RECENT WORK ON COPPER AND MOLYBDENUM IN PASTURES AND SOILS IN SASKATCHEWAN

J.W.B. Stewart, J.O. Moir and V.J. Racz

Saskatchewan Institute of Pedology, University of Saskatchewan, Saskatoon, Sask. and

Saskatchewan Department of Agriculture, East-Central Region, Yorkton, Sask.

Introduction

It has been clearly established that copper deficiency occurs in ruminant animals in parts of Saskatchewan. Evidence has accumulated (Brockman, 1976, 1977) of cases where copper deficiency diagnosed in animals on the basis of loss of hair color, blocd copper levels and liver copper levels, has been confirmed by field experiments in which a growth response to dietary copper supplementation has been obtained (Christensen[1], private communication).

Copper deficiency was first observed in cattle in 1931 and has received much attention since that date (Marsden, 1952). Unfortunately copper deficiency in animals is not caused solely by a low copper concentration in the diet as there is a complex relationship between copper, molybdenum and sulphur (Christensen and Cochran, 1975). Therefore, copper deficiency symptoms also could occur in an animal because of the high dietary intake of molybdenum, and there are various reports that sulphate both depresses and intensifies the effect of high molybdenum in the diet. Work in other parts of Canada on the occurrence of copper deficiency (Henderson, 1957; Miltmore et al., 1964, 1971, 1973) confirmed the existence of copper deficiency which was attributed to a high molybdenum intake in the diet rather than to low copper content in the herbage. Of particular interest to the present study is the work of Henderson (1957), who reported that copper deficiency occurred in the Swan River area of Manitoba, especially in a year of above average rainfall. It has been suggested that the cause of the copper deficiency was related to the presence of shales having abnormally high molybdenum content (Fletcher and Doyle, 1971). However, in the latter study the level of the molybdenum in the plant was not directly related to the total amount of molybdenum in the soil.

It has been established that a copper level in herbage of above 10 ug/g dry matter will contain sufficient copper for animals unless the copper to molybdenum ratio of that forage is 2:1 or less. Sulphur induces a deficiency in cattle when the forage sulphur level rises above 0.30%. Current United States regulations (N.R.C., 1971) state that ratios of copper to molybdenum of 2:1 or less may lead to copper deficiency particularly at high levels (>0.3%) of sulphur in the plant dry matter; copper to molybdenum ratios of 4:1 and higher should not cause any problems.

In Saskatchewan little information is currently available on the level of copper in forages other than that collected through the combined

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[1] Dr. D.A. Christensen, Prof. of Animal Science, Univ. of Saskatchewan, Saskatoon.

efforts of the Feed Testing Laboratory and Dept. of Animal Science (D.A. Christensen, private communication). Stewart (1969) carried out a survey of the levels of available soil copper in Saskatchewan soils but related these values to copper concentrations in cereal tissue at various growth stages and to the production of cereal grains. The latter study did not include pasture lands. The objectives of the current study were, 1) to determine the copper and molybdenum status of forages in soils in East Central Saskatchewan at locations where copper deficiency in animals had been diagnosed or suspected by animal scientists and veterinarians, and at adjacent sites where this deficiency had not been observed, 2) to develop diagnostic soil tests that will predict locations where a copper supplement would be required in the animal diet, and 3) to use this data to help establish guidelines for developing a more complete survey of Saskatchewan soils.

Materials and Methods

Field Survey

During the summers of 1976 and 1977 a total of 48 locations were sampled. Soil samples were taken at 15 cm intervals to 120 cm in early May, and plant samples were taken at monthly intervals until September in both years. Where possible at each location, water samples were collected from the main source of water supply for the animals. During the winter of 1976 hay samples were collected from each location.

Growth Chamber Studies

The response of bromegrass (*Bromus inermis* var. Carlton) to added molybdenum and copper was examined in a pot experiment carried out under controlled environmental conditions ($20^{o}C \pm 2^{o}C$, light intensity, 111 lux., 16-h light and 8-h dark periods) in a growth chamber. Molybdenum as sodium molybdate ($Na_2MoO_4 \cdot 2H_2O$) at 0, 1.25 and 2.5 µg/g of soil and/or copper as copper sulphate ($CuSO_4 \cdot 5H_2O$) at 0, 1.0 and 2.5 µg/g of soil was added to three different soils (Sample Nos. 3, 10 and 13, Table 1). In addition, a complete nutrient solution was mixed thoroughly into each 1500 g soil contained in a plastic container and 20 pregerminated seedlings were transplanted into each soil. The treatments were replicated three times. Plant samples were taken 43 and 96 days from transplanting and these were analyzed for micronutrients.

Soil Analyses

All soil samples were analyzed by the Saskatchewan Soil Testing Laboratory for pH, texture, electrical conductivity of saturated extracts, available N, P, K and S analyses. Micronutrient cations, Zn, Mn, Fe, and Cu, were determined using the DTPA extraction of Lindsey and Norvell (1978). The extraction of molybdenum from soil was carried out using anion exchange resin (Jackson and Meglen, 1975) and two extraction procedures. Extraction procedure A is carried out using the resin on soils which had been heated at $400^{o}C$ for 16 hours in a muffle furnace. Extraction procedure B is carried out on an unmuffled soil. The molybdate is removed from the resin with 10% NaCl. The NaCl extract was analyzed colorimetrically by the thiocyanate procedure (after H_2O_2-H_2SO_4 digestion to remove organic matter in extraction B).

Table 1. Data on the location, soil type and soil texture of sites from which forage and soil samples were taken in 1976 and 1977.

Sample No.	Legal Location	Year	Sample	Association and Texture
1	SW31-18-31-W1	1976	Alfalfa-brome	Whitesand - sandy loam
		1977	Alfalfa	
		1977	Brome	
2	NW10-19-32-W1	1976	Alfalfa-brome	Yorkton/Oxbow - loam/light loam
		1977	Brome	
3	SE10-19-32-W1	1976	Alfalfa-brome	Yorkton/Oxbow - loam/light loam
		1977	Alfalfa	
		1977	Brome	
4	SW10-19-30-W1	1976	Mixed	Yorkton/Canora - light loam
		1977	Alfalfa	
		1977	Brome	
5	NE25-18-31-W1	1976	Mixed	Whitesand - sandy loam/sand
		1977	Native	
6	NE3-20-32-W1	1976	Alfalfa-brome	Eroded
		1977	Alfalfa	
		1977	Brome	
7	NE11-20-32-W1	1976	Brome	Yorkton - loam
		1977	Alfalfa	
		1977	Brome	
8	SW24-28-7-W2	1976	Hay	Oxbow/Yorkton - loam
		1977	Alfalfa	
		1977	Brome	
9	SW24-28-7-W2	1976	Mixed	Oxbow/Yorkton - loam
		1977	Alfalfa	
		1977	Brome	
10	NE21-28-6-W2	1976	Hay	Whitesand - sandy loam
		1977	Alfalfa	
11	NE3-29-6-W2	1976	Brome	Whitesand - gravelly loam and sandy loam-stoney phase
		1976	Brome	
		1977	Brome	
12	NE30-32-19-W3	1976	Native	Biggar/Alkali - gravelly loam
		1977	Native	
13	SW30-32-19-W3	1977	Alfalfa	Biggar/Alkali - gravelly loam
		1977	Brome	

Table 1. Continued.

Sample No.	Legal Location	Year	Sample	Association and Texture
14	SE22-26-30-W1	1977	Alfalfa	Whitesand - gravelly loam and sandy loam-stoney phase
		1977	Brome	
15	SW20-26-30-W1	1977	Brome	Whitesand - gravelly loam and sandy loam

Plant Analyses

Zinc, manganese, iron, copper and sulphur were all determined on a perchlorate digest. In the procedure one gram of oven dried plant material was weighed into a block digestor 40 tube. Two hengar granules and 5 ml concentrated HNO_3 were added and the mixture allowed to stand overnight. Next day, the tubes were placed in the block digestor, the temperature raised to 180°C and heated for 15 minutes. After cooling, 5 ml of 60-70% $HClO_4$ was added and the mixture heated at 180-200°C until digested. To the cool solution, 1 ml of concentrated HCl was added and it was heated for a further 30 minutes. The solution was then cooled and diluted to a volume of 75 ml. Zinc, manganese, iron and copper were then determined directly by atomic absorption spectroscopy. Sulphur was analyzed as sulphate using a modification of the Technicon Autoanalyzer Method No. 118-7110.

An anion exchange resin was used to extract molybdenum from a plant ash. Two grams of oven dried plant material were weighed into evaporating dishes and placed in a cold muffle furnace. The temperature was raised and maintained at 400°C for 4 hours. The evaporating dishes were removed, allowed to cool and the plant ash transferred, using 75 ml of distilled/deionized water, to shaking flasks containing 1 g of Dowex 2-X4 anion exchange resin (>30 mesh). The suspension, having been shaken for 24 hours, was poured onto a 35 mesh sieve and washed free of plant ash. The resin was transferred to filtering tubes with fritted discs (medium porosity) and leached with three successive amounts of 4 ml 10% NaCl into 25 ml volumetric flasks. The color was then determined using the thiocyanate procedure as outlined in Jackson (1960).

Results

Preliminary data has been presented on the analyses of herbage, soil and water samples taken during 1976 (Stewart and Racz, 1977). The results presented here will be from those sites (Table 1) which were sampled in both years. These samples were selected from locations ranging from areas close to the Manitoba border, which are underlain by shales high in molybdenum, to the saline areas in the vicinity of Quill Lake. Many of the sites sampled were light in texture and almost none of the locations received any commercial fertilizer during the study period.

Soil analyses showed that the pH of the surface soils ranged from 6.2 to 7.7 and that salts were generally not a problem except at sample site No. 12. Without exception the available nitrate and phosphate levels were low. Sulphur levels were adequate for crop growth except at sites 10 and 11 where the available sulphur in the soil would be borderline for successful production of a legume forage. DTPA extractable copper levels ranged from 0.2 in the surface horizon to a high of 1.2 µg/g, and extractable zinc similarly ranged from 0.5 to 2.2 µg/g. Lindsay and Norvell (1978) found that the critical level of DTPA extractable copper was 0.2 µg/g and for DTPA extractable zinc 0.6 µg/g for sorghum and 0.8 µg/g for corn. Criteria have not been developed for zinc in forage crops under semi-arid conditions, but they would be expected to be slightly lower than the critical level for sorphum. From this it can be deduced that it is unlikely that zinc deficiency would be found on these soils. Available molybdenum levels ranged from 0.1 to 0.85 µg/g extractable molybdenum (Table 2).

Full details of the contents of copper and molybdenum (Table 3), and zinc, manganese and sulphur (Table 4) are presented for the forages sampled during 1977. These can be compared with the results obtained for 1976 samples (Stewart and Racz, 1977) as the results obtained from both years are graphed in Figs. 1 and 2. Fig. 1 gives a comparison of the data obtained in both years from the monthly sampling at the same location, and Fig. 2 represents the average of the monthly samplings at all sites for both years. It is immediately obvious that there was a great difference in the samples taken in 1977 compared to 1976, as all sites recorded copper in herbage at less than 10 µg/g in 1977, and invariably in 1976 the values were above 10 µg/g. The reverse appears to be true with molybdenum which in general had higher levels in the herbage during 1977 than in 1976. The difference between molybdenum in each year was not nearly as distinct as the differences with copper. The combination of these two effects, as seen in the copper/molybdenum ratio (Fig. 2), shows quite clearly that these herbage concentrations could have caused copper deficiency in cattle in 1977. In that year the copper/molybdenum ratio in the forage was often less than 2:1, and in many cases, the low copper level alone could have caused the deficiency. This was in complete contrast to 1976 where both values were generally adequate.

Some explantion for the difference between the two years may be found in the precipitation data for the Yorkton area. In 1976 the actual precipitation from April 1 to June 1 was 30 mm in contrast to the long term average of 67 mm for the same period. In 1977, the actual precipitation over the same period, April 1 to June 1, was 117 mm (approximately 4 times the precipitation in 1976 and 3 times the long term average). The total precipitation over the period April 1 to August 1 in both years was approximately 205 mm, in contrast to the normal precipitation of 198 mm. This extra precipitation in April and May resulted in a much higher growth or spring flush in 1977 with a consequent drain on the available copper within the soil. The excess moisture also would allow a greater uptake of molybdenum. In contrast, there appeared to be little difference in the zinc concentration between 1976 and 1977. Sulphate concentrations did not show much difference between years although these tended to be slightly higher in 1977 when there was more moisture in the soil. In general, sulphur concentrations in the herbage would be considered low, with alfalfa samples showing a slightly higher value than bromegrass samples (Figs. 3 and 4).

The predictive value of the DTPA test was found to be significant ($P > 0.01$) in 1976. A completely different result was found in 1977 when, with above average moisture and good growth conditions, the concentrations of copper in the herbage were diluted and there was no correlation between the amount of copper extracted by DTPA from the soil and that in the herbage. Similar results were obtained in a comparison of extracted molybdenum and plant molybdenum. This is not surprising as, for example, a similar comparison between available phosphate and phosphorus content in the herbage would have yielded similar results under good growing conditions, i.e. there would be no correlation. A much better approach would be to examine available soil nutrient status with yield responses to applied nutrients. As few of the test sites were receiving fertilizer of any sort, it was impossible to predict the concentration of micronutrients in plant material.

Such limitations did not apply to the growth chamber experiment, where the effect on yield and on plant concentration of added copper and molybdenum could be compared. Copper and molybdenum additions did not increase plant yields but had a significant effect on plant concentration. DTPA extractable copper was significantly correlated ($r = 0.856$, $n = 81$, $P > 0.001$) to plant copper concentrations (Fig. 5) and extractable molybdenum was significantly correlated ($r = 0.838$, $n = 81$, $P > 0.001$) to plant molybdenum concentration (Fig. 6).

Conclusions

Examination of the forage samples collected over two seasons showed that there was a tremendous difference in the copper and copper/molybdenum ratio of the herbage from one season to the next and that this difference in copper content could be related to the available moisture in the soil during the spring "flush" period of growth. In a dry season with low herbage production in spring, the concentrations of copper and molybdenum in the herbage were barely adequate for animals. A different result was found on an above-average wet year when the concentration of copper was lower and molybdenum levels higher. This meant that animals depending on forage for all their nutrients could be deficient in copper. The predictive value of extraction methods developed for fertilized crops were not sensitive enough to predict the levels of these nutrients in herbage on a wet year but were adequate in a dry year.

Levels of other major nutrients and micronutrients in the forage samples collected were low to borderline in some cases. This emphasizes the fact that forage is rarely adequately fertilized and is generally growing with a minimum of available nutrients in the soil.

Preliminary growth chamber studies showed that the soil extractant methods used in this work were useful tools to predict the concentration of copper and molybdenum in bromegrass growing in optimum conditions. Future work will examine the usefulness of these extractants to predict crop nutrient concentrations under limited nutrient and low availability of soil moisture.

Table 2. Extractable nutrients (NO_3-N, P, SO_4-S, Cu, Zn, Mn, Mo $\mu g\ g^{-1}$ soil), pH and conductivity of the soils at the sample sites.

Sample No.	Depth (in.)	pH	Conductivity	µg/g							
				NO_3-N	P	SO_4-S	Cu	Zn	Mn	Mo A	Mo B
1	0-6	7.1	0.3	4.0	4.5	4.5	0.8	1.6	37	.21	.08
	6-12	7.6	0.3	1.5	2.0	2.5	0.8	0.3	15	.07	.03
	12-24	8.3	0.4	1.5	1.0	1.5	1.1	0.1	11	.13	.05
2	0-6	7.5	0.4	2.5	3.5	12+	0.8	1.5	28	.26	.07
	6-12	7.8	2.1	2.5	2.0	12+	1.5	0.2	9	.19	.12
	12-24	8.2	2.5	1.0	1.0	12+	1.2	0.2	9	.23	.19
3	0-6	7.7	0.4	1.5	4.0	5.0	0.8	0.5	18	.16	.04
	6-12	8.1	0.3	1.0	1.0	2.0	1.0	0.2	8	.13	.05
	12-24	8.1	0.8	1.0	1.0	12+	1.5	0.2	8	.31	.19
4	0-6	7.4	0.3	4.0	2.5	4.5	0.7	1.6	34	.15	.04
	6-12	7.9	0.3	3.5	1.0	2.0	0.8	0.2	6	.06	.04
	12-24	8.2	0.2	1.0	1.0	1.0	0.7	0.6	5	.08	.04
5	0-6	7.5	2.6	3.5	3.5	12+	1.2	1.2	18	.20	.07
	6-12	7.7	4.4	2.5	1.5	12+	1.2	0.2	5	.16	.05
	12-24	7.8	4.6	2.0	1.0	12+	1.2	0.3	6	.25	.21
6	0-6	7.0	0.3	3.0	6.5	4.5	1.1	2.2	42	.19	.07
	6-12	7.4	0.6	2.5	2.5	12+	1.0	0.7	18	.16	.05
	12-24	7.7	3.9	2.0	1.5	12+	1.3	0.2	7	.11	.04
7	0-6	7.4	0.4	2.5	2.5	4.5	0.9	0.9	23	.14	.04
	6-12	7.8	0.4	1.0	1.5	5.0	0.8	0.1	11	.09	.04
	12-24	8.1	0.6	2.0	1.0	12+	0.8	0.2	11	.12	.08
8	0-6	7.1	0.4	4.5	6.5	4.0	0.8	1.6	34	.23	.08
	6-12	7.4	0.3	2.5	3.5	2.5	0.7	0.3	13	.15	.02
	12-24	7.7	0.3	2.5	2.0	1.0	0.9	0.2	9	.09	.02
9	0-6	7.3	0.3	2.5	2.0	2.0	0.9	0.6	25	.17	.02
	6-12	7.6	0.4	4.0	1.0	1.5	1.3	0.2	13	.19	.05
	12-24	7.9	0.3	1.5	1.0	1.0	1.2	0.2	10	.21	.03
10	0-6	6.8	0.1	2.5	10.5	1.5	0.4	1.2	28	.15	.04
	6-12	6.8	0.1	1.5	9.0	1.0	0.3	0.1	16	.08	.10
	12-24	7.5	0.2	1.0	6.0	1.0	0.5	0.2	9	.06	.03
11	0-6	6.2	0.2	1.5	6.5	3.0	0.3	2.6	25	.20	.17
	6-12	6.3	0.1	1.0	5.5	0.5	0.2	0.2	10	.09	.03
	12-24	7.7	0.2	2.0	3.5	0.5	0.3	0.2	5	.06	.05
12	0-6	7.7	5.5	4.5	2.0	12+	1.2	0.9	12	.33	.10
	6-12	7.9	7.9	2.5	1.0	12+	1.4	0.5	6	.45	.08
	12-24	8.1	6.1	2.0	1.0	12+	1.3	0.5	14	.59	.47

Table 2. Continued.

Sample No.	Depth (in.)	pH	Conductivity	µg/g							
				NO_3-N	P	SO_4-S	Cu	Zn	Mn	Mo	
										A	B
13	0-6	7.5	1.0	3.0	2.0	12+	1.1	1.2	26	.48	.10
	6-12	7.7	4.3	1.0	2.0	12+	1.5	0.3	10	.33	.15
	12-24	8.2	6.1	0.5	1.0	12+	1.9	0.2	7	.61	.02
14	0-6	7.4	0.4	2.0	8.5	12+	0.5	0.5	29	.29	.07
	6-12	7.7	0.3	1.0	7.5	3.5	0.7	0.3	15	.12	.03
	12-24	7.9	0.3	1.5	5.0	2.0	0.7	0.3	13	.14	.04
15	0-6	7.3	0.4	1.5	6.0	6.0	0.6	1.6	23	.23	.04
	6-12	7.5	0.3	1.5	6.0	2.0	0.6	0.3	15	.15	.03

Table 3. Copper and molybdenum concentration levels in forage samples collected at different time intervals in 1977.

Sample No.	Crop	Cu (μg/g)					Mo (μg/g)				
		June	July	August	Sept.	Mean	June	July	August	Sept.	Mean
1	Alfalfa	7.2	-	7.2	6.8	7.1	2.0	2.8	2.4	1.9	2.3
	Brome	6.9	-	6.5	5.1	6.2	4.1	4.8	2.6	3.3	3.7
2	Brome	6.7	5.3*	6.8	3.0	5.5	4.5	2.1*	3.7	2.1	3.1
3	Alfalfa	6.7	5.3	8.1	5.3*	6.4	2.5	2.7	1.5	3.2*	2.5
	Brome	9.8	3.8*	2.6	5.3*	5.4	1.8	2.3*	3.6	3.2*	2.7
4	Alfalfa	10.0	8.4*	9.5*	7.4*	8.8	6.6	5.0*	12.3*	7.2*	7.8
	Brome	6.4	8.4*	9.5*	7.4*	7.9	8.1	5.0*	12.3*	7.2*	8.2
5	Native	7.2	-	3.8	3.0	4.7	2.4	0.6	0.8	1.1	1.2
6	Alfalfa	7.3	6.9	12.0	8.0	8.6	1.2	2.1	2.4	2.4	2.0
	Brome	5.8	3.8	5.7	4.6	5.0	2.9	5.4	5.4	5.9	4.9
7	Alfalfa	7.4	6.9	6.4	10.6*	7.8	4.0	4.0	4.0	5.6*	4.4
	Brome	7.8	4.7	4.2	10.6*	6.8	1.4	-	4.4	5.6*	3.8
8	Alfalfa	9.5	4.7*	8.4	7.0	7.4	5.1	4.6*	4.7	4.8	4.8
	Brome	7.7	4.7*	6.5	5.2	6.0	4.5	4.6*	8.6	6.4	6.0
9	Alfalfa	9.1	5.5*	6.5*	5.6*	6.7	3.6	4.3*	5.1*	6.1*	4.8
	Brome	5.7	5.5*	6.5*	5.6*	5.8	7.1	4.3*	5.1*	6.1*	5.7
10	Alfalfa	5.2	9.7	8.2	7.0	7.5	1.2	2.4	2.4	1.9	2.0
11	Brome	5.1	3.5	6.5	3.8	4.7	1.7	1.6	3.5	6.3	3.3
12	Native	4.1	3.8	3.0	3.8	3.7	0.7	0.4	0.4	1.2	0.7

Table 3. Continued.

Sample No.	Crop	Cu (μg/g)					Mo (μg/g)				
		June	July	August	Sept.	Mean	June	July	August	Sept.	Mean
13	Alfalfa	8.2	6.0*	9.2	6.5	7.5	3.8	1.7*	6.3	3.0	3.7
	Brome	6.8	6.0*	5.5	5.5	6.0	1.9	1.7*	4.3	4.4	3.1
14	Alfalfa	8.2	6.2	8.0	6.5	7.2	4.6	3.0	2.8	1.7	3.0
	Brome	6.2	3.8	9.4	5.4	6.2	11.8	11.2	2.5	6.1	7.9
15	Brome	7.4	9.2	7.2	6.8	7.7	12.5	15.3	27.4	13.2	17.1

*Mixed alfalfa/brome sample.

Table 4. Zinc, manganese and sulphur concentration levels in samples collected at different time intervals in 1977.

Sample No.	Crop	Zn (µg/g)					Mn (µg/g)					S (%)				
		June	July	August	Sept.	Mean	June	July	August	Sept.	Mean	June	July	August	Sept.	Mean
1	Alfalfa	24.8	31.0	24.2	15.6	23.9	59.9	44.1	50.7	48.9	50.9	0.23	0.25	0.25	0.20	0.23
	Brome	22.9	18.2	18.8	20.3	20.1	72.1	93.4	105.1	131.0	100.4	0.21	0.17	0.22	0.21	0.20
2	Brome	21.9	22.9*	21.0	16.3	20.5	55.2	50.0*	91.5	37.1	58.5	0.26	0.20*	0.18	0.14	0.20
3	Alfalfa	17.3	15.4	16.1	17.8*	16.7	40.2	45.0	44.4	116.5*	61.5	0.25	0.17	0.16	0.15*	0.18
	Brome	19.9	10.8*	11.3	17.8*	15.0	71.4	60.8*	99.5	116.5*	87.1	0.25	0.12*	0.11	0.15*	0.16
4	Alfalfa	33.1	29.1*	30.0*	35.4*	31.9	63.8	65.1*	75.0*	127.5*	82.9	0.29	0.33*	0.30*	0.18*	0.28
	Brome	25.1	29.1*	30.0*	35.4*	29.9	81.0	65.1*	75.0*	127.5*	87.2	0.20	0.33*	0.30*	0.18*	0.25
5	Native	23.7	21.7	20.9	16.7	20.8	46.0	18.0	25.2	23.6	28.2	0.20	0.25	0.24	0.14	0.21
6	Alfalfa	25.5	21.5	40.7	16.8	26.1	41.7	31.5	62.6	45.3	45.3	0.30	0.25	0.26	0.25	0.27
	Brome	19.0	19.7	22.4	20.9	20.5	58.4	75.7	87.4	131.1	88.2	0.17	0.17	0.20	0.17	0.18
7	Alfalfa	17.6	15.9	16.1	26.5*	19.0	37.5	30.9	40.6	79.4*	47.1	0.19	0.16	0.09	0.27	0.18
	Brome	20.1	17.9	31.5	26.5*	24.0	77.4	85.2	161.3	79.4*	100.8	0.18	0.24	0.20	0.27	0.22
8	Alfalfa	24.6	17.3*	20.3	17.5	19.9	46.9	53.3*	78.8	86.4	66.4	0.21	0.17*	0.28	0.29	0.24
	Brome	23.3	17.3*	22.7	21.1	21.1	64.6	53.3*	99.6	101.3	79.7	0.19	0.17*	0.18	0.18	0.18
9	Alfalfa	22.6	16.8*	22.0*	31.7*	23.3	50.0	69.0*	95.1*	108.0*	80.5	0.26	0.15*	0.17*	0.17*	0.19
	Brome	21.7	16.8*	22.0*	31.7*	23.1	70.7	69.0*	95.1*	108.0*	85.7	0.16	0.15*	0.17*	0.17*	0.16
10	Alfalfa	13.3	27.0	22.0	25.9	22.1	32.5	40.9	45.7	52.0	42.8	0.11	0.23	0.15	0.12	0.15
11	Brome	18.4	16.2	27.0	24.0	21.4	50.3	73.2	128.3	78.8	82.7	0.14	0.10	0.17	0.13	0.14
12	Native	21.2	18.9	17.6	24.8	20.6	30.8	32.6	45.6	61.9	42.7	0.16	0.22	0.22	0.17	0.19
13	Alfalfa	28.6	15.1*	22.2	11.1	19.3	51.8	49.5*	65.5	59.8	56.7	0.37	0.17*	0.44	0.20	0.30
	Brome	25.5	15.1*	21.0	35.5	24.3	75.9	49.5*	99.6	113.3	84.6	0.28	0.17*	0.23	0.25	0.23

Table 4. Continued.

Sample No.	Crop	Zn (µg/g)					Mn (µg/g)					S (%)				
		June	July	August	Sept.	Mean	June	July	August	Sept.	Mean	June	July	August	Sept.	Mean
14	Alfalfa	20.4	8.6	18.2	13.1	15.1	73.9	43.2	59.0	64.5	60.2	0.19	0.09	0.19	0.13	0.15
	Brome	17.2	10.7	28.0	17.8	18.4	89.3	82.2	81.8	180.0	108.3	0.15	0.10	0.25	0.15	0.16
15	Brome	22.0	31.5	25.0	37.7	29.1	83.2	113.2	55.5	92.3	86.1	0.19	0.29	0.20	0.29	0.24

*Mixed alfalfa/brome sample.

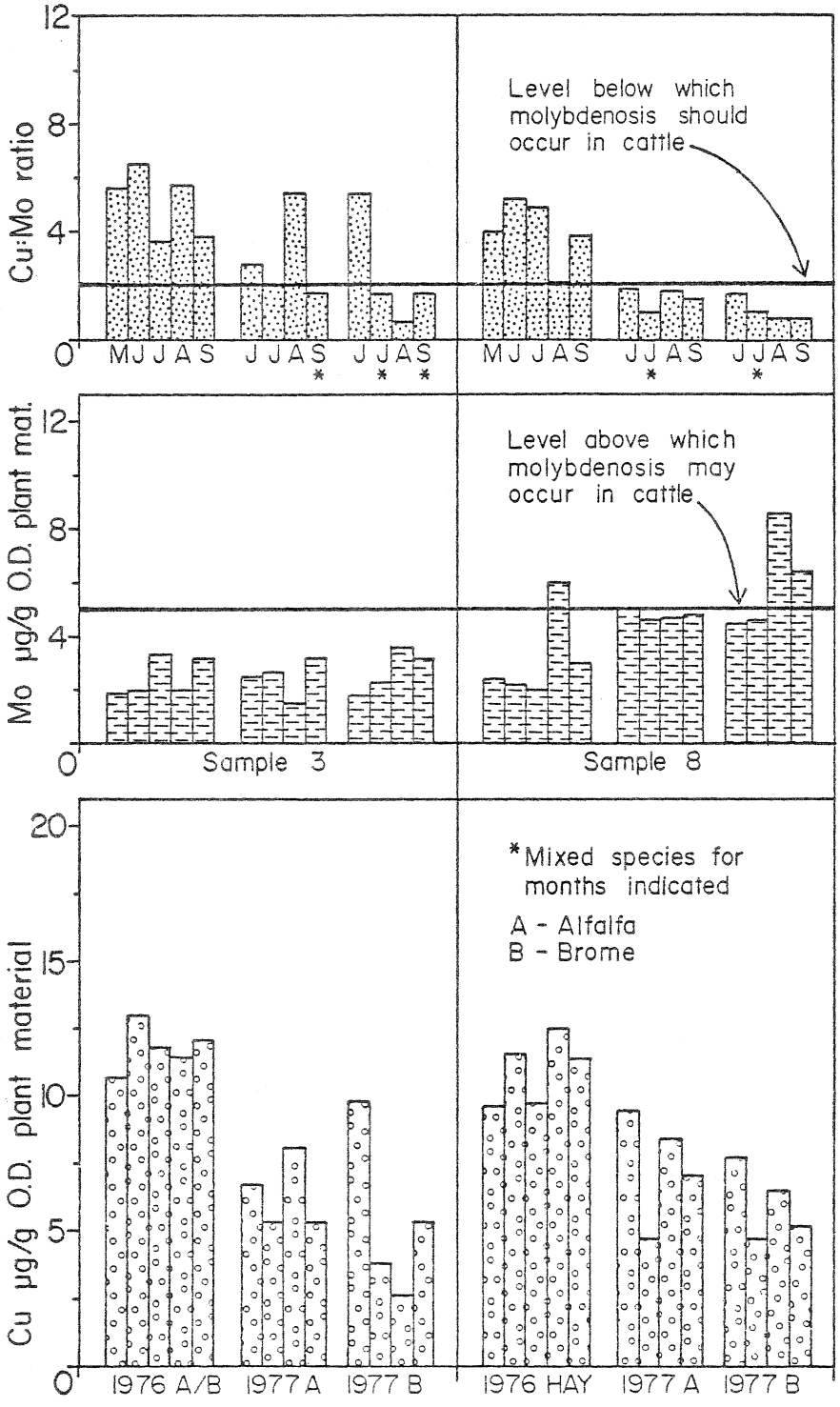

Fig. 1. Copper and molybdenum concentrations in herbage samples taken at monthly intervals from two sites in 1976 and 1977.

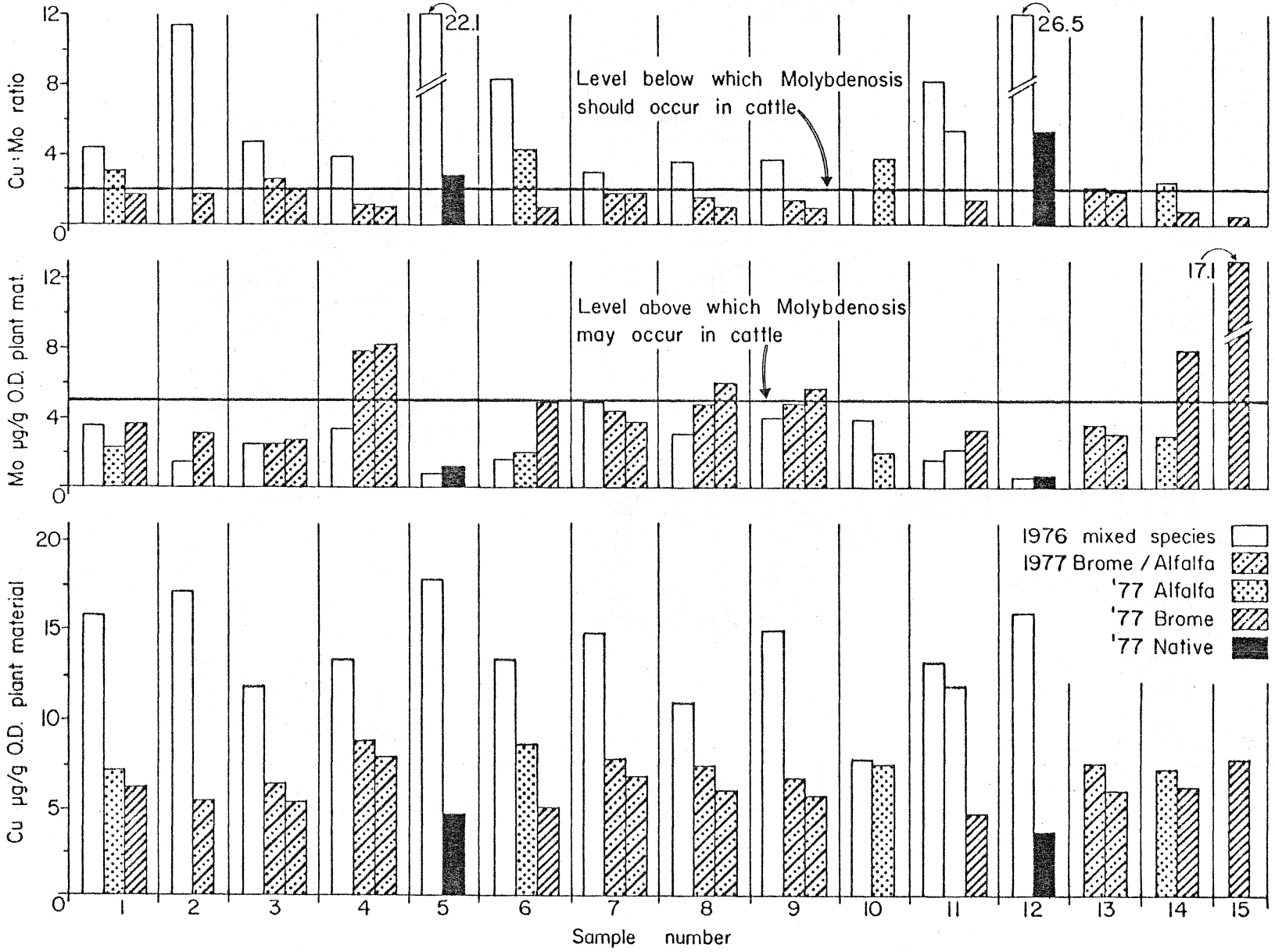

Fig. 2. Copper and molybdenum concentrations in herbage samples (averaged on a yearly basis) from 15 sites in 1976 and 1977.

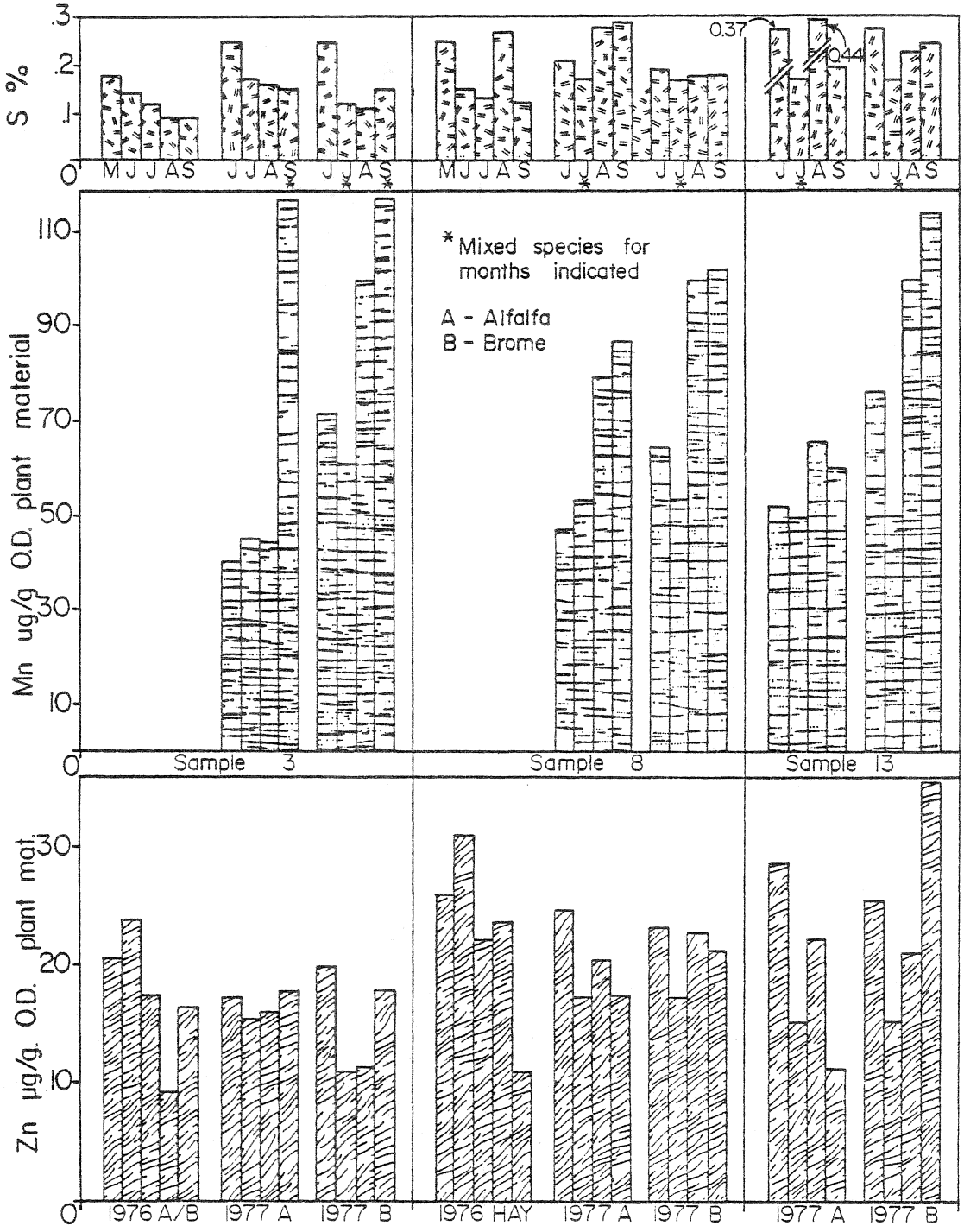

Fig. 3. Zinc, manganese and sulphur concentration in herbage samples taken at monthly intervals from three sites in 1976 and 1977.

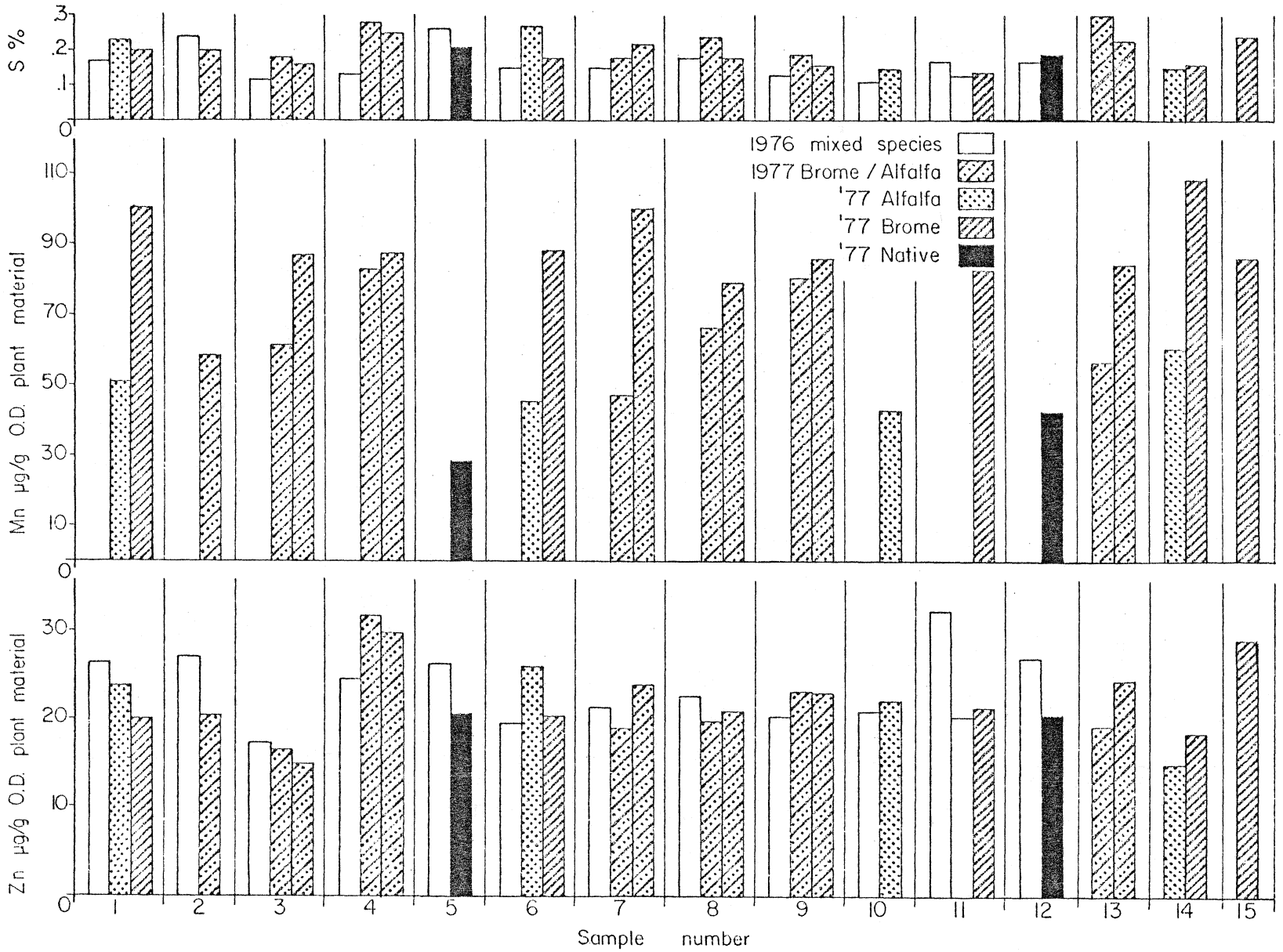

Fig. 4. Zinc, manganese and sulphur concentrations in herbage samples (averaged on a yearly basis) from 15 sites in 1976 and 1977.

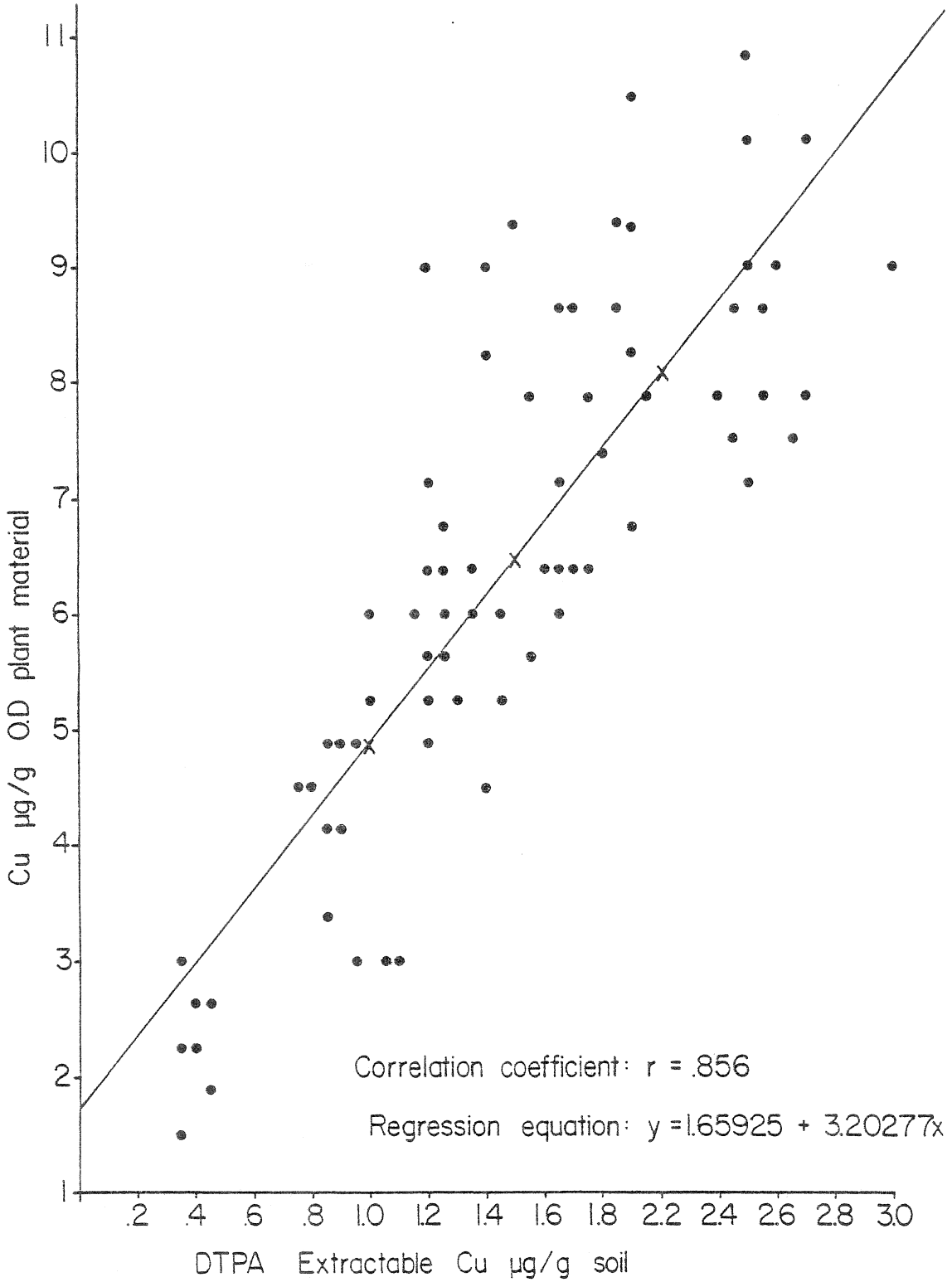

Fig. 5. Relationship between copper concentration in bromegrass grown under ideal conditions in a growth chamber and DTPA extractable soil copper.

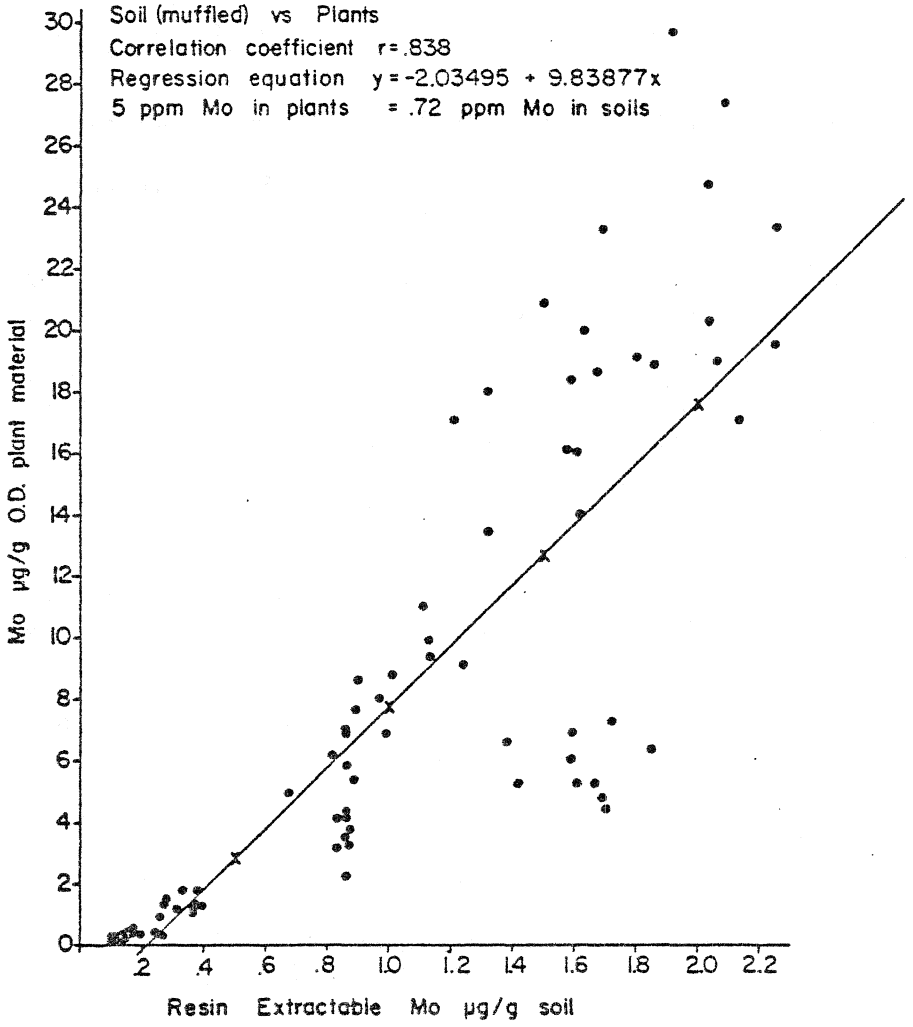

Fig. 6. Relationship between molybdenum concentration in bromegrass grown under ideal conditions in a growth chamber and resin extractable soil molybdenum.

References Cited

Brockman, R.P. 1976. Copper status in Saskatchewan cattle. Mimeo. Report to Sask. Dept. of Agriculture.

Brockman, R.P. 1977. Concentration of copper in the livers of Saskatchewan cattle at slaughter. Can. Vet. J.

Christensen, D.A. and M.A. Cochran. 1975. Copper requirement of beef and dairy cattle. Mimeo. Review to Dept. of Animal Science, Univ. of Saskatchewan.

Fletcher, P.J. and K. Doyle. 1971. Molybdenum content of bedrock, soils and vegetation and the incidence of copper deficiency in cattle in Western Manitoba. Mimeo. Report to Dept. of Geological Science, University of British Columbia.

Henderson, J.R. 1957. Conditional copper deficiency in Canadian cattle. Can. J. Comp. Med. 21: 332-335.

Jackson, D.R. and R.R. Meglen. 1975. A procedure for extraction of molybdenum from soil with anion-exchange resins. Soil Sci. Soc. Amer. Proc. 39: 373-374.

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice Hall Inc., New York.

Lindsay, W.L. and W.A. Norvell. 1978. Development of a DTPA micro-nutrient test for zinc, iron, manganese and copper. Soil Sci. Soc. Amer. J. 42: 421-428.

Marsden, H.A. 1952. Cobalt, copper and molybdenum in the nutrition of animals. Physiol. Revs. 32: 66-121.

Miltmore, J.E. and J.L. Mason. 1971. Copper to molybdenum ratio and molybdenum and copper concentration in ruminant feeds. Can. J. Anim. Sci. 51: 193-200.

Miltmore, J.E., J.L. Mason, J.M. McArthur and R.B. Carson. 1964. Ruminant mineral nutrition. Can. J. Comp. Vet. Sci. 28: 108-112.

Miltmore, J.E., J.L. Mason, J.M. McArthur, C.C. Strachan and J.B. Clapp. 1973. Response from copper and selenium with vitamin E injections to cattle pastured on mineral and organic groundwater soils. Can. J. Anim. Sci. 53: 237-244.

National Research Council. 1970. 1971. Nutrient requirements of beef cattle, 4th review edition. Nutrient requirements of dairy cattle, 4th review edition. NAS-NRC, Washington, D.C.

Stewart, J.W.B. 1969. Micronutrients in Saskatchewan soils. Report to West Sci. Nut. Soil Fert. Comm., Edmonton. pp. 24-35.

Stewart, J.W.B. and V.J. Racz. 1977. Copper and molybdenum status of pastures in Eastern Saskatchewan. Proc. Soil Fertility and Crops Workshop, Saskatoon. pp. 110-121.

Technicon Industrial Systems. Sulphate in water and digests. Industrial Method No. 118-7110.