	N%	P%	K%
untrellised plants grown on soil						
leaf	26.4	17.12	35.2	25.6	16.9	28.0
stem	9.9	9.7	17.2	7.6	5.6	11.5
fruit	62.0	71.9	46.1	63.6	75.1	57.4
root	1.6	1.2	1.5	3.2	2.4	3.1
trellised plants grown on soil						
leaf	21.6	13.7	33.8	20.5	13.9	12.1
stem	10.9	7.6	17.2	8.1	6.1	16.9
fruit	65.3	77.1	46.1	69.7	79.0	69.1
root	2.2	1.6	1.5	1.7	1.1	1.8
untrellised plants grown in container						
leaf	15.9	17.4	6.6	23.4	19.5	15.7
stem	6.3	8.0	23.4	7.7	7.2	27.9
fruit	73.6	70.3	66.4	60.4	63.9	49.9
root	4.2	1.6	3.6	8.4	9.4	6.5
trellised plants grown in container						
leaf	17.7	15.8	5.8	16.7	15.0	7.0
stem	6.0	5.7	23.1	10.8	9.3	21.9
fruit	71.2	73.3	66.2	62.3	63.1	63.3
root	5.1	5.1	5.0	9.9	12.5	7.7
untrellised plants in hydroponics						
leaf	27.1	13.7	7.7	9.4	6.7	5.9
stem	7.7	6.1	18.8	3.3	3.7	7.1
fruit	60.4	76.4	67.4	84.3	85.6	81.7
root	4.8	3.9	6.1	3.0	4.0	5.3
trellised plants in hydroponics						
leaf	18.1	11.9	4.3	20.4	14.5	8.7
stem	4.1	4.1	16.5	6.2	6.4	6.5
fruit	75.4	82.0	76.7	68.5	73.8	78.0
root	2.3	2.0	2.5	4.9	5.4	6.8

stem (2.1 mg/g and 2.0 mg/g). With each organ the range of fluctuation was greater than that observed for nitrogen. Between the two varieties, similarly to nitrogen, no significant difference could be found in terms of phosphorous content, either.

For potassium, as opposed to nitrogen and phosphorous, with both varieties the highest values were measured in the stem (71.2 mg/g and 48 mg/g, respectively), this was followed by the fruit (49.4 mg/g and 44.0 mg/g), then by the leaf (45.5 mg/g and 37.6 mg/g) and by the root (33.6 mg/g and 29.8 mg/g). The range of fluctuation was with each organ higher than those measured for nitrogen and phosphorous, in certain cases more than three or four times as much. Between the two varieties, in contrast to nitrogen and phosphorous, a significant difference was found.

As a result of the nutrient levels mentioned above the three main macro elements are distributed among the individual plant organs as illustrated in *Table 4*.

It can be seen from *Table 4* that when comparing the individual growing technologies a significant difference occurs in the distribution of the three macronutrients, which, first and foremost, is resulted form the differences in fruit yields and from the different foliage-fruit proportion.

Table 5 illustrates the specific nutrient contents calculated from the yields and the nutrient contents accumulated by the plants calculated for 1 hectare in the case of the individual technologies and varieties.

Table 5. Specific nutrient requirements (kg/t) of green pepper as influenced by the growing technology (in the average of three years)

Medium	Growing method	N		P		K	
		HRF F_1	Duna F_1	HRF F_1	Duna F_1	HRF F_1	Duna F_1
H	T2	2,5	3,0	0,4	0,5	4,7	4,1
	B	3,2	3,8	0,5	0,4	5,8	3,8
C	T2	2,8	3,4	0,3	0,4	4,2	4,5
	B	2,7	3,1	0,3	0,4	4,2	5,5
S	T2	2,4	3,3	0,3	0,4	4,5	5,2
	B	2,7	3,2	0,4	0,4	4,8	4,9
Average	2,7	3,3	0,4	0,4	4,7	4,7	

Explanation of the symbols: H=hydroponics, C=container, T=soil grown plants, T_2=trellised plants trained to two stems, B=bushy plants

Considering the differences deriving from the varieties and from the technologies, summing up the results of the experiments of a three years period, it can be concluded that the specific nutrient requirements of green pepper, which can be the base for the calculation of nutrient requirements, are as follows:

nitrogen (N):	2.4–3.8 kg/t fruit yield
phosphorous (P_2O_5):	0.7–1.1 kg/t (0.3–0.5 kg/t) fruit yield
potassium (K_2O):	4.9–6.9 kg/t (4.0–5.7 K kg/t) fruit yield

The results obtained on the basis of the above-mentioned trials, as regards nitrogen and phosphorous, are identical or similar to the calculations and estimates of several Hungarian researchers (*Balázs*, 1994; *Horinka*, 1997; *Slezák and Stefanovits*, 2003; *Csathó et al.*, 2004, *Péti Nitrokomplex*, 2004; *Gyúrós*, 2005). At the same time potassium is 30-80% higher, and is nearer or identical to the values provided by the German authors (*Geissler*, 1983).

Conclusions

In the course of the investigations carried out to determine the specific nutrient requirements of pepper it was concluded that nutrient levels detected in the organs of pepper were characterized by significant differences. For nitrogen the highest values were measured in the leaf and the greatest fluctuation was also found here, while the nitrogen content in the fruit could be considered uniform.

For phosphorous the highest values were measured in the fruit and in each organ the range of fluctuation was greater than that of nitrogen. It was the fruit phosphorous content that proved the most uniform.

As for potassium, as opposed to nitrogen and phosphorous, the highest values were measured in the stem. With each organ the range of fluctuation was higher than those of the other two elements, in certain cases more than three or four times as much.

Summing up the results of the experiments during the three year period it can be concluded that the specific nutrient requirements of green pepper, which can be the base for the calculation of nutrient requirements, are as follows:

nitrogen (N):	2.4–3.8 kg/t
phosphorous (P_2O_5):	0.7–1.1 kg/t
potassium (K_2O):	4.9–6.9 kg/t

Nutrient composition of the individual pepper plant organs, depending on the different environmental factors, but first and foremost due to the different nutrient supply, shows a significant variation. Soil nutrient levels influenced the N, P and K levels measured in the individual organs in an extent that was changing from plant organ to plant organ. The smallest variation was measured in the pepper fruit. Among the nutrients it is the fruit N content that has the smallest range of variation and potassium that shows the greatest difference.

From the results of the experiments it can be concluded that fruits are well-supplied with nutrients and in a relatively stable manner, independently of the production technologies used. Therefore, the nutrient content of the fruit should not be relied on in assessing the nutrient content of the plant or that of the soil, but can constitute the basis for estimating the amounts of nutrients removed from the soil by the fruits.

Nutrient content of the foliage, as opposed to that of the fruit, responds sensitively to the different technological and environmental factors, this way also to soil nutrient levels, which indicates that the foliage, in the case of the elements subject to reutilization the lower leaves, in the case of the elements not involved in reutilization the upper leaves, is more suitable for the evaluation of the nutritional status of plants than the fruit.

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