# Molybdenum in soils and plants and its potential importance to livestock nutrition, with special reference to sub-Saharan Africa

I. Haque

Soils and Plant Nutrition Section,
ILCA, P.O. Box 5689, Addis Ababa, Ethiopia

## Summary

SOILS IN *sub-Saharan Africa are low to very low in available molybdenum (Mo). Soil pH, organic matter, clay content, drainage and nutrient interactions seem to be the main factors affecting the availability of Mo to plants.*

*In sub-Saharan Africa, response to applied Mo has been observed in groundnuts, cowpea, soya bean, maize and sugarcane. Molybdenum can be applied by seed treatment and soil and foliar applications. Liming may also increase the availability of Mo in acid soils. The development of Mo-deficiency symptoms in maize is related to the Mo concentration in the seed. No seed that contained more than 0.13 ppm Mo produced Mo-deficient plants.*

*High concentrations of Mo seldom retard plant growth, but levels of more than 10 ppm in feed seem to be toxic to ruminants. Molybdenum deficiency has never been reported in farm animals, and nutritional interest in Mo for animals is concerned with its toxic effects and its interactions with copper (Cu) and sulphur (S).*

*The role of Mo in legumes with respect to N fixation and its toxicity in forages grown on soils with prolonged wetness, high pH and saline-sodic conditions merit special attention*.

## Introduction

Schutte (1954) reported that the soils of sub-Saharan Africa are low in micronutrients. In a review of micronutrient investigations in West Africa, Kang and Osiname (1972) stated that B, Mo and Zn problems are of greater economic importance than those of Cu, Fe and Mn. In a more recent review of micronutrient problems in tropical Africa, Kang and Osiname (1985) concluded that these problems are less common in the humid zone than in the subhumid and semi-arid zones.

Despite more than three decades of investigations on micronutrients, their role in the soil–plant–animal systems of sub-Saharan Africa has not yet been studied systematically. This is the first article in a planned series of reviews on micronutrients, and it summarises the role of Mo in soils and plants and its potential for livestock nutrition in sub-Saharan Africa, the aim being to provide background information for future work.

## The functions of Molybdenum in plants and animals

Molybdenum is involved in several enzyme systems including nitrate reductase, xanthine oxidase, aldehyde oxidase and sulphate oxidase (Nicholas, 1975). Molybdenum is also required in the synthesis of ascorbic acid and is implicated in making iron (Fe) physiologically available in plants.

Xanthine oxidase or xanthine dehydrogenase, which is widely distributed in animals, and nitrate reductase in plants, are the only known Mo-containing metalloproteins. Nitrate reductase activity is reduced by Mo deficiency. Molybdenum also plays an important role in N metabolism in that it catalyses the fixation, by rhizobia in legumes, of dinitrogen gas to ammonia, which can be utilised by the host plant. The only known biochemical function of Mo in animals, other than its interaction with Cu, is in the formation and activity of xanthine oxidase.

## Diagnosis

### Deficiency symptoms

Since Mo is closely involved in the N metabolism of plants, its deficiency resembles N deficiency. Molybdenum-deficient plants grow poorly, their leaves become pale and wither. Limp leaves are typical of Mo deficiency. The ‘yellow spot’ disease of citrus and ‘whip tail’ in cauliflower are well-known Mo-deficiency syndromes (Katyal and Randhawa, 1983).

Webb (1954) observed severe Mo deficiency in pot trials in Gambia. However, this was not confirmed in a field trial with groundnuts (Maremah, 1970). Molybdenum deficiency commonly occurs in the groundnut-growing areas of northwest Senegal (Martin and Fourrier, 1965), northern Ghana (Stephen, 1959) and northern Nigeria (Heathcote, 1970).

Using the sand culture technique, Aduayi and Idowu (1981) observed that at Mo levels of less than 1 ppm, okra (*Hibiscus esculentus)* leaves were pale yellow and curled upwards. At application rates between 1 ppm and 4 ppm Mo, plants were healthy with deep green leaves, while applying between 8 and 16 ppm Mo resulted in stunted plant growth and dark brownish coating on the roots.

### Soil testing

Several methods for assessing available Mo in soils have been evaluated, but only three have been used widely. The best known is probably the use of Tamm's reagent (acid 0.275M ammonium oxalate, pH 3.3) proposed by Grigg (1953), who showed that the amount of oxalate-extractable Mo was significantly correlated with plant Mo content. The method involves only shaking and filtration, followed by determination of Mo in a very clear extract with minimum matrix interferences and without the need for any background correction in the instrument (Lombin, 1985a).

Lombin (1985a) observed that acid ammonium oxalate solution extracted slightly more Mo than did NaOH and much greater amounts than did anion-exchange resin (Table 1). Nigerian savanna soils are generally high in sesquioxides, and the greater capacity of the oxalate solution to remove soil Mo may be attributable to the breakdown of Fe oxides which contain soil Mo (Reisenauer et al, 1962).

**Table 1**. *Range and average values of extractable Mo in some Nigerian savanna soils, using three common methods of extraction.*

| Method | Extractable Mo (ppm) | | SD |
|---|---|---|---|
| | Range | Mean | |
| $NH_4$ oxalate | 0.065–0.144 | 0.109 | 0.027 |
| NaOH | 0.050–0.160 | 0.092 | 0.025 |
| Anion-exchange resin | 0.023–0.109 | 0.055 | 0.018 |

Source: Lombin (1985a).

The linear correlations among Mo uptake, NaOH Mo and $NH_4$-oxalate Mo and pH, organic matter (OM) and silt + clay contents, were all highly significant. Anion-exchange-resin-extractable Mo was poorly correlated with soil properties (Lombin,1985a).

Anderson (1956) quoted Mo values critical for plant growth ranging from 0.04 to 0.12 ppm, while Grigg (1953; 1960) estimated values of between 0.14 and 0.20 ppm. Critical levels of Mo obtained by various extractants are shown in Table 2.

**Table 2**. *Critical levels of Mo obtained by various extractants*.

| Extractant | Extractable Mo (ppm) | | |
|---|---|---|---|
| | Deficiency | Adequate | Excess/toxicity |
| $NH_4$ oxalate + pH correction | <0.01–0.02 | – | >0.5–1.0 |
| $NH_4$ oxalate (soil pH 5) | <0.1 | 0.1–0.2 | – |
| $NH_4$oxalate (soil pH 6) | – | 0.1 | >0.5 |

Sources: Reisenauer et al (1973); Sillanpãã (1982).

Lombin (1985b) reported that only two out of 30 Nigerian savanna soils contained more than 0.20 ppm Mo, the others ranging from 0.07 to 0.17 ppm. However, the relative yields obtained on the 30 soils cropped in the greenhouse did not reflect the apparent deficiencies: on six soils containing 0.075 ppm Mo, relative yields ranged from 75 to 85%, compared) with a range of 89 to 136% for the remaining 24 soils. It would therefore seem that the critical level for these soils is below 0.1 ppm Mo.

Molybdenum availability is not routinely assessed anywhere, due to the difficulty of determining accurately very small quantities of Mo. More often, Mo availability is assessed by soil pH. Soils with pH values of more than 6.0 to 6.5 rarely require Mo (Katyal and Randhawa, 1983), although there are areas, for example the northern plains in China, where soils are alkaline but still deficient in Mo (Liu Zheng et al, 1983).

## Leaf analysis

Molybdenum concentrations in plants vary from less than 0.1 ppm to more than 30 ppm. However, typical plant concentrations range between 0.1 and 0.2 ppm Mo. It is believed that crops will respond to Mo if they contain less than 0.1 ppm Mo (Katyal and Randhawa, 1983). Mwakatundu (1977) found that the average Mo content of East African pastures ranged from 0.09 to 6.6 ppm. In all locations where Mo was deficient in the pasture, grazing animals had deficient plasma Mo levels. Working with Nigerian savanna soils, Lombin (1985b) reported that on four soils where the relative plant yields dropped below 90%, the plant Mo concentration varied from 0.10 to 0.12 ppm compared with a range of 0.13 to 0.30 ppm for others.

# Molybdenum content of soils

## Total Mo

Few data are available on the total content and distribution of Mo in African soils. Peyue (1963) reported very low total Mo contents (0.44 – 0.75 ppm) for Malian surface soils. Cottenie et al (1981) also found a wide range of total Mo contents (3 – 4.2 ppm) for selected Nigerian soil profiles.

## Extractable Mo

Dabin and Leneuf (1960) determined the levels of Mo extractable with 2.5% acetic acid from 58 soils in the banana-growing areas of Ivory Coast. Except for the organic and hydromorphic soils, the rest of the soils were all low in Mo. Mwakatundu (1977) concluded that Mo is deficient in soils derived from sedimentary and metamorphic rocks and from Kainozoic rocks. Cottenie et al (1981), who studied the micronutrient status of selected soils from the humid zone of southern Nigeria and Togo, reported low levels of $NH_{4^-}$ oxalate-extractable Mo. Ibrahim (1982) found low levels of extractable Mo in three major soils in the Gezira scheme in Sudan.

As a part of a global study on soil micronutrients, Sillanpãã (1982) investigated the micronutrient status of a large number of soils from Ghana, Nigeria, Sierra Leone, Malawi, Tanzania and Zambia. He reported generally low to deficient levels of Mo. The Mo levels found by Lombin (1985b) in Nigeria's semi-arid savanna soils are given in Table 3.

**Table 3**. *Extractable Mo in semi-arid savanna soils in Nigeria.*

| Soil order | Extractable Mo (ppm) | |
|---|---|---|
| | Range | Mean |
| Inceptisols | 0.065–0.142 | 0.099 |
| Alfisols | 0.07–0.173 | 0.121 |
| Oxisols | 0.067–0.135 | 0.093 |

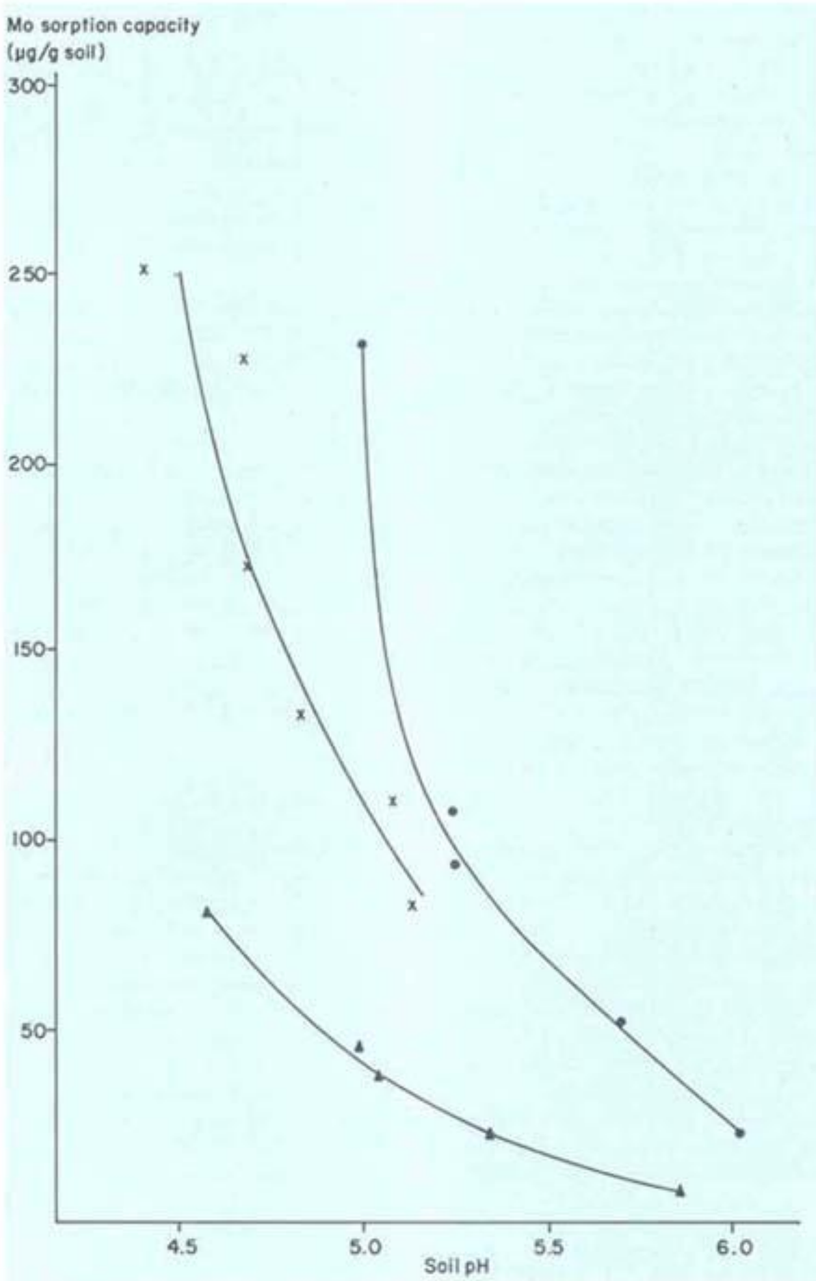
## Factors affecting availability of Molybdenum to plants

### Soil pH

Soil pH is one of the most important factors affecting the availability of Mo to plants (Gupta and Lipsett, 1981). The $MoO_4^{2-}$ concentration increases 100-fold for each unit increase in pH (Lindsay, 1972). With increasing pH, the amount of soluble $MoO_4^{2-}$ species in equilibrium with soil Mo is much greater than for $HMoO_4^{-}$ and $H_2MoO_4$. At a pH of 5 or 6, the ion $HMoO_4^{-}$ becomes dominant and at very low pH values the unionized acid $H_2MoO_4$ and the cation $MoO_2^{2+}$ are the principal species present (Krauskopf, 1972). The $MoO_4^{2-}$ anion exists in an exchangeable form in the soil. Thus, the fact that Mo availability to plants increases with increasing pH may be explained by an anion exchange of the type $2OH^- \rightleftarrows MoO_4^{2-}$ (Berger and Pratt, 1965). Even wulfenite ($PbMoO_4$), the least soluble of soil Mo compounds, becomes more soluble as pH increases (Vlek and Lindsay, 1974).

Like $PO_4^{2-}$ and $SO_4^{2-}$ the $MoO_4^{2-}$ anion is strongly adsorbed by Fe and Al oxides, which markedly increase at low pH. As a result, Mo deficiency is normally a problem on acid soils. Tanner (1978a) reported that the values for Mo sorption capacity ranged from 6 µg/g in a sandy clay loam of pH 5.85 to 267 µg/g in a clay of pH 4.40 and averaged 125 µg/g . At each site there was a close inverse relation between Mo sorption capacity and soil pH (Figure 1). The sorption of Mo was significantly related to other factors such as exchange capacity and acidity, exchangeable A1 and dithionite/citrate- and oxalate-extractable Fe. Lombin (1985b) reported that the amount of Mo removed by greenhouse peanuts and that extracted chemically were both well correlated with the pH of Nigerian savanna soils.

**Figure 1**. *Relationship between Mo sorption capacity and soil pH for three soils in Zimbabwe.*




Source: Tanner (1987a).

## Organic matter

The level of available Mo has been found to be closely related to soil organic matter (Karimian and Cox, 1978). Lombin (1985b) reported that the amount of ammonium-oxalate-extractable Mo correlated significantly with organic matter content ($r = 0.52$, $P<0.01$). It is conceivable that the Mo tied up in organic matter will be released for plant use through mineralisation. It is also possible that Fe oxide bound to organic matter may be responsible for Mo adsorption. However, since the West African savanna soils in general contain low levels of organic matter and the rate of mineralisation is high, only Mo complexed with organic matter may be unavailable to plants in the short term. This fraction is unlikely to limit Mo availability seriously under field conditions.

## Clay

The role of clay in the micronutrient status of soils is well documented (Mortvedt et al, 1972; Davies, 1980). Lombin (1985b) reported that extractable Mo was significantly correlated with clay fraction. Using multiple regression, he also evaluated the relative importance of soil factors for Mo uptake by plants. The factors which contributed significantly to Mo uptake by peanuts are shown below in a descending order of significance in a predictive equation:

Mo uptake =

0.33+5.87 Ext Mo – 1.90 OM + 9.86 C

$R^2 = 0.66$, $P<0.01$

where:

Ext Mo = extractable Mo

OM = organic matter content (%)

C = clay content (%)

## Drainage

Soil wetness seems to be one of the main factors affecting the availability of Mo. Wet soils tend to have high organic matter content and large amounts of Mo that may be readily available (Kubota et al, 1961). Poorly drained soils accumulate so much $MoO_4^{2-}$ that the plants grown on them are toxic to animals (Davies, 1956; Kubota et al,1961).

## Crop sensitivity

Table 4. lists crops according to their susceptibility to Mo deficiency. Crucifers and legumes have high Mo requirements. These crops are frequently affected by Mo deficiency on soils on which cereals may grow without suffering this deficiency (Katyal and Randhawa, 1983).

**Table 4.** *Relative susceptibility of crops to Mo deficiency*.

| Susceptible | Moderately susceptible | Tolerant |
|---|---|---|
| Alfalfa | Cabbage | Apples |
| Beans | Citrus | Barley |
| Broccoli | Maize | Carrots |
| Cauliflower | Oats | Celery |
| Clover | Radish | Cotton |
| Lettuce | Sugar beet | Grapes |
| Peas | Tomato | Potatoes |
| Soya bean | Turnip | Peaches |
| Spinach | Wheat | Raspberry |
| | | Rice |
| | | Sorghum |

Sources: Lucas and Knezek (1972); Shorrocks (1984).

## Nutrient interactions

Uptake of Mo by plants is usually enhanced by soluble P and decreased by available S (Gupta and Lipsett, 1981). The effect of P on increasing the concentration of Mo in plants seems to be associated with the stimulating effect of $PO_4^{3-}$ ions on the uptake of Mo and the formation of a complex phosphomolybdate anion, which is absorbed more readily by the plants (Barshad,1951).

Applying S has been found to decrease the Mo content of plants. The antagonistic effects of $SO_4^{2-}$ on Mo content of plants have been suggested to occur primarily during the absorption process, with an antagonistic mechanism involved during translocation from roots to leaves (Gupta and Lipsett, 1981). Ryding (1982) observed that increasing the rate of Mo application increased Mo concentration in and uptake by plants, while both decreased with increasing rates of sulphate application.

Copper-molybdenum antagonism is well known, and toxicity arising from excess Mo in herbage is effectively prevented by applying Cu to the soil. Soils high in $Fe_2O_3$ are frequently deficient in Mo (Katyal and Randhawa,1983).

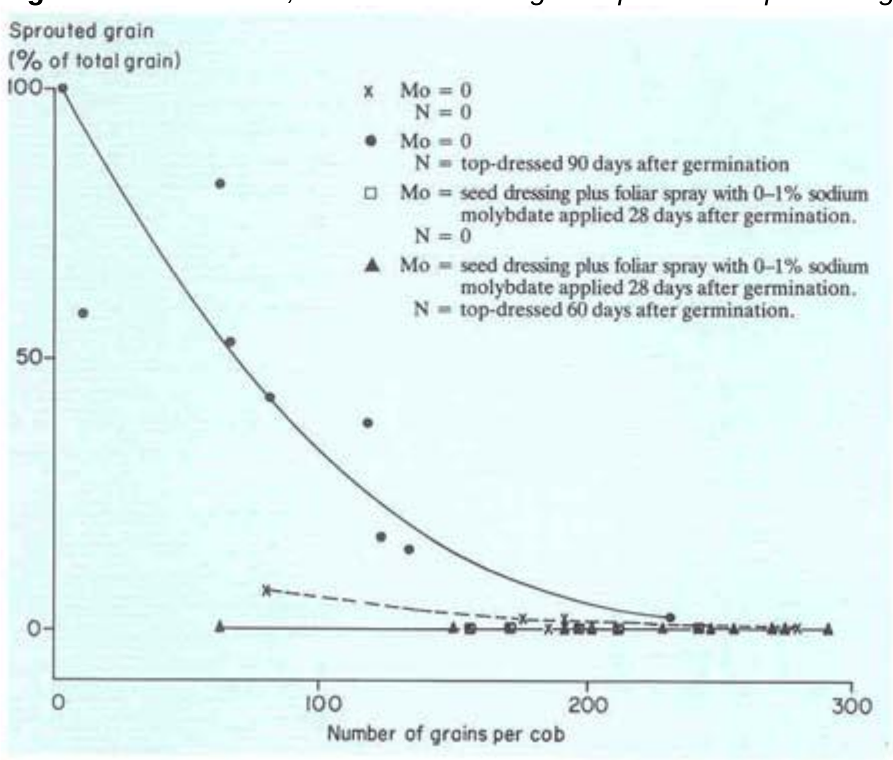
## Molybdenum responses

### Seed molybdenum content

Plants have very small Mo requirements. Seed Mo reserves, especially in large-seeded crops such as peas and maize, can make a significant contribution to the Mo status of the crop (Hagstrom and Berger, 1963). Tassel, anther and pollen development in maize seems to be sensitive to Mo deficiency (Agarwala et al, 1979).

Tanner (1978b) observed that the Mo concentration of maize grain was a controlling factor in the premature sprouting of grain on the cob, and that when the level of Mo fell below 0.05 ppm, the severity of sprouting was enhanced by heavy, late side-dressings of N fertilizer. The effect of Mo deficiency on premature sprouting is likely to operate through its limitation of nitrate reductase activity and the subsequent accumulation of inorganic nitrates which promote sprouting. This mechanism would explain the increased severity of sprouting with a decreasing number of grains per cob (Figure 2), as it is possible that the smaller grain ‘sink’ results in a greater concentration of nitrates in the remaining grains.

**Figure 2**. *Effect of Mo, N and number of grains per cob on percentage of sprouting in maize.*




Source: Tanner (1978b).

Tanner (1979) noticed that plant mass, plant stand and grain yield were significantly lower from R 200 maize seed containing 0.03 ppm Mo than from seed containing 0.50 ppm Mo, even though the seed had been dressed with sodium molybdate. On acid red clay loam soils in Zimbabwe, Mo deficiency symptoms developed in SR 52 maize grown from seed containing 0.13 ppm Mo or less. In contrast, none of the maize plants grown on granite sand soils which contain adequate Mo developed deficiency symptoms (Table 5).

**Table 5**. *Effect of soil type and of seed Mo content on the percentage of SR 52 maize plants showing Mo deficiency symptoms*.

| Site | Soil | Seed Mo (ppm): | Plants showing Mo deficiency (%) | | |
|---|---|---|---|---|---|
| | | | <0.04 | 0.04–0.13 | >0.13 |
| Mt. Hampden | Red clay loam | | 33 | 17 | 0 |
| Marandellas | Granite sand | | 0 | 0 | 0 |

Source: Tanner (1982).

The effect of seed Mo content on crop performance following seed dressing with sodium molybdate has been examined at two other sites in Zimbabwe (Tanner, 1982). All seed germinated satisfactorily and there were no Mo deficiency symptoms in the young plants. At one site, the mass of young SR 52 maize plants decreased from seed containing less than 0.04 ppm Mo even though seed dressing had been applied. Despite lower plant mass there was no significant relationship between seed Mo content and yield.

The development of deficiency symptoms in the maize plants was clearly related to the Mo concentration of the SR 52 seed. The largest percentage of plants showing distinct symptoms of Mo deficiency was produced from seed containing 0.01 ppm Mo, and the incidence of symptoms decreased as the Mo content of the seed increased. No seed containing more than 0.13 ppm Mo produced Mo-deficient plants (Tanner, 1982).

Commonly used sources of Mo are given in Table 6. Molybdenum deficiencies can be corrected by seed treatment and soil and foliar application of Mo carriers. Molybdenum deficiency can also be rectified by liming acid soils.

**Table 6**. *Sources of molybdenum*.

| Source | Formula | % Mo |
|---|---|---|
| Sodium molybdate | $NaMoO_4 2H_2O$ | 39 |
| Ammonium molybdate | $(NH_4)_6Mo_7O_{24}4H_2O$ | 54 |
| Molybdenum trioxide | $MoO_3$ | 66 |
| Molybdenite | $MoS_2$ | 60 |
| Molybdenum frits | – | 2–3 |

Source: Murphy and Walsh (1972).

## Seed treatment

Molybdenum salts are applied to seed in a liquid or slurry form at a rate equivalent to 50 to 100 g Mo/ha. (Katyal and Randhawa, 1983). Applying 28 g ammonium molybdate/ha as seed dressing increased kernel yield of groundnuts by more than 300 kg/ha in Senegal (Martin and Fourrier,1965).

Pelleting seed with 0.2, 0.4 and 0.8 g sodium molybdate per 100 g seed plus inoculation with rhizobia was tested on groundnuts grown on an upland soil in Sierra Leone. Sodium molybdate at 0.2 g/100 g seed increased DM yield by 17.2% , N uptake by 38.5%, grain yield by 14.0% and protein content by 4.21% (Haque and Amara, 1978).

Rhodes and Nangju (1979) conducted two field experiments to evaluate the effectiveness of several pelleting materials in increasing the yields of cowpea and soya bean on an acid soil in Sierra Leone. Applied either alone or in combination with phosphate rock, Mo increased the growth and yield of cowpeas but had no effect on soya bean growth and yield, although it significantly increased the number of nodules per plant.

Haque and Bundu (1980) observed that inoculation and Mo application (0.4 g sodium molybdate/100 g seed) increased soya bean grain yield and protein content by 154% and 14.6% respectively over the control on an upland soil in Sierra Leone.

Rhodes and Kpaka (1982) found that applying Mo increased DM, pod weight and seed yield of cowpeas. Pelleting seed with nitromolybdenum at 0.4 g/100 g seed increased seed yield by 1.39 t/ha, or 21%, over the control (Table 7). This method of applying Mo should prove attractive to small farmers because it is simple, cheap, does not require spraying equipment and is less subject to the vagaries of rain and wind.

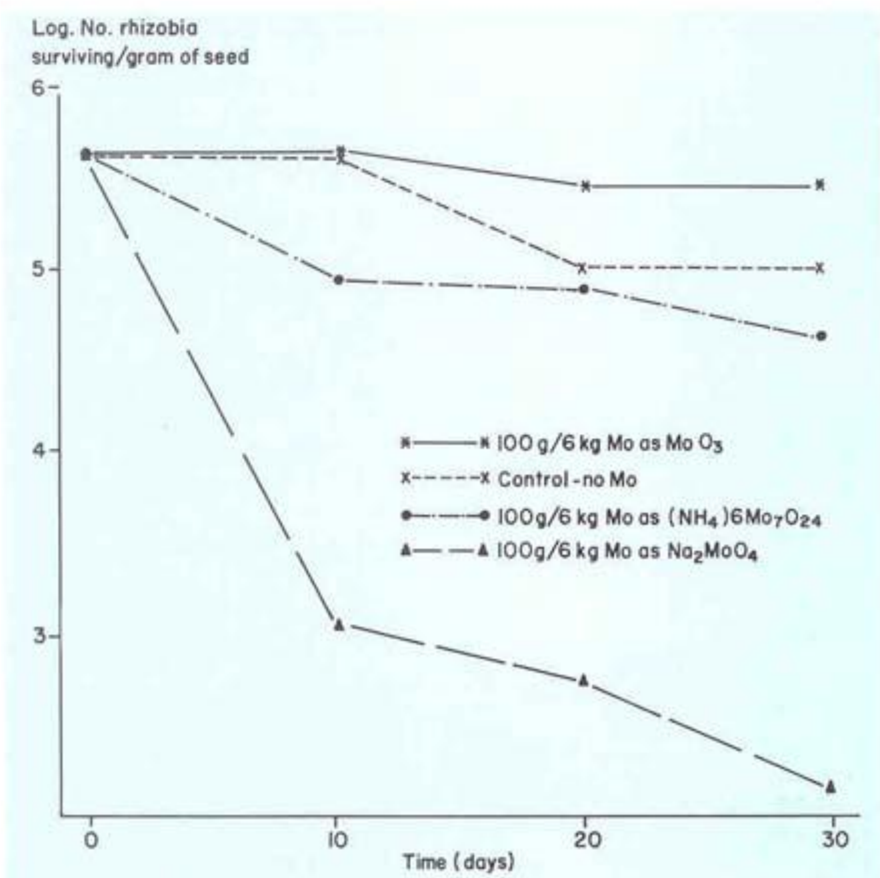
**Table 7**. *Effects of Mo on cowpea performance.*

| Treatment | Dry matter (g/plant) | Nodule weight (mg/plant) | Pod weight (t/ha) | Seed yield (t/ha) |
|---|---|---|---|---|
| No Mo | 10.47a | 144.0a | 1.445a | 1.15a |
| Mo sprayed[1] | 13.09b | 146.3b | 1.519a | 1.15a |
| Mo pelleted[2] | 13.56b | 179.0a | 1.892b | 1.39b |
| LSD (O.05) | 2.08 | 49.3 | 0.22 | 0.18 |

[1] 60 g Mo/ha as ammonium molybdate.
[2] 0.4 g nitromolybdenum/100 g seed.
Figures followed by the same letter are not significantly different at the 5% level.
Source: Rhodes and Kpaka (1982).

Graham and Morales (1974) reported on the influence of source and level of applied Mo on the survival of rhizobia in *Macroptilium atropurpureum* seed. Figure 3 shows that sodium molybdate cannot be used in contact with rhizobia. By contrast, both molybdic oxide and ammonium molybdate showed little evidence of toxicity. Even at the highest level of molybdic oxide applied (100 g Mo/6 kg seed) there was no significant decline in rhizobium numbers with storage. A slow decline in numbers surviving was evident with ammonium molybdate applied at this level, but this differed significantly from the molybdic oxide results only at the 20- and 30-day storage periods.

**Figure 3**. *Influence of form of Mo used on survival of rhizobia in Mo-treated seeds of Macroptilium atropurpureum.*



Source: Graham and Morales (1974)

## Foliar application

Molybdenum deficiencies in growing crops can be controlled using foliar sprays. A typical spray solution contains 0.1 to 0.3% of soluble Mo (Katyal and Randhawa, 1983). Lombin et al (1985) studied the effect of Mo (30 g ammonium molybdate/ha) sprayed 3 weeks after sowing on groundnut yields at Samaru, northern Nigeria, in a wet (1971) and a dry (1972) year (Table 8).

**Table 8**. *Effect of Mo application on groundnut yield at Samaru, Nigeria, 1971 and 1972*[a].

| Year | Variety | Plant part | Pod yield (kg/ha) | | |
|---|---|---|---|---|---|
| | | | No Mo | With Mo | Difference |
| 1971 | $S.6_1$ | kernel | 1718 | 1894 | + 176 |
| | | haulm | 2078 | 2892 | + 814 |
| 1972 | $S.6_1$ | kernel | 1416 | 1293 | – 123 |
| | | haulm | 2992 | 3633 | + 614 |
| 1972 | Spanish 205[b] | kernel | 1893 | 2298 | + 405 |
| | MK 374[b] | kernel | 1922 | 2095 | + 173 |

[a] 1971 = wet year; 1972 = drought year.
[b] Spanish 205 and MK 374 varieties mature in 95 and 120 days respectively.

They found that in a dry year, Mo is more likely to increase the kernel yields of short-season groundnut varieties. In an earlier experiment, foliar application of Mo increased the kernel yield of groundnuts by 200 kg/ha (Kang and Osiname,1972).

In Zimbabwe, foliar sprays of 100 g sodium molybdate/ha applied to maize 10 days after emergence eliminated Mo-deficiency symptoms (Tanner, 1982). However, applied 4 weeks after emergence, sprays of the same rate were ineffective. Tanner (1982) further observed that spraying 100 g sodium molybdate/ha on to a seed maize crop 10 days after emergence was sufficient to raise the seed Mo content above critical concentration (0.08 ppm Mo) on all but the most deficient soils.

## Soil application

The optimum Mo dose varies among soils and crops. Generally, 70 to 200 g Mo/ha is sufficient for forage legumes and other field crops. Cauliflower may need up to 400 g Mo/ha. One application may produce residual effects on pasture and fodder plants for several years, but cauliflower may need Mo application every year (Katyal and Randhawa,1983). In New Zealand and Australia, where pasture and arable crops are treated with Mo-enriched super-phosphate giving 20 to 60 g Mo/ha, residual effects last for 1 to 15 years (Shorrocks, 1984).

Parish et al (1965) found that Mo applied to a low humic Latosol in Mauritius significantly improved sugar-cane growth. Molybdenum applications on the sandy aeolian soils in the West African semi-arid zone had beneficial effects on the growth, nodulation, N fixation and seed yield of groundnuts (Martin and Fourrier, 1965; Gillier,1966).

In an experiment with cowpeas, positive growth response to Mo was observed on the acid Shante soil at Ogbomosho, which is typical of the sandy soils in the forest/ savanna transition zone of Nigeria, and on the Adio soil at Ibadan. Applying 0.05 ppm Mo gave the largest response, with smaller responses occurring at rates up to 4 ppm Mo. However, Mo application decreased the weight and number of nodules as well as nitrogenase activity (IITA, 1975).

Maize appears to be relatively susceptible to Mo deficiency in acid soils. Greenhouse trials in Zimbabwe have shown Mo deficiency to be a major growth-limiting factor on a red clay-loam soil (Tanner, 1976). In field trials, applying Mo increased early maize growth on soils with pH between 4.4 and 4.8 (Tanner and Grant, 1977).

## Liming

Applying lime may correct Mo deficiency on acid soils. In Kenya, Birch (1960) observed that Mo deficiency may be prevented by liming soils to pH 5.5. Rhodes and Nangju (1979) reported that the beneficial effect of Mo applications was comparable to or greater than that of liming with 3 t basic slag/ha.

## Molybdenum–Copper–Sulphur inter-relationships in livestock

High concentrations of Mo (>10 to 20 ppm) seldom retard plant growth but are toxic to ruminants (Gupta and Lipsett, 1981). The dietary requirement for Mo in ruminants has not been determined accurately, since it is apparently very low. However, it has been accepted that a dietary concentration of 0.01 µg Mo/kg DM is adequate (ARC, 1980) .

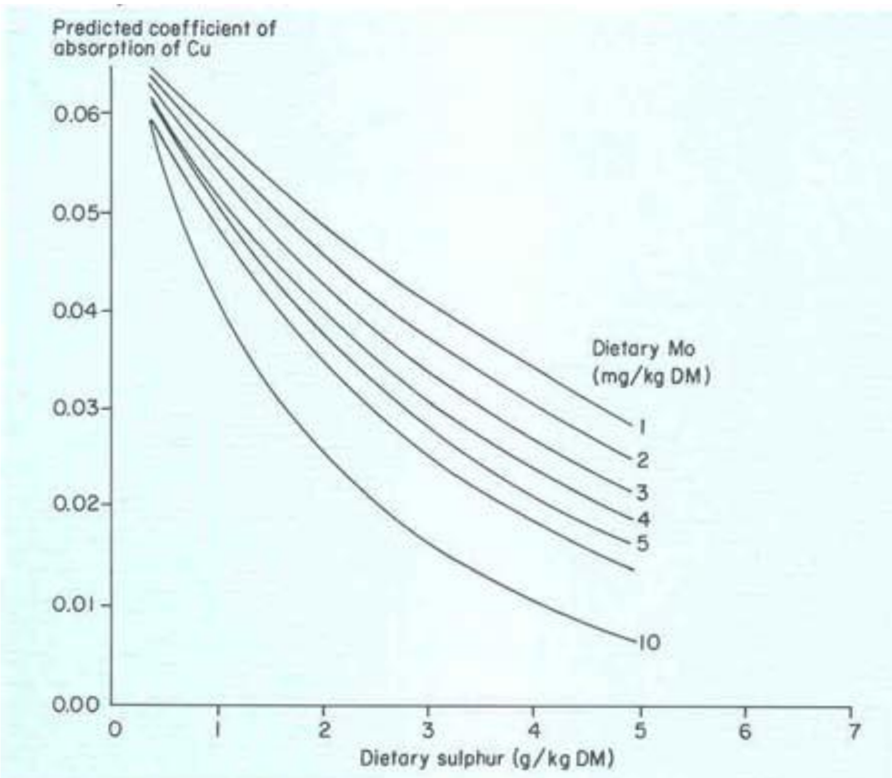
Mwakatundu (1977) found that plasma Mo concentrations in cattle ranged from 0.03 µg/100 ml at Morogoro (Tanzania) to 8.43 µg/100 ml at Egerton (Kenya). If the normal range of Mo in blood is taken to be 1 to 6 µg/100 ml, then animals at nine stations had sufficient Mo in their blood. Correlation coefficients between Mo concentrations in pasture and in plasma were highly significant ($r = 0.856$, $P<0.001$) for data obtained during the dry season.

Molybdenum toxicity (molybdenosis) operates mainly by inducing Cu deficiency, and affected animals respond to Cu supplements. The disease is known as *teart* in England and *peat scours* in New Zealand. Common symptoms include faded hair coats and profuse diarrhoea with foul-smelling faeces. Scouring of cattle and sheep may occur in restricted areas where the pastures contain subnormal levels of Cu and higher than normal levels of Mo, even though the Mo levels are well below those typical of teart herbage (Underwood, 1976).

Swayback, a Cu defficiency in lambs born of ewes that were Cu deficient during pregnancy, was found on pastures containing sufficient Cu, but having an imbalance of Cu, Mo and S (Todd, 1976). The fact that inorganic sulphate potentiates the adverse effect of Mo on the utilisation of Cu by sheep was first discovered by Dick (1953a; b): sulphate accelerates the clearance of Mo (Dick, 1956) and Mo influences the ruminal metabolism of sulphide (Mills, 1960; Gawthorne and Nader, 1976). Organic sulphur and inorganic sulphate share common metabolic fates (Anderson, 1956) and influence the output of soluble Cu from the rumen (Bird, 1970) by interacting with Mo (Suttle, 1975).

Suttle and McLauchlan (1976) reported that S exerts an independent effect on the availability of Cu to sheep or cattle, and that the effect of S alone is greater than the S-dependent effect of Mo (Figure 4). Involving S in the interaction is preferable to the use of Cu:Mo ratios.

**Figure 4**. *Relationship for sheep of coefficient of absorption of dietary Cu to dietary content of total S and Mo.*




Sources: Suttle and McLauchlan (1976); ARC (1980).

A totally different pathological entity that has been associated with diets and crops low in Mo is the high incidence of cancer of the oesophagus in parts of China and in the Transkei in South Africa. In both countries it is thought that the carcinogens are nitrosamines produced in the stomach from a diet rich in nitrites, but it is acknowledged that the connection between cancer and Mo is likely to be complicated by several other dietary and environmental factors (Shorrocks, 1984).

## Future outlook

In view of its role in N fixation, Mo could become more important in sub-Saharan Africa with the adoption of legumes in cropping systems. Studies on Mo toxicity in forages grown on soils with relatively prolonged wetness, high pH and under saline-sodic conditions merit particular attention.

## Reference

Aduayi E A and Idowu E O. 1981. The response of okra to molybdenum in sandculture. *Commun. Soil Sci. Plant Anal.* 12(10):965–977.

Agarwala S C, Chattterjee C, Sharma P N, Sharma C P and Nuatiyal N. 1979. Pollen development in maize plants subjected to molybdenum deficiency. *Can. J. Bot.* 57(18): 1946–1950.

Anderson A J. 1956. Molybdenum as a fertilizer. *Adv. Agron.* 8: 163–202.

ARC (Agricultural Research Council). 1980. *The nutrient requirements of ruminant livestock*. CAB, Farnham Royal, Slough, England.

Barshad I. 1951. Factors affecting the molybdenum content of pasture plants: II. Effect of solublephosphates, available nitrogen and soluble sulphates. *Soil Sci*. 71: 387–398.

Berger K C and Pratt P F. 1965. Advances in secondary and micronutrient fertilization. In: M M McVickar, G L Bridger and L B Nelson (eds), *Fertilizer technology and usage.* Soil Science Society of America, Madison, Wisconsin, USA. pp. 287–340.

Birch W R. 1960. High-altitude ley agronomy in Kenya. 3. The effects of lime and molybdenum and some observations on the use of legumes. *East Afr. Agric. J.* 25:156–164.

Bird P R. 1970. Sulphur metabolism and excretion studies in ruminants. III. The effect of sulphur intake on the availability of copper in sheep. *Proc. Aust. Soc. Anim. Prod.* 8: 212–218.

Cottenie A, Kang B T, Kiekens L and Sajjaponse A. 1981. Micronutrient status. In: D J Greenland (ed.), *Characterization of soils.* Academic Press. pp. 149–163.

Dabin B and Leneuf N. 1960. Les sols de bananeraies en Cote d'Ivoire. [The soils of banana plantations in Ivory Coast]. *Fruits* 15:117–127.

Davies F B. 1956. Factors affecting molybdenum availability in soils. *Soil Sci*. 81: 209–221.

Davies E B (ed). 1980. *Applied soil trace elements.* John Wiley and Sons, New York, USA. 496 pp.

Dick A T. 1953a. The effect of inorganic sulphate on the excretion of molybdenum in the sheep. *Aust. Vet. J*. 29: 18–26.

Dick A T. 1953b. The control of copper storage in the liver of sheep by inorganic sulphate and molybdenum. *Aust Vet. J.* 29: 233–239.

Dick A T. 1956. Molybdenum and copper relationships in animal nutrition. In: W D McElroy and H B Glass (eds), *Inorganic nitrogen metabolism: Function of metallo-flavoproteins.* John Hopkins Press, Baltimore. pp. 445–473.

Gawthorne J M and Nader C J. 1976. The effect of molybdenum on the conversion of sulphate to sulphide and microbial protein sulphur in the rumen of sheep. *Brit. J. Nutr*.35: 11–23.

Gillier P. 1966. Groundnut and molybdenum. R.R. Seanc. Hebd. Acad. Agric. Fr. 52: 446–449. *Soils Fert*. 29: Abstr. 4399.

Graham P H and Morales V M. 1974. Seed pelleting of a legume to supply molybdenum. *Turrialba* 24(3): 335–336.

Grigg J L. 1953. Determination of the available molybdenum in soils. *N. J. Sci. Tech*. A 34: 405–415.

Grigg J L. 1960. The distribution of molybdenum in the soils of New Zealand. *N. Z. J. Agric*. *Res.* 3: 69–86.

Gupta U C and Lipsett J. 1981. Molybdenum in soils, plants and animals. *Adv. Agron.* 34: 73–115.

Hagstrom G R and Berger K C. 1963. Molybdenum status of three Wisconsin soils. *Soil Sci*. 100: 52.

Haque I and Amara D S. 1978. Effects of inoculation and sodium molybdate on groundnuts. *Trop. Grain Legumes Bull.* 11/12: 11–12.

Haque I and Bundu H S. 1980. Effects of inoculation, nitrogen, molybdenum and mulch on soybean in Sierra Leone. *Commun. Soil Sci. Plant Anal*. 11(5): 477–483.

Heathcote R G. 1970. Soil fertility under continuous cultivation in northern Nigeria. II. Response to fertilizers in the absence of organic manures. *Exp. Agric.* 6: 345–350.

Ibrahim A A. 1982. Mineralogy and micronutrient status of the major soils in the Gezira scheme. Ph.D. thesis, Texas A and M University, Texas, USA.

IITA (International Institute of Tropical Agriculture). 1975. Study on micronutrients. 1. Molybdenum response in cowpea. In: *Annual Report.* IITA, Ibadan, Nigeria. p. 20.

Kung B T and Osiname O A. 1972. Micronutrient investigations in West Africa. Paper presented at the Ford Foundation/IITA/ IRAT International Seminar on Tropical Soil Research, Ibadan, Nigeria, May 22–26.

Kang B T and Osiname O A. 1985. Micronutrient problems in tropical Africa. *Fert. Res*. 7(1–3): 131–150.

Karimian N and Cox F R. 1978. Adsorption and extractability of molybdenum in relation to some chemical properties of soil. *Soil Sci. Soc. Am. Proc.* 42: 757–760.

Katyal J C and Randhawa N S. 1983. Micronutrients (molybdenum). *FAO Fert. Plant Nutr*. *Bull*. 7: 69–76.

Krauskopf K B. 1972. Geochemistry of micronutrients. In: J J Mortvedt, P M Giordano and W L Lindsay (eds), *Micronutrients in agriculture.* Soil Science Society of America, Madison, Wisconsin, USA. pp. 7–40.

Kubota J, Lazar V A, Langan L N and Beeson K C. 1961. The relationship of soils to molybdenum toxicity in cattle in Nevada. *Proc. Soil Sci. Soc. Am.* 25: 227–232.

Lindsay W L. 1972. Inorganic phase equilibria of micronutrients in soils. In: J J Mortvedt, P M Giordano and W L Lindsay (eds), *Micronutrients in agriculture.* Soil Science Society of America, Madison, Wisconsin, USA. pp. 41–57.

Liu Zheng, Zhu Qi-Qimg and Tang Li-Hua. 1983. Microelements in the main soils of China. *Soil Sci*. 135(1): 40–46.

Lombin G. 1985a. Micronutrient soil tests for semi-arid savanna of Nigeria: Boron and molybdenum. *Soil Sci. Plant Nutr.* 31(1): 1–11.

Lombin G. 1985b. Evaluation of the micronutrient fertility of Nigeria's semi-arid savanna soils: Boron and molybdenum. Soil Sci. *Plant Nutr.* 31(1): 13–25.

Lombin G, Singh L and Yayock J Y. 1985. A decade of fertilizer research on groundnuts in the savanna zone of Nigeria. *Fert. Res.* 6(2):157–170.

Lucas R E and Knezek B D. 1972. Climate and soil conditions promoting micronutrient deficiencies in plants. In: J J Mortvedt, P M Giordano and W L Lindsay (eds), Micronutrients in agriculture. Soil Science Society of America, Madison, Wisconsin, USA. pp. 265–288.

Maremah L J. 1970. Agronomic research on groundnuts in the Gambia. Paper presented at the Ford Foundation/IITA/IRAT International Seminar on Grain Legumes Research in West Africa, Ibadan, Nigeria.

Martin G and Fourrier P. 1965. Les oligo-éléments dans la culture de l'arachide du Nord Sénégal. [The elements of groundnut cultivation in northern Senegal]. *Olèagineux* 20: 287–291.

Mills C F. 1960. Comparative studies of copper, molybdenum and sulphur metabolism in the ruminant and rat. *Proc. Nutr. Soc*. 18: 162–169.

Mortvedt J J, Giordano P M and Lindsay W L (eds). 1972. *Micronutrients in agriculture.* Soil Science Society of America, Madison, Wisconsin, USA. 666 pp.

Murphy L S and Walsh L M. 1972. Correction of micronutrient deficiencies with fertilizers. In: J J Mortvedt, P M Giordano and W L Lindsay (eds), *Micronutrients in agriculture.* Soil Science Society of America, Madison, Wisconsin, USA. pp. 347–388.

Mwakatundu A G K. 1977. A study of the nutritive value of East African pastures for ruminant livestock with special reference to mineral nutrition in grazing dairy cattle. Ph.D. thesis, University of Nairobi, Kenya.

Nicholas D J D. 1975. The function of trace elements in plants. In: D J D Nicholas and A R Edan (eds), *Trace elements in soil–plant–animal systems.* Academic Press, New York, USA. pp. 181–198.

Parish D H, Vignes E C, Cavalot C and Abel M. 1965. Trace elements status of sugar-cane in Mauritius. Report of the Mauritius Sugar Industry Research Institute, 12: 60–61.

Peyue Y V. 1963. Microelements in the savanna soils of the Republic of Mali. *Pochvovedenije* 11*:* 1050–1053.

Reisenauer H M, Fabikh A A and Stout P R. 1962. Molybdenum reaction with soils and the hydrous oxides of iron, aluminium and titanium. *Soil Sci. Soc. Am. Proc.* 26: 23–27.

Reisenauer H M, Walsh L M and Hoeft R G. 1973. Testing soils for sulphur, boron, molybdenum and chlorine. In: L M Walsh and J D Beaton (eds), *Soil testing and plant analysis*. Soil Science Society of America, Madison, Wisconsin, USA. pp. 173–200.

Rhodes E R and Kpaka M. 1982. Effects of nitrogen, molybdenum and cultivar on cowpea growth and yield on an Oxisol. *Commun. Soil Sci. Plant Anal*. 13(4): 279–283.

Rhodes E R and Nangju D. 1979. Effects of pelleting cowpea and soybean seed with fertilizer dusts. *Exp*. *Agric*. 15: 27–32.

Ryding W W. 1982. Effect of molybdenum and sulphur on flue-cured tobacco seedlings. *Zimbabwe J. Agric. Res*. 20(1): 85–90.

Schutte K. 1954. .A survey of plant minor element deficiencies in Africa. *Afr. Soils* 3: 285–292.

Sillanpaa M. 1982. Micronutrients and nutrient status of soils: A global study. *FAO Soils Bull*. 48. pp. 343–409.

Shorrocks R M. 1984. Micronutrients and their use world wide. *Fertilizer* 1*:* 63–85.

Stephen D. 1959. Field experiments with trace elements on annual food crops in Ghana. *Emp*. *J. Exp*. Agric. 27: 324–332.

Suttle N F. 1975. Trace element interactions in animals. In: I) J D Nicholas and R Egan (eds), *Trace elements in soil–plant–animal systems.* Academic Press, New York. pp. 271–289.

Suttle N F and McLauchlan M. 1976. Predicting the effects of dietary molybdenum and sulphur on the availability of copper to ruminants. *Proc. Nutr. Soc.* 35: 22A–23A.

Tanner P D. 1976. Manganese toxicity and molybdenum deficiency effects on maize grown in an acid fersialllitic red sandy clay loam. *Rhod. J. Agric. Res*. 14: 95.

Tanner P D. 1978a. Relations of sorption of molybdate and phosphate by clays and clay loams to soil pH and other chemical factors. *Rhod. J. Agric. Res*. 16: 31–41.

Tanner P D. 1978b. A relationship between premature sprouting on the cob and the molybdenum and nitrogen status of maize grain. *Plant Soil* 49: 427–432.

Tanner P D. 1979. The effects of molybdenum on maize seed quality. *Rhod. J. Agric. Res*. 17:125–129.

Tanner P D. 1982. The molybdenum requirements of maize in Zimbabwe. *Zimbabwe Agric. J.* 79(2): 61–64.

Tanner P D and Grant P M. 1977. Response of maize to lime and molybdenum on acid red and yellow-brown clay loams. *Rhod. J. Agric. Res*. 15: 143–149.

Todd J R R. 1976. Problems of copper-molybdenum imbalance in the nutrition of ruminants in Northern Ireland. In: W R Chappell and K K Peterson (eds), *Molybdenum in the environment. Vol. 1. The biology of molybdenum.* Marcel Dekker, New York. pp. 39–49.

Underwood E J. 1976. Molybdenum in animal nutrition. In: W R Chappell and K K Peterson (eds), *Molybdenum in the environment. Vol. 1. The biology of molybdenum.* Marcel Dekker, New York. pp. 9–31.

Vlek P L G and Lindsay W L. 1974. *Agron. Abstr.* American Society of Agronomy, Madison, Wisconsin, USA. p. 126.

Webb R A.1954. The mineral deficiencies of the Gambian soils. *Second Int. Afr. Soils Conf. Proc.* 1: 419–424.