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ORIGINAL ARTICLE

Molybdenum status and critical limit in the soil for green gram (*Vigna radiata*) growing in Madurai and Sivagangai districts of Tamil Nadu, India

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Abstract

A survey was undertaken during 2008 to determine molybdenum (Mo) status of soils and to establish critical limits in soils of Madurai and Sivagangai districts of Tamil Nadu. A total of 202 surface soil samples were collected from 16 soil series of the study areas based on their percent coverage. The samples were analyzed for extractable or available Mo. Extractable Mo varied from 0.028 to 0.661 mg kg^{-1} and 0.035 to 0.961 mg kg^{-1} at Madurai and Sivagangai districts, respectively. Based on the results of a pot culture experiment, the critical limit of available Mo was determined to be 0.043 mg kg^{-1} for green gram [*Vigna radiata* (L.) Wilczek] (Var; CO 6) in both the districts. Based on this critical limit, we classified the soils into three categories: (1) low: <0.043 mg kg^{-1} (2) medium: 0.043–0.082 mg kg^{-1} (3) high: >0.082 mg kg^{-1}. Green gram responded highly to Mo application in soils below the critical limit whereas soils with Mo greater than 0.082 mg kg^{-1} did not respond. Among rates of Mo application, 0.075 mg kg^{-1} showed better yield than others. Overall, 3–41% and 7–46% of total area in Madurai and Sivagangai districts were in the low to medium Mo status, respectively. The application of 0.075 mg of Mo kg^{-1} or 0.4 kg ha^{-1} as sodium molybdate was sufficient to optimize green gram yield in the major soil series of the districts. These results will be useful in decision-making to apply Mo for improving green gram yields in the two districts studied.

Key words: Soil available Mo, critical limit, green gram, application of Mo, Madurai, Sivagangai.

INTRODUCTION

Soils in Tamil Nadu are mainly Alluvial and Laterite, and characterized by low pH, low in organic carbon and poor in nutrient status. Leguminous crops are being cultivated in various crop rotations (cereals – pulses or pulses – cereals) to improve soil fertility (Prakash *et al.* 2008). Green gram [*Vigna radiata* (L.) Wilczek] is one of the major pulse crops in Tamil Nadu. The total crop area under green gram was 158,000 ha in 2007–2008 (Department of Economics and Statistics, Chennai 2009); and this contributes about 25% of the total pulse production of the state. Average crop productivity of green gram in Tamil Nadu is 291 kg ha^{-1} which is far less than the national average (362 kg ha^{-1}), and the productivity is also lower than those in other Indian states (486 kg ha^{-1} in Punjab; 529 kg ha^{-1} in Maharashtra; 511 kg ha^{-1} in Kerala). However, the potential crop productivity of green gram in this region is reported to be as high as 820 kg ha^{-1} (Prakash *et al.* 2008) which indicates that there exists a scope for improving productivity.

Introduction of high-yielding varieties and higher use of nitrogen (N), phosphorus (P), and potassium (K), however, increased crop production several fold higher

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after the green revolution but this has led to micronutrient deficiency in most of the Indian soils (Singh 2001; Sahrawat *et al.* 2010). Copper and Mo are likely to become critical in the future for sustaining high productivity in certain areas of India (Singh 2004). Indian soils are low in total Mo content, i.e., traces to 12 mg kg^{-1} (Sakal 2001), and about 11% of soils in India are deficient in available Mo (Singh 2001). Mo is one of the important micronutrients which helps in biological N fixation. Mo is a component of the enzymes nitrogenase and nitrate reductase, which is required in N fixation and also plays an important role in P utilization and protein synthesis (Jones 1987). The critical limit is the threshold level of a given nutrient in the soil which helps separate deficient soils from non-deficient ones. The critical limit of Mo for different crops has been established by many studies. Available Mo concentration in soils of Gujarat range between 0.06 to 0.23 mg kg^{-1} and 1–26% of land area is found deficient (Annual Report 1981); and available Mo was 0.05 mg kg^{-1} for Jhargram soils in West Bengal (Nandi *et al.* 1992). No study has been reported on the Mo status of soils of Tamil Nadu. Therefore, this study aimed to determine Mo status and critical limit of Mo in the soil for green gram in the Madurai and Sivagangai districts of Tamil Nadu.

MATERIALS AND METHODS

Baseline characterization

An intensive survey was conducted during the year of 2008 to determine Mo status of soils in the Madurai and Sivagangai districts of Tamil Nadu. In the study, 102 surface soil samples were collected from Madurai and 100 samples from Sivagangai district based on percent coverage by major soil series. Samples were processed for analysis for ammonium oxalate (pH 3.3) extractable Mo using the dithiol method (Grigg 1953). Soils were categorized into three groups as suggested by Kanwar and Randhawa (1974): low (<0.05 mg kg^{-1}), medium (0.05 to 0.1 mg kg^{-1}) and high (>0.1 mg kg^{-1}).

A pot experiment was conducted at the Agricultural College and Research Institute, Madurai, Tamil Nadu, during 2008. From the above developed baseline database, 12, 5 and 3 locations were selected, having low, medium and high Mo status respectively, and bulk amounts of soil were collected from the fields for the pot experiment (Badrinath *et al.* 1986). These soils were arranged in ascending order based on Mo concentration and numbered from S_1 to S_{20}. The pot experiment comprised five levels of Mo application (treatment: 0, 0.025, 0.050, 0.075 and 0.10 mg kg^{-1} soil) with two replications for each soil location; all together there were a total of 200 pots arranged in a completely randomized design (CRD). Approximately 14 kg of air-dried soil was filled in each earthen pot. Urea, di-ammonium phosphate and potassium chloride were used in equivalent bases as sources of N, P and K to supply 25 Kg N, 50 Kg phosphorus pentoxide (P_2O_5) and 12.5 Kg potassium oxide (K_2O), and the soils were thoroughly mixed. Entire doses of P and K were applied as basal in the experiment, but N was split into two doses. Mo treatments were given before the seed sowing. The experiment was conducted using green gram, variety CO 6.

The critical limit of Mo was determined by plotting the Bray's percent yield (Y-axis) against soil available Mo (X-axis) as described by Cate and Nelson (1965). Bray's percent yield was calculated according to this equation:

$$\text{Bray percent yield} = \frac{\text{Control yield}}{\text{Maximum crop yield}} \times 100 \quad (1)$$

RESULTS

Base line Mo characterization

Results obtained from baseline analysis of soil samples for available Mo are given in Fig. 1a and b, which show the average of mean Mo content along with maximum

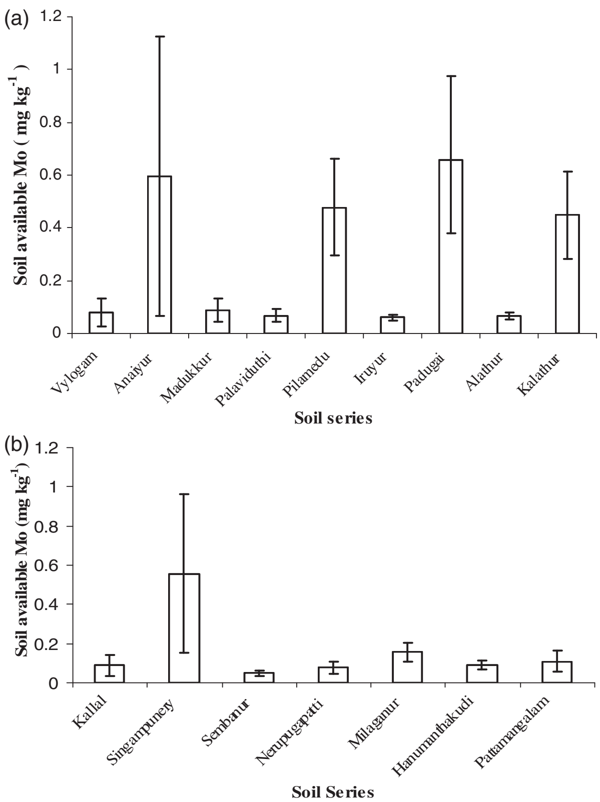

Figure 1 Available molybdenum (Mo) in soil series in (a) Madurai district and (b) Sivagangai district. Data represent mean ± range of soil available Mo for each soil series.

Table 1 Response of green gram seed yield to applied molybdenum (Mo) in different soils

Soil No.	Soil location	Seed yield (g pot^{-1}) Levels of molybdenum (mg kg^{-1}) 0	0.025	0.05	0.075	0.1	Mean
S_1	Ulaganeri	7.78	12.03	13.15	14.48	11.47	**11.78**
S_2	Thanakankulam	8.05	11.41	13.45	14.86	11.65	**11.88**
S_3	Kooturavupatti	8.44	10.11	11.36	15.48	11.83	**11.44**
S_4	Mangudi	11.19	12.93	12.38	15.44	12.23	**12.83**
S_5	Kalkulam	9.49	14.25	14.05	16.18	15.63	**13.92**
S_6	Vadaku Sandhanur	10.16	14.43	15.95	16.42	15.69	**14.53**
S_7	S. Karaikudi	10.99	13.50	14.18	16.20	11.49	**13.27**
S_8	Thirumohur	11.71	15.87	15.72	15.84	14.41	**14.71**
S_9	Kayankulam	12.12	16.04	15.65	17.18	15.88	**15.37**
S_{10}	Madakulam	10.15	14.44	15.65	16.02	13.71	**13.99**
S_{11}	Alanganallur	14.75	16.67	18.52	21.18	17.85	**17.79**
S_{12}	Gudalore	10.21	12.67	11.69	13.08	11.95	**11.92**
S_{13}	Palamedu	14.35	15.99	16.72	14.90	14.01	**15.19**
S_{14}	Alangulam	15.04	16.75	15.16	14.40	16.21	**15.51**
S_{15}	Silayampatti	13.98	15.65	16.12	15.10	16.33	**15.44**
S_{16}	Kadaneri	14.87	15.78	17.72	18.46	16.43	**16.65**
S_{17}	Munaivenri	16.32	15.35	18.18	17.84	16.89	**16.92**
S_{18}	Thenur	12.45	14.93	15.68	16.05	16.18	**15.06**
S_{19}	Kancharankulam	16.61	18.02	20.18	19.85	20.32	**19.00**
S_{20}	Anaiyur	17.42	19.13	19.95	20.11	20.78	**19.47**
	Mean	**12.30**	**14.80**	**15.57**	**16.45**	**15.04**	
		SEd	CD ($p = 0.05$)		CD ($p = 0.01$)		
	Soil (S)	0.19		0.38	0.50		
	Molybdenum (Mo)	0.10		0.19	0.25		
	S × Mo	0.43		0.85	1.12		

SEd, standard error deviation; CD, critical difference.

and minimum range of each soil series in Madurai and Sivagangai districts, respectively. Extractable Mo had a wide range and varied from 0.028 to 0.661 mg kg^{-1} soil in Madurai and 0.035 to 0.961 mg kg^{-1} soil in Sivagangai district.

Crop yield response to Mo application

CRD was employed for the pot experiment to study the Mo response of green gram. The results are given in Table 1 for the 20 soil locations. Statistical analysis of the results showed that the application of 0.075 mg kg^{-1} of Mo recorded the highest mean seed yield (16.45 g pot^{-1}) followed by 0.05 (15.57 g pot^{-1}) and 0.1 mg kg^{-1} (15.04 g pot^{-1}), and the lowest mean seed yield was recorded at 0 mg kg^{-1} Mo level (12.30 g pot^{-1}) across all 20 soil series locations. This indicated that the graded levels of Mo increased the seed yield of green gram significantly. Whereas, among the tested soils, the highest mean seed yield was obtained from Anaiyur soil (19.47 g pot^{-1}), and it was significantly superior to the rest of the soils across all five levels of Mo application. The lowest seed yield was recorded under Ulaganeri soil (11.78 g pot^{-1}). Thus experimental soils also evidently influenced the seed yield of green gram significantly. Interaction between the soil and applied Mo at Alanganallur soil (S_{11}) registered the highest seed yield, i.e., 21.18 g pot^{-1} at the level of 0.075 mg kg^{-1} of applied Mo, whereas Ulaganeri soil (S_1) recorded the lowest seed yield, i.e., 7.78 g pot^{-1} at the level of zero mg kg^{-1} of applied Mo. The application of Mo at the 0.075 mg kg^{-1} level was found to give maximum seed yield in 13 out of the 20 tested soils. The lowest seed yield was recorded in 17 soils at the 0 mg kg^{-1} Mo level. This interaction of soil and Mo was statistically significant at 1% in all the soils.

Establishing the critical limit of Mo for green gram

Bray's percent yields were calculated from pot experiment results for ascertaining the critical limit of Mo by plotting Bray percent yield against available soil Mo content as suggested by Cate and Nelson (1965). From the plots, we found 0.043 mg kg^{-1} Mo as the critical

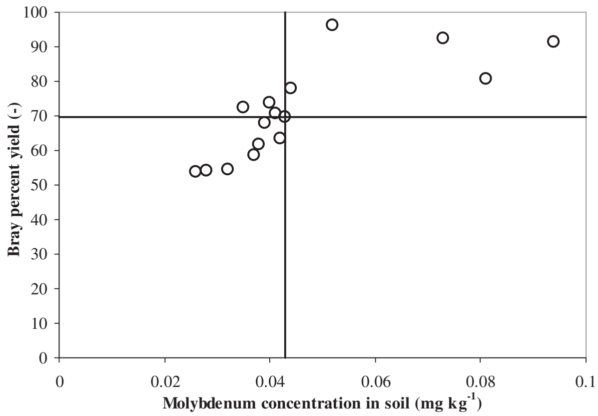

Figure 2 Determining critical limit of molybdenum (Mo) in soils from Madurai and Sivagangai districts.

limit for green gram crop (Fig. 2). Among 20 soils tested in the present study, 11 soils (S_1 to S_{11}) were found to be below the critical level of Mo, whereas the remaining soils (S_{12} to S_{20}) contained Mo above the critical level. The three-way model of Nelson and Anderson (1975) was employed to subdivide the experimental soils into highly responsive, moderately responsive and non-responsive to applied Mo. Based on this model, the soils of Madurai and Sivagangai districts have been justifiably and profitably grouped into highly responsive soils for Mo application (the soil test Mo values of $<0.043\,mg\,kg^{-1}$), moderately responsive soils (the soil test value for Mo of 0.044 to $0.081\,mg\,kg^{-1}$) and non-responsive soils (the soil test value for Mo of $>0.082\,mg\,kg^{-1}$). This suggests that soils with $<0.043\,mg\,kg^{-1}$ are low, 0.043 to $0.083\,mg\,kg^{-1}$ are medium and $>0.083\,mg\,kg^{-1}$ are high in available Mo. Similarly, Kanwar and Randhawa (1974) defined Mo concentration in Indian soils of less than $0.05\,mg\,kg^{-1}$ as low, between 0.05 and $0.10\,mg\,kg^{-1}$ as medium, and of more than $0.10\,mg\,kg^{-1}$ as high, respectively. Bhattachariyya *et al.* (1998) also reported that the critical limit of soil available $Mo < 0.05\,mg\,kg^{-1}$ is deficient and $Mo > 0.5–1.0\,mg\,kg^{-1}$ is excessive for common crops grown in the red and laterite group of soils in India. For Assam soils, Sharma Barua *et al.* (1992) and Adhikari *et al.* (1997) indicated $0.05\,mg\,kg^{-1}$ as the critical limit for Mo.

Mo mapping in Madurai and Sivagangai districts

Based on the defined critical limit ($0.043\,mg\,kg^{-1}$), the total soils collected from each major soil series were categorized as low, medium and high for available Mo. The results showed that 15 and 5% areas of soils in Vylogam and Madukkur series, respectively, in Madurai district (Fig. 3a) are low in Mo status. In about 63% of the area of the soils in the Palaviduthi series, 60% in the Vylogam series, 45% in the Madukkur series and 4% in the Anaiyur series fell in the medium category, as did 100% of soils in the Irugur and Kalathur series (Fig. 3a). In Sivagangai district, 15 and 35% of the areas of the soils in the Kallal and Sembanur series, respectively, were under low Mo status (Fig. 3b). The percent areas of the soils under medium Mo status were 86% in Nerupugapatti, 75% in Pattamangalam, 65% in Sembanur, 55% in Kallal and 40% in Hanumanthakudi. Contrary to other soils, 100% of the soils in the Singampunary and Milaganur series were recorded as high Mo status. Overall, the results indicated that out of 102 surface soil samples evaluated from the Madurai district, 3% of the total area was deficient in available Mo, while 41 and 56% of the areas were found to be medium and high status, respectively. Similarly, out of 100 soil samples from the Sivagangai district, 7, 46 and 47% samples had low, medium and high Mo status, respectively.

DISCUSSION

The present study of soils from two districts of Tamil Nadu, namely Madurai and Sivagangai, showed that there was a wide range in available Mo – from 0.028 to 0.976 and from 0.035 to $0.961\,mg\,kg^{-1}$ – in the respective districts. Similarly, available Mo content in different soils of India was discussed by Singh (1999) and Gupta *et al.* (1994), which showed that the available Mo ranged from 0.07 to $2.67\,mg\,kg^{-1}$. The difference between the lower and higher values of Mo content in both districts was very high. This indicates that soil series in both districts differ greatly and such manifestation of differences in available Mo content in the soils series might be ascribed to the larger variation in soil characteristics such as pH, calcium carbonate and soil texture, which greatly influence the amount of extractable or available Mo in soils, and its eventual availability to growing plants (Gupta and Dabas 1980; Adhikari *et al.* 1997; Sharma *et al.* 2003).

Responses of various crops to Mo application have been reported only in a few studies for Indian soils. In these studies, cereals and leguminous crops showed a higher response to Mo compared to other crops. Sarkar and Surendra Singh (2003) reported that the soil application of 0.6 to $1.5\,kg\,ha^{-1}$ as ammonium molybdate to groundnut (*Arachis hypogea* L.), soybean (*Glycine max* L.), cauliflower (*Brassica oleracea* L.) and Lucerne (*Medicago sativa* L.) grown on red sandy loam soils of Jharkhand was beneficial and gave increased yield by 19.5, 25.8, 32.5, and 9.3%. Sakal *et al.* (1997) reported that the application of $0.4\,kg\,ha^{-1}$ Mo significantly increased the yield of maize (*Zea mays* L.),

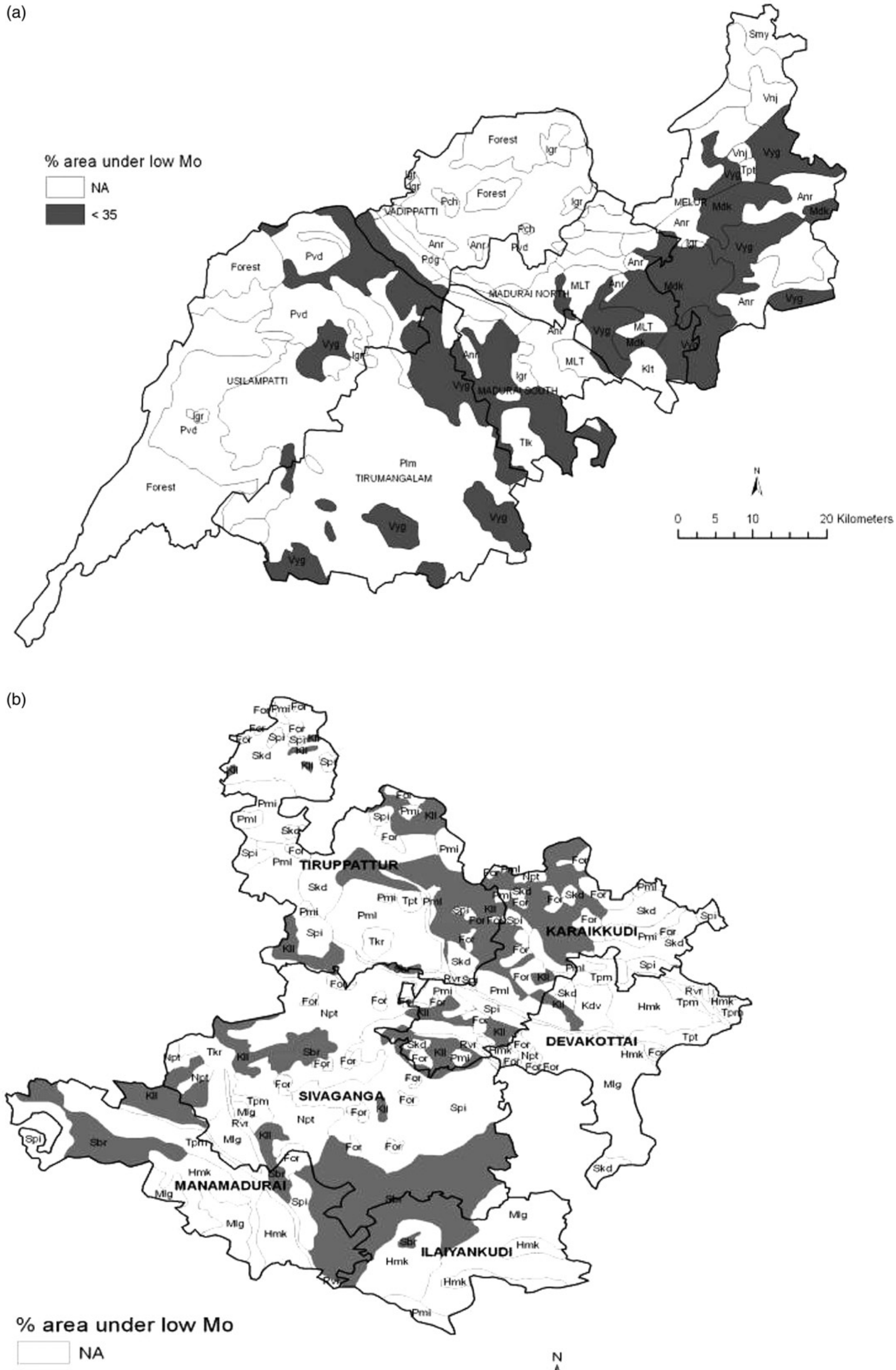

Figure 3 Percent area in various soil series deficient or low in available molybdenum (Mo) in (a) Madurai and (b) Sivagangai districts.

soybean, and groundnut pods by 53.6%, 26% and 40.3%, respectively; in red loam Inceptisols of Jharkhand. Subba Rao and Adinarayana (1995) reported an increase in average grain yield by 5–35.2% in rice (*Oryza sativa* L.) and 0.6–22.7% in wheat (*Triticum aestivum* L.) to 0.6 kg ha^{-1} Mo applications in different soils. Singh and Kumar (1979) reported increased grain yield of Sonalika wheat by 38% in sandy soils of West Bengal with the application of 0.5 kg Mo ha^{-1}. The above studies evidently indicate the role of Mo application in achieving increased crop yield, though the rates of Mo application may vary in different locations and/or crops.

In this study, we noted that the application of Mo (0, 0.025, 0.05, 0.075, 01 mg kg^{-1} soil) significantly increased the seed yield of green gram up to the rate of 0.075 mg kg^{-1} of Mo application over the control. The response of applied Mo to crop yield at the rate of 0.075 mg kg^{-1} recorded the highest mean yield of 16.45 g pot^{-1} across all 20 soil locations. At 0.075 mg kg^{-1} of Mo application, 13 soil locations out of 20 showed a better yield over other rates of Mo application. However, further higher application of Mo (0.1 mg kg^{-1}) declined the yield (15.04 g pot^{-1}). In the control treatment (0 mg kg^{-1} Mo application), the lowest seed yields were recorded in 17 out of 20 soils. These responses of green gram to different levels of Mo applications showed that soils were responsive to Mo application due to low availability of Mo, and 0.075 mg kg^{-1} Mo application seemed sufficient for green gram in most of the soil series, whereas a higher level (0.1 mg kg^{-1}) of Mo is not only superfluous, but may be detrimental as it might affect the availability of other nutrients or might be toxic to the growing plants, resulting in reduced growth and yield. For example, Bhupal *et al.* (2002) reported that soil application of Mo as sodium molybdate (0.5, 0.75, 1 kg ha^{-1}) significantly increased the maize cob yield over the control, and the yield difference between the treatments was more than 0.5 kg ha^{-1} Mo through soil application was not significant and the results were on par. Adesoji *et al.* (2009) reported the highest soybean grain yield through soil application of Mo at the rate of 0.150 kg ha^{-1}, and beyond this rate of Mo they observed decreased yield in samaru soil of Nigeria. Similar results were also reported by Velu and Savithri (1983), Sharma and Minhas (1986) and Laltlanmawia *et al.* (2004). In the present study, we observed a marked increase in seed yield of green gram, about 33.2% at 0.075 mg kg^{-1} level of Mo. A similar increase (28%) was also observed by Quaggio *et al.* (2004) in peanut yield at the rate of 0.186 kg ha^{-1} Mo through soil application. Bhattacharya *et al.* (2004) reported that adequate NPK fertilization increased green gram and black gram [*Vigna mungo* (L.) Hepper] yields by 13 and 38%, respectively, over the control but further inclusion of B and Mo improved yield by 38% in green gram and 50% in black gram over the control in red and lateritic soils. Jat and Rathore (1994) also reported that soil application of Mo significantly increased the various yield attributes and seed yield of pulses and recorded an 8.4% increase in seed yield over no Mo. Thus, increased yield in low Mo soils could be attributed to improved nutrient availability such as increased N fixation by the application of Mo, which eventually increased plant growth. The increase could also be related to more availability of Mo for nitrogenase and nitrate reductase enzymes required for the assimilation of nitrate N. Therefore, we could say that the function of Mo is closely related to plant N metabolism (Mendel and Hansch 2002).

Mo application in soil plays an important role in fixing N through biological N assimilation. Many horticulture, cereals and legume crops grown at deficient Mo levels even in the presence of nitrate fertilizers may develop pale green leaves and necrotic regions at the leaf margin. Mo-deficient green gram plants may show symptoms of N such as yellowing of leaves and stunted growth (Chatterjee *et al.* 1985; Chatterjee and Nautiyal 2001). In the present study, we observed stunted growth of green gram plants, and lower number and poor weight of nodules in low Mo pots. Moreover, seed yield at 0 ppm Mo level was recorded lowest during the experiment.

The critical limit is the level of an extractable nutrient in a soil that separates the deficient from the non-deficient ones; it is that concentration below which deficiency occurs and it designates the lower end of the sufficiency range. The critical level is quite often employed for a wide variety of soils and crops. In India, due to the diversified nature of soils, it is not possible to establish a fixed value of the critical limit for available Mo in different soils. Therefore, the critical limits of Mo for different soils and crops have been established by many workers. Anonymous (1980) observed that the critical limit was 0.5 and 0.6 mg kg^{-1} of ammonium oxalate extractable Mo for rice and wheat, respectively, on red and yellow soils of Madhya Pradesh. Das and Saha (1999) reported a critical limit of Mo in soils of West Bengal for ammonium oxalate extractant as 0.05 mg kg^{-1} for cereals, oilseeds, vegetables and fruit and 0.20 mg kg^{-1} for flowers and cauliflowers. Bhattachariyya *et al.* (1998) also reported 0.05 mg kg^{-1} as a critical limit for red and laterite soils for commonly grown crops in India. In the present study, we found 0.043 mg kg^{-1} as the critical limit of Mo as for green gram in different soils of Madurai and Sivagangai districts. Based on this critical limit, we categorized soils as low, medium and high in Mo availability and we found that a total of 3 and 7% area of soils were under low Mo for Madurai and Sivagangai district, respectively. This low availability of Mo extends to about 55% in Alfisols of Bihar plateau (Singh 1990–1993), 10% in soils of Gujarat, 18% in soils of Madhya Pradesh (Takkar 1993), and 28% soils in Haryana (Gupta *et al.* 1994) states. However, our study represents the soils of two districts of Tamil Nadu, i.e., Madurai and Sivagangai, and showed 3 and 7% deficient areas in respective districts; but this value could be high for the whole state of Tamil Nadu. Thus, it may be inferred from the above studies and from the results of the present study on Mo status that a significant area in India might be deficient in available Mo.

Conclusion

The critical limit of Mo was found to be 0.043 $\mathrm{mg\,kg^{-1}}$ in soils of Madurai and Sivagangai districts of Tamil Nadu for green gram. About 3–41% and 7–47% of the land area was found to be in the low to medium range in available Mo for cultivating green gram in Madurai and Sivagangai districts, respectively. The deficient soils showed a positive response to the applied Mo, and the seed yield of green gram increased with increasing levels of Mo. The study concludes that the application of 0.075 $\mathrm{mg\,kg^{-1}}$ (0.4 $\mathrm{kg\,ha^{-1}}$ as sodium molybdate) of Mo might be sufficient to alleviate the deficiency for green gram in the two districts. Information on the Mo status of soils generated in the present study is important for increasing the yields of green gram in the two districts studied.

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