Dear Editor and Referees,

We thank you very much for providing constructive and useful suggestion for our manuscript. We have modified the manuscript incorporating the suggestions. The details of our responses and revisions are given below.

Comments of Editor:- Both reviewers indicate that the manuscript is of limited merit, in its current form, for publication in soil. Both indicates concisely which are the major points to be addressed for a possible resubmission, and one of them also expand these comments in an annotated version of the manuscript. I agree with both reviewers and endorse their recommendation for rejection, considering possible resubmission if the authors considered that they can rework the manuscript to address the comments indicated by the two reviewers.

Our response:- We have revised the manuscript according to the comments of both of the reviewers. We feel that the quality of the manuscript has improved by incorporating the suggestions of the reviewers. We have attached the revised manuscript for your kind perusal. Thanks a lot to you and to the reviewers.

Comments of Anonymous referee # 1:-

Comment:- The article is of limited scientific merit for publication in "SOIL". Some suggestions are given below: 1. Introduction. - It is not clear as to where the research is leading to: the problem of soil acidity regarding to crop production? Zinc-deficient soils for crops? the combination of acid soils and zinc-deficient soils? You should clearly define the starting situation that generates the need for research and avoid redundancy in drafting the text.

Our response:- Thank you sir for this suggestion. We have modified the introduction part of the manuscript and deleted unwanted portions. The present study was carried out to examine the influence of lime and farmyard manure and Zn addition on dry matter yield, Zn concentration and uptake by maize and soil properties and extractable Zn by different extractants in acid soils. The information would be useful for assessment of extractable Zn and its management in acid soils where Zn availability is one of the main problems and Zn application is imminent and application of lime and FYM is a common practice to obtain higher crop yield. This information has been incorporated in introduction part to bring the clarity of the study.

Comment:- The evaluation of the different Zn-extractants is not relevant for this research, although this assessment could be the subject of another more specific work.

Our response: Yes, we do agree with the reviewer that evaluation of different Zn- extractants is more specific work. We have used different extractants to extract Zn in post harvest soil in order to establish relationship among the extracted Zn by different extractants and dry matter yield and Zn concentration and uptake by maize. Based on this relationship, we have identified the suitability of different extracts for extraction of Zn in acid soils.

Comment:- Objectives should be reworked once the problem has been well defined (and also the title of the article, according to them).

Our response: We have clarified the problem in the introduction part of the manuscript as mentioned earlier. We have also modified the title of the article and the objectives of the study.

Comment:-What relevance does the assessment have of the effect of the application of farmyard manure on the soil OC content (since OM was added)? (as well as the influence of lime application in pH). This is not relevant.

Our response: We agree with the reviewer. We have assessed the soil properties like Ph, EC and OC content along with extracted Zn in post-harvest soils to visualize the influence lime and FYM addition and to assess the relationship among the soil properties, dry matter yield and Zn concentration and uptake by maize.

Comment:- Materials and methods The experiment was in pots, of which the diameter was not indicated, although the weight of soil was.

Our response:- We have included diameter of each pot in the manuscript.

Comment:- However, the added amount of farmyard manure was expressed in t/ha. You should indicate the amount (g) of FYM applied to each pot for to know the nutrients (i.e., Zn) added to the soil with FYM as you are evaluating Zn extraction by crop (and by extractants) by varying Zn and lime doses.

Our response: Yes, we agree with the reviewer. We have indicated the amount of FYM in g added in the manuscript.

Comment:-What type of farmyard manure is it? The results of chemical analysis indicate FYM: OC 0.12.

Our response:- Locally available farmyard manure was used for the study and it was decomposed mixture of left over fodder (predominantly) fed to farm animals, animal dung and animal urine. There was a typo error in providing the OC content of FYM. It is 0.22% instead of 0.12% as mentioned earlier. We have corrected it in the manuscript and the information has been provided in Table 1.

Comment:-Results - Irrelevant results were included (e.g., adding farmyard manure increased the soil OC, the addition of lime increased soil pH, ..., adding Zn (and FYM) to soil increased Zn concentration in plant).

Our response: We have modified the result as per the suggestions. We have also changed the sequence of the results presented in the manuscript to make it more relevant.

Comment:- No critical levels of Zn in soil and/or plant tissues were indicated. Was the concentration of Zn in plants for unfavorable treatment below the critical values (literature)? Was there observed Zn deficiency symptoms in the plants with lower Zn concentration?

Our response:- We have include critical concentration of DTPA-Zn in soils (0.8 mg kg^{-1})(in table 1) and plant tissues in the manuscript. We have also compared the values of Zn concentration in plant tissues under different treatments with critical values available in literature. We have mentioned that the Zn concentration in maize under all the treatments were well above the critical Zn concentration of 15 to 22 mg kg^{-1} for maize crop (Alloway, 2008) and no visual Zn deficiency symptoms in plants were recorded.

Comment:- The Figures presented are redundant (and unnecessary), since data are also shown in tables.

Our response: In agreement with the reviewer, we have deleted the figures no. 1 from the manuscript. We have modified the figures no. 2 and 3 as per the suggestions of the referee #2.

Comment:-The Tables do not clarify the results of statistical analysis (comparison of means). The differences observed between means of the different treatments should be indicated by adding the corresponding letter (a, b, c...) to each mean value.

Our response: Yes it is correct. We have provided different letters to identify the observed differences between means in the tables.

Comments of Anonymous referee # 2:-

Comment:-My overall assessment of this manuscript is that although it covers a subject of potential interest to the journal, it does it without a clear objective and combining information on subjects that are well proven (e.g. liming) and very little in others (such as in a more detailed discussion of the interaction among treatments).

Our response:- We thank the reviewer for visualizing the importance of our study. We have modified the introduction part of the manuscript to clarify the problem and clearly stated the objectives of the study. Since liming and farmyard manure application is common by the farmers in acid soils, many researchers have worked in this line. But the information regarding the influence of lime, farmyard manure and Zn in acid soils on crop yield, Zn concentration in plant tissue and extracted Zn and their relationship is lacking. Therefore, the present study was carried out. We have tried our best to improve the discussion part of the manuscript by incorporating information about the significant interaction effects among the treatments.

Comment:-I have indicated several comments in the annotated version of the manuscript, but I summarize here some major points in case the authors want to rework the manuscript for a possible resubmission.

Our response:-We have gone through the comments given in the annotated version of the manuscript. We have modified the manuscript as per the comments provided in the different parts of the manuscript.

Comment:-The article lacks clear objectives, stated at the end of the introduction. There are apparently three overlapping studies: 1. Field experiments, greenhouse pot experiments, and effect of the extractant used in determining Zn concentration. However, it is unclear how they are coordinated for a final objective, giving the impression of been three related (but not properly coordinated) experiments.

Our response: We agree with you that we have collected bulk soil from field to conduct green house study. The objective of the present study was to study the influence of lime and farmyard manure and Zn addition on dry matter yield, Zn concentration and uptake by maize and soil properties and extractable Zn by different extractants in acid soils. The information would be useful for assessment of extractable Zn and its management in acid soils where Zn availability is one of the main problems and Zn application is imminent and application of lime and FYM is a common practice to obtain higher crop yield. This information has been incorporated in introduction part to bring the clarity of the study. We have modified and properly coordinated the introduction part of the manuscript to make it better understandable.

Comment:-The manuscript might be reorganized and edited, particularly in the introduction and M&Methods to address this problem.

Our response:- We have modified and reorganized the introduction and material and method section of the manuscript and made it systematic.

Comment:- There is missing some key information in the material and methods sections (for instance a better definition of the soil sampling in the field studies, or the properties of the manure, . . .).

Our response: We have incorporated the information regarding soils collected from field and methods used for analysis of manures as per the comments given in the annotated version of the manuscript.

Comment:-There are many other examples of these in the annotated version of the manuscript. They should be addressed.

Our response:- We have modified the manuscript as per the comments given.

Comment:-There is duplication in results presented in the Tables and Graphs while at the same time the statistical models uses (and in their major results, particularly in the case of interactions between variables) This should be addressed.

Our response: In agreement with the reviewer, we have deleted the figures no. 1 from the manuscript. We have modified the figures no. 2 and 3 as per the suggestions of the reviewers given in the manuscript. We have also tried our best to describe the results including the interaction effects of different treatments as per the statistical test used in the study.

Comment:- The discussion ad conclusions suffer the same lack of focus already mentioned in the overall organization for the manuscript. This should also been addressed.

Our response: We have modified the discussion and conclusion parts of the manuscript. Now we feel that is properly ordered and systematic.

Comment:-For these reasons my recommendation is that the manuscript should be returned to the authors for major modifications before been reconsidered for possible publication.

Our response:- Thank you very much. We have modified the manuscript as per the suggestions.

With above modifications, we are hereby submitting the revised manuscript for your kind perusal.

With kind regards,

Sanjib Kumar Behera

Effect of lime, farmyard manure and zinc application on soil properties, dry matter yield, zinc concentration and uptake by maize and extractable zinc in Alfisols

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ABSTRACT

Zinc (Zn) deficiency is widespread in all types of soils of world including acid soils affecting crop production and nutritional quality of edible plant parts. There is, however, limited information available regarding effects of lime and farmyard manure (FYM) and Zn addition to acid soils on dry matter yield, Zn concentration and uptake by maize (*Zea mays* L.) and soil properties and extractable Zn by different extractants. Green house pot experiments were carried out in two acid soils to study the effect of five levels of lime (0, 1/10 lime requirement (LR), 1/3 LR, 2/3 LR and LR), three levels of Zn concentration (0, 2.5 and 5.0 mg Zn kg^{-1} soil) and two levels of FYM (0 and 10 t ha^{-1}) addition on dry matter yield, Zn concentration and uptake by maize plant grown up to 60 days and soil pH, EC and OC content and extractable Zn in soil. Lime rate of 1/3rd LR was found to be optimum as dry matter yield of maize increased significantly with lime application up to 1/3rd LR in soils of both the series and decreased subsequently. Addition of FYM with and without lime increased dry matter yield. Application of Zn up to 5.0 mg kg^{-1} to soil increased dry matter yield with and without FYM application in soils of Hariharapur series. Addition of higher doses of lime significantly reduced Zn concentration in maize crop grown in soils of both the

series. Mean Zn uptake values were at par for no lime, $1/10^{th}$ LR and $1/3^{rd}$ LR with and without FYM application and it was significantly higher than Zn uptake by $2/3^{rd}$ LR and LR treatments. However, FYM application improved Zn uptake by maize crop. Increased level of lime application reduced Zn extracted by DTPA, Mehlich 1, 0.1 N HCl and ABDTPA extractants. However, application of FYM along with lime improved Zn extraction. The amount of Zn extracted by different extractants followed the order DTPA-Zn < ABDTPA-Zn < Mehlich-1 Zn < 0.1 M HCl. Zn extracted by different extractants like DTPA, ABDTPA, Mehlich 1 and 0.1 M HCl was positively and significantly correlated amongst themselves and with dry matter yield, Zn concentration and Zn uptake by maize. Among the extractants, ABDTPA was found to be the best extractant for extraction of Zn in acid soils.

Keywords: Alfisol, Dry matter yield, Farmyard manure, Lime, Zinc concentration

1. Introduction

Soil acidity is a serious problem affecting crop production across the world including India which is having 34.5% of arable land with acid soils (Maji et al., 2012). Ameliorating acid soils with suitable amendments and proper nutrient especially zinc (Zn) management in Zn-deficient acid soils (Rautaray et al., 2003; Behera et al., 2011) are areas of concern for obtaining higher crop yield. Amelioration of acidic soils is beneficial to plant growth because it improves soil pH and replenishes nutrients (Moon et al., 2014). Application of liming material is an effective method for amelioration of acid soils (Ponnette et al., 1991; Quoggio et al., 1995). Lime is normally oxides, carbonates and hydroxides of calcium or magnesium. There are about four types of lime viz., quicklime (CaO), slaked lime ($Ca(OH)_2$), limestone ($CaCO_3$) and dolomite. Application $CaCO_3$ to acid soils reduces soil acidity, improves basic cations status and significantly increases the yields of crops grown on Ultisol (Cifu et al., 2004). It also improves physical structure in nitric soils. However, adoption of standard recommendation of lime requirement (LR) for different groups of acid soils is difficult for farmers, which is uneconomical and unsustainable (Barman et al., 2014). Therefore, lower doses of LR like $1/10^{th}$, $1/3^{rd}$ and $2/3^{rd}$ of LR are applied by the farmers.

Soil pH and organic matter content are the most important soil factors affecting phyto-availability of Zn in soil (Suman, 1986; Lindsay, 1992). Increased soil pH due to addition of lime can influence availability of Zn in soil by altering its equilibrium (Verma and Minhas, 1987). Higher level of soil pH results in reduced extractable Zn content due to increased adsorptive capacity, formation of hydrolyzed forms of zinc, chemisorption on calcium carbonate and co- precipitation in iron oxides (Cox and Kamprath, 1972). Available organic materials such as farmyard manure (FYM) are generally used by the farmers along with chemical fertilizers because it improves soil physical, chemical and biological properties (Nambiar, 1994). Addition of organic matter to soil results in enhanced microbiological activity which adds complexing agents as well as influences the redox status of soil. According to Moody et al. (1997), higher levels of organic matters enhance Zn availability by increasing exchangeable and organic fractions of Zn and reducing oxide fractions of Zn. The effect of addition of organic matter on Zn availability in soils has also been reported by different workers (Murthy, 1982; Ghanem and Mikkelsen, 1987). But the information regarding influence of addition of lime with and without FYM to acid soils on Zn availability in soil and Zn concentration and Zn uptake by crops is limited.

Appropriate soil tests for plant available Zn is not yet available for all types of agricultural soils around the world. However, extractants like diethylene triamine penta acetic acid (DTPA), ethylene diamine tetra acetic acid (EDTA), hydrochloric acid, ammonium bicarbonate-DTPA (ABDTPA) , Mehlich 1 and Mehlich 3 are used for extraction of plant available Zn from soils (Alloway, 2008). But DTPA extractant is the most widely used. The DTPA soil test was originally developed to categorize near-neutral and calcareous soils with insufficient plant available Zn to support maximum yield of crops

(Lindsay and Norvell, 1978). But the same has been used for acid soils also for extraction of plant available Zn. According to O'Connor (1988), whenever one strays from the original design of the test, one should be aware of the possible consequences and pass that awareness on to others. Based on correlation among the extracted Zn by different extractants and with soil properties, Behera et al. (2011) reported the usefulness of DTPA, Mehlich 1, Mehlich 3, 0.1 N HCl and ABDTPA extractant for extraction of plant available Zn in acid soils of India. However, 0.1 N HCl was found to be best extractant (based on higher values of correlation coefficient with soil pH and OC) for extraction of plant available Zn in acid soils. But there is scanty information available regarding the relationship of extracted Zn by different extractants with Zn concentration and uptake by crop plants.

The information from the present study would be useful for assessment of extractable Zn and its management in acid soils where Zn availability is one of the main problems and Zn application is imminent and application of lime and FYM is a common practice. Keeping above facts in view, the present study was carried out (i) to evaluate the influence of lime, FYM and Zn addition on dry matter yield, Zn concentration and uptake by maize (*Zea mays* L.) crop and (ii) to evaluate the influence of lime, FYM and Zn addition to acid soils on soil pH, EC and OC content, extractable Zn as extracted by different extractants.

2. Materials and methods

2.1 Soil and farmyard manure characteristics

The bulk surface (0-15 cm depth) soils collected from Hariharpur series (Oxic Haplustalf, Alfisol (Soil Survey Staff, 2014)) and Debatoli series (Udic Rhodostalf, Alfisol (Soil Survey Staff, 2014)) of Bhubaneswar and Ranchi (India), respectively were used in the study. The collected soils were air dried and stone and debris were removed and then ground to pass a 2 mm sieve and analysed for selected properties (Table 1). Soil properties like pH and EC were determined done on 1: 2.5 soil water ratio (w/v) suspension using pH meter and EC meter following half an hour equilibrium (Jackson, 1973). Soil organic carbon (OC) content was estimated by chromic acid digestion-back titration method (Walkley and Black, 1934). The clay, silt and sand per cent of soils were determined by hydrometer method (Bouyoucos, 1962). Calcium carbonate ($CaCO_3$) content was determined by rapid titration method (Puri, 1930) and cation exchange capacity (CEC) by neutral normal ammonium acetate method (Richards, 1954). Lime requirement (LR) of the soil was estimated by extractant buffer method (Shoemaker et al., 1961). The plant available Zn in soils was extracted by DTPA method (Lindsay and Norvell, 1978). Estimation of Zn concentration was done on the clear extract by atomic absorption spectrophotometer (AAS). After drying of FYM at 70 ^{o}C for 24 h followed by grinding to pass through 20 mesh sieve, one gram of ground FYM was dry-ashed at 450 ^{o}C for 2h. Ashed samples were extracted using 0.5 N HCl. Zn concentration was determined in filtered extracts. The total OC (loss on ignition), N (Kjeldahl method), P (nitric-perchloric 9:4 digestion) and K (nitric-perchloric 9:4 digestion) concentrations in FYM were estimated according to Tandon (2009) (Table 1).

2.2 Green house study, soil and plant analysis

Pot experiments were carried out in two Hariharapur and Debatoli series soils. The experiments were carried out in plastic pots (each with diameter of 20 cm) having 4 kg of soil with five levels of LR (0, 1/10 LR, 1/3 LR, 2/3 LR and LR), three levels of Zn concentration (0, 2.5 and 5.0 mg Zn kg^{-1} soil) and two levels of fresh FYM (35% moisture) (0 and 4.5 g FYM kg^{-1} soil viz., 0 and 10 t FYM ha^{-1}). Locally available FYM was used for the study and it was decomposed mixture of left over fodder fed to farm animals, animal dung and urine. All the pots received basal treatments of N-P_2O_5-K_2O @ 150-60-40 kg ha^{-1} (equivalent to 66.7-26.7-17.8 mg N-P_2O_5-K_2O kg^{-1} soil, respectively). Fertilizer N, P and K were applied through analytical grade urea, calcium dihydrogen orthophosphate and muriate of potash, respectively. Lime and Zn were added to soil through laboratory grade $CaCO_3$ and $ZnSO_4$ respectively. All nutrients were mixed in soil thoroughly before sowing of seeds. The soil in each pot was then irrigated to field capacity with deionized water and kept for incubation for one week. Each treatment combination was replicated thrice in a factorial completely randomized design. Four seeds of cv. KH 101 of maize were sown in each pot. Two seedlings of maize per each pot were maintained after emergence. Pots were irrigated with water daily as per requirement of water on weight basis to maintain the field capacity. Above-ground biomass of plants from each pot was harvested at the end of 60 days of growth.

Harvested above-ground biomass of each pot was washed in deionized water, and then dried in oven at 70 ^{o}C for 48 h. After drying, dry matter yield (DMY) of each pot was recorded. Dried plant material was then ground in a stainless steel Wiley mill, and digested in a di-acid mixture of HNO_3 and $HClO_4$ (Jackson, 1973). Zn concentration was then determined in aqueous extracts of the digested plant material by atomic absorption spectrophotometer (AAS). Zn uptake was calculated as DMY multiplied by the Zn concentration.

Soil sample from each pot were collected after harvesting of maize plants. Collected soil samples were processed and analyzed for pH, EC, OC content and DTPA-Zn concentration following the methods described above. The plant available Zn in soils was also extracted by DTPA (Lindsay and Norvell, 1978), Mehlich 1 (Perkins, 1970), 0.1 M HCl (Sorensen et al., 1971) and ABDTPA (Soltanpour and Schwab, 1977) extractants by following the respective prescribed methods. Estimation of Zn concentration was done on the clear extract by AAS.

2.3 Statistical analysis

The data regarding soil properties, DMY, Zn concentration, Zn uptake and extracted Zn by different extractants subjected to analysis of variance method (Gomez and Gomez 1984). Least square difference (LSD) at $P \leq .01$ was used to compare among the treatment means.

Pearson's correlation coefficient values were estimated to establish relationship among soil properties, DMY, Zn concentration, Zn uptake and extracted Zn by different extractants.

3. Results

3.1 Dry matter yield

DMY of maize increased significantly with lime application up to 1/3rd LR (Table 2, Fig. 1 a) in soils of both the series. This indicated that lime application @ 1/3rd of LR was optimum for these soils. Application of higher doses of lime (2/3rd LR and LR) did not result in increased DMY. However, this finding needs to be verified by conducting field experiment. The mean DMY in 1/3rd LR treatment without FYM and with FYM was 139% and 149% of control respectively in Harihpur series soils. Similarly in Debatoli series soil, the mean DMY was 84% and 120% of control without and with FYM application respectively in combination with 1/3rd LR. Application of graded doses of Zn upto 5.0 mg kg^{-1} to soil increased DMY with and without FYM application in Hariharapur series. Whereas in Debatoli series, application of graded doses of Zn up to 5 mg kg^{-1} without FYM and application of Zn @ 2.5 mg kg^{-1} with FYM enhanced DMY.

3.2 Zinc concentration and uptake by maize

Addition of higher doses of lime significantly reduced Zn concentration in maize crop grown in soils of both the series (Table 2, Fig. 1 b). In contrast, application of Zn (@ 2.5 and 5.0 mg kg^{-1}) and FYM (@ 10 t ha^{-1}) increased Zn concentration in maize crop significantly in soils of both the series (Table 2, Fig 1c). In soils of Hariharapur series, application Zn @ 2.5 and 5 mg kg^{-1} without and with FYM augmented Zn concentration in maize by 67.5 and 93.5 to 109 % respectively, as compared to control (No Zn). Similarly, increased Zn concentrations of 22 to 35 and 58 to 73% were recorded with application of Zn @ 2.5 and 5 mg kg^{-1} without and with FYM respectively in comparison to no Zn control in soils of Debatoli series. However, the Zn concentration in maize under all the treatments were well above the critical Zn concentration of 15 to 22 mg kg^{-1} for maize crop (Alloway, 2008) and no visual Zn deficiency symptoms in plants were recorded. Mean Zn uptake values were at par for no lime, $1/10^{th}$ LR and $1/3^{rd}$ LR with and without FYM application and it was significantly higher than Zn uptake by $2/3^{rd}$ LR and LR treatments in soils of both the series (Table 2, Fig. 1 d). However, Zn and FYM application improved Zn uptake by maize crop in soils of both series (Fig. 1 e). Addition of Zn @ 2.5 and 5 mg kg^{-1} enhanced Zn uptake by 67 to 100 and 122 to 150% respectively as compared to no Zn control in soils of Hariharapur series. Whereas, the enhancements in Zn uptake were 36 to50, 73 to 117% due to application of Zn @ 2.5 and 5 mg kg^{-1} respectively as compared to no Zn control in soils of Debatoli series.

3.3 Soil properties

Application of lime at different rates significantly increased pH in soils of both Hariharapur and Debatoli series (Table 3). With addition of graded doses of limes viz. from no lime, $1/10^{th}$ LR, $1/3^{rd}$ LR, $2/3^{rd}$ LR and LR, soil pH increased from 4.58 to 7.16 (without FYM addition) and from 4.89 to 7.23 (with FYM addition) in Hariharapur series and from 5.83 to 6.95 (without FYM addition) and from 6.04 to 7.02 (with FYM addition) in Debatoli series. Application of FYM without lime increased soil pH in both the soils (Table 3). Interaction effect of combined application of lime and FYM on soil pH was significant. Soil pH values obtained by addition of $2/3^{rd}$ LR and LR along with FYM were at par. Addition of Zn did not have any effect on soil pH. Sole application of lime, FYM and Zn and their interaction did not influence soil EC levels in soils of both the series (Table 3). However application of FYM increased soil OC content in soils of both series. Addition of lime and Zn and their interaction did not influence soil OC.

3.4 Extractable zinc in post-harvest soil

Data regarding amount Zn extracted by DTPA, Mehlich 1, 0.1 M HCl and ABDTPA extractants in post harvest soil are given in Table 4 and Figure 2. Perusal of data revealed significant effect of individual application of lime, FYM and Zn and their interaction on extracted Zn by different extractants. The amount of extracted Zn by DTPA, Mehlich 1, and ABDTPA extractants decreased with increased level of lime application in soils of both the series (Fig. 2 a, b, d). But addition of FYM (@ 10 t ha^{-1}) in combination of different levels of lime led to marked enhancement of extracted Zn by different extractants in both the soils compared to only application of different lime levels (Table 4). Application Zn at different levels viz. 2.5 and 5.0 mg kg^{-1} with and without FYM increased the concentration of extracted Zn by the different extractants. The amount of Zn extracted by DTPA, Mehlich 1, 0.1 M HCl and ABDTPA extractant varied from 1.10 to 1.76, 1.90 to 2.72, 2.70 to 3.26 and 1.72 to 2.42 mg kg^{-1} respectively, under different levels of lime application across FYM and Zn application in soils of Hariharpur series. Whereas, the Zn extracted by DTPA, Mehlich 1, 0.1 M HCl and ABDTPA extractant varied from 1.82 to 2.69, 3.34 to 4.39, 4.22 to 5.07 and 2.82 to 3.36 mg kg^{-1} respectively, under different levels of lime application across FYM and Zn application in soils of Debatoli series. In both the series, the extracted Zn followed the order DTPA-Zn < ABDTPA-Zn < Mehlich1-Zn < 0.1 M HCl-Zn.

4. Discussion

Significant increase in DMY was recorded with application of lime up to 1/3rd LR. Increase in DMY with lime application up to 1/3rd LR may be ascribed to increase in soil pH and positive influence on nutrient availability in soil (Tisdale, 2005). Our finding is in line with the observations made by Barman et al. (2014) who reported lime application at 1/3rd LR was optimum for obtaining cauliflower yield in Typic Fluvaquent soil of West Bengal, India. There was reduction in DMY with lime application at 2/3rd LR and LR in soils of both the series. This may be ascribed to reduced availability Zn in soil with 2/3rd LR and LR rate of lime application and adverse effect on other soil properties. This needs to be verified by conducting filed experiment. Increased DMY due to FYM addition may be due to positive influence of on nutrient availability and uptake. Increased DMY due to Zn addition in soils of Hariharapur series revealed that Zn is a limiting nutrient in this soil. It was evident from low initial DTPA-Zn status (0.47 mg kg^{-1}) of this soil. Grain and vegetative tissue (stover) yield of maize increased significantly with successive application of Zn up to 1 kg ha^{-1} in a Zn-deficient (DTPA-Zn 0.38 mg kg^{-1}) (Critical DTPA-Zn concentration 0.80 mg kg^{-1}) Vertisol of India (Behera et al., 2015). Zn addition to a soil with 0.18 mg kg^{-1} Zn enhanced wheat grain yield (Cakmak et al., 2010a; Cakmak et al., 2010b). However in Debatoli series, DMY response to Zn application was obtained in spite of high initial DTPA-Zn status (1.45 mg kg^{-1}) which needs further investigation. In contrast to our findings, Zhang et al. (2012) and Wang et al. (2012) reported that zinc fertilizer application did not improve the biomass and grain yields of wheat and maize in rain-fed and low Zn calcareous soils of China. This may be attributed to Zn availability in soil influenced by several factors (Alloway, 2009) and efficiency of the crops/genotypes to utilize available Zn in soils (Cakmak et al., 1998).

Addition of lime significantly reduced Zn concentration. This may be due to reduced availability Zn in soil due to increased soil pH. Soil pH significantly influences Zn distribution among different fractions and availability in soil (Sims, 1986; Smith, 1994) and the plant uptake is primarily related with different Zn fractions (Behera et al., 2008). However, FYM and Zn application improved Zn concentration in maize but not Zn uptake. Application of 5 and 10 mg Zn kg^{-1} enhanced Zn concentration of navy bean shoot from 19.93 mg kg^{-1} to 38.12 and 54.8 mg kg^{-1} respectively (Gonzalez et al., 2008). Significant increase in Zn concentration in ear leaves of spring maize, shoots of wheat and in maize and wheat grains was also reported by Wang et al. (2012). Payne et al. (1988) also reported increased Zn concentration in maize grain under highest $ZnSO_4$ application from a long-term experiment.

Application of increased rate of lime also enhanced soil pH. Anikwe et al. (2016) also reported increase in soil pH due to lime addition in an Ultisol of Nigeria. Application of lime along with FYM also enhanced soil pH. This is in line with the findings of Saha et al. (2012). Normally, addition of organic matter lowers soil pH by releasing H^+ ions associated with organic anions or by nitrification in an open system (Porter et al., 1980). But in contrary, it may cause pH increases either by mineralization of organic anions to CO_2 and water (thereby removing H^+ ions) or because of the 'alkaline' nature of the organic material (Helyar, 1976). Increase in soil pH due to addition FYM in our study may be due to operation of the second mechanism. Application of lime reduced the concentrations of extractable Zn extracted by DTPA, Mehlich 1 and ABDTPA extractants. Reduced availability of Zn in soil due to liming has also been reported by Tlustos et al. (2006) and Vondrackova et al. (2013). It is because of conversion of plant available fractions of Zn to plant unavailable fractions resulting in effective immobilisation (Davis-Carter and Shuman, 1993). But application of FYM improved the concentrations of extracted Zn. Addition of organic matter led to formation of organic acids by microbial decomposition, which mobilize soil bound Zn and restrict the fixation of soluble Zn by chelating it (Shukla, 1971; Sarkar and Deb, 1982; Tagwira et al., 1992). It has also been reported by Saha et al. (1999) that application of organic matter to cultivated acid soils was essential to counteract the adverse effect of lime application on Zn availability. Application Zn with and without FYM enhanced the concentrations of extracted Zn significantly. Rupa et al. (2003) also reported increased concentration of exchangeable plus water soluble, inorganically, organically and oxide bound Zn in two Alfisols due to addition of increased Zn rates. Soil pH was negatively and significantly correlated with Zn concentration (r = -0.509**, r = -0.343**) and Zn uptake by maize (r = -0.397**, r = -

0.326**) in both the soil series (Table 5). This revealed that increased soil pH resulted in decreased Zn concentration and Zn uptake in maize and vice versa. Wang et al. (2006) also recorded increased Zn concentration in *Thlaspi caerulescens* with decreased soil pH. Soil OC content was positively and significantly correlated with DMY (r = 0.221*), Zn concentration (r = 0.232*) and Zn uptake (r = 0.294**) in Hariharpur series only. It was also positively and significantly correlated with DTPA, Mehlich 1 and 0.1 M HCl extracted Zn in soils of both the series. This is in line with the findings of Katyal and Sharma (1991) and Shidhu and Sharma (2010). DMY was positively and significantly correlated with Zn uptake(r = 0.605**, 0.727**) in soils of both the series.

Among the extractants used in this study, DTPA extracted lowest amount of Zn. This is in agreement with the findings of Behera et al. (2011) who reported lowest amount of Zn extracted by DTPA compared other extractants like Mehlich 1, Mehlich 3, 0.1 M HCl and ABDTPA, by analysing four hundred soil samples collected from cultivated acid soils of India. This may be ascribed to lower extracting power of DTPA in these soils owing to reduced active sites of DTPA at lower pH values. Higher extractability of ABDTPA compared to DTPA in these soils because of ABDTPA solution pH of 7.6 which allowed DTPA to chelate and extract more Zn from soil. Mehlich 1 extractant which was originally developed for prediction of plant available P in acidic coastal plain soil (pH<6.5) with low cation exchange capacity (CEC<10meq/100g) and low organic matter (<5%), extracted more amount of Zn compared to DTPA and ABDTPA extractants. Higher extractability of Zn by 0.1 M HCl has also been reported by Naik and Das (2010) as compared to DTPA and 0.05 M HCl extracted Zn in low land rice soils. This is because 0.1 M HCl extracts Zn from freshly adsorbed iron and manganese oxides, carbonates, or decomposing organic matter and Zn bound with the octahedral-OH in layer silicates (Hodgson, 1963). Dilute mineral acids of pH 1-2 showed the greatest extracting power for extraction of Zn, followed by buffered solutions of pH 7-9 containing chelating agents and buffers or very dilute acids of pH 4-5 (Misra et al., 1989). Zhang et al. (2010) reported Zn extraction capacity of different extractants in the order of EDTA > Mehlich 3 > Mehlich 1 > DTPA > NH_4OAc > $CaCl_2$ in polluted soils of rice in south-eastern China. The amount Zn extracted in polluted soils of central Iran followed the order Mehlich 3 > ABDTPA > DTPA > Mehlich 2 > $CaCl_2$ > HCl (Hosseiwwnpur and Motaghian, 2015). DMY was positively and significantly correlated with Zn extracted by DTPA, Mehlich 1, 0.1 M HCl and ABDTPA extractants in Hariharpur series and Zn extracted by Mehlich 1, 0.1 M HCl and ABDTPA extractants in Debatoli series (Table 5). Zn concentration in maize was positively and significantly correlated with Zn uptake by maize and extracted Zn by different extractants in soils of both the series. Positive and significant correlation coefficient values were also obtained for Zn uptake vs Zn extracted by different extractants in soils of both the series. Zn extracted by different extractants in soils of both series were positively and significantly correlated with each other. The values of correlation coefficients ranged from r = 0.811** to r = 0.937**. This indicated that the trend of extraction of Zn from both the soils, by different extractants used in the study is similar. It corroborates the findings of Gartley et al. (2002), Mylavarapu et al. (2002) , Nascimento et al. (2007) and Behera et al. (2011) who have reported the suitability of extractants like DTPA, ABDTPA, Mehlich 1, Mehlich 3 and 0.1 M HCl for extraction of phyto-available Zn in acids of different parts of the world. Since Zn extracted by different extractants like DTPA, ABDTPA, Mehlich 1 and 0.1 M HCl, was positively and significantly correlated amongst themselves and with DMY, Zn concentration and Zn uptake by maize, all these extractants can be used for extraction of Zn from acid soils. However, ABDTPA extractant was found to be the best extractant for extraction of Zn in acid soils as the values of correlation coefficients between Zn concentration and Zn uptake by maize with extracted Zn by ABDTPA extractant were highest compared to that by other extractants.

5. Conclusion

Lime application of 1/3LR was found to be optimum for amelioration of acid soils. The concentration of Zn in maize tissue and extracted Zn by different extractants like DTPA, Mehlich 1, 0.1 M HCl and ABDTPA in both the soils reduced with lime application. Application of FYM along with lime improved the Zn concentration in maize plant and extractable Zn in soils. Since DTPA, Mehlich 1, 0.1 M HCl and ABDTPA extractable Zn in soils of both the series were positively and significantly correlated with dry matter yield, Zn concentration and Zn uptake, these extractants could be used for extraction of Zn in acid soils. However based on higher correlation coefficient values, ABDTPA was found to be best extractant for extraction of Zn in acid soils.

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Table 1 Some selected characteristics of the experimental soils and farmyard manure.

Characteristics	Experimental soils	
	Hariharapur series	Debatoli series
Taxonomic classification	Oxic Haplustalfs	Udic Rhodustalfs
pH (1:2.5)	4.50	5.80
EC (dS m^{-1})	0.14	0.23
Organic carbon (%)	0.31	0.22
Clay (%)	12.1	14.2
Silt (%)	15.0	11.6
Sand (%)	73.2	75.1
$CaCO_3$ (%)	20.0	32.0
CEC (cmol(p^+) kg^{-1})	3.90	5.10
Lime requirement (g kg^{-1})	3.34	1.51
DTAP-Zn (mg kg^{-1})	0.47	1.45
	Farmyard manure	
Total organic carbon (%)	0.22	
Total N (%)	0.48	
Total P (%)	0.10	
Total K (%)	0.55	
Total Zn (mg kg^{-1})	12	

*Critical concentration of DTPA-Zn is 0.80 mg kg^{-1}

T able 2 Effect of FYM, lime and Zn application on dry matter yield, Zn concentration and Zn uptake by maize.

Treatments	No FYM				FYM (10 t ha^{-1})				
	No Zn	2.5 mg Zn kg^{-1}	5.0 mg Zn kg^{-1}	Mean	No Zn	2.5 mg Zn kg^{-1}	5.0 mg Zn kg^{-1}	Mean	Overall mean
Hariharapur series									
					Dry matter (g pot^{-1})				
No lime	1.64	2.02	2.04	1.90a	2.06	2.60	2.23	2.30d	2.10
1/10th LR	2.43	2.37	2.16	2.32b	2.21	2.74	2.66	2.53ef	2.43
1/3rd LR	2.88	2.87	2.96	2.83c	2.57	2.89	3.66	2.98f	2.91
2/3rd LR	2.65	2.37	2.66	2.64c	2.40	2.40	3.01	2.66d	2.65
LR	1.77	2.06	2.52	2.12ab	1.94	2.05	2.71	2.23d	2.18
Mean	2.27aa	2.34aa	2.47bb	-	2.23cc	2.53cce	2.85dde	-	-
LSD (0.01)	Lime = 0.30, Zn level = 0.11, FYM level = 0.25, Lime x Zn level =0. 50, Lime x FYM level = 0.61, Zn level x FYM level = 0.42								
					Zn concentration (mg kg^{-1})				
No lime	54.0	84.0	112	83.3a	57.4	104	119	93.2e	88.4
1/10th LR	53.3	87.4	113	84.6a	59.2	99.5	119	92.7e	88.6
1/3rd LR	38.5	63.5	75.0	59.0b	46.3	72.8	80.0	66.4f	62.7
2/3rd LR	27.4	52.7	60.8	47.0c	35.4	59.8	67.6	54.g	50.6
LR	25.2	44.8	54.2	41.4d	31.2	48.9	58.1	46.1h	43.7
Mean	39.7aa	66.5bb	83.0cc	-	45.9dd	76.9ee	88.8ff	-	-
LSD (0.01)	Lime = 3.50, Zn level = 0.11, FYM level = 2.00, Lime x Zn level =3.21, Lime x FYM level = 5.70, Zn level x FYM level = 3.15								
					Zn uptake (mg pot^{-1})				
No lime	0.11	0.14	0.23	0.16a	0.12	0.27	0.26	0.22f	0.19
1/10th LR	0.13	0.21	0.24	0.19b	0.13	0.27	0.32	0.24g	0.22
1/3rd LR	0.10	0.18	0.22	0.17c	0.11	0.21	0.29	0.20h	0.19
2/3rd LR	0.08	0.13	0.16	0.12d	0.09	0.14	0.20	0.15i	0.13
LR	0.05	0.09	0.14	0.09e	0.06	0.10	0.16	0.11j	0.10
Mean	0.09aa	0.15bb	0.20cc	-	0.10dd	0.20dd	0.25dd	-	-
LSD (0.01)	Lime = 0.002, Zn level = 0.005, FYM level = 0.004, Lime x Zn level =0.008, Lime x FYM level = 0.007, Zn level x FYM level = 0.012								

Debatoli series									
	Dry matter (g pot^{-1})								
No lime	2.84	3.55	4.19	3.53a	3.45	3.72	3.44	3.57d	3.55
$1/10^{th}$ LR	3.37	3.94	4.52	3.94b	3.56	4.06	4.21	3.91d	3.93
$1/3^{rd}$ LR	3.71	4.32	4.54	4.19b	3.80	4.84	4.46	4.37d	4.28
$2/3^{rd}$ LR	3.55	3.67	4.43	3.88b	3.53	3.74	3.76	3.68d	3.78
LR	3.27	3.54	3.46	3.42c	3.46	3.59	3.55	3.54d	3.48
Mean	3.35aa	3.80bb	4.23cc	-	3.56dd	3.99dd	3.88dd	-	-
LSD (0.01)	Lime = 0.32, Zn level = 0.22, FYM level = ns, Lime x Zn level =0. 58, Lime x FYM level = ns, Zn level x FYM level =ns								
	Zn concentration (mg kg^{-1})								
No lime	62.2	85.0	119	88.7a	71.0	86.2	126	94.4f	91.6
$1/10^{th}$ LR	60.4	78.4	105	81.3b	70.7	84.3	116	90.3g	85.8
$1/3^{rd}$ LR	55.3	68.9	94.8	73.0c	71.6	77.3	97.9	82.3h	77.6
$2/3^{rd}$ LR	47.8	66.5	75.2	63.2d	52.4	69.5	80.2	67.4i	65.3
LR	39.7	60.6	64.8	55.0e	44.8	62.6	70.6	59.4j	57.2
Mean	53.1aa	71.9bb	91.8cc	-	62.1dd	76.0ee	98.1ff	-	-
LSD (0.01)	Lime = 1.80, Zn level = 0.20, FYM level = 1.50, Lime x Zn level =2.10, Lime x FYM level = 3.80, Zn level x FYM level = 2.10								
	Zn uptake (mg pot^{-1})								
No lime	0.18	0.30	0.50	0.33a	0.25	0.32	0.44	0.34e	0.33
$1/10^{th}$ LR	0.20	0.31	0.47	0.33a	0.24	0.34	0.49	0.36f	0.34
$1/3^{rd}$ LR	0.21	0.30	0.43	0.31b	0.27	0.37	0.44	0.36f	0.34
$2/3^{rd}$ LR	0.17	0.24	0.33	0.25c	0.19	0.26	0.30	0.25g	0.25
LR	0.13	0.21	0.23	0.19d	0.15	0.23	0.25	0.21h	0.20
Mean	0.18aa	0.27bb	0.39cc	-	0.22dd	0.30ee	0.38ff	-	-
LSD (0.01)	Lime = 0.03, Zn level = 0.11, FYM level = 0.02, Lime x Zn level =ns, Lime x FYM level = 0.08, Zn level x FYM level = ns								

*Letters indicate observed differences among the means of different treatments

T able 3 Soil pH, EC and OC content as influence by FYM, lime and Zn application.

Treatments	No FYM				FYM (10 t ha^{-1})				
	No Zn	2.5 mg Zn kg^{-1}	5.0 mg Zn kg^{-1}	Mean	No Zn	2.5 mg Zn kg^{-1}	5.0 mg Zn kg^{-1}	Mean	Overall mean
Hariharapur series									
					pH				
No lime	4.56	4.57	4.61	4.58a	5.16	5.10	5.34	5.20f	4.89
1/10th LR	4.80	5.01	4.83	4.88b	5.46	5.42	5.44	5.44f	5.16
1/3rd LR	5.69	6.14	5.57	5.80c	5.93	6.49	5.97	6.13g	5.97
2/3rd LR	6.45	6.53	6.62	6.53d	6.92	7.08	6.57	6.86h	6.70
LR	7.23	7.25	6.99	7.16e	7.37	7.17	7.38	7.31h	7.23
Mean	5.75aa	5.90aa	5.72aa	-	6.17bb	6.25bb	6.14bb	-	-
LSD (0.01)	Lime = 0.19, Zn level = ns, FYM level = 0.25, Lime x Zn level = ns, Lime x FYM level = 0.51, Zn level x FYM level = ns								
					EC (dS m^{-1})				
No lime	0.14	0.11	0.13	0.13a	0.13	0.15	0.14	0.14a	0.13
1/10th LR	0.14	0.10	0.10	0.12a	0.15	0.11	0.12	0.13a	0.12
1/3rd LR	0.13	0.13	0.11	0.12a	0.12	0.10	0.14	0.12a	0.12
2/3rd LR	0.12	0.13	0.11	0.12a	0.12	0.15	0.10	0.12a	0.12
LR	0.13	0.14	0.12	0.13a	0.15	0.14	0.15	0.15a	0.14
Mean	0.13aa	0.12aa	0.11aa	-	0.13aa	0.13aa	0.13aa	-	0.13
LSD (0.01)	Lime = ns, Zn level = ns, FYM level = ns, Lime x Zn level = ns, Lime x FYM level = ns, Zn level x FYM level = ns								
					OC (%)				
No lime	0.26	0.27	0.25	0.26a	0.32	0.37	0.34	0.34b	0.30
1/10th LR	0.27	0.24	0.27	0.26a	0.33	0.34	0.39	0.35b	0.31
1/3rd LR	0.25	0.24	0.27	0.25a	0.31	0.36	0.37	0.35b	0.30
2/3rd LR	0.27	0.25	0.23	0.25a	0.30	0.34	0.32	0.32b	0.29
LR	0.24	0.21	0.22	0.22a	0.25	0.34	0.33	0.31b	0.27
Mean	0.26aa	0.24aa	0.25aa	-	0.30bb	0.35bb	0.35bb	-	-
LSD (0.01)	Lime = ns, Zn level = ns, FYM level = 0.03, Lime x Zn level = ns, Lime x FYM level = ns, Zn level x FYM level = ns								

Debatoli series									
				pH					
No lime	5.88	5.85	5.77	5.83a	6.14	6.17	6.45	6.25f	6.04
1/10th LR	5.93	5.88	5.94	5.92b	6.28	6.42	6.56	6.42f	6.17
1/3rd LR	6.38	6.21	6.21	6.27c	6.44	6.57	6.58	6.53f	6.40
2/3rd LR	6.64	6.67	6.6	6.64d	6.76	6.75	6.65	6.73g	6.68
LR	6.96	6.99	6.9	6.95e	7.27	6.87	7.14	7.09g	7.02
Mean	6.36aa	6.32aa	6.28aa	-	6.58bb	6.56bb	6.67bb	-	-
LSD (0.01)	Lime = 0.17, Zn level = ns, FYM level = 0.20, Lime x Zn level = ns, Lime x FYM level = 0.47, Zn level x FYM level = ns								
				EC (dS m^{-1})					
No lime	0.23	0.22	0.27	0.24a	0.21	0.26	0.23	0.23a	0.24
1/10th LR	0.27	0.27	0.23	0.25a	0.21	0.23	0.20	0.21a	0.24
1/3rd LR	0.23	0.23	0.24	0.23a	0.17	0.29	0.25	0.24a	0.24
2/3rd LR	0.23	0.21	0.21	0.21a	0.23	0.19	0.24	0.22a	0.22
LR	0.24	0.17	0.29	0.23a	0.19	0.30	0.26	0.25a	0.24
Mean	0.24aa	0.22aa	0.25aa	-	0.20aa	0.25aa	0.24aa	-	-
LSD (0.01)	Lime = ns, Zn level = ns, FYM level = 0.04, Lime x Zn level = ns, Lime x FYM level = ns, Zn level x FYM level = ns								
				OC (%)					
No lime	0.21	0.28	0.22	0.24a	0.22	0.29	0.30	0.27b	0.25
1/10th LR	0.22	0.22	0.21	0.22a	0.28	0.28	0.28	0.28b	0.25
1/3rd LR	0.21	0.25	0.24	0.23a	0.28	0.26	0.29	0.28b	0.26
2/3rd LR	0.18	0.22	0.25	0.21a	0.31	0.25	0.28	0.28b	0.25
LR	0.21	0.25	0.26	0.24a	0.28	0.30	0.28	0.28b	0.26
Mean	0.21aa	0.24aa	0.24aa	-	0.27bb	0.27bb	0.29bb	-	-
LSD (0.01)	Lime = ns, Zn level = ns, FYM level = 0.04, Lime x Zn level = ns, Lime x FYM level = ns, Zn level x FYM level = ns								

*Letters indicate observed differences among the means of different treatments

T able 4 Effect of FYM, lime and Zn application on extractable Zn in soils.

Treatments	No FYM				FYM (10 t ha^{-1})				
	No Zn	2.5 mg Zn kg^{-1}	5.0 mg Zn kg^{-1}	Mean	No Zn	2.5 mg Zn kg^{-1}	5.0 mg Zn kg^{-1}	Mean	Overall mean
Hariharapur series									
				DTPA-Zn (mg kg^{-1})					
No lime	0.40	1.44	2.95	1.60a	0.88	1.68	3.21	1.92f	1.76
1/10th LR	0.40	1.24	2.30	1.31b	0.66	1.67	3.20	1.84f	1.58
1/3rd LR	0.38	1.06	1.64	1.03c	0.61	1.62	2.68	1.64fh	1.33
2/3rd LR	0.37	0.86	1.45	0.89d	0.44	1.59	2.55	1.53gh	1.21
LR	0.34	0.77	1.25	0.79e	0.44	1.27	2.53	1.41gh	1.10
Mean	0.38aa	1.08bb	1.92cc	-	0.61dd	1.57ee	2.83ff	-	-
LSD (0.01)	Lime = 0.02, Zn level = 0.25, FYM level = 0.20, Lime x Zn level =0. 35, Lime x FYM level = 0.28, Zn level x FYM level = 0.47								
				Mehlich 1-Zn (mg kg^{-1})					
No lime	0.78	1.68	3.85	2.10a	1.23	3.70	5.08	3.34f	2.72
1/10th LR	0.77	1.66	3.74	2.06b	1.17	3.20	4.88	3.08f	2.57
1/3rd LR	0.74	1.50	3.27	1.84c	1.05	2.64	4.79	2.83gi	2.33
2/3rd LR	0.66	1.48	2.26	1.47d	1.03	2.54	4.49	2.69hi	2.08
LR	0.51	1.24	1.92	1.22e	0.94	2.54	4.25	2.58hi	1.90
Mean	0.69aa	1.51bb	3.01cc	-	1.09dd	2.92ee	4.70ff	-	-
LSD (0.01)	Lime = 0.10, Zn level = 0.42, FYM level = 0.25, Lime x Zn level =0. 55, Lime x FYM level = 0.37, Zn level x FYM level = 0.70								
				0.1 M HCl-Zn (mg kg^{-1})					
No lime	0.90	2.50	4.62	2.67a	1.50	3.81	6.24	3.85f	3.26
1/10th LR	0.89	2.31	4.61	2.60b	1.34	3.72	6.20	3.75fi	3.18
1/3rd LR	0.84	2.25	4.28	2.46c	1.33	3.39	5.68	3.47gi	2.96
2/3rd LR	0.84	2.18	3.94	2.32d	1.22	3.05	5.62	3.30g	2.81
LR	0.84	1.93	3.91	2.23e	1.06	3.03	5.43	3.17g	2.70

Mean	0.86aa	2.23bb	4.27cc	-	1.29dd	3.40ee	5.83ff	-	-
LSD (0.01)	Lime = 0.02, Zn level = 0.30, FYM level = 0.27, Lime x Zn level =0. 37, Lime x FYM level = 0.30, Zn level x FYM level = 0.60								
	ABDTPA-Zn (mg kg^{-1})								
No lime	0.71	2.03	4.06	2.27a	1.16	2.54	3.98	2.56f	2.42
1/10th LR	0.68	1.98	3.19	1.95b	1.11	2.43	3.92	2.49f	2.22
1/3rd LR	0.59	1.70	2.62	1.64c	1.00	2.43	3.84	2.42f	2.03
2/3rd LR	0.52	1.52	2.29	1.44d	0.95	2.37	3.61	2.31f	1.88
LR	0.49	1.25	2.12	1.29e	0.93	2.21	3.31	2.15f	1.72
Mean	0.60aa	1.70bb	2.85cc	-	1.03dd	2.40ee	3.73ff	-	-
LSD (0.01)	Lime = 0.05, Zn level = 0.28, FYM level = 0.32, Lime x Zn level =0. 32, Lime x FYM level = 0.41, Zn level x FYM level = 0.62								
Debatoli series									
	DTPA-Zn (mg kg^{-1})								
No lime	1.45	2.62	3.29	2.45a	1.63	2.80	4.33	2.92f	2.69
1/10th LR	1.30	2.32	2.93	2.18b	1.37	2.54	4.01	2.64fh	2.41
1/3rd LR	1.08	1.94	2.91	1.98bd	1.32	2.37	3.79	2.49fh	2.24
2/3rd LR	0.99	1.78	2.80	1.86cd	1.08	2.25	2.95	2.09gh	1.98
LR	0.77	1.72	2.73	1.74c	0.99	2.21	2.48	1.89g	1.82
Mean	1.12aa	2.08bb	2.93cc	-	1.28dd	2.43ee	3.51ff	-	-
LSD (0.01)	Lime = 0.21, Zn level = 0.50, FYM level = 0.35, Lime x Zn level =0. 75, Lime x FYM level = 0.78, Zn level x FYM level = 0.98								
	Mehlich 1-Zn (mg kg^{-1})								
No lime	1.73	3.61	6.78	4.04a	2.64	4.78	6.78	4.73a	4.39
1/10th LR	1.63	3.60	6.59	3.94b	2.44	4.20	6.28	4.31b	4.12
1/3rd LR	1.51	3.44	6.12	3.69c	2.42	4.10	6.21	4.24b	3.97
2/3rd LR	1.49	3.33	4.13	2.98d	2.40	4.06	5.69	4.05b	3.52
LR	1.26	3.15	4.06	2.82e	2.37	3.74	5.46	3.86b	3.34
Mean	1.53aa	3.43bb	5.54cc	-	2.45dd	4.18ee	6.08ff	-	-
LSD (0.01)	Lime = 0.09, Zn level = 0.50, FYM level = 0.28, Lime x Zn level =0. 45, Lime x FYM level = 0.42, Zn level x FYM level = 0.85								

					0.1 M HCl-Zn (mg kg^{-1})				
No lime	2.35	4.26	4.66	3.76a	2.80	4.54	6.69	4.68e	4.22
1/10th LR	2.32	4.42	5.34	4.03b	2.75	4.70	6.93	4.79e	4.41
1/3rd LR	2.22	4.40	6.07	4.23c	2.86	5.25	7.61	5.24f	4.74
2/3rd LR	2.23	3.87	7.46	4.52d	2.91	5.14	7.01	5.02f	4.77
LR	2.22	4.53	6.96	4.57d	2.85	6.06	7.79	5.57g	5.07
Mean	2.27aa	4.30bb	6.10cc	-	2.83dd	5.14ee	7.21ff	-	-
LSD (0.01)	Lime = 0.06, Zn level = 0.35, FYM level = 0.37, Lime x Zn level =0. 45, Lime x FYM level = 0.45, Zn level x FYM level = 0.79								
					ABDTPA-Zn (mg kg^{-1})				
No lime	2.10	3.19	4.23	3.18a	2.12	3.34	5.17	3.54e	3.36
1/10th LR	1.82	3.46	4.19	3.16a	1.98	3.37	5.89	3.75e	3.46
1/3rd LR	1.61	2.77	4.60	2.99b	1.93	3.46	5.17	3.52e	3.26
2/3rd LR	1.36	2.05	5.12	2.84c	1.75	3.02	4.26	3.01f	2.93
LR	1.22	2.17	4.22	2.54d	1.53	3.36	4.42	3.10f	2.82
Mean	1.62aa	2.73bb	4.47cc	-	1.86dd	3.31ee	4.98ff	-	-
LSD (0.01)	Lime = 0.10, Zn level = 0.35, FYM level = 0.20, Lime x Zn level =0. 47, Lime x FYM level = 0.40, Zn level x FYM level = 0.70								

*Letters indicate observed differences among the means of different treatments

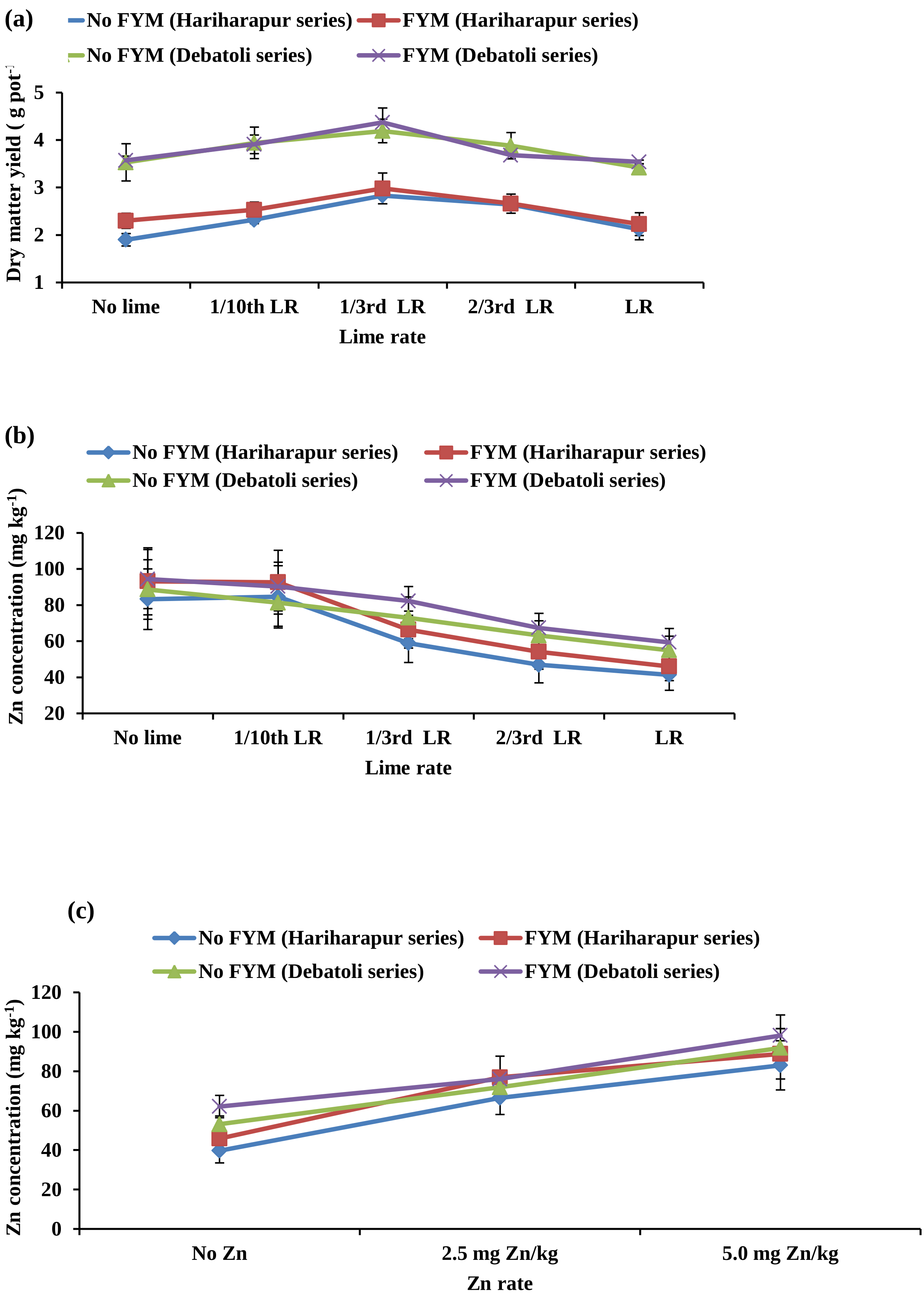
Table 5 Pearson's correlation coefficient values revealing relationship among soil properties, dry matter yield, Zn concentration, Zn uptake and extracted Zn in soils (n = 90).

	pH	EC	OC	Dry matter yield	Zn conc.	Zn uptake	DTPA-Zn	Mehlich 1-Zn	0.1 M HCl-Zn	ABDTPA-Zn
Hariharapur series										
pH	1									
EC	0.058	1								
OC	-0.089	-0.084	1							
Dry matter yield	0.059	0.093	0.221*	1						
Zn conc.	-0.590**	-0.029	0.232*	0.047	1					
Zn uptake	-0.397**	0.036	0.294**	0.605**	0.792**	1				
DTPA-Zn	0.010	-0.073	0.211*	0.391**	0.610**	0.523**	1			
Mehlich 1-Zn	0.130	-0.045	0.272**	0.281**	0.510**	0.545**	0.897**	1		
0.1 M HCl-Zn	0.046	-0.076	0.242*	0.260*	0.633**	0.626**	0.871**	0.929**	1	
ABDTPA-Zn	-0.011	-0.013	0.136	0.285**	0.656**	0.673**	0.887**	0.922**	0.923**	1
Debatoli series										
pH	1									
EC	0.032	1								
OC	0.113	-0.098	1							
Dr matter yield	-0.154	0.096	0.011	1						
Zn conc.	-0.343**	0.042	0.158	0.384**	1					
Zn uptake	-0.326**	0.086	0.110	0.727**	0.905**	1				
DTPA-Zn	-0.087	0.061	0.290**	0.133	0.741**	0.715**	1			
Mehlich 1-Zn	0.168	0.091	0.317**	0.330**	0.589**	0.568**	0.811**	1		
0.1 M HCl-Zn	0.188	0.130	0.294**	0.333**	0.562**	0.545**	0.822**	0.937**	1	
ABDTPA-Zn	-0.074	0.108	0.193	0.419**	0.772**	0.748**	0.889**	0.890**	0.887**	1

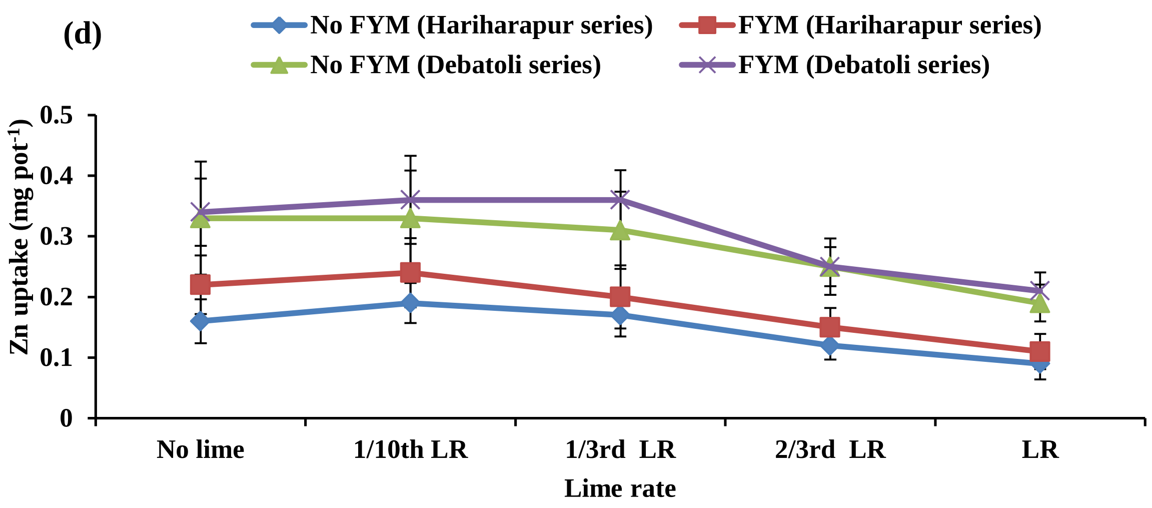
*p ≤ 0.05; **p ≤ 0.01.

Fig. 1. Dry matter yield, Zn concentration and Zn uptake by maize as influenced by interaction of Zn application and lime rate in Hariharapur and Debatoli series. Error bars represent ± SE.

Fig. 2. Extractable Zn by different extractants as influenced by interaction of Zn application and lime rate in Hariharapur and Debatoli series. Error bars represent ± SE.



(a)
No FYM (Hariharapur series)
FYM (Hariharapur series)
No FYM (Debatoli series)
FYM (Debatoli series)
Dry matter yield (g pot-1)
5
4
3
2
1
No lime
1/10th LR
1/3rd LR
2/3rd LR
LR
Lime rate
(b)
No FYM (Hariharapur series)
FYM (Hariharapur series)
No FYM (Debatoli series)
FYM (Debatoli series)
Zn concentration (mg kg-1)
120
100
80
60
40
20
No lime
1/10th LR
1/3rd LR
2/3rd LR
LR
Lime rate
(c)
No FYM (Hariharapur series)
FYM (Hariharapur series)
No FYM (Debatoli series)
FYM (Debatoli series)
Zn concentration (mg kg-1)
120
100
80
60
40
20
0
No Zn
2.5 mg Zn/kg
5.0 mg Zn/kg
Zn rate



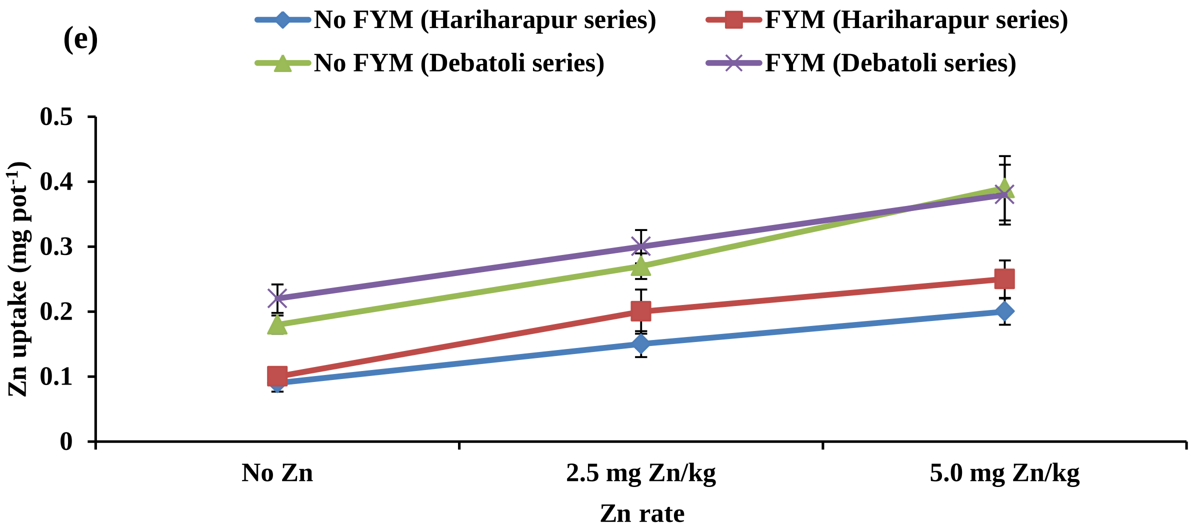
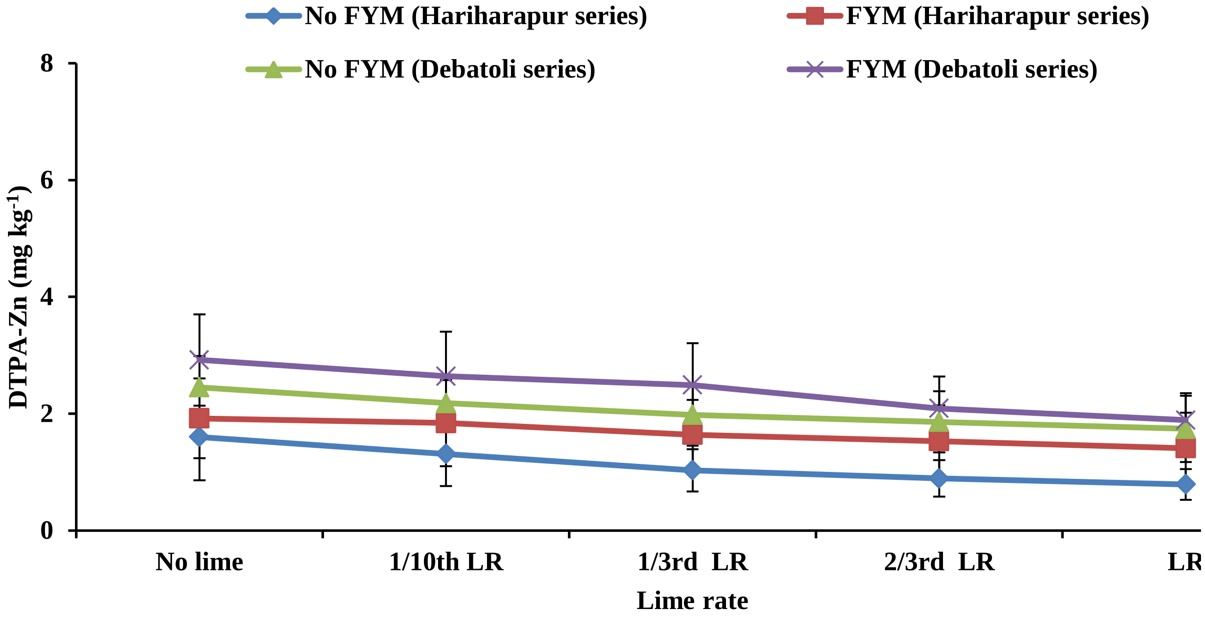
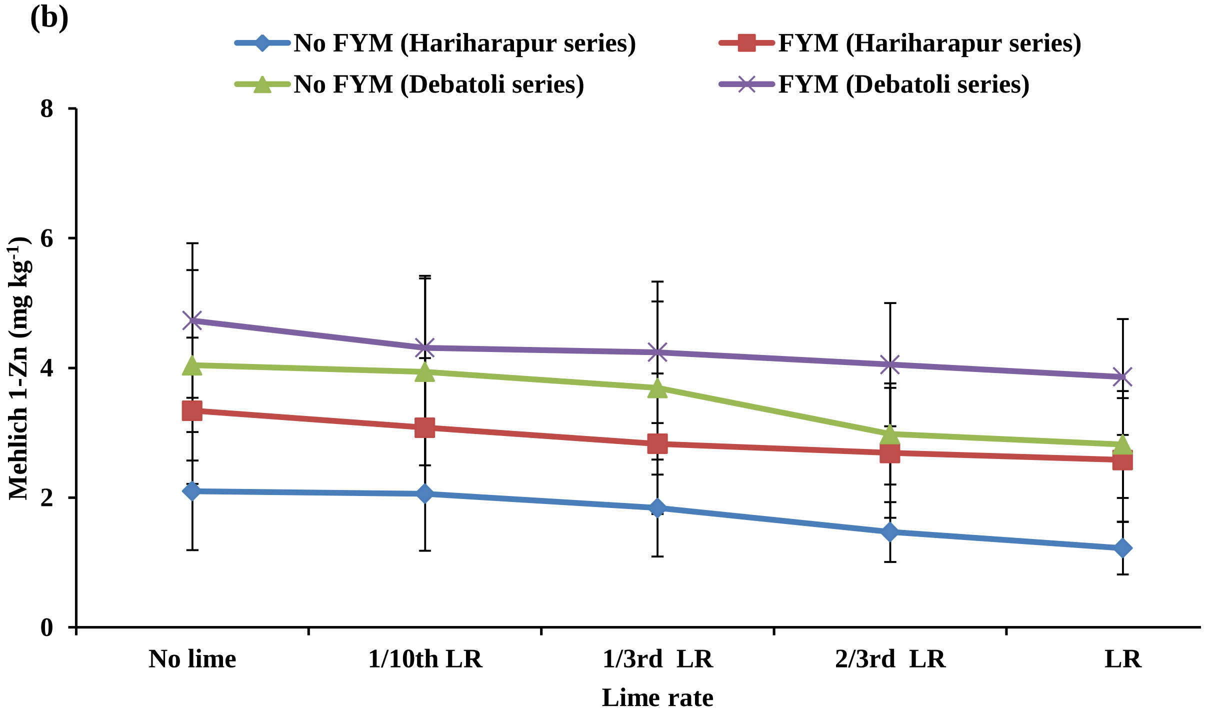


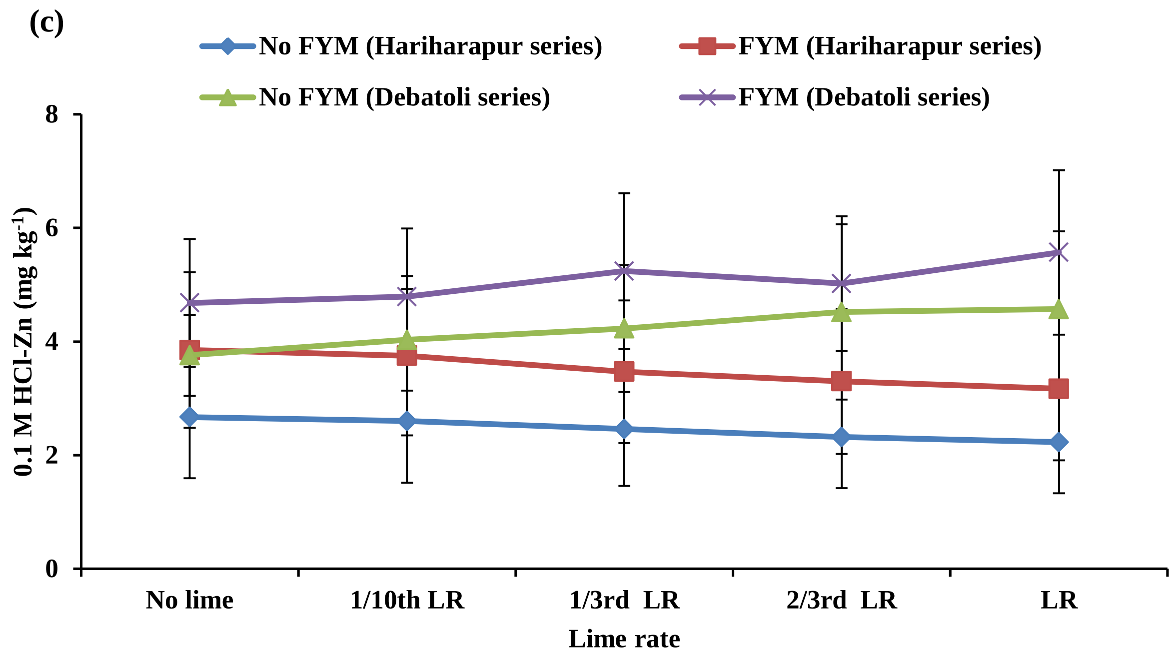
Fig. 1. Dry matter yield, Zn concentration and Zn uptake by maize as influenced by interaction of Zn application and lime rate in Hariharapur and Debatoli series. Error bars represent ± SE.

(a)


No FYM (Hariharapur series)
FYM (Hariharapur series)
No FYM (Debatoli series)
FYM (Debatoli series)
DTPA-Zn (mg kg^{-1})
8
6
4
2
0
No lime
1/10th LR
1/3rd LR
2/3rd LR
LR
Lime rate

(b)


No FYM (Hariharapur series)
FYM (Hariharapur series)
No FYM (Debatoli series)
FYM (Debatoli series)
Mehlich 1-Zn (mg kg^{-1})
8
6
4
2
0
No lime
1/10th LR
1/3rd LR
2/3rd LR
LR
Lime rate



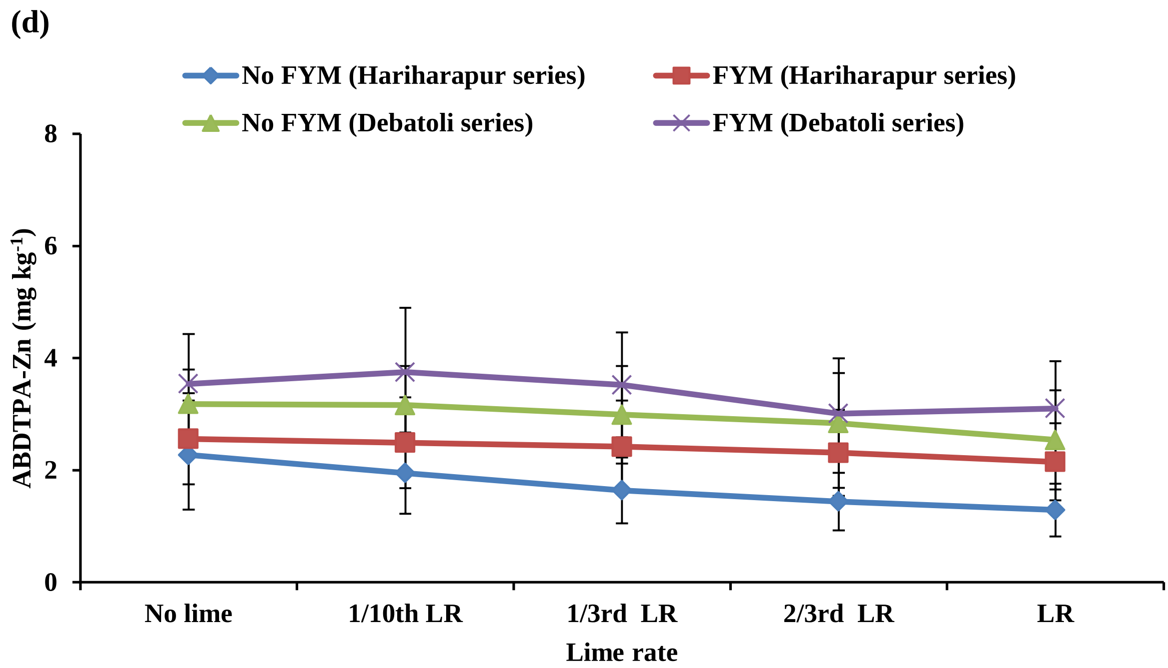


Fig. 2. Extractable Zn by different extractants as influenced by interaction of Zn application and lime rate in Hariharapur and Debatoli series. Error bars represent ± SE.