RELATIONSHIP BETWEEN LEAF NUTRIENT CONCENTRATION AND THE YIELD OF FIBRE HEMP (*CANNABIS SATIVA L.*)

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***Abstract**: This study was conducted to determine the optimum time for plant analysis, which can provide useful indications of nutrient deficiencies in plants, and to establish limit values for nutrient supplies to fibre hemp (Cannabis sativa L.). The effect of nutrient supplies on the nutritional status of fibre hemp was estimated by leaf analysis in a long-term field fertilisation experiment at four NPK levels on chernozem meadow soil in Szarvas, Hungary in 1999 (good water supplies) and 2003 (dry). The optimum time for the diagnostic analysis of fibre hemp was found to be late May or early June, when plants in the 5–7-leaf stage are 70–100 cm in height, with a biomass of 2–5 t ha^{-1} dry matter, depending on water and nutrient supplies, variety and production condition. Nutrient supplies to hemp can be considered satisfactory if plant analysis reveals 5–6 % N, 0.5–0.6 % P and 2.7–3.3 % K in the youngest fully developed leaves in late May. A stem yield (10 % moisture content) of 12–17 t ha^{-1} was achieved when rainfall supplies were adequate (1999), while in the dry year (2003) the lower nutrient concentrations in the uppermost leaves, indicating nutrient deficiency, resulted in a maximum stem yield of only 6–8 t ha^{-1}. The low, satisfactory and high values for the concentrations of N, P, K, Ca, Mg, Fe, Mn, Zn and Cu reported in the paper could be used to elaborate a fertiliser recommendation system for hemp.*

***Key words**: fibre hemp, soil analysis, plant analysis, nutrient deficiencies, nutrient limit values, dry matter yield*

INTRODUCTION

With the spread of the theory and practice of sustainable development, renewed interest has been shown in hemp in Western European countries, where there is a wide-ranging demand for natural, rapidly renewable, naturally decomposing, environment-friendly raw materials suitable for recycling.

If hemp production is to be modernised, it will be necessary to rethink production technologies. The damaging effects of under- or over-fertilisation (yield losses or environmental problems caused by superfluous mineral fertilisers) can be avoided if more exact knowledge is obtained on how nutrient supplies influence the crop. Soil analyses combined with plant analysis can be efficiently employed in the elaboration of a nutrient supply system for hemp and in evaluating the fertilisation practices applied. The correlation between plant nutrient contents and growth can be described by response curve. In the case of nutrient deficiencies the plants have a low mineral concentration and low yields. If the nutrient uptake rate accelerates but other factors, such as water deficiency, inhibit growth, there may be relatively low yields even at higher concentrations. As the supply of nutrients improves, the yield may increase more rapidly than the nutrient uptake, with the result that the plant element concentrations may drop at first. Later, as the nutrient uptake rate catches up and gradually exceeds the growth rate, the plant element concentration rises again, finally reaching the limit value required for maximum yield. Any further increase in the supplies will not be reflected in the yield (luxury uptake), and if the supplies are excessive the yield will decline. Some nutrients can be accumulated in the plant to a great extent without causing any visible or measurable damage, while the optimum range for other elements is very narrow (SMITH 1962, KÁDÁR 1992).

According to KÁDÁR (1987) the following rules must be followed when taking plant samples: the plant should be in the early phases of development when the nutrient uptake rate is high but the nutrient effects are pronounced and any nutrient deficiency symptoms are clearly visible; the plant organ examined should be metabolically active (this is primarily true of the youngest fully developed leaves); sampling should take place just prior to or at the beginning of the intensive nutrient uptake period, so that any deficiencies in the nutrient status can be remedied by means of top dressing or leaf manure; the date of leaf sampling, the developmental stage of the plant, the plant height, the number of fully developed leaves and the sample mass should be recorded, i.e. the plant status at sampling should be described by as many parameters as possible. A sufficiently representative mean sample is required if the plant stand is to be reliably characterised.

Very few authors have reported on the fertilisation of hemp, either in Hungary or elsewhere. KÁDÁR and TÁRKÁNY (2003) found that the optimum nutrient supply levels for hemp were indicated by values of 150 mg kg^{-1} AL-P_2O_5 and 250–300 mg kg^{-1} AL-K_2O, with 100 kg ha^{-1} $year^{-1}$ N fertiliser. No significant decrease in yield was observed as the result of over-fertilisation. N fertilisation reduced the plant number, while N and K fertilisation led to longer, thicker stems and a higher fibre yield.

Work on the elaboration of a nutrient supply system and plant analysis method for hemp grown on chernozem meadow soil has been underway in Szarvas since 1990. In earlier reports, the most favourable supply levels for hemp were given as 110–130 mg kg^{-1} AL-P_2O_5 and 310–330 mg kg^{-1} AL-K_2O, with a N fertiliser rate of 80 kg ha^{-1} $year^{-1}$. The maximum nutrient uptake data of the stem yield were used to determine the specific nutrient uptake of fibre hemp. The following values were found for macronutrients: N 10–14 kg t^{-1}, P_2O_5 3.3–3.9 kg t^{-1}, K_2O 14–20 kg t^{-1}, CaO 14–16 kg t^{-1}, MgO 5–6 kg t^{-1} (5- 7).

In the present paper, nutrient supply limit values are reported for hemp leaf samples taken at the optimum date, based on the general rules of leaf analysis, and calculated for nine nutrients from the analytical data of one average and one dry year.

MATERIAL AND METHODS

Since 1990 a long-term, small-plot field experiment on the mineral fertilisation of a full crop rotation system involving four crops (annual legume, fibre hemp, spring cereal, hoed crop) each year has been underway in Szarvas on chernozem meadow soil (pH (KCl 5-5,2, humus).

In the first four-year cycle the optimum date for diagnostic plant analysis was determined from data on the dry matter accumulation, nutrient uptake rate and nutrient concentrations of fibre hemp.

The present paper reports the limit values for nutrient supplies to fibre hemp (*Cannabis sativa* L.) on the basis of the results achieved in 1999 (good water supplies) and 2003 (dry), which could provide a useful indication of nutrient deficiencies in plants.

All possible combinations of four levels of N, P and K were included, giving a total of 64 fertiliser treatments arranged in a split-split plot design with three replications on 192 plots, where the size of the split-split plot was 4×5=20 m^2. The fertilizer levels applied were N_0= 0, N_1= 80, N_2= 160, N_3= 240 kg N ha^{-1} $year^{-1}$ for nitrogen; P_0= 0, P_1= 100 kg ha^{-1} $year^{-1}$, P_2= 500 kg ha^{-1} in 1989, 1993 and 2001, P_3= 1000 kg ha^{-1} in 1989, 1993 and 2001 for phosphorus (P_2O_5); and K_0= 0, K_1= 300 kg ha^{-1} $year^{-1}$ from 1989–1992, 100 kg ha^{-1} $year^{-1}$ from 1993, K_2= 600 kg ha^{-1} in 1989 and 2001, 1000 kg ha^{-1} in 1993, K_3= 1200 kg ha^{-1} in 1989 and 2001, 1500 kg ha^{-1} in 1993 for potassium (K_2O). The high rates of P and K replenishment fertilisers were applied to ensure clearly distinguishable differences in the supply levels in the soil for the investigation of nutrient supply situations.

Nitrogen fertilizer was applied as ammonium nitrate, while the P and K fertilizers were broadcast in autumn prior to ploughing, in the form of superphosphate and potassium chloride.

The soil NO_3-N assessment was made by sampling the soil at depths of 0–20, 20–40 and 40–60 cm in autumn. The NO_3-N content was determined after extraction with 1 N KCl. The ammonium lactate (AL) method was used to determine the available phosphorus and potassium content of the soil.

The hemp varieties sown in the experiment were Kompolti in 1999 and Tiborszállási in 2003. In both years leaf samples for leaf analysis were taken in late May. The samples, consisting of the topmost fully developed pair of leaves from each plant on an area of 2×1 m per plot, were taken when the average plant height was 70–100 cm, the plants had 5–7 pairs of leaves and the hemp stand had a total air-dry mass of 2–5 t ha^{-1}.

After determining the fresh weight, the samples were dried in air until they reached the air-dry state, then in a drying cabinet at 105°C until constant weight in order to determine the dry matter mass. Analysis was carried out for nine elements: N, P, K, Ca, Mg, Fe, Mn, Cu and Zn. The determination of N, P and K was carried out after digestion first with sulphuric acid, then with hydrogen peroxide, using photometry at room temperature for N and P (at wavelengths of 640 nm and 400 nm, respectively) and flame photometry for K. The elements Ca, Mg, Fe, Mn, Cu and Zn were determined after hydrolysis with 2 N HCl in a closed system at 105°C, using an atomic absorption spectrometer (MOM). The plants were harvested with a sickle from the full net area of the plots (15,75 m^2), bound into sheaves and stacked to dry. The mass was recorded at a moisture content of 10 %. The mass data of the stem yield also include remnants of dried flowers, which remained on the tips of the stems even after the sheaves were moved.

From 1998 to 2003, the annual precipitation in three of the six years was less than the average of the previous 75 years. The second part of summer 1999 was wet, with a rainfall surplus of 183 mm. In summer 2003 there was a drought, with a rainfall deficiency of about 217 mm).

The results were statistically evaluated using analysis of variance. Data on the dry matter accumulation and nutrient uptake during the vegetation period were evaluated using analysis of variance for a single-factor random block design, after which the analysis of variance for the yield data of all 64 treatments were evaluated as a three-factor split-split plot design. Correlations between the yields and nutrient concentrations were examined by fitting envelope curves.

RESULTS AND DISCUSSIONS

Effect of N supply on the stem yield and leaf N % of hemp

The optimum date for leaf analysis in hemp was established in earlier experiments on the basis of dry matter accumulation and nutrient uptake. The results indicated that the best time for leaf analysis is when the hemp stand reaches a height of 70–100 cm and has 5–7 leaf pairs and a total dry matter mass of 2–5 t ha^{-1}.

The two years discussed in the present paper differed from each other in the NO_3-N reserves available the previous autumn and the rainfall supplies during the vegetation period. The effect of N supplies was clearly illustrated by the N concentrations recorded in leaf analysis in late May, which approached the 5 % level even at the N1 rate, averaged over the P and K treatments, and exceeded this level at the higher N2 and N3 rates. With an improvement in the N supplies, higher N contents were associated with higher stem yields, which exceeded

12 t ha $^{-1}$ in the wet year (1999), though in the dry year the stem yield was much lower, being only slightly over 6 t ha^{-1} averaged over the P and K treatments (Table 1). Based on the n=128 yield and N % data pairs for two years with different rainfall supplies, a leaf N concentration of 5–6 % was found to be optimum for the achievement of a high yield (in excess of 16 t ha^{-1}), if yield development was not limited by other factors, such as rainfall, during the vegetation period. Low or high concentrations, below or above this optimum value, may lead to yield depression. Excessive N supplies resulting in yield reduction were not observed in the present experiment (Fig 1).

Table 1

Effect of N supply on the stem yield an leaf N% of hemp (SZARVAS, 1999, 2003)

Examined parameters	NO$_3$-N kg ha^{-1} in 0-60 cm soil layer					Mean
	N_0	N_1	N_2	N_3	$LSD_{5\%}$	
	1999					
N supply	12	20	24	25	-	20,25
Stem yield t ha^{-1}	7,95	10,41	12,42	14,32	5,83	-
Leaf N%	3,86	4,75	5,37	5,54	1,5	4,88
	2003					
N supply	39	55	61	77	-	58
Stem yield t ha^{-1}	5,23	5,57	6,17	6,2	0,42	5,79
Leaf N%	4,64	4,99	5,15	5,15	-	4,98

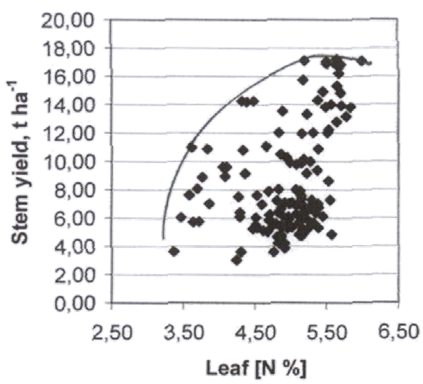

Fig 1

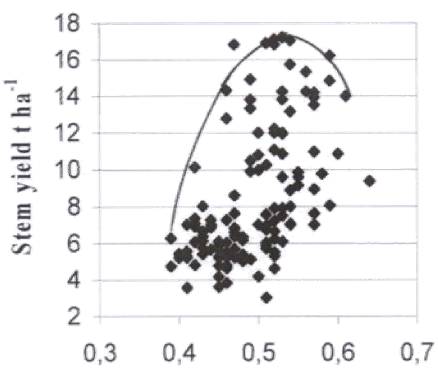

Fig 2

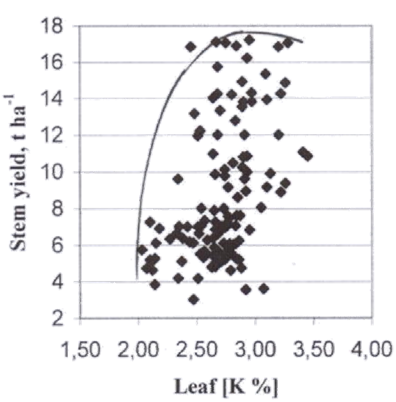

Fig 3

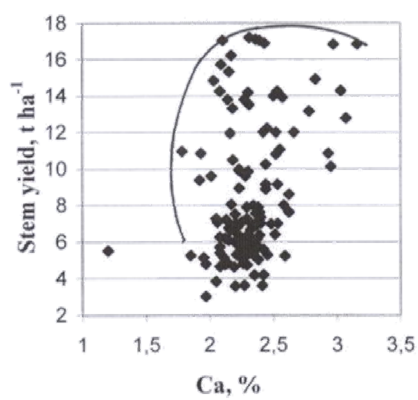

Fig 4

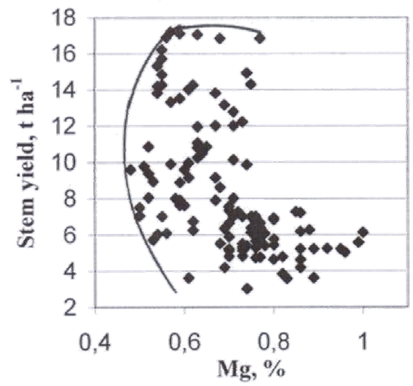

Fig 5

Fig 1-5. Relationship between the N, P, K, Ca and Mg concentration of the hemp leaf and the stem yield (SZARVAS, 2001-2004)

Effect of P supply on the stem yield and leaf P % of hemp

There was no great difference between the two years in the phosphorus supply level in the soil in autumn. In 1999, which had better water supplies, the average leaf P concentration was higher (0.52 %) than in the dry year of 2003 (0.45 %). The phosphorus concentration in hemp leaves at the date of leaf analysis gave a good indication of the phosphorus supply level. In 1999 the leaf P concentration at P supply levels higher than the P0 control (P1 = 175, P2 = 217, P3 = 267 mg AL-P_2O_5 kg^{-1}) was over 0.5 % for a stem yield of 12 t ha^{-1}, while in 2003 it only approached this level in the P3 = 339 mg AL-P_2O_5 kg^{-1} treatment (Table 2). Based on the n=128 yield and leaf concentration data pairs for the two experimental years, if a high stem yield is to be achieved, the optimum P concentration in the upper 5th–7th leaf pairs of hemp is 0.5–0.6 % (Fig 2). Concentrations above 0.6 % led to yield depression.

Table 2

Effect of supply on the stem yield and the leaf P% of hemp (SZARVAS, 1999, 2003)

Examined parameters	AL-P_2O_5 mg ha^{-1} in cultivated soil layer					Mean
	P_0	P_1	P_2	P_3	$LSD_{5\%}$	
			1999			
P supply	158	175	217	267	-	204,25
Stem yield t ha^{-1}	8,99	11,97	12,16	11,95	5,83	11,27
Leaf P%	0,49	0,51	0,52	0,57	-	0,52
			2003			
P supply	128	183	195	339	-	211,25
Stem yield t ha^{-1}	4,98	5,66	5,97	6,54	5,83	5,79
Leaf P%	0,43	0,44	0,45	0,48	0,04	0,45

Effect of K supply on the stem yield and leaf K % of hemp

In the year with better rainfall supplies (1999) the average potassium concentration in the uppermost 5th–7th leaf pairs of hemp was a little higher (2.87 %) than in the dry year of 2003 (2.55 %). In 1999 the stem yield was over 11 t ha^{-1} even at the K0 level. As the potassium supply level rose there was only a slight increase in the stem yield, averaged over the N and P treatments. Improved potassium supplies caused a significant increase in the K concentration compared with the control in both years at all the K rates. In 1999 the leaf K concentration was as high as 2.7 % even at the K0 level (290 mg AL-K_2O kg^{-1}), while in 2003 this concentration was only reached at the highest soil K rate (K3 = 465 mg AL-K_2O kg^{-1})

(Table 3).

Table 3

Effect of supply on the stem yield and the leaf K% of hemp (SZARVAS, 1999, 2003)

Examined parameters	AL-K_2O mg ha^{-1} in cultivated soil layer					Mean
	K_0	K_1	K_2	K_3	$LSD_{5\%}$	
	1999					
P supply	290	401	445	490	-	406
Stem yield t ha^{-1}	11,46	11,65	9,45	12,51	-	11,27
Leaf K%	2,72	3,02	2,8	2,92	0,17	2,87
	2003					
P supply	215	347	394	465	-	355,25
Stem yield t ha^{-1}	5,38	6,04	5,79	5,95	-	5,79
Leaf K%	2,22	2,56	2,62	2,78	0,2	2,55

Based on the n=128 yield and leaf concentration data pairs for the two experimental years, if a high stem yield is to be achieved, the optimum K concentration in the upper 5th–7th leaf pairs of hemp is 2.7–3.3 % (Fig 3).

In addition to the three major nutrients described above, investigations were also made on the relationship between the stem yield and the leaf contents of Ca, Mg, Mn, Fe, Zn and Cu. The results are in Table 4 and illustrated in Figures 6–9 and were used to determine the limit values for satisfactory supplies of these nutrients.

Table 4

Plant nutrient element status for hemp (SZARVAS, 1999, 2003)

Nutrients	Low	Optimum	High
N %	< 5	5-6	6 <
P %	< 0,5	0,5-0,6	0,6 <
K %	< 2,7	2,7-3,3	3,3 <
Ca %	< 2,4	2,4-3,0	3,0 <
Mg %	< 0,6	0,6-0,8	0,8 <
Fe $mgkg^{-1}$	< 65	65-105	105 <
Mn $mgkg^{-1}$	< 85	85-130	130 <
Zn $mgkg^{-1}$	< 25	25-40	40 <
Cu $mgkg^{-1}$	< 2,5	2,5-5	5 <

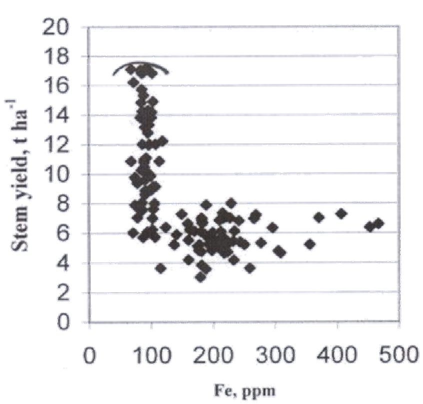

Fig 6

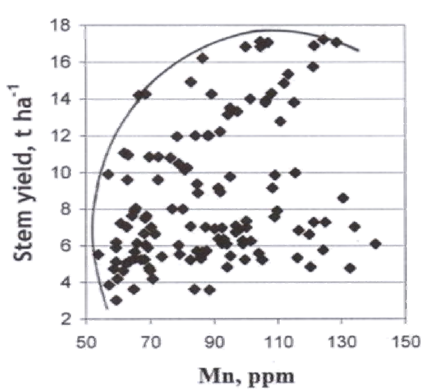

Fig 7

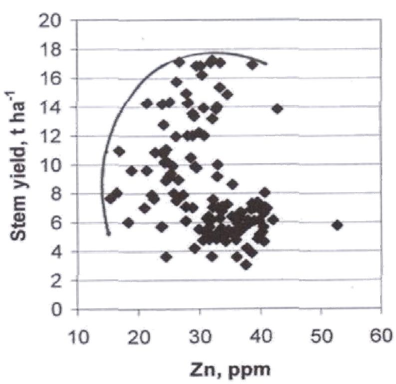

Fig 8

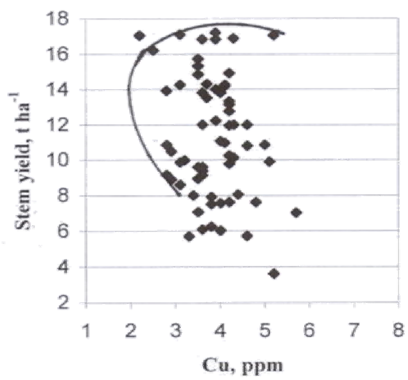

Fig 9

Fig 6-9. Relationship between the Fe, Mn, Zn and Cu concentration of the hemp leaf and the stem yield (SZARVAS, 2001-2004)

CONCLUSIONS

Nutrient supplies to hemp can be considered satisfactory if plant analysis reveals 5–6 % N, 0.5–0.6 % P and 2.7–3.3 % K, 2.4–3.0 % Ca, 0.6–0.8 % Mg, 65–105 mg kg^{-1} Fe, 85–130 mg kg^{-1} Mn, 25–40 mg kg^{-1} Zn and 2,5–5 mg kg^{-1} in the youngest fully developed (5th–7th) leaf pairs in late May.

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