

# Responses of Greenhouse-grown *Cannabis sativa* L. to Nitrogen, Phosphorus, and Potassium<sup>1</sup>

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## ABSTRACT

Growers of illegal *Cannabis sativa* L. use various cultural practices to maximize crop production. The objective of this study was to evaluate the morphological and biochemical responses of greenhouse grown *C. sativa* to soil incorporated N, P, and K as they reflect the geographical origin of *Cannabis* derivatives. Fertilizers were blended with Ap horizon soil from a Gilpin silt loam before placement in 12-cm pots.  $\text{NH}_4\text{NO}_3\text{-N}$  was applied at 0, 25, and 125 ppm. Phosphorus and K from superphosphate and KCl, respectively, were applied at 0, 50, and 150 ppm. Forty-five-day-old anthesis *Cannabis* plants were harvested and combined leaf and flower tissues were analyzed for cannabidiol (CBD) and  $\Delta^9$ -tetrahydrocannabinol ( $\Delta^9\text{THC}$ ). Nine essential elements were also measured in plant tissue. Plant growth, tissue yield, and concentration of CBD and  $\Delta^9\text{THC}$  were positively correlated with extractable  $\text{P}_2\text{O}_5$  ( $p < 0.01$ ). Phosphorus concentrations in tissue were similarly related to yield of dry matter and cannabinoid concentrations. Uptake of K was positively correlated with extractable  $\text{K}_2\text{O}$  across all treatment levels ( $r=0.40^{**}$ ), but was negatively correlated with tissue yield ( $r=-0.36^{**}$ ). Growth and tissue yields were negatively related to total plant N ( $p < 0.01$ ). Levels of extractable  $\text{P}_2\text{O}_5$ , Mn, B, and Mg were associated with specific concentration ranges for several plant elements plus  $\Delta^9\text{THC}$ . Thus, it was possible to partially characterize a soil by tissue analysis. For example, all of the plants grown on soil with less than 100 ppm of extractable  $\text{P}_2\text{O}_5$  contained less than 8,000 ppm  $\Delta^9\text{THC}$ . Usefulness of such relationships will be dependent upon extensive evaluation of *Cannabis* on different soils under various cultural conditions. At this time, the reliability required for determination of origin of *Cannabis* derivatives via chemical analysis does not exist when only essential elements and cannabinoids are considered.

**Additional index words:** Marihuana, Hemp, Narcotics, Drugs, Cannabinoids, *Cannabis* growth, Elemental content of *Cannabis*.

HEALTH problems are often associated with abuse of *Cannabis sativa* L. derivatives. The detrimental effects of *Cannabis* consumption on driving ability (NIDA, 1974) and on plasma testosterone concentration and oligospermia in young heterosexual men (Hofman, 1975) have been reported.

Decreased availability of *Cannabis* products through their confiscation or through on-site destruction of the plants may reduce the level of their abuse. Destruction of *C. sativa* can be accomplished by use of EPA-labeled chemicals or cultural techniques. However, it is difficult to determine the source of marihuana, hashish, or hash oil derived from clandestine world-wide plant-

ings of *C. sativa*. Analytical procedures that relate plant morphological and biochemical characteristics to the plant growth environment may make it possible to locate the general area of plant growth or even sur-reptitious *Cannabis* fields within such an area.

Coffman and Gentner (1975) grew *C. sativa* on 11 soils and observed significant relationships among several chemical characteristics of plants and soils. They found that extractable soil Mg and P were negatively correlated with leaf concentrations of  $\Delta^9$ -tetrahydrocannabinol ( $\Delta^9\text{THC}$ ) and cannabidiol (CBD), respectively. Cannabinols are nonnitrogenous compounds associated with the narcotic properties of *C. sativa* and have been described by Mechoulam et al. (1970). Soil-plant relationships must be ascertained which exhibit either a predictable variation or no variation in response to the application of agricultural chemicals in order for analyses of *Cannabis* derivatives to be useful for the determination of their origin. Growers of furtive fields of *Cannabis* are presently using modern agronomic techniques that involve pest control procedures and fertilizer applications to improve the quality and yield of their produce. The objective of this study was to determine the influence of soil incorporated N, P, and K on the morphological and chemical characteristics of greenhouse-grown *C. sativa*, as they reflect the origin of *Cannabis* derivatives.

## MATERIALS AND METHODS

Soil from the Ap horizon of a Gilpin loam (Typic Hapludult) was used in this investigation. Commercial fertilizers used were  $\text{NH}_4\text{NO}_3$ , superphosphate, and KCl. Nitrogen was applied at 0, 25, and 125 ppm; P and K were applied at 0, 50, and 150 ppm. Collection difficulties precluded accumulation of a sufficient quantity of soil to establish a complete  $3 \times 3 \times 3$  factorial experiment. Treatments are reported in Table 1. Soil and fertilizer were thoroughly mixed in a twin shell dry blender. Twelve-centimeter diameter tapered plastic pots were filled to 2.5 cm below the rim with the soil-fertilizer mixtures. Five *Cannabis* seeds of Afghan origin (P.I. 378939), were planted in each pot. Pots were arranged in the greenhouse in a randomized block design with three replicates. Seedlings were thinned to one plant per pot several days after germination. Plants were grown 45 days after germination under a 12-hour photoperiod with ambient light supplemented by high intensity mercury vapor lamps (approximate intensity 27,000 lux). Plants were in flower when harvested. Leaves and flowers were separated from the stem and rinsed with distilled water. Tissues were lyophilized for 48 hours before grinding and chloroform extraction for gas chromatographic analysis following methods reported by Coffman and Gentner (1975). All analyses were performed on combined leaves of all ages plus flowers, hereafter referred to as combined leaf tissue.

Elemental analysis of combined leaf tissue was performed by X-ray fluorescence and emission spectroscopic methods. A Diano<sup>3</sup> X-ray milliprobe with a He path was employed in the former procedure and a 3.5-meter Ebert Arc Jarrell-Ash Spectrograph was used for the latter procedure. Total N was determined by the semimicro Kjeldahl method with N measurement by a Technicon Autoanalyzer.

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<sup>3</sup>Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the USDA, and does not imply its approval to the exclusion of other product that may also be suitable.

After 10 weeks of soil-fertilizer equilibrium at field capacity, available  $P_2O_5$ ,  $K_2O$ , Mg, Ca, Mn, Zn, B, and pH were determined by the University of Maryland Soil Testing Laboratory following published procedures (Method for testing soil samples at the University of Maryland Soil Testing Laboratory, University of Maryland, Mimeo, No. 37).

## RESULTS AND DISCUSSION

### Elemental Analyses of Soil and Plants

Results of soil analyses are presented in Table 1. Significant differences were found among treatments for all measurements except Ca and pH which ranged from 950 to 1,500 ppm and 6.1 to 6.6, respectively. Applied P was very significantly correlated with extractable P and Mn ( $r = 0.94$  and  $-0.66$ , respectively).

Results of elemental analyses of combined leaf tissue are presented in Table 2. Highest concentrations of P and K were found in plants grown in soils which had received 150 ppm of the respective element.

Tissue Mn concentrations exceeded 1,000 ppm for plants subjected to 11 of the 21 treatments. Labanaus-

kas (1966) indicated that Mn concentrations exceeding 1,000 ppm were generally considered toxic to plant growth. However, the plants used in this study did not exhibit characteristic visual Mn toxicity symptoms (i.e., interveinal chlorosis of younger leaves).

Extractable soil Mg levels of 9 to 21 ppm (Table 1) were within the deficiency range for field crops, and apparently caused the development of visual Mg deficiency symptoms (interveinal chlorosis of older leaves) in most plants by harvest time. Plant Mg concentrations of 0.22 to 0.49% (Table 2) were relatively low for optimum growth of dicots. Jones (1967) reported Mg sufficiency concentration ranges in alfalfa and soybeans to be 0.31 to 1.00 and 0.26 to 1.00 %, respectively.

Correlations between available soil elements and tissue element concentrations are presented in Table 3. Soil  $K_2O$  and  $P_2O_5$  were positively correlated with tissue K and P concentrations, respectively. Plant K, N, Ca, Mn, and B concentrations were negatively correlated with soil  $P_2O_5$ .

Extractable Mn was positively correlated with plant K, N, Ca, Mn, and B, and negatively correlated with plant P. Plant Zn, Mg, Mn, and B were all negatively correlated with soil Mg.

Soil Ca was negatively correlated with plant Mn and B, whereas extractable B was positively correlated with plant Zn, N, and B. Available Zn was positively correlated with plant N. Soil pH was positively correlated with plant K and Ca and negatively correlated with plant Mg.

Correlations among elements in plant tissue are presented in Table 4. Zn was positively correlated with five other elements, including Fe and Mn. We previously reported (Coffman and Gentner 1975) similar correlations between Zn and Fe, and Zn and Mn in *C. sativa* leaves. The possible role of Fe or Mn as regulators of enzyme systems associated with cannabinoid biosynthesis has been mentioned by Latta and Eaton (1974). Correlations between Zn and B were not found in our previous study, but have been reported in maize tissue by Agboola and Corey (1973).

Manganese was positively correlated with Zn plus five other elements. Agboola and Corey (1973) re-

Table 1. Treatments and corresponding soil chemical characteristics.

Treatment numbers	Applied			Extracted						
	N	P	K	Mg	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Mn	Zn	B	pH
	ppm									
1	0	0	0	9 i*	45 k	44 m	210 a	9 i	0.5 a	6.3ns
2	0	50	0	10 h	69 i	42 m	122 ef	9 i	0.5 a	6.2
3	0	150	0	11 gh	150 d	42 m	135 de	9 i	0.4 c	6.2
4	0	0	50	9 i	41 l	66 i	192 ab	8 j	0.4 c	6.4
5	0	0	150	9 i	48 k	105 d	180 b	12 f	0.4 c	6.3
6	25	0	0	12 fg	35 m	50 k	160 c	9 i	0.4 c	6.3
7	25	50	0	11 gh	60 j	48 kl	90 hi	10 h	0.4 c	6.3
8	25	150	0	12 fg	137 e	44 m	76 ij	10 h	0.4 c	6.2
9	25	0	50	13 ef	35 m	79 g	182 b	8 j	0.3 d	6.3
10	25	0	150	12 fg	31 n	114 c	135 de	8 j	0.3 d	6.2
11	125	0	0	11 gh	30 n	45 lm	152 cd	16 c	0.3 d	6.2
12	125	50	0	16 c	92 g	61 j	100 gh	15 d	0.5 a	6.5
13	125	150	0	21 a	197 a	69 i	84 h-j	13 e	0.4 c	6.3
14	125	0	50	16 cd	68 i	86 f	110 fg	11 g	0.4 c	6.4
15	125	0	150	21 a	75 h	134 a	130 e	13 e	0.4 c	6.5
16	0	50	50	18 b	106 f	74 h	128 ef	29 a	0.4 c	6.6
17	0	50	150	13 ef	69 i	100 e	100 gh	8 j	0.3 d	6.3
18	0	150	50	16 cd	160 c	74 h	85 hi	8 j	0.4 c	6.1
19	0	150	150	17 c	167 b	120 b	78 ij	9 i	0.2 e	6.4
20	25	50	50	15 d	70 i	75 h	65 j	12 f	0.1 f	6.3
21	25	50	150	14 e	71 hi	122 b	100 gh	26 b	0.4 c	6.3

\* Values within a column not followed by the same letter differ significantly at the 5% level.

Table 2. Mean element content of *C. sativa* in combined leaf tissue.

Treatment	Mg	P	K	Ca	N	Mn	Cu	B	Fe
	%								
	ppm								
1	0.38 a-d*	0.35 c-h	2.1 c-g	4.6 ab	4.5 a-c	1,767 a	106 b-e	282 b-e	101 a-c
2	0.35 b-e	0.49 c-h	2.0 c-g	2.0 e-h	4.9 a-c	655 f-h	92 b-f	350 a-b	71 b-d
3	0.46 ab	0.61 ab	1.6 g	1.6 gh	3.8 c-e	483 hi	93 b-f	167 e-i	85 b-d
4	0.32 c-f	0.28 f-h	2.5 a-c	4.4 a-c	4.5 a-c	1,210 b-d	95 b-f	290 b-d	84 b-d
5	0.35 b-e	0.23 gh	2.8 a	4.0 a-d	4.6 a-c	1,509 ab	145 a	400 a	76 b-d
6	0.34 b-f	0.30 e-h	1.5 g	4.6 ab	4.1 bc	1,717 a	67 f	250 b-g	85 b-d
7	0.49 a	0.34 c-h	2.1 c-g	2.4 d-h	4.6 a-c	1,076 c-e	124 ab	312 a-c	99 a-c
8	0.35 b-e	0.67 a	1.7 e-g	1.0 h	5.4 a	638 gh	108 b-d	200 c-i	94 a-d
9	0.29 d-f	0.33 c-h	2.3 a-e	3.7 b-e	4.5 a-c	1,355 bc	72 d-f	240 b-g	83 b-d
10	0.34 b-f	0.29 e-h	2.3 a-e	3.4 b-g	4.6 a-c	1,761 a	108 bc	257 b-g	103 ab
11	0.30 c-f	0.21 h	1.5 g	4.0 a-d	3.8 cd	1,011 c-g	84 c-f	260 b-f	84 b-d
12	0.35 b-e	0.38 c-h	1.9 c-g	3.5 b-f	4.3 a-c	863 d-h	95 b-f	230 c-h	89 a-d
13	0.31 c-f	0.43 c-f	1.7 e-g	1.6 gh	4.1 bc	226 i	71 ef	90 i	80 b-d
14	0.22 f	0.31 d-h	2.7 ab	4.4 a-c	4.7 a-c	796 e-h	91 b-f	165 e-i	74 b-d
15	0.35 b-f	0.27 f-h	2.1 c-g	5.7 a	5.1 ab	1,035 c-f	94 b-f	185 d-i	94 a-d
16	0.24 ef	0.41 c-g	2.2 b-f	3.3 b-g	3.7 c-e	1,029 c-f	108 b-d	150 f-i	127 a
17	0.28 d-f	0.30 e-h	2.0 c-g	2.9 b-g	2.7 ef	791 e-h	80 c-f	120 hi	62 cd
18	0.30 d-f	0.44 c-f	1.6 fg	1.9 f-h	2.8 d-f	775 e-h	81 c-f	230 c-h	95 a-c
19	0.37 b-d	0.49 b-d	2.2 a-e	1.7 f-h	2.5 f	670 f-h	81 c-f	160 f-i	85 b-d
20	0.35 b-f	0.37 c-h	1.9 df	1.8 f-h	2.9 d-f	588 h	73 c-f	140 g-i	54 d
21	0.42 a-c	0.46 b-c	2.0 c-g	2.7 c-h	3.0 d-f	1,150 b-e	109 bc	172 e-i	67 b-d

\* Values within a column not followed by the same letter differ significantly at the 5% level.

Table 3. Simple correlations of several soil parameters with *C. sativa* combined leaf elements.

Soil variable	Tissue variable							
	N	K	Ca	Mg	B	Zn	Mn	P
Mn	0.34**	0.28*	0.58*	--	0.48**	--	0.68*	-0.39**
P <sub>2</sub> O <sub>5</sub>	-0.26**	-0.30*	-0.58**	--	-0.46**	--	-0.70**	0.59**
Mg	--	--	--	-0.27*	-0.62**	-0.34**	-0.44**	--
Ca	--	--	--	--	-0.32*	--	-0.27*	--
B	0.46**	--	--	--	0.29*	0.28*	--	--
pH	--	0.30*	0.29*	-0.30*	--	--	--	--
K <sub>2</sub> O	--	0.40*	--	--	--	--	--	--
Zn	0.40**	--	--	--	--	--	--	--

\*,\*\* Significant at the 5 and 1% levels, respectively.

Table 4. Simple correlations among several elements in *C. sativa* combined leaf tissue.

	Zn	K	N	P	Ca	B
Mn	0.30*	0.28*	0.31*	-0.41**	0.60**	0.47**
Mg	0.26*	--	--	--	--	0.30*
Fe	0.46**	--	0.32*	--	--	--
N	0.40**	0.28*	--	--	0.29*	--
Ca	--	0.29*	--	-0.54**	--	--
B	0.51**	0.28*	0.46**	--	--	--

\*,\*\* Significant at the 5 and 1% levels, respectively.

Table 5. Mean morphological and biochemical characteristics of *C. sativa* plants.

No.	Treatment				28 day height	Harvest height	Dry weight	CBD	$\Delta^9$ THC	Total yield $\Delta^9$ THC
	N†	P	K							
				cm		g		ppm		mg
1	L	L	L	11.0 f*	25.3 j	0.59 e	210ns	4,676ns	2.7 de	
2	L	M	L	19.3 a-f	63.3 b-g	2.91 d	2,532	4,707	13.7 b-e	
3	L	H	L	23.7 a-d	66.3 a-f	4.55 bc	463	8,948	40.4 a-c	
4	L	L	M	14.0 d-f	51.7 e-j	1.15 e	528	4,972	5.6 c-e	
5	L	L	H	26.7 ab	61.0 b-h	0.91 e	183	4,516	4.0 de	
6	M	L	L	11.7 f	33.7 h-j	0.71 e	466	4,052	2.8 de	
7	M	M	L	22.7 a-e	76.0 a-e	3.96 cd	864	4,788	19.0 b-e	
8	M	H	L	14.0 d-f	55.3 d-i	3.41 cd	2,269	9,251	31.4 a-e	
9	M	L	M	18.7 b-f	43.0 f-j	1.06 e	652	3,362	3.6 de	
10	M	L	H	14.3 d-f	27.7 j	0.75 e	356	5,768	0.4 e	
11	H	L	L	16.3 c-f	37.0 g-j	0.75 e	342	4,537	0.3 e	
12	H	M	L	27.6 ab	84.7 ab	5.33 ab	389	2,434	12.8 b-e	
13	H	H	L	24.3 a-c	74.7 a-e	6.58 a	2,374	9,310	61.2 a	
14	H	L	M	13.0 ef	39.0 g-j	1.42 e	1,168	4,681	6.7 c-e	
15	H	L	H	14.0 d-f	36.7 h-j	0.67 e	504	5,339	3.6 de	
16	L	M	M	20.7 a-f	57.7 c-i	3.41 cd	712	8,768	30.0 a-e	
17	L	M	H	27.3 ab	90.7 a	5.32 ab	614	7,885	42.0 ab	
18	L	H	M	28.7 a	91.7 a	5.54 ab	2,190	9,472	52.6 a	
19	L	H	H	23.0 a-d	75.0 a-e	5.67 ab	866	4,968	28.3 a-e	
20	M	M	M	24.7 a-c	79.7 a-d	5.34 ab	1,398	7,146	37.9 a-d	
21	M	M	H	27.3 ab	83.0 a-c	5.44 ab	410	4,891	26.6 a-e	

\* Values within a column not followed by the same letter differ significantly at the 5% level.  
 † N; L = 0, M = 25, H = 125 ppm applied element.  
 P, K; L = 0, M = 50, H = 150 ppm applied element.

ported positive correlations between Mn and Ca, and Mn and B in maize tissue. A negative correlation between Mn and P (Table 4), reflected decreased plant Mn with higher levels of applied P and P uptake (Tables, 2, 3).

Total plant N was positively correlated with six elements (Table 4), relationships that were not observed in our earlier study (Coffman and Gentner, 1975). Although N and K were correlated in tissue, no relationship was detected between soil K and plant N (Table 3). Soil Zn, B, and Mn were all positively correlated with plant N (Table 3).

Plant Mg and K were positively correlated with B (Table 4). Similar relationships were also found in our earlier *Cannabis* study (Coffman and Gentner, 1975), although B and K were negatively related therein.

Plant K was positively correlated with B, Ca, Mn, and N (Table 4). Soil Mn was positively correlated with plant K (Table 3). Agboola and Corey (1973) reported a negative correlation between K and Ca in maize leaves.

Plant P was positively correlated with Ca and negatively correlated with Mn (Table 4). Soil P<sub>2</sub>O<sub>5</sub> and plant Ca were also negatively correlated (Table 3). These relationships reflected a growth response to applied P and carbohydrate dilution of plant Ca and Mn. Other tissue element correlations are presented in Table 4.

### Growth of *C. sativa*

Mean height and tissue yield measurements are presented in Table 5. These parameters were positively correlated with extractable P<sub>2</sub>O<sub>5</sub> (Table 6) and with applied P ( $r = 0.47, * 0.61, **$  and  $0.78**$  for 28 days and harvest height measurements, and dry tissue yield, respectively). Neither applied N and K nor extractable K were statistically related to plant growth and tissue yield. The largest plants obtained in this study were associated with treatments 12, 13, and 17 through 21 (Table 5). Plants generally grew taller and were heavier with increased P but exhibited a greater growth response when increased P was accompanied by high levels of applied N or by low or moderate N applications and moderate or high K applications.

Extractable Ca and Mg were positively correlated with yield of dry tissue (Table 6). These relationships were probably more reflective of a yield response to P because extractable P<sub>2</sub>O<sub>5</sub> was positively correlated with soil Ca and Mg ( $r = 0.35, ** 0.54, **$  respectively). Plant Ca was negatively correlated with plant height and yield (Table 7). This relationship appears to contradict the soil Ca plant growth propinquity shown in Table 6. However, plant growth response to P may have diluted plant Ca concentrations and created an inverse relationship between Ca concentration and growth.

Soil Mn was negatively correlated with plant growth and tissue yield (Table 6), suggesting that the high Mn levels in the soil had deleterious effects on plant performance even though there were no obvious toxicity symptoms. Tissue Mn levels were also negatively correlated with plant growth and yield of dry matter (Table 7). However, growth response to applied P probably caused a carbohydrate dilution of Mn, and contributed to the development of the negative correlation.

**Table 6.** Simple correlations among extractable soil elements and growth and cannabinoid content of *C. sativa*.

Soil variable	Plant variable				
	Dry weight	28-day height	Harvest height	[CBD]	[ $\Delta^9$ THC]
P <sub>2</sub> O <sub>5</sub>	0.71**	0.35**	0.47**	0.33**	0.38**
Mn	-0.76**	-0.38**	-0.58**	--	--
Ca	0.32**	0.26*	--	--	--
Mg	0.40**	--	--	--	--

\*,\*\* Significant at the 5 and 1% levels, respectively.

Nitrogen, B, and K of combined leaf tissue were negatively correlated with plant growth and/or dry tissue yield (Table 7). We found in our study (Coffman and Gentner, 1975) that plant N was negatively correlated with *Cannabis* growth, whereas plant K was positively correlated with tissue yield. Tissue P levels were positively correlated with dry matter yield. Phosphorus was consistently associated with increased plant growth and tissue yield, although there were no visible P deficiency symptoms such as purpling of petioles or leaf veins for the low P treatment.

### Cannabinoid Content of Tissue

Concentration means of CBD and  $\Delta^9$ THC ranged from 183 to 2,532 ppm and 2,434 to 9,472 ppm, respectively, but did not differ significantly among treatments (Table 5). Mean total yields of  $\Delta^9$ THC ranged from 0.3 mg to 61.2 mg/plant and were significantly different among treatments. The significance of these differences was largely due to growth responses to P. Total  $\Delta^9$ THC yield was significantly correlated with soil P<sub>2</sub>O<sub>5</sub> and applied P ( $r = 0.82, ** 0.84, **$  respectively). Concentrations of CBD and  $\Delta^9$ THC were both positively correlated with soil P<sub>2</sub>O<sub>5</sub> (Table 6) and plant P (Table 7).

Plant Mn and Ca were negatively correlated with CBD and  $\Delta^9$ THC concentrations (Table 7). These relationships probably reflected the influence of P on cannabinoid concentrations and on Mn and Ca levels in the plants. Plant B and Zn were also negatively correlated with concentration of  $\Delta^9$ THC. The biochemical mechanisms responsible for synthesis of cannabinoids are not clearly understood; therefore, we cannot yet explain how previously discussed elements affect cannabinoid production. Phosphorus may be involved in cannabinoid biosynthesis via the interaction of geraniol phosphate and olivetol (Mechoulam, 1973). The other elements may affect related enzymatic reactions.

### Determination of Geographic Origin

Novotny et al. (1976) reported that marihuana from different origins could be differentiated by highly specific gas-chromatographic methods when non-cannabinoid compounds were characterized. However, they have neither statistically analyzed their results nor evaluated the effects of plant processing and storage on the stability of the organic constituents of *Cannabis*. Decreased cannabinoid concentrations have been reported in leaf tissue exposed to varied temperatures over several time periods (Coffman and Gentner, 1974). Nevertheless, continued investigations involving the organic and inorganic constituents of *Cannabis*

**Table 7.** Simple correlations among growth, cannabinoid content, and combined leaf element concentrations of *C. sativa*.

Elements	Plant variable				
	Dry weight	[ $\Delta^9$ THC]	[CBD]	28-day height	Harvest height
Mn	-0.68**	-0.33**	-0.31*	-0.34**	-0.48**
Ca	-0.64**	-0.34**	-0.24*	-0.34**	-0.46**
N	-0.59**	--	--	-0.53**	-0.44**
P	0.41**	0.26*	0.36**	--	--
B	-0.50**	-0.34**	--	--	--
Zn	--	-0.24*	--	--	--
K	-0.36**	--	--	--	--

\*,\*\* Significant at the 5 and 1% levels, respectively.

**Table 8.** Percentage of all plants having combined leaf element concentrations related to level of extractable soil P<sub>2</sub>O<sub>5</sub>, Mn, B, and Mg.

Leaf element concentrations		
Soil P <sub>2</sub> O <sub>5</sub>		
< 50 ppm†		> 50 ppm
72% > 4% Ca‡		86% < 4% Ca
86% ≥ 250 ppm B		86% < 240 ppm B
86% > 1,200 ppm Mn		100% < 1,200 ppm Mn
< 100 ppm		> 100 ppm
100% < 8,000 ppm [ $\Delta^9$ THC]		83% > 8,000 ppm [ $\Delta^9$ THC]
Soil Mn		
≤ 100 ppm		> 100 ppm
89% ≤ 3% Ca		83% > 3% Ca
89% < 240 ppm B		67% ≥ 240 ppm B
78% < 1,000 ppm Mn		75% > 1,000 ppm Mn
Soil B		
< 0.4 ppm		> 0.4 ppm
67% < 4% N		70% > 4% N
84% < 90 ppm Zn		80% > 90 ppm Zn
Soil Mg		
≤ 13 ppm		> 13 ppm
75% ≥ 240 ppm B		100% < 240 ppm B
≤ 14 ppm		> 14 ppm
70% > 1,000 ppm Mn		75% < 1,000 ppm Mn

† Read-less than 50 ppm extractable P<sub>2</sub>O<sub>5</sub>.‡ Read-72% of plants grown on soil having < 50 ppm extractable P<sub>2</sub>O<sub>5</sub> contained more than 4% Ca in combined leaf tissue.

derivatives may make possible the determination of their origin by chemical analyses.

Table 8 shows relationships among several plant (combined leaf tissue) and soil analyses. Extractable P levels (as P<sub>2</sub>O<sub>5</sub>) of 50 and 100 ppm were associated with specific concentration ranges of Ca, B, Mn, and  $\Delta^9$ THC. Extractable Mn, B, and Mg levels were also related to specific concentration ranges of several elements. Thus, it was possible to partially characterize a soil by tissue analyses. For example, marihuana containing 4.1 % Ca, 300 ppm B, 1,250 ppm Mn, and 100 ppm Zn would probably have been derived from plants grown in soil having less than 50 ppm P<sub>2</sub>O<sub>5</sub>, more than 100 ppm Mn, over 0.4 ppm B, and less than 13 ppm Mg. These relationships are not without exception in this study, as demonstrated by the use of percentages of plants having certain elemental concentrations relative to specific soil element levels.

*Cannabis* appears to be a Mn accumulator. Therefore, marihuana containing high amounts of Mn may

indicate that it was grown on soils developed from material high in Mn. The soil used herein was developed from shale that contains pockets of Mn ore.

Knowledge of the chemical characteristics of soils or geologic materials is necessary for information of this nature to be useful for the determination of the origin of marihuana. In addition, accumulation of specific elements by *Cannabis* may be influenced by other environmental factors. Furthermore, genetic characteristics of *Cannabis* may also affect elemental uptake.

Additional studies should involve nonessential elements in both plants and soils because the reliability required for determination of the origin of marihuana via chemical analysis does not appear to exist when only essential elements are considered.

### SUMMARY

Growth of *C. sativa*, concentration of the hallucinogen  $\Delta^9$ THC, and yield of  $\Delta^9$ THC were positively related to soil P levels in a greenhouse study employing anthesis 45-day-old plants. There were no significant growth or cannabinoid responses to varied rates of applied N and K, although maximum plant growth and  $\Delta^9$ THC yields were associated with soil P in conjunction with high N or moderate to high K levels in the soil. *C. sativa* plants accumulated Mn up to 1,800 ppm under low P without exhibiting visual toxicity symptoms although plant and soil Mn concentrations were negatively correlated with plant growth.

Levels of several elements in leaf tissue were shown to be related to soil  $P_2O_5$ , Mn, B, and Mg concentra-

tions, suggesting an approach to determination of origin of *Cannabis* derivatives by their chemical analyses.

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