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The Effects of Fertilization and Manuring on the Content of Some Nutrients in Potato (var. Provita)

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ABSTRACT

The effects of fertilization and manuring on the content of some nutrients in potato (var. Provita) were studied by agronomic field experiments and chemical analysis. The different treatments included the application of 53·9 tonnes ha^{-1} compost manure with and without bio-dynamic sprays, 30 tonnes ha^{-1} raw manure alone, 15 tonnes ha^{-1} raw manure in combination with 228 kg ha^{-1} inorganic NPK fertilizer, 456 kg ha^{-1} inorganic NPK fertilizer alone, 908 kg ha^{-1} inorganic NPK fertilizer with and without 369 kg ha^{-1} ammonium nitrate. A control variant was left unfertilized. The potato dry matter content increased due to the application of inorganic fertilizer. There was only 1·5% increase in protein content, when ammonium nitrate was included with a higher amount of inorganic NPK fertilizer. Compost manure in comparison with raw manure was more effective for the improvement of protein content. We did not find any significant differences in the concentrations of fat, dietary fibre and crude fibre between samples treated with organic manure and inorganic fertilizer. The content of starch increased with a higher application of inorganic NPK fertilizer. The inclusion of bio-dynamic preparations and sprays with organic manure did not alter significantly the content of trace elements except zinc which was 25% lower when compared to the sample treated with organic manure and bio-dynamic preparations. Iron content was 11–45% lower in inorganically fertilized potato samples than those treated with organic manure. The content of zinc was lower in samples treated with a higher amount of inorganic NPK fertilizer. Inclusion of inorganic NPK fertilizer along with raw manure decreased the content of iron, copper and zinc. Higher application of inorganic NPK fertilizer increased the content of iron but decreased the zinc content and *the concentrations of copper and manganese remained unchanged. The study indicates a complex pattern of trace element contents due to the application of different manuring and fertilization techniques.*

INTRODUCTION

Potato is cultivated and consumed as a main basic food in at least 75 countries (FAO, 1986). It has become an important staple food also in northern Europe, partly due to the short period of maturity to harvest (60 days). During 1985 an area of about 29 000 ha was utilized for cultivation of potato for food purposes and 9700 ha was used for the cultivation of potato for industrial usage. Yearly import of potatoes to Sweden, to be used as food, is about 11 000 tonnes. Besides a considerable amount of potato starch (20 500 tonnes) and other dried potato products are imported to Sweden every year for use in industry. The average per capita consumption of potato in Sweden is about 85 kg per year in various forms (Department of Agriculture of Sweden, 1982–84).

Potato is an important source of digestible carbohydrates, dietary fibre, vitamin C, and minerals like calcium, potassium, iron and zinc. Boiled (unpeeled) potato tuber is a good source of water-soluble vitamins (Finglas & Faulks, 1984). It contains very low amounts of heavy metals (Ocker *et al.*, 1984). A typical daily intake of 200 g potato is estimated to supply 172 kcal of energy, 3·8 g of protein, 36·6 g of carbohydrate, 1·2 mg of iron, 18 mg of copper, 0·82 mg of zinc, 0·44 mg of calcium, 48 mg of magnesium and 90 mg of phosphorus (Swedish National Food Administration, Livsmedelskonsumtion, 1984). Thus, potato contributes significantly to daily requirements of iron, magnesium and phosphorus. Increasing the yield of high quality potato which can supply enough nutrients has been the aim of prime importance to agriculturists and plant breeders. Consequently, the cultivation practices include intensive use of artificial inorganic fertilizers, insecticides, pesticides and occasionally also chemicals which inhibit germination of potatoes during storage. The effects of inorganic fertilization on the content of various nutrients in potato have been studied previously (Holm *et al.*, 1974; Munoz & Wieczorak, 1978; Pettersson *et al.*, 1979; Klien *et al.*, 1980; Trehan *et al.*, 1981).

The content of nutrients in potato depends on the type of soil in which it is produced, mode of cultivation, climatic conditions, state of maturity at harvest, conditions of storage, mode of processing and way of cooking. The addition of small amounts of trace elements along with inorganic fertilizers improves the trace element content in the soil. But the amount already present in the soil is more important. The availability of nutrient elements to the plants depends on the soil pH (Lutz *et al.*, 1972). The uptake can be stimulated by lowering the soil pH, but this is not applicable to all elements (molybdenum and selenium are some exceptions). Sarkar and Wyn Jones (1982*a*) studied the effect of risosphere pH on the uptake of iron, manganese and zinc by dwarf beans and found that their contents were inversely proportional to the risosphere pH.

The addition of too large amounts of inorganic elements to the soil may damage the soil structure and its biological activity. In view of the negative effect of the increased usage of inorganic fertilizers on the environment and public health, many investigations are being carried out in order to determine if alternative cultivation methods, where organic manuring and biological methods of insect and pest control is practised, could yield at least an equivalent quantity of crops retaining acceptable quality.

The present paper deals with an investigation of the effects of various manuring and fertilization practices on the nutritional quality of potatoes. The effects of compost manure with and without bio-dynamic sprays, raw manure alone, raw manure in combination with inorganic fertilizer, inorganic fertilization alone and addition of ammonium nitrate along with inorganic fertilizer were studied.

MATERIALS AND METHODS

Experimental design

The field experiments were carried out during May–September 1986 on a clay-loam soil in Järna, situated between 59° 09″ North latitude and 17° 30″ East longitude at a height of 10 m above the sea level in Sweden. The eight different fertilizer treatments were performed on a 48 m × 24 m field divided into eight equal plots. Each plot was subdivided into subplots of 36 m^2 and each treatment was performed on four subplots.

Fertilization scheme

The amount and type of manures and fertilizers applied are presented in Table 1. The content of some elements in the different preparations are given in Table 2.

Chemical analysis

Fifteen potato tubers from each subplot were collected, cleaned with distilled water and rinsed with deionized water and dried at room

TABLE 1
Amounts of Manures and Fertilizers Applied to the Test Potato Tubers and the Respective Soil pH

Variant	*Compost manure* ($t\ ha^{-1}$)	*Raw manure* ($t\ ha^{-1}$)	*Urine (pig)* ($t\ ha^{-1}$)	*Inorganic (NPK)* ($kg\ ha^{-1}$)	*Ammonium nitrate* ($kg\ ha^{-1}$)	*Soil pH*
K1[a]	53·9		8·3			6·7
K2[b]	53·9		8·3			6·4
K3		30	8·3			6·5
K4		15	4·2	228		6·4
K5	Unfertilized control					6·4
K6				456		6·2
K7				908		6·3
K8				908	369	6·2

NPK (11-5-18): 3·4% NO_3—N, 7–8% NH_4—N, 5% P, 18% K, 0·4% Ca, 2% Mg, 10–11% S, 1% Cl, 0·1% Mn, 0·05% Cu, 0·03% B, 0·2% Fe, 0·03% Zn, 0·002% Mo.
[a] Treated with bio-dynamic preparation 502-507 and bio-dynamic sprays 500 & 501 (Koepf *et al.* 1977).
[b] Treated with bio-dynamic preparation 502-507.

temperature for an hour. The whole tubers with peels were homogenised using a laboratory homogenizer (Ultra Turrax, Jarke & Kunkel, Staufen, FRG) and lyophilized, then stored in a desiccator before further analysis.

Nitrogen was assayed by the Kjeldahl method (Kjeltec, Tecator AB, Höganäs, Sweden) and the amount of protein calculated as 6·25 × N. Dry matter content was assayed according to the AOAC (Association of the

TABLE 2
Amount ($kg\,ha^{-1}$) of Some Minerals and Trace Elements Present in the Manures and Fertilizers Used for the Field Experiment
(Data on the amount of copper, iron, zinc and manganese in the organic raw manure were not measured)

Variant	*N*	*P*	*K*	*Cu*	*Fe*	*Zn*	*Mn*
K1	95	27	82				
K2	95	27	82				
K3	172	34	132				
K4	110	28	107	0·11	0·46	0·07	0·23
K5	Unfertilized control sample						
K6	50	23	82	0·23	0·91	0·14	0·46
K7	100	45	163	0·45	1·82	0·27	0·91
K8	200	45	163	0·45	1·82	0·27	0·97

Official Analytical Chemists, VA, USA) method 14004 of 1984. Fat analysis was performed gravimetrically after extraction with petroleum-ether, according to the method described by Croon and Fuchs (1980). The determination of the quantity of starch was performed by enzymatic and colorimetric methods described by Holm *et al.* (1985 and 1986). The content of dietary fibre was analysed gravimetrically after solubilization of the protein and starch with enzymes as described by Asp *et al.* (1983) and the crude fibre was determined by Tecator's method (Tecator AB, Höganäs, Sweden. Application note No. AN 01/78, 15 March 1978).

Trace element analysis

Some 0·5 g of each freeze-dried sample were wet digested using a mixture of 4 ml of conc. HNO_3 and 1 ml of 70% $HClO_4$. This method was adopted based on the methodological experiments discussed under 'Results'. Concentrations of zinc, copper, iron and manganese were determined using atomic absorption spectrophotometry (Varian Techtron AA5, Victoria, Australia) with air-acetylene flame having a deuterium background corrector. Sample solutions were diluted (1/5) with demineralized water. Commercially available standard solutions (BDH chemicals, Poole, UK) were used to construct standard curves. Duplicate analyses of each sample were performed every time.

Statistical analysis

Mean values are presented as mean $\pm$SD. n = number of analysis. Mean values were compared using Student's t-test. p values of <0.05, <0.01 and <0.001 were considered as significant.

RESULTS AND DISCUSSION

Comparison of digestion techniques

Dry ashing was carried out as described by Saari and Passo (1980). This procedure took nearly 2 days for complete analysis, and the concentrations of the elements analysed were lower (Table 3) compared with other methods. Among the wet ashing techniques, digestion with a mixture of HNO_3 and $HClO_4$ was found most effective for the analysis of zinc, copper, manganese and iron. Boer and Massen (1983) reported that wet digestion with a mixture of HNO_3 and $HClO_4$ for the analysis of zinc, copper, manganese and iron in Bovine liver standard material gave good recoveries. Clegg *et al.* (1981) and

TABLE 3
Concentrations (mg kg^{-1} dry weight) of Zinc, Copper, Iron and Manganese Obtained from the Potato Samples Treated with Various Ashing Techniques

Ashing technique	*Zinc*	*Copper*	*Iron*	*Manganese*
Dry ashing	15·6 (1·6)[a]	6·2 (0·71)[b]	26·7 (1·6)[c]	3·8 (0·49)[a]
$HNO_3 + H_2O_2$	16·3 (2·5)	6·1 (0·63)[a]	23·4 (1·7)[b]	4·7 (0·61)
$HNO_3 + H_2SO_4$	17·2 (1·7)	7·3 (1·2)	27·2 (1·9)[a]	4·3 (0·92)
$HNO_3 + HClO_4$	17·6 (1·6)[a,b]	7·0 (1·1)[a,b]	29·6 (1·1)[a,b,c,d]	4·7 (0·86)[a,b]
HNO_3	16·9 (1·76)[b]	6·8 (0·81)	26·0 (1·7)[d]	3·3 (0·91)[b]

Mean values are presented as means with SD in parentheses and $n = 7$. Values with the same superscripts were significantly different.

Lonnerdal *et al.* (1980) studied various wet ashing techniques and found that HNO_3 alone was enough for the determination of these elements. In our experiment the ratio of the potato sample to the HNO_3 added (0·5 g:7 ml) was considerably higher than in the method of Lonnerdal *et al.* (1980) and the colour of the net solution obtained was yellow which could be due to incomplete digestion. The final solution obtained by treating the sample with a mixture of HNO_3 and H_2SO_4 was pale yellow and it was found difficult to aspirate into the nebulizer of the atomic absorption spectrophotometer. Even though complete digestion was achieved with a mixture of HNO_3 and H_2O_2, the results were lower when compared with those obtained from the sample treated with a mixture of HNO_3 and $HClO_4$. Hoenig and De Borger (1983) employed a mixture of H_2SO_4, HNO_3 and H_2O_2 and found good results for the analysis of zinc, copper, iron and manganese. But we found this method time consuming since H_2O_2 had to be added dropwise during the digestion process. Therefore a mixture of HNO_3 and $HClO_4$ was adopted for the wet digestion of potato samples in this study.

Protein

Results of the proximate analysis of potato samples are presented in Table 4. Protein content of the sample treated with 908 kg ha^{-1} inorganic NPK fertilizer was higher than in the one treated with 456 kg ha^{-1} of inorganic NPK fertilizer (K6 versus K7, $p < 0{\cdot}001$). Addition of ammonium nitrate along with a higher amount of inorganic fertilizer increased the content of protein (K7 versus K8, $p < 0{\cdot}001$). Inclusion of bio-dynamic sprays along with organic manure slightly improved the content of protein (K1 versus K2, $p < 0{\cdot}05$) and compost manure in comparison with raw manure was favourable in this case (K1 versus K3, $p < 0{\cdot}01$). The protein content of the organically manured sample was higher than in the inorganically fertilized

TABLE 4
Proximate Analysis of Potato Samples
(Data are expressed as g per 100 g dried sample. Values given in parentheses are the contents on fresh weight basis)

Samples	*Dry matter*	*Protein*	*Fat*	*Crude fibre*	*Dietary fibre*	*Starch*
K1	29·57	8·16 ± $0·28^{c,d,e}$	0·23 ± 0·02	2·03 ± 0·26	8·51 ± 0·76	73·64 ± $1·16^{c}$
		(2·61 ± $0·17)^{o,p,q}$	(0·06 ± 0·02)	(0·61 ± 0·06)	(2·72 ± 0·03)	(20·92 ± $1·96)^{o}$
K2	28·61	7·73 ± $0·17^{e}$	0·23 ± 0·01	1·89 ± 0·17	8·60 ± 0·81	73·74 ± 1·50
		(2·18 ± $0·13)^{q}$	(0·07 ± 0·02)	(0·51 ± 0·04)	(2·83 ± 0·08)	(20·41 ± 2·06)
K3	29·16	7·51 ± $0·31^{d}$	0·26 ± 0·04	1·89 ± 0·14	8·52 ± 0·77	74·58 ± $0·97^{d}$
		(1·93 ± $0·27)^{p}$	(0·09 ± 0·03)	(0·54 ± 0·06)	(2·69 ± 0·06)	(22·03 ± $1·59)^{p}$
K4	30·27	7·49 ± 0·22	0·25 ± 0·07	1·92 ± 0·21	8·46 ± 0·83	72·59 ± $1·63^{d}$
		(1·87 ± 0·25)	(0·08 ± 0·02)	(0·56 ± 0·04)	(2·53 ± 0·05)	(20·14 ± $1·09)^{p}$
K5	26·19	7·60 ± 0·16	0·22 ± 0·05	1·71 ± 0·29	9·56 ± 0·69	72·48 ± 1·71
		(1·67 ± 0·18)	(0·06 ± 0·01)	(0·55 ± 0·07)	(2·62 ± 0·04)	(19·52 ± 1·72)
K6	31·66	6·96 ± $0·23^{a,c}$	0·24 ± 0·07	1·66 ± 0·31	7·88 ± 0·82	73·57 ± $1·57^{a}$
		(1·90 ± $0·13)^{m,o}$	(0·07 ± 0·02)	(0·50 ± 0·04)	(2·56 ± 0·05)	(22·81 ± $1·39)^{m}$
K7	32·28	8·09 ± $0·14^{a,b}$	0·27 ± 0·08	1·88 ± 0·16	7·59 ± 0·91	76·39 ± $1·26^{a,b,c}$
		(2·53 ± $0·19)^{m,n}$	(0·09 ± 0·03)	(0·59 ± 0·06)	(2·89 ± 0·09)	(25·09 ± $1·27)^{m,n,o}$
K8	31·42	9·63 ± $0·16^{b}$	0·21 ± 0·08	1·75 ± 0·24	8·59 ± 0·86	73·67 ± $1·64^{b}$
		(3·14 ± $0·26)^{n}$	(0·07 ± 0·02)	(0·51 ± 0·08)	(2·76 ± 0·04)	(18·55 ± $1·36)^{n}$

Mean values are presented as means ± SD and $n = 7$. Data with the same superscripts were significantly different.

sample (K1 versus K6, $p < 0{\cdot}001$). This could be due to the influence of bio-dynamic preparations (compost additives and sprays) which probably improved the humus content of the soil, thereby stimulating the transition of nutrients between subsoil and topsoil. Eppendorfer *et al.* (1979) reported that the dry matter content of potato was directly proportional to the amount of inorganic chemical elements applied to the soil, and Sharma and Arora (1988) found that the increase in the protein content is associated with the tuber dry matter content which explains our result above (K6 versus K7). Bečka *et al.* (1982) also reported that tuber nitrate-nitrogen increased with increasing the rate of inorganic NPK fertilizer application. Talley (1983) reported that nitrogen fertilization improved the protein content of potato tubers. The conversion of low-molecular-weight non-protein nitrogen compounds into protein is partly influenced by the climatic conditions. The contents of different nitrogen compounds were not analysed in our study. Potato is a good source of protein compared with other root and staple foods.

Starch

A major part of potato dry matter was starch (>70%). The use of bio-dynamic sprays did not influence the content of starch. The starch content of samples treated with a higher amount of inorganic fertilizer was higher than in the one treated with organic manure (K1 versus K7, $p < 0{\cdot}01$). Szukalski and Sikora (1977) also reported that nutrient-enriched fertilizers increased the starch content of potato tuber. The application of a higher level of inorganic fertilizer (enriched with trace elements) improved the starch content (K6 versus K7, $p < 0{\cdot}01$) which could be due to a high dry matter production under the influence of minerals added to the soil. The content of starch was slightly lower in samples treated with a mixture of a higher amount of inorganic fertilizer and ammonium nitrate (K7 versus K8, $p < 0{\cdot}01$). A similar finding was reported by Ciecko (1977). Sharma and Arora (1988) found that applied nitrogen along with farmyard manure significantly decreased the starch content due to the dilution effect as a result of a higher dry matter production and we found that the inclusion of inorganic fertilizer along with raw manure decreased the starch content (K3 versus K4, $p < 0{\cdot}05$).

Fat, dietary fibre and crude fibre

The content of these nutrients in all the samples remained unchanged irrespective of type or level of manures and fertilizers applied to the soil (Table 4). The content of dietary fibre was much higher than the crude fibre which was also reported by Woolfe (1987). Dietary fibre content in potatoes is the sum of lignin and non-starch polysaccharides of which the latter constitutes the major part.

Trace elements

Zinc

Table 5 presents the contents of zinc, copper, iron and manganese in the test samples. The application of a higher level of inorganic NPK fertilizer resulted in the lower content of zinc (K6 versus K7, $p < 0.001$) which was also reported by Songin *et al.* (1980). Rebowska (1983) found that a higher application of inorganic NPK fertilizer to wheat did not increase the content of zinc, copper, manganese, boron and molybdenum. The uptake of the minerals might be high but the distribution of these elements in different parts of the plant might not be uniform (Graham, 1979). The content of zinc in the unfertilized sample K5 was higher than the inorganically fertilized sample (K5 versus K6, $p < 0.01$). This higher content of zinc in the potato tuber could be due to the Steenberg effect as described by Jansson (1981). The organically manured sample had a higher content of zinc when

TABLE 5
Concentrations (mg kg^{-1} dry weight) of Zinc, Copper, Iron and Manganese Determined in Potato Samples
(Values given in parentheses are the contents on fresh weight basis)

Variant	*Zinc*	*Copper*	*Iron*	*Manganese*
K1	12.2 ± 0.96^{f}	5.6 ± 0.92	46.9 ± 2.3	4.3 ± 1.3^{a}
	$(3.6 \pm 0.31)^{r}$	(1.4 ± 0.40)	(13.6 ± 1.6)	$(1.3 \pm 0.11)^{m}$
K2	$16.1 \pm 1.4^{c,f}$	5.5 ± 0.74^{a}	47.6 ± 2.1	4.8 ± 0.72^{b}
	$(4.7 \pm 0.26)^{o,r}$	$(1.5 \pm 0.33)^{m}$	(13.4 ± 2.2)	$(1.3 \pm 0.21)^{n}$
K3	14.1 ± 1.1^{e}	5.7 ± 0.31^{b}	53.9 ± 1.1^{a}	5.1 ± 0.91
	$(4.3 \pm 0.42)^{q}$	$(1.3 \pm 0.14)^{n}$	$(15.3 \pm 1.7)^{m}$	(1.6 ± 0.39)
K4	11.1 ± 1.3^{e}	4.1 ± 0.81^{b}	32.8 ± 1.9^{a}	4.8 ± 1.4
	$(3.5 \pm 0.39)^{q}$	$(1.9 \pm 0.36)^{n}$	$(9.7 \pm 1.3)^{m}$	(1.7 ± 0.21)
K5	18.2 ± 1.9^{b}	$8.3 \pm 0.53^{a,c}$	29.6 ± 2.7	4.7 ± 1.7
	$(4.4 \pm 0.32)^{m}$	$(2.6 \pm 0.13)^{m,o}$	(7.3 ± 1.4)	(1.9 ± 0.17)
K6	$16.1 \pm 1.3^{a,b}$	6.6 ± 0.40^{c}	30.6 ± 1.5^{b}	6.3 ± 0.81^{a}
	$(5.3 \pm 0.26)^{m,n}$	$(2.1 \pm 0.17)^{o}$	$(9.5 \pm 1.3)^{n}$	$(2.1 \pm 0.36)^{m}$
K7	$13.2 \pm 0.9^{a,c,d}$	6.1 ± 0.25	$40.8 \pm 1.3^{b,c}$	6.8 ± 0.61^{b}
	$(4.0 \pm 0.28)^{m,o,p}$	(1.6 ± 0.81)	$(13.1 \pm 2.6)^{n}$	$(2.4 \pm 0.41)^{n}$
K8	15.7 ± 1.4^{d}	6.2 ± 0.44	42.9 ± 1.6^{c}	6.4 ± 0.73
	$(5.1 \pm 0.21)^{p}$	(1.7 ± 0.79)	(13.7 ± 1.7)	(1.8 ± 0.63)

Mean values are presented as means $\pm$ SD and $n = 7$. Data with the same superscripts were significantly different.

compared with the one treated with a higher level of inorganic NPK fertilizer (K2 versus K7, $p < 0{\cdot}01$). The organo-metal complex formation of zinc in the risosphere soil has been described earlier by Hodgson *et al.* (1965). The contents of zinc in the organically manured samples (K1, K2 and K3) were not significantly lower when compared with those treated with inorganic fertilizer (K6, K7 and K8) but iron content was significantly higher in organically manured samples (in both dry matter and tuber). This was probably due to the antagonistic effect of various elements as described by Pendias and Pendias (1984). The addition of ammonium nitrate improved the content of zinc (K7 versus K8, $p < 0{\cdot}01$). This could be due to the positive effect of NH_4^+-N which lowers the risosphere pH (Sarkar & Wyn Jones, 1982*b*) and favours the uptake of the element by the tubers. Giordano and Mortvedt (1980) noticed that the uptake of zinc by agricultural crops depended on its interactions with other applied nutrients.

Copper

We did not find any significant difference in the content of copper between organically manured and inorganically fertilized potato samples, but the unfertilized control sample had a higher concentration of copper (K2 versus K5, $p < 0{\cdot}001$ and K6 versus K5, $p < 0{\cdot}001$). This could be due to the Steenberg effect as in the case of zinc. Copper can also have an antagonistic effect with iron and a synergistic effect with nitrate. The additional use of bio-dynamic sprays along with organic manure did not show any positive effect. Inclusion of inorganic NPK fertilizer with raw manure decreased the content of copper (K3 versus K4, $p < 0{\cdot}001$). A higher application of inorganic NPK fertilizer did not influence the content of copper. Songin *et al.* (1980) found that increasing the rate of NPK fertilizer application (700 kg ha^{-1}) decreased the content of copper. In this study the content of copper remained unchanged even at a higher (908 kg ha^{-1}) rate of inorganic NPK application but the potato varieties used for the two studies were different and Kubiak *et al.* (1978) found that the nutrient contents were different in different varieties of potatoes. The addition of ammonium nitrate along with a higher application of NPK fertilizer increased the content of zinc and iron but the copper content remained unchanged.

Iron

The contents of iron in all the organically manured samples (K1, K2 and K3) were significantly higher than those treated with inorganic fertilizer (K6, K7 and K8). Obukhov *et al.* (1985) also reported that organic manuring increased the content of iron in potato tuber. This could be due to the complex formation property of iron with organic materials in the risosphere which made the plant take up the element more easily (Olomu *et al.*, 1973).

The additional use of bio-dynamic sprays did not increase the content of iron in the potato tubers. Inclusion of inorganic fertilizer along with raw manure decreased the content of iron (K3 versus K4, $p < 0.001$). Sharma and Arora (1987) reported that the uptake or iron by potato increased up to the application of 30 kg ha^{-1} of phosphorus in the presence of 30 tonnes ha^{-1} of farm yard manure. A higher application of inorganic NPK fertilizer increased the content of iron (K6 versus K7, $p < 0.001$) and this stimulating effect could be due to a lowering of soil pH by using more acidified fertilizers and by the addition of more minerals with the fertilizer being maintained in the solution. The addition of ammonium nitrate along with a higher level of inorganic NPK fertilizer slightly increased the content of iron in the dry matter (K7 versus K8, $p < 0.05$). By the addition of ammonium nitrate, the soil pH is lowered and also iron exhibits a synergistic effect with nitrate. The type of soil is important for the uptake of iron by potato, and those grown in sandy soil contain higher amounts of iron than those grown in clay-loam soil.

Manganese

The inorganically fertilized samples contained comparatively higher concentrations of manganese than organically manured samples (K1 versus K6, $p < 0.001$ and K2 versus K7, $p < 0.05$). The explanation may be that the trace elements present in the rootzone do not tend to fix with the inorganic NPK fertilizer constituents, and thus the availability of micronutrients to the plant is higher, which facilitates the uptake. Sharma and Arora (1987) found that the higher uptake of manganese by potato was due to the increase in the dry matter production. Also Lag and Dev (1964) reported about the presence of more exchangeable manganese in the surface soils than in the lower horizons. A higher application of inorganic NPK fertilizer did not increase the content of manganese. The concentration of the element also remained unchanged among the different organically manured samples. Addition of inorganic NPK fertilizer along with raw manure did not influence the content of manganese. Also the additional use of bio-dynamic sprays did not show any positive effect.

CONCLUSIONS

A higher application of inorganic fertilizer improved the starch and protein contents of potato tubers. None of the fertilization or manuring techniques studied, influenced the contents of dietary fibre, crude fibre or fat either in the tubers or in their dry matter substance. The study showed that potato tubers treated with organic manure contained higher concentrations of iron than those treated with inorganic fertilizers. Addition of inorganic fertilizer along with raw manure did not show any positive effect on the content of nutrients studied when compared to various other treatments. Higher application of inorganic NPK fertilizer did not improve the content of zinc, copper and manganese, but increased the content of iron. A normal application of inorganic fertilizer increased the content of zinc, copper and manganese when compared to organic manuring. The higher content of some trace elements in the inorganically fertilized samples could be due to lowered pH resulting from the use of acidified fertilizers and by the addition of trace elements along with the fertilizers being maintained in the solution. The complex formation property of trace elements with organic compounds explains a higher content of some trace elements in the case of organically manured samples. The higher content of trace elements in some of the unfertilized samples could be due to the Steenberg effect and a synergistic effect with nitrate might have also increased their contents. Additional use of bio-dynamic preparations did not increase the content of zinc, copper, iron, manganese or other nutrients studied.

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