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Research Article

A controlled experiment to verify the effect of magnesium fertilizers on soil pH and available soil nutrients in acid soil of Nilgiris, India

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Abstract
An incubation experiment was conducted in laboratory conditions for 60 days to observe the impact of different Magnesium fertilizers on soil chemical properties, *i.e.* pH, available nitrogen, phosphorus, potassium, and DTPA extractable micronutrient cations. A complete factorial complete randomized block design (FCRD)with two replications and six levels was selected as the experimental layout. The levels included were (L_0) Absolute control (L_1) soil + Mg @ 10 kg ha^{-1}, (L_2) soil + Mg @ 20 kg ha^{-1}, (L_3) soil + 30 kg ha^{-1}, (L_4) soil + 40 kg ha^{-1}, (L_5) soil + 50 kg ha^{-1}. Findings revealed that applying magnesium fertilizers to soil significantly ($p \leq 0.05$) affects soil parameters. The impacts of magnesium fertilization on soil pH altered with sources and incubation period. The application of $CaMg(CO_3)_2$ @ 50 kg ha^{-1} recorded significantly ($p \leq 0.05$) higher soil pH (5.67) as compared to $MgCO_3$ @ 50 kg ha^{-1} that increased the pH up to 5.57 due to the impact of carbonate ion whereas $MgSO_4.7H_2O$ decreased the soil up to 4.80 because of dissolution of SO_4^{2-} ions to the soil solution. Applying $CaMg(CO_3)_2$ significantly ($p \leq 0.05$) influenced soil available N, P, K, Fe, Mn, and Cu content which is due to the decrease in acidity, which indirectly enhanced the nutrient availability. The positive effects persisted throughout the experimental duration, indicating the potential long-term benefits of magnesium fertilization in acid soil management. This study contributes to the current body of knowledge by providing novel insights into applying magnesium fertilizers as an effective strategy for addressing soil acidity and improving nutrient availability in acid soil.

Keywords: Acid soil, Agricultural productivity, Magnesium fertilizers, Nutrient availability,Soil pH, Sustainable soil management

INTRODUCTION

One of the crucial secondary nutrients for plants, magnesium (Mg) is taken up as Mg^{2+} from the soil solution (Marschner, 2011). Many of the rocky minerals contain magnesium as a common component. It makes up around 2% of the earth's crust, but 90–98% of the soil's magnesium is bound up in crystal lattices and isn't readily available to plants (Senbayram *et al*., 2015). Magnesium (Mg) performs a variety of physiological activities in biological systems (Cakmak, 2013) and (Peng *et al*., 2018). Numerous factors, particularly soil acidity, have a considerable impact on its availability (Adnan *et al*., 2021). But a lack of magnesium prevents plants from growing and developing, which ultimately leads to low yields and poor quality (Cakmak and Yazici, 2010), (Verbruggen and Hermans, 2013),(Yang *et al*., 2012). Unfortunately, among the different cations, the peculiarity of Mg bears the smallest ionic radius with greatest hydrated radius (Senbayram *et al*., 2015), making it susceptible to leaching. Furthermore, extreme heat and precipitation lead to significant leaching and loss of soil magnesium (X. Sun *et al*., 2018). The low utilization rates and easy leaching of these Mg fertilizers result in wasteful resource [(Grzebisz, 2011); (Gransee and Führs, 2013)].

When added to soils of variable pH levels, Mg fertilizers from various mineral sources behave differently due to variances in their chemical composition, particle size, and behavior, which frequently results in variations in their solubility [(Härdter *et al*., 2005), (Loganathan *et al*., 2005)]. According to Härdter *et al*. (2005), the chemical composition of fertilizers, such as oxide, sulfate, phosphate, carbonate, chloride, nitrate, or silicate, affects the quantity of magnesium soluble in water. A number of variables, including cation exchangeable capacity (CEC), organic matter (OM), and soil texture, influence the availability of magnesium in soil and (Senbayram *et al*., 2015). According to (Bian *et al*., 2013) and (Cremer and Prietzel, 2017), a lack of soil exchangeable Mg is associated with a drop in soil pH. However, hazardous elements can accumulate in acidic soils, especially manganese (Mn) and aluminum (Al). Plants do not need Al, whereas Mn is an essential micronutrient (Klug and Horst, 2010). Due to the harmful impacts of Al^{3+}, Mn^{2+}, along with H^+, plants are less able to absorb magnesium (Mg), and as a result, the jeopardy leaching of Mg in acidic soils increases [(Senbayram *et al*., 2015); (Gransee and Führs, 2013)]. According to Gransee and Führs (2013), excessive H^+ ion saturation of the soil CEC results in magnesium insufficiency in acid soils due to subsequent magnesium leaching, which impairs the uptake of magnesium by crops.

Due to the fact that Mg deficiency typically arises in the acidic soils of the Nilgiri region (Bose *et al*., 2008), so for sustainable agricultural production, it is crucial to understand the nutrient emancipation properties of various Mg fertilizers as well as their accessibility. Therefore, we sought to determine whether there was a difference in fertilizer efficacy between Epsomite-$MgSO_4.7H_2O$ fertilizers and Slow release magnesium fertilizers (S-Mg), also known as S-Mg fertilizers (Magnesite-$MgCO_3$ and Dolomite-$CaMg(CO_3)_2$). The main goal was to investigate the impact of three typical elemental Mg fertilizers on soil parameters through a controlled experiment.

MATERIALS AND METHODS

Details of the incubation experiment

Soil incubation samples were obtained from The Nilgiris and transported to the Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore. Individually homogenized soil samples (100 g) were transferred into plastic bottles of 150 g capacity, saturated to 80% of their water-holding capacity, and incubated at 25± 2°C for 8 weeks aerobically while loosely covered with aluminum foil to reduce evaporative loss. A total of 108 plastic bottles were taken for the incubation experiment (6 treatments × 2 replications × 3 incubation periods). Every week, soil moisture was adjusted gravimetrically after the cups were left open for one hour (Hirzel *et al*., 2010). In factorial completely randomized design (FCRD) with two replications, three fertilizer sources—$MgSO_4.7H_2O$ (S_1), $MgCO_3$ (S_2), and $CaMg(CO_3)_2$ (S_3)—were applied to two soils, each of which received L_0, L_1, L_2, L_3, L_4 and L_5 @ 0, 10, 20, 30, 40, and 50 kg of magnesium per hectare respectively. Following every incubation interval, soil samples were air-dried, ground, and ready for testing to determine the chemical composition of the soil from all treatments. The soils were dried and tested for soil pH and nutrients available at each sampling date (20, 40, and 60 days). Two replicates of each fertilizer level were chosen at random for each sampling date.

Soil chemical properties

The International pipette method was used to determine Soil texture (Piper, 1966). The cylinder method was used to determine bulk density taking five cores per soil (Blake, 1965). Soil pH was estimated with a pH electrode by taking a 1: 2.5 ratio soil: water solution (Thomas, 1996). The electrical conductivity of the extract (clear), collected from soil: water at a 1:2 ratio, was estimated using an electrical conductivity meter (Jackson, 1973). The walkley-Black wet digestion method was used to measure Soil organic carbon (Walkley and Black, 1934). Available Nitrogen was determined by oxidative hydrolysis using alkaline $KMnO_4$ as reported by (Subbiah, 1956). Available P in the soil sample was estimated by Bray-1 method (Bray, R. H., 1945). Exchangeable Ca, Mg, and K were estimated

Table 1. Initial physicochemical properties of the experimental soil (Replications=3)

Soil properties	Value
Texture	Sandy loam
Bulk density (Mg m^{-3})	1.32
pH	5.24
EC (dS m^{-1})	0.29
OC (%)	6.36
Available N (kg ha^{-1})	282
Available P (kg ha^{-1})	55
Available K (kg ha^{-1})	442
Exch. Ca (mg kg^{-1})	18
Exch. Mg (mg kg^{-1})	10.5
DTPA Extractable Fe (mg kg^{-1})	100
DTPA Extractable Mn (mg kg^{-1})	2.56
DTPA Extractable Zn (mg kg^{-1})	2.26
DTPA Extractable Cu (mg kg^{-1})	2.49

using 1 M ammonium acetate extraction followed by flame photometer (K), and versenate method (Ca and Mg)(Schwarzenbech, G., Biedermann and Bangerter, 1946). DTPA-extractable micronutrient cations *viz.,* Fe, Mn, Zn, and Cu were quantified by atomic absorption spectrometry (AAS) (Lindsay and Norvell, 1978).

Statistical analysis

The obtained data were subjected to factorial completely randomized design in SPSS 16.0 software for Windows (SPSS Inc., Chicago and USA) in two-way analysis of variance (ANOVA) for studied soil. The mean was compared using Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$.

RESULTS AND DISCUSSION

The present study showed that the soil of Nilgiris in Tamil Nadu was acidic, low in EC, and high in organic matter. The texture of the soil was found to be sandy loam (66.02% sand, 17.18 silt, and 16.08 clay), and the bulk density was 1.32 Mg m^{-3}. Exchangeable Mg^{2+} was 10.5 mg kg^{-1}. The selected chemical and physical properties of the experimental soil are mentioned in Table 1.

Magnesium fertilization on soil pH

The current research findings elucidated that the treatment of Magnesium fertilizer, i.e. Epsom salt ($MgSO_4.7H_2O$) in acidic soil reduced soil pH significantly ($p \leq 0.05$) (Fig. 1). But, magnesite ($MgCO_3$) and Dolomite [$CaMg(CO_3)_2$] significantly ($p \leq 0.05$) increased the pH during incubation (Fig. 1). Among all the treatments, the application of $MgSO_4.7H_2O$ @ 50 kg Mg ha^{-1} significantly documented lesser pH, i.e. 4.94, 4.88, and 4.80 at 20, 40 and 60 days of incubation, respectively as compared to the control. After 60 days of incubation, soil pH decreased from 5.20 to 4.80 for applying $MgSO_4.7H_2O$ @ 50 kg Mg ha^{-1}. However, applying magnesite ($MgCO_3$) enhanced soil pH from 5.25 to 5.57 @ 50 kg Mg ha^{-1}, and Dolomite [$CaMg(CO_3)_2$] enhanced soil pH from 5.24 to 5.67 @ 50 kg Mg ha^{-1}. The minimum soil pH values were noticed when $MgSO_4.7H_2O$ fertilizer was added to the experimental soil. The maximum soil pH was documented in the fertiliser-treated soil with Dolomite [$CaMg(CO_3)_2$]. The reduction in soil acidity with the Mg fertilizer sources in acidic soil was in the order of Dolomite > Magnesite > Epsom salt (Fig. 1). The present findings revealed that the soil pH in acidic soil was altered by the influence of the type of magnesium fertilizer was in line with Zhang *et al*., (2022). Study by Wei *et al*. (2018) reported a decrease in soil pH with magnesium sulphate application. The pH steadily declined with time in the case of $MgSO_4.7H_2O$ as it has a subsequent acidifying influence on the soil as it releases a variable amount of SO $-_4^{2-}$. The present findings are also in line with the previous research by Havlin *et al*. (1985) in montmorillonite mica containing soil with alfalfa as a test crop. Fast release Mg fertilizer lessened the soil pH, whereas there was a rise in soil pH in the case of slow release Mg fertilizers. Recent research furnished that dolomite can raise soil pH (Loganathan *et al*., 2005), and magnesite ($MgCO_3$) raises pH by 0.2–1.5 units (Huang *et al*., 2014). However, important characteristic of dolomitic limestone is its high neutralizing capacity, featured by Calcium Carbonate Equivalent (CCE) of 109, so the initial increase in soil pH is due to the hydrolysis of dolomite and magnesite into calcium and carbonates,

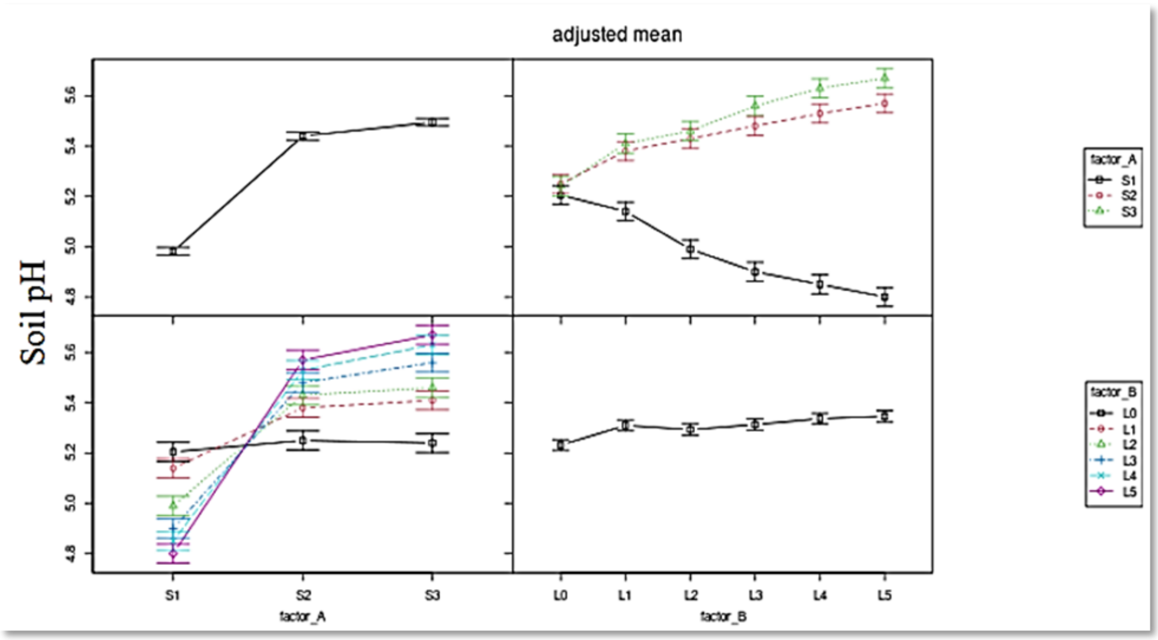

Fig. 1. *Impact of various Magnesium fertilizer sources on soil pH after 60 days of incubation*

which raises the pH of the soil (Tisdale *et al*., 1993).

Impact of magnesium fertilization on soil available nitrogen

The nitrogen content in the soil as affected by various Magnesium fertilizers treatment is displayed in Fig. 2. Diverse Mg fertilizers treatment on soil had a significant influence on soil available nitrogen, which was significantly enhanced with a rise in levels of carbonate fertilizers whereas it declined in the case of sulfate fertilizer. Among all the treatments, Dolomite [$CaMg(CO_3)_2$] @ 50 kg Mg ha^{-1} application documented significantly superior available N, *i.e.* 295, 297, and 299 kg ha^{-1} at 20, 40, and 60 days of incubation, respectively, as compared to control. The maximum rise was up to 299 kg ha^{-1} with the application of Dolomite [$CaMg(CO_3)_2$] @ 50 kg Mg ha^{-1} over the initial N content in soil (282 kg ha^{-1}). The observation was in parallel with Sun *et al*. (2006) while experimenting on black pepper treated with $MgSO_4$. However, the application of $MgSO_4.7H_2O$ @ 50 kg Mg ha^{-1} showed a decrease in N content 267, 264, and 262 kg ha^{-1} at 20, 40, and 60 days of incubation, respectively, which was at par with treatment $MgSO_4.7H_2O$ @ 40 kg Mg ha^{-1}. According to the study by Barman *et al*. (2014), applying Mg to soil has a good impact on soil nutrient dynamics. An increase in available N indicates improved nitrogen availability for plant uptake. The upsurge in soil available N might be due to increased pH, leading to mineralization of organically bound N to inorganic form. If N is present in the soil, it will emit NO_3^-, electrical neutrality is internally maintained by its reduction in the synthesis of organic acids by releasing anions from the roots such as OH^- or HCO_3^-, these are associated with cations such as Ca^{2+}, Mg^{2+}, and Na^+ (Barber, 1995). Magnesium (Mg) fertilization can influence nitrogen availability in the soil by affecting microbial activity and nutrient mineralization processes. Magnesium's impact on soil pH (Wei *et al*. 2018) and microbial activity (Yang *et al*. 2021) can enhance the breakdown of organic matter, resulting in the release of nitrogen in plant-available forms.

Magnesium fertilization influence on soil-available phosphorus

The soil available phosphorus as altered by the application of different Magnesium fertilizers is furnished in Fig 3. Applying Magnesium fertilizers raised the phosphorus availability significantly in acidic soil compared to the control. The interaction effect of (sources X levels) on phosphorus availability was statistically significant. The minimum value of soil-available phosphorus was exhibited by applying $MgSO_4.7H_2O$ @ 50 kg Mg ha^{-1} after 60 days of incubation. The maximum rise in available soil phosphorus was in Dolomite [$CaMg(CO_3)_2$] @ 50 kg Mg ha^{-1} treated soil at the end of incubation. The application of Dolomite [$CaMg(CO_3)_2$] @ 50 kg Mg ha^{-1} increased phosphorus content (70.22, 73.18, and 75.16 kg ha^{-1} at 20, 40 and 60 days of incubation, respectively) over the control, which showed 55.33, 55.51 and 55.31 kg ha^{-1} at 20, 40 and 60 days of incubation, respectively. Whereas application of $MgSO_4.7H_2O$ @ 50 kg Mg ha^{-1} decreased the P content 40, 37, and 35 kg ha^{-1} at 20, 40, and 60 days of incubation, respectively, compared to control, *i.e.* 56 kg ha^{-1}. The efficacy of the Mg fertilizers in this experiment on the rise in available phosphorus followed the trend, i.e. Dolomite [$CaMg(CO_3)_2$] @ 50 kg Mg ha^{-1} > magnesite ($MgCO_3$).

In the present investigation, all treatments' availability of phosphorus tended to rise as incubation time increased. The increase in exchangeable Mg reduced the formation of Fe-P precipitation and thus positively affected phosphorus availability. Due to the addition of slow-release magnesium fertilizers like dolomite and magnesite, which increased the solubility of insoluble

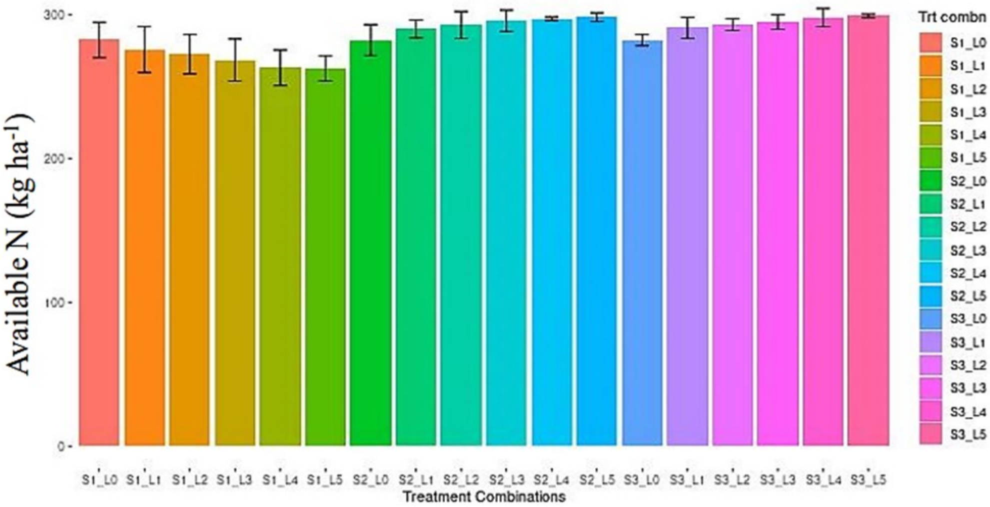

Fig. 2. *Impact of various Magnesium fertilizer sources on Available N (kg ha^{-1}) content of soil after 60 days of incubation*

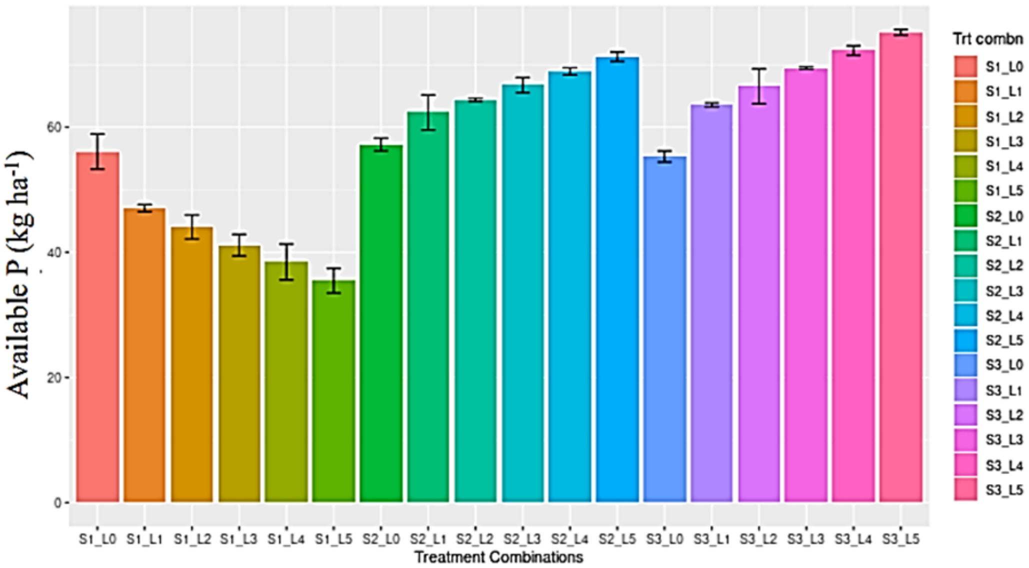

Fig. 3. *Impact of various Magnesium fertilizer sources on Available P (kg ha^{-1}) content of soil after 60 days of incubation*

phosphate compounds and thereby phosphorus availability in the acidic soil was increased as a result of the incorporation of magnesium fertilizers. These findings were consistent with earlier research, which showed that adding dolomite to acidic soil enabled the availability of phosphorus to gradually rise over an increasing incubation period (Loganathan *et al*., 2005).

Additionally, magnesium fertilization can affect soil microbial activity and organic matter decomposition, thereby influencing phosphorus mineralization and release. This may lead to the soil's pH reduction, which helps in the solubility of native insoluble phosphates, which boosts the availability of nutrients in the soil. These present findings were consistent with the previous study by Yang et al. (2021), who reported that Mg fertilization increased phosphatase activity and microbial population, increasing available phosphorus in acidic soils. The decrease in P content with $MgSO_4.7H_2O$ in soil may lead to the P fixation in the form of Fe phosphates due to further reduction in pH. The parallel findings were documented by Sun *et al*. (2006) while experimenting on black pepper treated with $MgSO_4$.

Impact of magnesium fertilization on soil available potassium

The potassium concentration in the soil as altered by the treatment of various Magnesium fertilizers is depicted in Fig. 4. The interaction effect of (sources and levels) on potassium availability was noted to be statistically significant (Fig. 4). Among all the treatments, the K content followed the same decreasing trend for all incubation periods overall fertilizer sources. The initial K concentration in soil was 443 kg ha^{-1} which was decreased to 425, 422, and 419 kg ha^{-1} in treatment of

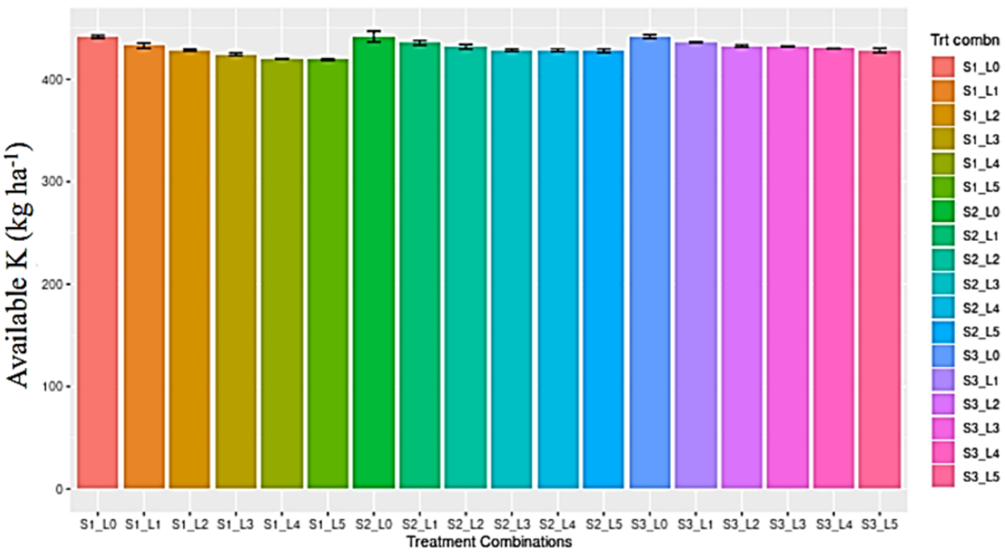

Fig. 4. *Impact of various Magnesium fertilizer sources on Available K (kg ha^{-1}) content of soil after 60 days of incubation*

$MgSO_4.7H_2O$ @ 50 kg Mg ha^{-1} at 20, 40, and 60 days of incubation. The decrease in the content of available Potassium in soil followed the order Epsom salt ($MgSO_4.7H_2O$) > magnesite ($MgCO_3$) > Dolomite [$CaMg(CO_3)_2$] @ 50 kg Mg ha^{-1}. Magnesium fertilization can impact potassium availability in the soil. Plants take up mineral Mg and K only in the cationic form (as Mg^{2+} and K^+). Due to the application of Mg fertilizers there was a decrease which might be due to the increase in Mg availability in soil solution. Qubaie (2013) stated that antagonistic reaction between Mg and K in soil could be due to the differences in their ionic mobility. Bergmann (1992) suggested that the optimum ratio between K and Mg is to be maintained in soil because the excess concentration of either of the two elements can negatively affect plant growth. High K concentrations in the soil solution inhibit Mg uptake and may induce plant Mg deficiency (Salmon 1963, Heenan and Campbell 1981). Maintaining an appropriate magnesium-to-potassium ratio in the soil is essential to optimize potassium availability and prevent nutrient imbalances that may adversely affect various physiological processes, including various enzymes activation and regulation of the cation-anion balance (Marschner, 2012).

Impacts of magnesium fertilization on soil DTPA-extractable micronutrient cations

Compared to the control, the concentrations of DTPA-extractable Fe were significantly superior in the case of $MgSO_4.7H_2O$ @ 50 kg Mg ha^{-1} in the soil solution after 60 days of incubation (Fig. 5). The content of DTPA-extractable Fe increased significantly with increasing levels in case of $MgSO_4.7H_2O$ whereas with the application of Dolomite [$CaMg(CO_3)_2$] as well as magnesite ($MgCO_3$) decreased the Fe content. The interaction effects of sources and levels on the DTPA-extractable Fe were significant (Fig. 5). The lowest concentrations of DTPA-extractable Fe were recorded in the dolomite @ 40 kg Mg ha^{-1} treatment, which is on par with dolomite @ 50 kg Mg ha^{-1}. At the end of 60 days of incubation, the DTPA-extractable Mn was upsurged from 2.64 mg kg^{-1} soil in control to 5.73, 5.23, and 5.13 mg kg^{-1} soil for Epsom salt, Dolomite, and Magnesite respectively (Fig. 6). The lowest DTPA-extractable Mn was obtained in case of control *i.e.* 2.63 mg kg^{-1} at 60 days of incubation. At the end of 60 days of incubation, the DTPA-extractable Cu and DTPA-extractable Zn were increased, but the interaction (sources x levels) was not significantly different among the fertilizer sources *viz.,* Epsom salt, Dolomite, as well as Magnesite. Magnesium fertilization can indirectly influence the availability of micronutrients such as iron (Fe), manganese (Mn), and zinc (Zn) by affecting soil pH and nutrient interactions. Magnesium-induced changes in soil pH can alter the solubility and availability of micronutrients for plant uptake. The present study is consistent with Disch *et al.* (1994), who observed a significant rise in Fe concentration in soil with the treatment of Mg as $MgSO_4$. Goss *et al.* (1992) reported a synergistic interaction between Mg and Mn concentration in the soil, which supports the present findings. Dolomite was preferred by considering its frequency of use as a reliable source of liming material in agriculture. It supplies Ca and Mg concurrently while reducing soil acidity (Shaaban *et al.*, 2015; Wu *et al.*, 2020).

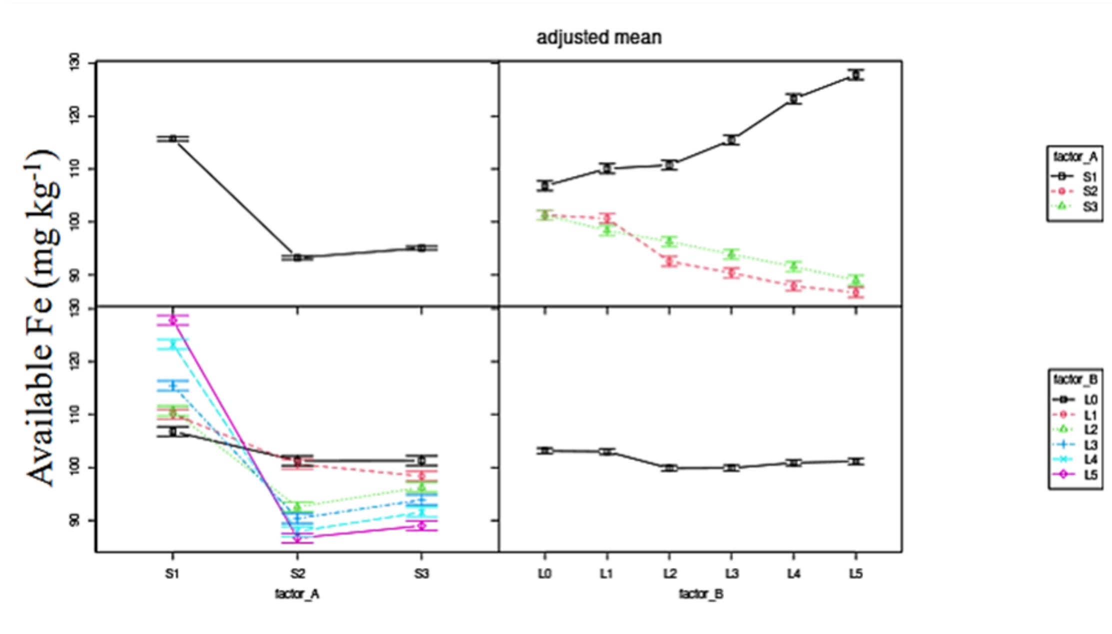

Fig. 5. *Impact of various Magnesium fertilizer sources on DTPA-Extractable Fe content (mg kg^{-1}) in soil after 60 days of incubation*

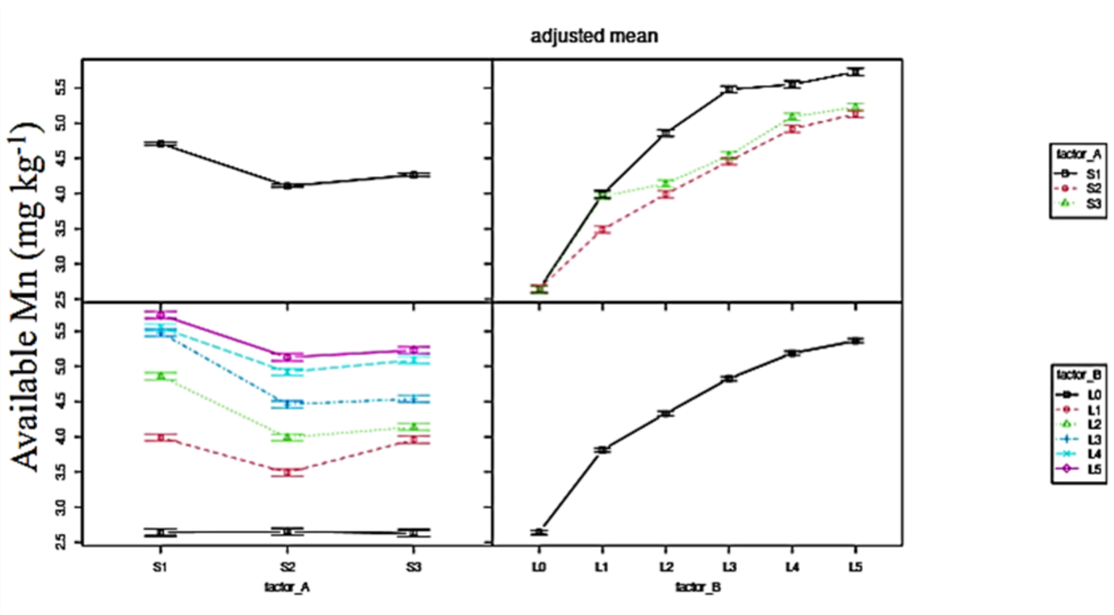

Fig. 6. *Impact of various Magnesium fertilizer sources on DTPA-Extractable Mn content (mg kg^{-1}) in soil after 60 days of incubation.*

Conclusion

The present study concluded that to boost soil nutrient release, different magnesium fertilizers *viz.,* $MgSO_4.7H_2O$, $MgCO_3$, and $CaMg(CO_3)_2$ can be applied in soil, which is the key finding. The magnesium fertilization in the sulfate form increased soil acidity, while magnesium fertilization in the carbonate form lowered soil acidity. Acidity significantly impacts many chemical characteristics and processes in the soil. The $CaMg(CO_3)_2$ (Dolomite) @ 50 kg Mg ha^{-1} had the highest N, P, K, and micronutrient content. Its application had the most noticeable impact of all the treatments on soil macro- and micronutrient content, followed by magnesium carbonate application at 50 kg Mg ha^{-1}, significantly affecting soil characteristics during the 60-day incubation phase. As a result, carbonate fertilizers were preferred in acidic soil over other fertilizers. The study might be a theoretical foundation for raising Mg fertilizer utilization rates and choosing high-efficiency Mg fertilizers for agricultural production that could boost quality and yields in acidic soil conditions. The findings provide valuable insights into the selection and application of magnesium fertilizers, highlighting the preference for carbonate fertilizers in acidic soils to optimize soil characteristics and enhance nutrient availability.

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Conflict of interest

The authors declare that they have no conflict of interest.

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