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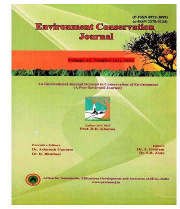

Influence of molybdenum application on soil nutrient status and uptake by cauliflower (*Brassica oleracea* var. *botrytis* L.) in an Acid Alfisol soil

Anmoldeep Singh Chakkal
Department of Soil Science, CSK Himachal Pradesh Agricultural University, Palampur (HP), India

Pardeep Kumar ✉
Department of Soil Science, CSK Himachal Pradesh Agricultural University, Palampur (HP), India

Nagender Pal Butail
Department of Soil Science, CSK Himachal Pradesh Agricultural University, Palampur (HP) , India

Munish Sharma
Department of Soil Science, CSK Himachal Pradesh Agricultural University, Palampur (HP) , India

Praveen Kumar
Department of Soil Science, CSK Himachal Pradesh Agricultural University, Palampur (HP), India

Deepika Suri
Department of Soil Science, CSK Himachal Pradesh Agricultural University, Palampur (HP), India

Arvind Kumar Shukla
ICAR, Indian Institute of Soil Science, Bhopal, Madhya Pradesh, India.

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ABSTRACT

A field investigation was carried out to evaluate the impact of molybdenum (Mo) application on the yield and nutrient status of cauliflower in an acid Alfisol. The experiment comprised eleven treatments, replicated thrice in a randomized block design (RBD). The highest marketable yield of 558.8 g plant^{-1} was recorded in treatment with a recommended dose of NPK + FYM, with an increase of 29.1 percent over control (T_1). The same treatment enhanced the uptake of macro-and micronutrients. Mo application positively influenced the curd productivity and soil nutrient status, with the conjoint application (soil plus foliar) out performing other treatments. In conclusion, cauliflower crop grown on Mo deficient soil responds positively to its conjoint application (soil plus foliar). However, the sole foliar application of Mo @0.1% recorded the highest apparent nutrient recovery (ANR) and bioaccumulation factor (BAF), with corresponding values of 2.2% and 41.2, respectively.

Introduction

Green revolution renovated the agriculture sector in terms of agriculture productivity with its broader impacts on the environment. The unbalanced and unregulated use of fertilizers led to multi-nutrient deficiencies and molybdenum (Mo) not being an exception. Mo is one of the essential ultra-micro nutrient and major component of the enzymes *nitrogenase* and *nitrate reductase* that plays an important role in phosphorus utilization and protein synthesis. Cauliflower (*Brassica oleracea* var. *botrytis* L.) is one of the major cole crop grown throughout the world. In India, it is being cultivated in an area of 0.45 million hectares (mha) with a production of 8.7 million MT (Anonymous, 2018). In India, 49 mha area is occupied by acid soils, of which 24.4 mha are considered moderately acidic (pH 4.5-5.5) and in the Himachal Pradesh, about 1.57 lakh ha area is under moderately acid soils (Maji *et al*., 2012). In Himachal Pradesh, cauliflower is grown in an area of 5.56 thousand ha with a production of 131.01 thousand MT (Anonymous, 2018). Cauliflower requires a high amount of fertilizers and is very sensitive to Mo deficiency. Most common Mo deficiency symptom

Corresponding author E-mail: *drpardeep1968@gmail.com*
Doi:https://doi.org/10.36953/ECJ.12132320

in cauliflower is whiptail where leaf-blades are not fully developed and only the midrib is present which appears as a whip (Sharma, 2002). Mo availability to the plants is strongly dependent on the soil reaction (Rutkowska *et al*., 2017), soil N levels (Elkhatib, 2009), concentration of adsorbing oxides (viz., Fe oxides), organic compounds found in the soil colloids and the extent of water drainage (Rutkowska *et al*., 2017). Molybdenum largely occurs in the soil as an oxy-complex molybdate (MoO_4^{2-}) (Mengel and Kirkby, 2001).

Mo is likely to become critical in the future for sustaining high productivity in certain areas, particularly in acidic soils. Keeping in view the future scenario, the present study was carried out with an objective to find out the appropriate method of Mo application to arrest the Mo deficiency which will have substantial effects on productivity and nutrient status. The lack of sufficient information prompted us to carry out this study in an Acid Alfisol soil of Himachal Himalaya, India. The application of Mo plays a significant role in enhancing productivity, quality, and profitability in cauliflower (Chakkal *et al.,* 2022). The present work will focus on the influence of Mo application on soil nutrient status and its uptake, which will provide major input for tackling micronutrient deficiency, particularly in areas having similar nutrient status and acidity problems.

Material and Methods

Experimental site: A field trial was carried out during *rabi* season in 2019-20 on cauliflower cv. Pusa Snowball K-1 at the experimental farm of Department of Soil Science, CSK HPKV, Palampur located at 32°09' N latitude and 76°55' E longitude at an altitude of about 1291 m above mean sea level. The study area lies in the Palam valley, district Kangra, Himachal Pradesh, India (Figure 1) representing mid-hills sub-humid agro-climatic conditions receiving an average rainfall of 2500 mm of which 25 percent is received during October to April. Taxonomically, the soil falls under order Alfisol (Typic Hapludalfs). The soils of the experimental site were silty clay loam in texture, strongly acidic with pH 5.29, organic carbon (OC) 7.11 g/kg and available nitrogen, phosphorus, potassium and molybdenum were 251, 21.2, 170 kg/ha, and 0.13 mg/kg, respectively. The respective contents of DTPA extractable iron, manganese, zinc, and copper were 16.11, 11.43, 0.71, and 0.38 mg/kg respectively.

Randomized Block Design (RBD) was used in the experiment with eleven treatments allocated randomly and replicated thrice. The treatments comprised of T_1, NPK (control); T_2, NPK + FYM (GRD); T_3, NPK+ Lime; T_4, NPK+Lime+FYM; T_5, GRD+Mo at recommended rate i.e., 1.0 kg/ha (soil); T_6, GRD+Mo at 1.5 times the recommended rate i.e., 1.5 kg/ha (soil); T_7, GRD+Mo at recommended rate of 0.1% (foliar sprays); T_8, GRD + Mo at 1.5 times the recommended rate (0.15% as foliar sprays); T_9, GRD along with Mo @1 kg/ha (soil) and @0.1% as foliar sprays; T_{10}, GRD along with Mo @1 kg/ha (soil) and @0.15% (foliar sprays); and T_{11}, *Subhash Palekar's Natural Farming* (SPNF).The experimental field was ploughed twice and the recommended FYM @20 t/ha was added to all treatments except in treatment NPK (control) (T_1), NPK + Lime (T_3), and SPNF (T_{11}). Lime application @ 10 t/ha was done in the treatments NPK + Lime (T_3) and NPK + Lime + FYM (T_4). In treatment SPNF (T_{11}), the cauliflower seedlings were raised by seeds soaked overnight with *beejamrit* solution @1 L/kg before sowing.

Soil application of Mo was done at the time of transplanting and its foliar sprays were applied at 45 and 60 days after transplanting (DAT). The cauliflower seedlings were transplanted in October, 2019 at row to row and plant to plant spacing of 60 and 45 cm, respectively. The N, P_2O_5, and K_2O were applied @ 115: 60: 75 kg ha^{-1} through urea (N), single super phosphate (P_2O_5) and muriate of potash (K_2O), respectively, except in treatment SPNF (T_{11}). Half dose of urea, full dose of single super phosphate (SSP), and half dose of muriate of potash (MOP) was applied at the time of transplanting. The remaining half dose of urea was applied later in two equal splits at 30 DAT and at curd initiation whereas the remaining half dose of MOP was applied at curd initiation. The *ghanjeevamrit* was applied @250 kg/ha along with FYM @250 kg/ha in the plots before transplanting. The *jeevamrit* was applied at 3-weeks interval through foliar application @50 L/ha per spray (Mahankuda and Tiwari, 2020).

Soil sampling and analysis: During layout from experimental plots three composite soil samples and individual plot samples at harvest were collected, processed and analysed for different soil properties *i.e*., available N, P, K, available Mo, and DTPA extractable micronutrient cations (Fe, Mn, Zn, and Cu) by employing standard methods (Subbiah and Asija, 1956; Olsen *et al*., 1954; Black, 1965; Lindsay and Norvell, 1978, respectively).

Plant sampling and analysis: Five plants were randomly selected at harvest to record observations for curd yield plant^{-1} and nutrient uptake i.e., nitrogen, phosphorus, and micronutrient cations by following the standard protocol (Fe, Mn, Zn, and Cu) (Jackson, 1973) and potassium (Piper, 1950) and molybdenum (Eivazi *et al.,* 1982).

Apparent nutrient recovery: It was calculated at harvest and defined as Mo accumulation in plants, divided by the total amount of Mo fertilizer (Jalpa *et al*., 2020).

Bioaccumulation factor: Bioconcentration factor (*BAF*) was calculated using standard procedure (Yashim *et al.*, 2014).

$$BAF = \frac{concentration\ of\ molybdenum\ in\ plant\ tissue\ (mg/kg)}{concentration\ of\ molybdenum\ in\ soil\ (mg/kg)}$$

Statistical analysis: One-way ANOVA (analysis of variance) for randomized complete block design was used to statistically compare (P=0.05) the effect of different treatments on yield, and quality of cauliflower as suggested by Gomez and Gomez (1984).

Results and Discussion

The results for the curd yield and the nutrient uptake are presented in the following subheadings:

Curd yield plant^{-1}: Curd yield was significantly influenced by different treatments as depicted in Figure 2(a) and varied from lowest (186.5 g/plant) in treatment SPNF (T_{11}) to highest (558.8 g/plant) in treatment GRD along with Mo @1 kg/ha (soil) and @0.15% (foliar sprays) (T_{10}) which recorded a significant increase of 57.5, 29.1, 40.6, and 22.9 percent over NPK (control) (T_1), NPK + FYM (GRD) (T_2), NPK + Lime (T_3), and NPK + Lime + FYM (T_4) treatments, respectively. Similar results showing an increase in marketable yield/plant with Mo application when compared to the individual plots treated with NPK, NPK + FYM, NPK + Lime, and NPK + Lime + FYM have also been reported in pigeonpea and broccoli (Reddy *et al.,* 2007; Chowdhury and Sikdar, 2017). The higher yields in these treatments might be due to the constructive role of FYM in improving the soil health and increasing the nutrient content of soil in cauliflower (Chander and Verma, 2009) and role of lime in increasing the availability of nutrients by positively affecting the soil pH in cauliflower (Santos *et al*., 2018). Among treatments comprising of Mo application (soil or foliar), curd yield in foliar sprayed treatments (T_7 and T_8) was higher to the basal applied treatments (T_5 and T_6). The significant effect of Mo application in increasing the curd yield might be due to the role of Mo in phosphorus utilization which might have played a significant role in causing early maturity of the plant (Sahito *et al*., 2018) which prevented the curd deformation and better marketable curds compared to control. A similar experimental outcome has also been reported in cauliflower, lentil, mungbean and blackgram (Hossain *et al.,* 2018; Islam *et al.,* 2018; Khan *et al.,* 2019; Qudus *et al.,* 2020; Hossain *et al.,* 2020; Mahesh *et al.,* 2021).

Effect of treatments on nutrient uptake at harvest

Nitrogen uptake: Different treatments registered a significant effect on total nitrogen uptake (Figure 2b) and varied from 24.6 kg/ha in treatment T_{11} to 84.2 kg/ha under treatment GRD along with Mo @1 kg/ha (soil) and @0.15% (foliar sprays) (T_{10}). The treatment T_{10} registered highest nitrogen uptake when compared to the rest of the treatments, however, it remained statistically at par with treatment GRD along with Mo @1 kg/ha (soil) and @0.1% as foliar sprays (T_9). Molybdenum cofactors participate in the active site of *nitrate reductase*, which plays an important role in nitrate assimilation and might have improved the utilization rate of N fertilizer (Li *et al.,* 2017). A similar increase in the nitrogen uptake due to the Mo application was reported in many other crops *i.e*., broccoli, hairy vetch, lentil, mungbean and wheat (Ahmed *et al.,* 2011; Alam *et al.,* 2015; Pawar and Tambe, 2016; Islam *et al.,* 2018; Hossain *et al.,* 2020; Qudus *et al.,* 2020; Moussa *et al.,* 2021).

Phosphorus uptake: Significantly superior total phosphorus uptake was recorded in treatment GRD along with Mo @1 kg/ha (soil) and @0.15% (foliar sprays) (T_{10}) when compared to the rest of the

Table 1: Effect of treatments on available nitrogen, phosphorus, potassium and DTPA extractable micronutrient cations.

Treatment	N	P	K	DTPA-Fe	DTPA-Mn	DTPA-Cu	DTPA-Zn
	(kg/ha)			(mg/kg)			
T_1 (NPK)	$249 \pm 1.13^{a*}$	22.2 ± 0.25^{abc}	176 ± 0.59^{a}	16.87 ± 0.13^{a}	11.58 ± 0.23^{ns}	0.47 ± 0.02^{ns}	0.79 ± 0.01^{ns}
T_2 (NPK + FYM)	245 ± 1.40^{b}	22.0 ± 0.20^{abc}	170 ± 1.48^{bc}	16.79 ± 0.17^{ab}	11.56 ± 0.10	0.45 ± 0.03	0.72 ± 0.02
T_3 (NPK + Lime)	241 ± 1.83^{cde}	22.1 ± 0.26^{abc}	167 ± 1.56^{cd}	15.81 ± 0.21^{d}	11.48 ± 0.14	0.36 ± 0.01	0.68 ± 0.03
T_4 (NPK + Lime + FYM)	244 ± 1.48^{bc}	22.7 ± 0.14^{a}	176 ± 2.09^{a}	16.09 ± 0.13^{cd}	11.54 ± 0.23	0.43 ± 0.00	0.70 ± 0.04
T_5 (T_2 + Mo @ 1.0 kg ha^{-1})	245 ± 0.70^{b}	22.4 ± 0.15^{ab}	175 ± 0.87^{a}	16.43 ± 0.15^{bc}	11.51 ± 0.22	0.45 ± 0.02	0.76 ± 0.02
T_6 (T_2 + Mo @ 1.5 kg ha^{-1})	243 ± 0.97^{bcd}	22.4 ± 0.12^{ab}	175 ± 2.40^{a}	16.41 ± 0.17^{bc}	11.49 ± 0.18	0.43 ± 0.02	0.78 ± 0.05
T_7 (T_2 + Mo @ 0.1%)	242 ± 0.99^{bcde}	22.1 ± 0.38^{abc}	172 ± 1.32^{ab}	16.37 ± 0.23^{bc}	11.47 ± 0.15	0.42 ± 0.01	0.74 ± 0.03
T_8 (T_2 + Mo @ 0.15%)	240 ± 1.63^{de}	22.0 ± 0.39^{abc}	169 ± 2.16^{bc}	16.31 ± 0.14^{c}	11.46 ± 0.13	0.41 ± 0.02	0.75 ± 0.03
T_9 (T_2 + Mo @ 1.0 kg ha^{-1} + Mo @ 0.1%)	240 ± 0.94^{de}	21.7 ± 0.16^{bcd}	167 ± 0.75^{cd}	16.31 ± 0.08^{c}	11.50 ± 0.17	0.43 ± 0.03	0.77 ± 0.01
T_{10} (T_2 + Mo @ 1.0 kg ha^{-1} + Mo @ 0.15%)	239 ± 1.28^{e}	21.6 ± 0.19^{cd}	167 ± 1.46^{cd}	16.25 ± 0.14^{c}	11.49 ± 0.11	0.41 ± 0.02	0.78 ± 0.05
T_{11} (SPNF)	232 ± 0.75^{f}	21.1 ± 0.30^{d}	163 ± 0.95^{d}	16.08 ± 0.10^{cd}	11.45 ± 0.22	0.40 ± 0.02	0.70 ± 0.03
Initial value	251	21.2	170	16.11	11.43	0.38	0.71

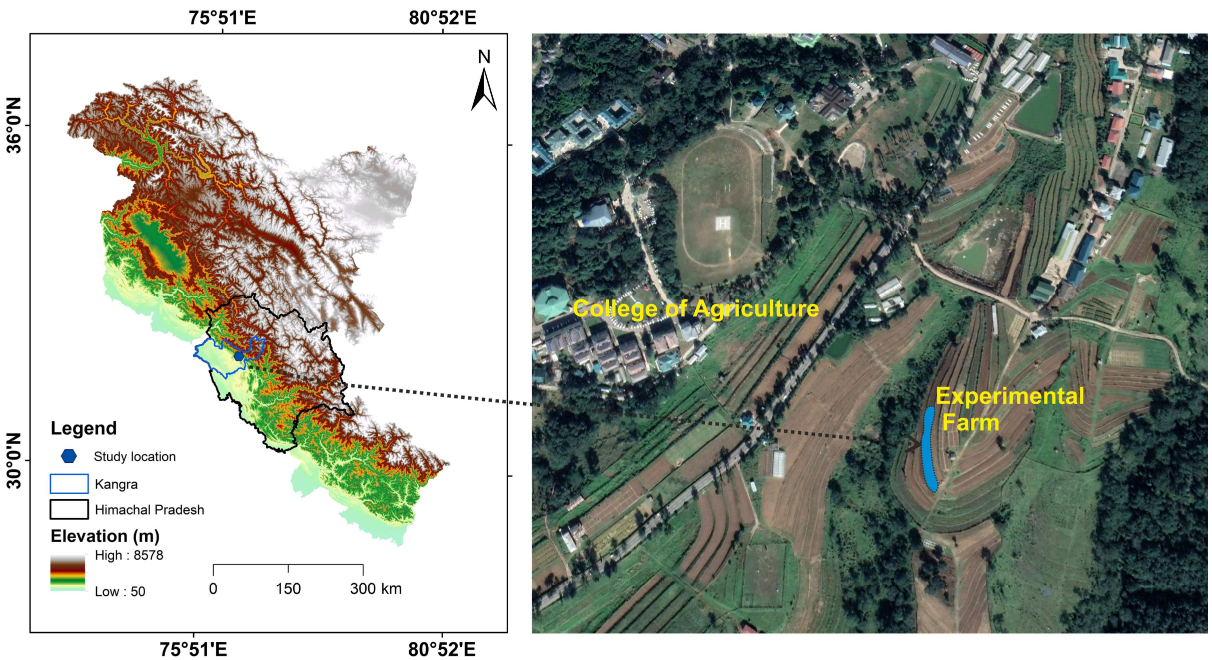

Figure 1: Location map of the study area with respect to Himachal Pradesh, India

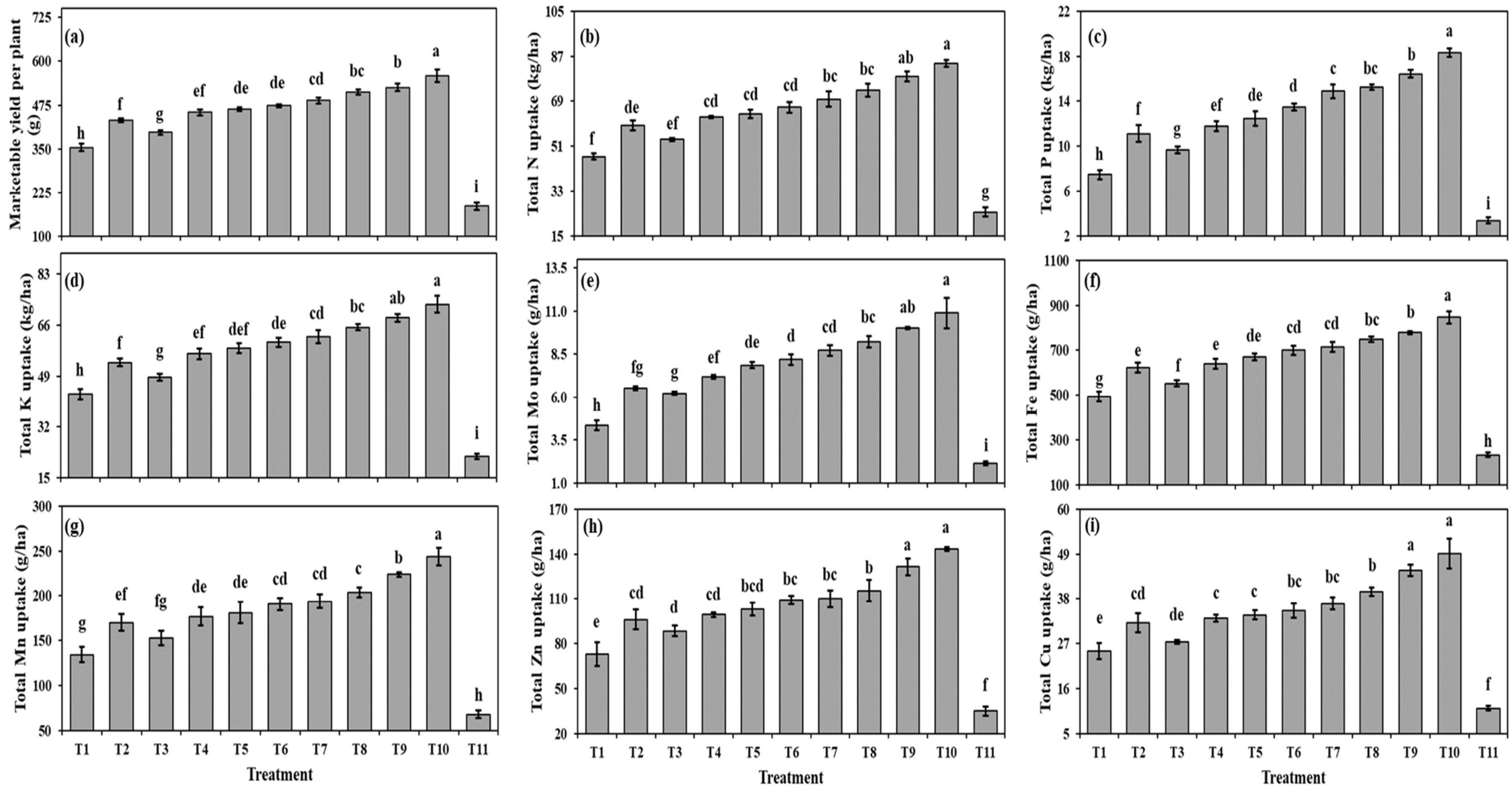

Figure 2: Effect of different treatments on (a) marketable yield plant^{-1}, (b) total nitrogen uptake, (c) total phosphorus uptake, (d) total potassium uptake, (e) total molybdenum uptake, (f) total iron uptake, (g) total manganese uptake, (h) total zinc uptake, and (i) total copper uptake.

Bars above are ± SEM, mean followed by different lower cases are significantly different by LSD (P = 0.05). Note: T$_1$, NPK; T$_2$, NPK + FYM (GRD); T$_3$, NPK + Lime; T$_4$, NPK + Lime + FYM; T$_5$, GRD + Mo @ 1 kg ha^{-1} (soil); T$_6$, GRD + Mo @ 1.5 kg ha^{-1} (soil); T$_7$, GRD + Mo @ 0.1% (foliar); T$_8$, GRD + Mo @ 0.15% (foliar); T$_9$, GRD + Mo @ 1 kg ha^{-1} (soil) + @ 0.1% (foliar); T$_{10}$, GRD + Mo @ 1 kg ha^{-1} (soil) + @ 0.15% (foliar); T$_{11}$, SPNF.

treatments (Figure 2c). However, phosphorus uptake recorded in treatment GRD along with Mo @1 kg/ha (soil) and @0.15% (foliar sprays) (T_{10}) was statistically at par with the treatment GRD along with Mo @1 kg/ha (soil) and @ 0.1% as foliar sprays (T_9). The total phosphorus uptake ranged from 3.4 kg/ha in treatment SPNF (T_{11}) to 18.3 kg/ha in the treatment GRD along with Mo @1 kg/ha (soil) and @0.15% (foliar sprays) (T_{10}). A synergistic effect between phosphorus and Mo application might have led to the formation of anionic complexes between Mo and P, resulting in higher phosphorus uptake by the crop. The stimulative effect of Mo application on phosphorus uptake has also been reported by many researchers in lentil and mungbean (Islam *et al.,* 2018; Hossain *et al.,* 2020; Qudus *et al.,* 2020).

Potassium uptake: The potassium uptake varied from 22.1 kg/ha under treatment SPNF (T_{11}) to 73.0 kg/ha in the treatment GRD along with Mo @1 kg/ha (soil) and @0.15% (foliar sprays) (T_{10}) (Figure 2d). Treatment T_{10} enhanced the potassium uptake followed by GRD along with Mo @1 kg/ha (soil) and @0.1% as foliar sprays (T_9) as compared to the treatments where no Mo application was applied *viz.* treatment T_1, T_2, T_3, T_4, and T_{11}. As uptake is a function of yield and higher yields were registered in the plots where Mo application was done, might have led to an increase in the potassium uptake. Similar stimulative effects of Mo application on potassium uptake were also reported by many researchers in lentil, mungbean and loquat (Islam *et al.,* 2018; Qudus *et al.,* 2020; Hossain *et al.,* 2020; Ali *et al.,* 2021).

Molybdenum uptake: The molybdenum uptake varied from 2.14 g/ha under treatment SPNF (T_{11}) to 10.89 g/ha in the treatment T_{10} as depicted in Figure 2(e). The maximum molybdenum uptake was recorded in the treatment GRD along with Mo @1 kg/ha (soil) and @0.15% (foliar sprays) (T_{10}) which was significantly superior over rest of the treatments but it was statistically at par with the treatment GRD along with Mo @1 kg/ha (soil) and @0.1% as foliar sprays (T_9). As uptake is a function of yield, higher yields registered in the plots where Mo application was done, leading to an increase in the soil available Mo content, might have led to an increase in the molybdenum uptake. The results are in concordance with the finding for Mo uptake by many researchers in common bean, rice and hairy vetch (Elkhatib, 2009; Zakikhani *et al.,* 2014; Alam *et al.,* 2015). The significant increase in the molybdenum uptake in treatment NPK + Lime + FYM (T_4), over control might be due to lime's role on soil reaction and FYM creating a chelating effect, enhancing the overall uptake.

Micronutrient cations (Fe, Mn, Zn, and Cu) uptake: The lowest micronutrient cations uptake was registered in treatment SPNF (T_{11}) and highest in treatment GRD along with Mo@1 kg/ha (soil) and @0.15% (foliar sprays) (T_{10}) as shown in Figure 2(f-i). The micronutrient cations uptake was found to be highest in the treatment GRD along with Mo@1 kg/ha (soil) and @0.15% (foliar sprays) (T_{10}) which was significantly superior over rest of the treatments and was statistically at par with the treatment GRD along with Mo @1 kg/ha (soil) and @0.1% as foliar sprays (T_9). Mo and Fe have a similar uptake mechanism and most Mo enzymes also require Fe-containing redox groups such as Fe-sulfur clusters or hemes resulting in higher uptake of the same nutrients. The uptake is a function of yield and the increased uptake by plant indicates easy availability of Mn, Cu, and Zn in soil and higher yields were also recorded in treatments where Mo was applied. A similar finding showing an increase in Fe, Mn, Cu, and Zn uptake on Mo application were also reported by Nandi and Nayak (2008) in hybrid cabbage and Kannan *et al* (2014) in black gram.Generally, higher macronutrients and micronutrient cations uptake was recorded in all the treatments where Mo was applied along with the recommended dose of NPK as compared to the treatments devoid of Mo application *viz.,* NPK (control) (T_1), NPK + FYM (GRD) (T_2), NPK + Lime (T_3), NPK + Lime + FYM (T_4), and SPNF (T_{11}). Moreover, the incorporation of FYM was also done uniformly in all the plots where Mo was applied which improved the soil health, except in treatment NPK (control) (T_1), NPK + Lime (T_3), and SPNF (T_{11}). FYM also enhances the macronutrients and their availability by converting non-available forms into available one by its chelating action. The Mo application also improved the crop growth parameters as reported by many researchers in cauliflower and broccoli (Ningawale *et al.,* 2016; Singh *et al.,* 2018). Consequently, due to better growth parameters of cauliflower, the micronutrients present in soil were absorbed in an efficient manner which ultimately enhanced their uptake.

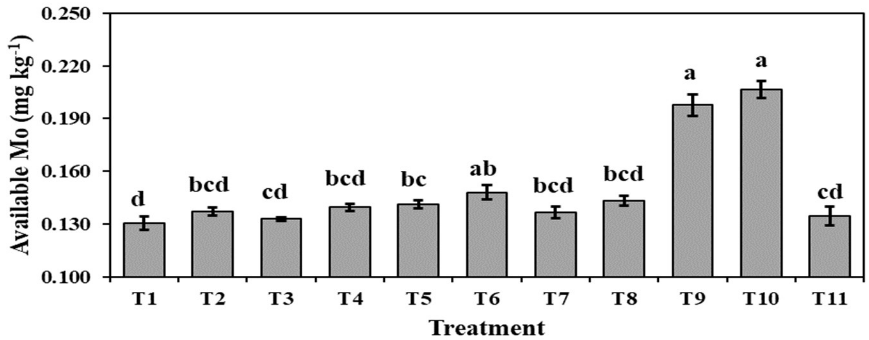

Figure 3: Effect of different treatments on available molybdenum.

Bars above are ± SEM, mean followed by different lower cases are significantly different by LSD (P = 0.05). Note: T_1, NPK; T_2, NPK + FYM (GRD); T_3, NPK + Lime; T_4, NPK + Lime + FYM; T_5, GRD + Mo @ 1 kg ha^{-1} (soil); T_6, GRD + Mo @ 1.5 kg ha^{-1} (soil); T_7, GRD + Mo @ 0.1% (foliar); T_8, GRD + Mo @ 0.15% (foliar); T_9, GRD + Mo @ 1 kg ha^{-1} (soil) + @ 0.1% (foliar); T_{10}, GRD + Mo @ 1 kg ha^{-1} (soil) + @ 0.15% (foliar); T_{11}, SPNF.

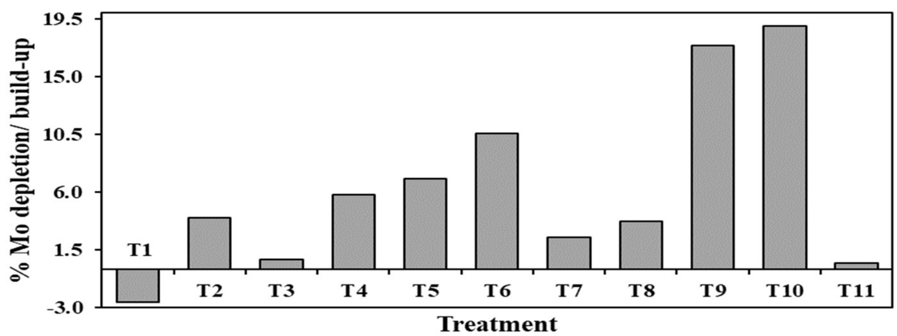

Figure 4: Effect of different treatments on build-up/depletion of soil available molybdenum over its initial status.

Bars above are ± SEM, mean followed by different lower cases are significantly different by LSD (P = 0.05). Note: T_1, NPK; T_2, NPK + FYM (GRD); T_3, NPK + Lime; T_4, NPK + Lime + FYM; T_5, GRD + Mo @ 1 kg ha^{-1} (soil); T_6, GRD + Mo @ 1.5 kg ha^{-1} (soil); T_7, GRD + Mo @ 0.1% (foliar); T_8, GRD + Mo @ 0.15% (foliar); T_9, GRD + Mo @ 1 kg ha^{-1} (soil) + @ 0.1% (foliar); T_{10}, GRD + Mo @ 1 kg ha^{-1} (soil) + @ 0.15% (foliar); T_{11}, SPNF.

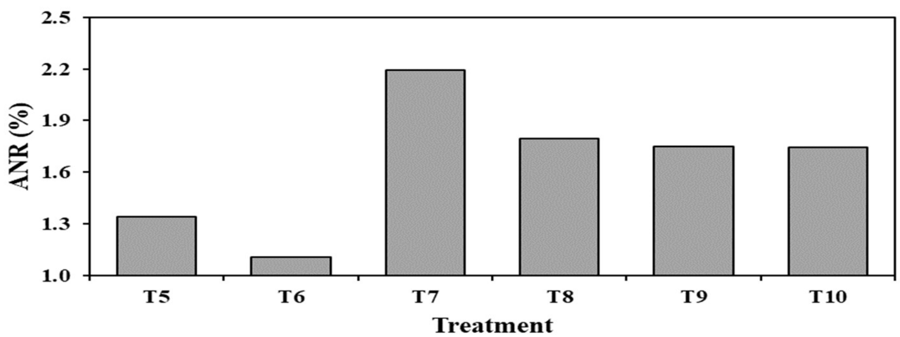

Figure 5: Effect of different rate and method of Mo application on apparent nutrient recovery (ANR).

Bars above are ± SEM, mean followed by different lower cases are significantly different by LSD (P = 0.05). Note: T_5, GRD + Mo @ 1 kg ha^{-1} (soil); T_6, GRD + Mo @ 1.5 kg ha^{-1} (soil); T_7, GRD + Mo @ 0.1% (foliar); T_8, GRD + Mo @ 0.15% (foliar); T_9, GRD + Mo @ 1 kg ha^{-1} (soil) + @ 0.1% (foliar); T_{10}, GRD + Mo @ 1 kg ha^{-1} (soil) + @ 0.15% (foliar).

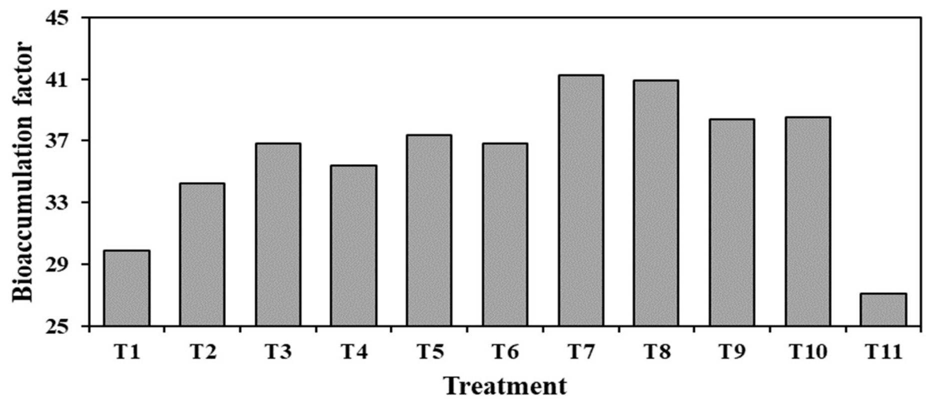

Figure 6: Effect of different treatments on bioaccumulation factor (BAF).
Bars above are ± SEM, mean followed by different lower cases are significantly different by LSD (P = 0.05). Note: T_1, NPK; T_2, NPK + FYM (GRD); T_3, NPK + Lime; T_4, NPK + Lime + FYM; T_5, GRD + Mo @ 1 kg ha^{-1} (soil); T_6, GRD + Mo @ 1.5 kg ha^{-1} (soil); T_7, GRD + Mo @ 0.1% (foliar); T_8, GRD + Mo @ 0.15% (foliar); T_9, GRD + Mo @ 1 kg ha^{-1} (soil) + @ 0.1% (foliar); T_{10}, GRD + Mo @ 1 kg ha^{-1} (soil) + @ 0.15% (foliar); T_{11}, SPNF.

The higher macronutrient cations uptake which resulted from the combined (soil and foliar) application of Mo when compared to the sole foliar feeding method of Mo might be attributed to the availability of Mo in early growth stages, which was lacking in the latter method.

Effect of treatments on soil properties at harvest

Available nitrogen: There was significant difference in the nitrogen content at harvest in different treatments (Table 1) that showed a lower available nitrogen in soil, when compared with initial value (251 kg ha^{-1}). The nitrogen content at harvest in varied from 232 kg/ha under treatment SPNF (T_{11}) to 249 kg/ha in treatment NPK (control) (T_1). The treatment T_1 recorded a significant increase of available nitrogen in soil over rest of the treatments. Among the treatments receiving Mo application, recorded a depletion in available N when compared to the control. A lower N content in soil at harvest might be due to an increase in Mo application which led to an increase in growth and yield of the cauliflower and resulted in higher N uptake. Also, Mo is directly responsible for nitrogen assimilation. These similar results for the depletion in available N content with the application of Mo was also reported in pigeon pea by Reddy *et al* (2007) indicating the increased requirement of the plants.

Available phosphorus: The available phosphorus ranged from a minimum value of 21.1 kg/ha under treatment SPNF (T_{11}) to maximum value of 22.7 kg/ha in the treatment NPK + Lime + FYM (T_4) (Table 1). The highest build-up of soil phosphorus was recorded in the treatment T_4, however, it was statistically at par with treatment NPK (control) (T_1), NPK + FYM (GRD) (T_2), NPK + Lime (T_3), and the treatments where soil and foliar application of Mo was done (T_5–T_8). A higher phosphorus uptake caused due to an increase in Mo application which led to an increase in growth and yield of cauliflower might have resulted in lower phosphorus availability. These results were in conformity with the findings of Reddy *et al* (2007) in piegonpea.

DTPA extractable iron: The DTPA extractable iron was significantly affected by different treatments (Table 1) and it ranged from a minimum value of 15.81 mg/kg in treatment NPK + Lime (T_3) to the maximum value of 16.87 mg/kg in treatment NPK (control) (T_1). The highest DTPA extractable iron was registered in treatment T_1 and it was statistically at par with treatment NPK + FYM (GRD) (T_2). This increase in DTPA-Fe might be due to the effect of urea application on soil reaction and as a result of relatively lower yields registered compared to other treatments, leading to its build-up. Similar results showing an increase of DTPA extractable iron over its initial status on Mo application has also been reported earlier in piegonpea by Reddy *et al* (2007).

Available molybdenum: It ranged from a minimum value of 0.129 mg/kg in treatment NPK (control) (T_1) to the maximum value of 0.157 mg/kg (soil) in the treatment GRD along with Mo @1 kg/ha (soil) and @0.15% (foliar sprays) (T_{10}) (Figure 3). The highest soil available Mo content recorded in treatment T_{10}, was statistically at par with the treatment GRD + Mo at 1.5 times the recommended rate i.e., 1.5 kg/ha (soil) (T_6) and GRD along with Mo @1 kg/ha (soil) and @0.1% as foliar sprays (T_9). This increase in the soil available Mo content recorded in treatments where conjoint application of Mo through both, soil, and foliar application was done might be due to the addition of Mo through soil application and the drippage caused due to the foliar application. These similar results showing an increase in available Mo content on Mo application were also observed in piegonpea and hairy vetch by Reddy *et al* (2007) and Alam *et al* (2015).

Build-up/ depletion (%) of soil available molybdenum over its initial content

All the treatments registered a build-up of soil available Mo content, except for treatment NPK (control) (T_1) (Figure 4). Among different treatments, the highest build-up in soil was recorded in treatment GRD along with Mo @ 1 kg/ha (soil) and @ 0.15% (foliar sprays) (T_{10}) followed by treatment GRD along with Mo @ 1 kg/ha (soil) and @ 0.1% as foliar sprays (T_9). Furthermore, the treatment GRD + Mo at 1.5 times the recommended rate @ 0.15% (foliar sprays) (T_8), where the foliar application of Mo was done at 1.5 times the recommended rate (0.15%), registered the highest Mo use efficiency when compared to rest of the treatments. The higher build-up recorded in treatment GRD along with Mo @ 1 kg/ha (soil) and @ 0.15% (foliar sprays) (T_{10}) and GRD along with Mo @ 1 kg/ha (soil) and @ 0.1% as foliar sprays (T_9), might be due to the higher dose of Mo being applied conjointly through foliar and soil compared to its sole application.

Effect of rate and method of Mo application on apparent nutrient recovery (ANR)

Different rates and methods of Mo application influenced the ANR (Figure 5). The highest ANR was registered in treatment GRD + Mo at recommended rate @ 0.1% (foliar sprays) (T_7) (2.2%) while lowest was recorded in treatment GRD + Mo at 1.5 times the recommended rate @ 1.5 kg/ha (soil) (T_6) (1.1%). In general, the sole foliar application of Mo registered higher ANR when compared to the other methods of Mo application. This might be due to the lower rate of Mo being applied at the crucial growth and reproductive stages of cauliflower which might have led to higher uptake of fertilizer.

Bioaccumulation factor

Bioaccumulation factor ranged from the minimum value of 27.1 in the treatment SPNF (T_{11}) to the maximum value of 41.2 in the treatment GRD+ Mo at recommended rate @0.1% (foliar sprays) (T_7) (Figure 6). In general, higher bioaccumulation of Mo in plant tissue was recorded in plots treated with sole application of Mo through foliar followed by the conjoint application of Mo (soil plus foliar).

Conclusion

From the present investigation, it can be concluded that the application of Mo plays a significant role in enhancing the uptake of macro and micro-nutrients in cauliflower grown in Mo deficient soil. As a result of higher uptake, the availability of macro and micro-nutrients in soil was reduced. This demands the addition of nutrients on soil test basis for harvesting optimum crop production and subsequently maintaining soil health on a sustainable basis. The conjoint application of Mo (soil plus foliar) @1.0 kg/ha as basal and @0.15 % as foliar feeding, respectively, along with the GRD proved to be the best Mo application method to increase productivity. However, treatment with the sole application of Mo through foliar spray @0.1% recorded the highest Mo nutrient recovery and accumulation in cauliflower

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Conflict of interest

The authors declare that they have no conflict of interest.

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