

1 Dear Editor and Referees,

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

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

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

15 Comments of Anonymous referee # 1:-

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

74 Our response:- We have include critical concentration of DTPA-Zn in soils (0.8 mg kg^{-1})(in
75 table 1) and plant tissues in the manuscript. We have also compared the values of Zn
76 concentration in plant tissues under different treatments with critical values available in
77 literature. We have mentioned that the Zn concentration in maize under all the treatments
78 were well above the critical Zn concentration of 15 to 22 mg kg^{-1} for maize crop (Alloway,
79 2008) and no visual Zn deficiency symptoms in plants were recorded.

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

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

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

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

89 Comments of Anonymous referee # 2:-

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

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

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

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

109 Comment:-The article lacks clear objectives, stated at the end of the introduction. There are
110 apparently three overlapping studies: 1. Field experiments, greenhouse pot experiments, and

111 effect of the extractant used in determining Zn concentration. However, it is unclear how they
112 are coordinated for a final objective, giving the impression of been three related (but not
113 properly coordinated) experiments.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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154 With kind regards,

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156 Sanjib Kumar Behera

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

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188
189 **ABSTRACT**

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

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

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

216 **1. Introduction**

217 Soil acidity is a serious problem affecting crop production across the world including
218 India which is having 34.5% of arable land with acid soils (Maji et al., 2012). Ameliorating
219 acid soils with suitable amendments and proper nutrient especially zinc (Zn) management in
220 Zn-deficient acid soils (Rautaray et al., 2003; Behera et al., 2011) are areas of concern for
221 obtaining higher crop yield. Amelioration of acidic soils is beneficial to plant growth because
222 it improves soil pH and replenishes nutrients (Moon et al., 2014). Application of liming
223 material is an effective method for amelioration of acid soils (Ponnette et al., 1991; Quaggio
224 et al., 1995). Lime is normally oxides, carbonates and hydroxides of calcium or magnesium.
225 There are about four types of lime viz., quicklime (CaO), slaked lime (Ca(OH)₂), limestone
226 (CaCO₃) and dolomite. Application CaCO₃ to acid soils reduces soil acidity, improves basic
227 cations status and significantly increases the yields of crops grown on Ultisol (Cifu et al.,
228 2004). It also improves physical structure in nitric soils. However, adoption of standard
229 recommendation of lime requirement (LR) for different groups of acid soils is difficult for

230 farmers, which is uneconomical and unsustainable (Barman et al., 2014). Therefore, lower
231 doses of LR like 1/10th, 1/3rd and 2/3rd of LR are  applied by the farmers.

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

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

255 (Lindsay and Norvell, 1978). But the same has been used for acid soils also for extraction of
256 plant available Zn. According to O'Connor (1988), whenever one strays from the original
257 design of the test, one should be aware of the possible consequences and pass that awareness
258 on to others. Based on correlation among the extracted Zn by different extractants and with
259 soil properties, Behera et al. (2011) reported the usefulness of DTPA, Mehlich 1, Mehlich 3,
260 0.1 N HCl and ABDTPA extractant for extraction of plant available Zn in acid soils of India.
261 However, 0.1 N HCl was found to be best extractant (based on higher values of correlation
262 coefficient with soil pH and OC) for extraction of plant available Zn in acid soils. But there is
263 scanty information available regarding the relationship of extracted Zn by different
264 extractants with Zn concentration and uptake by crop plants.

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

272 **2. Materials and methods**

273 *2.1 Soil and farmyard manure characteristics*

274 The bulk surface (0-15 cm depth) soils collected from Hariharpur series (Oxic Haplustalf,
275 Alfisol (Soil Survey Staff, 2014)) and Debatoli series (Udic Rhodostalf, Alfisol (Soil Survey
276 Staff, 2014)) of Bhubaneswar and Ranchi (India), respectively were used in the study. The
277 collected soils were air dried and stone and debris were removed and then ground to pass a 2
278 mm sieve and analysed for selected properties (Table 1). Soil properties like pH and EC were



279 determined done on 1: 2.5 soil water ratio (w/v) suspension using pH meter and EC meter
280 following half an hour equilibrium (Jackson, 1973). Soil organic carbon (OC) content was
281 estimated by chromic acid digestion-back titration method (Walkley and Black, 1934). The
282 clay, silt and sand per cent of soils were determined by hydrometer method (Bouyoucos,
283 1962). Calcium carbonate (CaCO_3) content was determined by rapid titration method (Puri,
284 1930) and cation exchange capacity (CEC) by neutral normal ammonium acetate method
285 (Richards, 1954). Lime requirement (LR) of the soil was estimated by extractant buffer
286 method (Shoemaker et al., 1961). The plant available Zn in soils was extracted by DTPA
287 method (Lindsay and Norvell, 1978). Estimation of Zn concentration was done on the clear
288 extract by atomic absorption spectrophotometer (AAS). After drying of FYM at 70 °C for
289 24 h followed by grinding to pass through 20 mesh sieve, one gram of ground FYM was dry-
290 ashed at 450 °C for 2h. Ashed samples were extracted using 0.5 N HCl. Zn concentration was
291 determined in filtered extracts. The total OC (loss on ignition), N (Kjeldahl method), P
292 (nitric-perchloric 9:4 digestion) and K (nitric-perchloric 9:4 digestion) concentrations in
293 FYM were estimated according to Tandon (2009) (Table 1).

294 *2.2 Green house study, soil and plant analysis*

295 Pot experiments were carried out in two Hariharapur and Debatoli series soils. The
296 experiments were carried out in plastic pots (each with diameter of 20 cm) having 4 kg of soil
297 with five levels of LR (0, 1/10 LR, 1/3 LR, 2/3 LR and LR), three levels of Zn concentration
298 (0, 2.5 and 5.0 mg Zn kg^{-1} soil) and two levels of fresh FYM (35% moisture) (0 and 4.5 g
299 FYM kg^{-1} soil viz., 0 and 10 t FYM ha^{-1}). Locally available FYM was used for the study and
300 it was decomposed mixture of left over fodder fed to farm animals, animal dung and urine.
301 All the pots received basal treatments of $\text{N-P}_2\text{O}_5-\text{K}_2\text{O}$ @ 150-60-40 kg ha^{-1} (equivalent to
302 66.7-26.7-17.8 mg $\text{N-P}_2\text{O}_5-\text{K}_2\text{O}$ kg^{-1} soil, respectively). Fertilizer N, P and K were applied
303 through analytical grade urea, calcium dihydrogen orthophosphate and muriate of potash,

304 respectively. Lime and Zn were added to soil through laboratory grade CaCO_3 and ZnSO_4
305 respectively. All nutrients were mixed in soil thoroughly before sowing of seeds. The soil in
306 each pot was then irrigated to field capacity with deionized water and kept for incubation for
307 one week. Each treatment combination was replicated thrice in a factorial completely
308 randomized design. Four seeds of cv. KH 101 of maize were sown in each pot. Two
309 seedlings of maize per each pot were maintained after emergence. Pots were irrigated with
310 water daily as per requirement of water on weight basis to maintain the field capacity. Above-
311 ground biomass of plants from each pot was harvested at the end of 60 days of growth.

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

318 Soil sample from each pot were collected after harvesting of maize plants. Collected soil
319 samples were processed and analyzed for pH, EC, OC content and DTPA-Zn concentration
320 following the methods described above. The plant available Zn in soils was also extracted by
321 DTPA (Lindsay and Norvell, 1978), Mehlich 1 (Perkins, 1970), 0.1 M HCl (Sorensen et al.,
322 1971) and ABDTPA (Soltanpour and Schwab, 1977) extractants by following the respective
323 prescribed methods. Estimation of Zn concentration was done on the clear extract by AAS.

324 *2.3 Statistical analysis*

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

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

330 **3. Results**

331 *3.1 Dry matter yield*

332 DMY of maize increased significantly with lime application up to 1/3rd LR (Table 2, Fig. 1 a)
333 in soils of both the series. This indicated that lime application @ 1/3rd of LR was optimum for
334 these soils. Application of higher doses of lime (2/3rd LR and LR) did not result in increased
335 DMY. However, this finding needs to be verified by conducting field experiment. The mean
336 DMY in 1/3rd LR treatment without FYM and with FYM was 139% and 149% of control
337 respectively in Harihpur series soils. Similarly in Debatoli series soil, the mean DMY was
338 84% and 120% of control without and with FYM application respectively in combination
339 with 1/3rd LR. Application of graded doses of Zn upto 5.0 mg kg⁻¹ to soil increased DMY
340 with and without FYM application in Hariharapur series. Whereas in Debatoli series,
341 application of graded doses of Zn up to 5 mg kg⁻¹ without FYM and application of Zn @ 2.5
342 mg kg⁻¹ with FYM enhanced DMY.

343 *3.2 Zinc concentration and uptake by maize*

344 Addition of higher doses of lime significantly reduced Zn concentration in maize crop grown
345 in soils of both the series (Table 2, Fig. 1 b). In contrast, application of Zn (@ 2.5 and 5.0 mg
346 kg⁻¹) and FYM (@ 10 t ha⁻¹) increased Zn concentration in maize crop significantly in soils of
347 both the series (Table 2, Fig 1c). In soils of Hariharapur series, application Zn @ 2.5 and 5
348 mg kg⁻¹ without and with FYM augmented Zn concentration in maize by 67.5 and 93.5 to 109
349 % respectively, as compared to control (No Zn). Similarly, increased Zn concentrations of 22
350 to 35 and 58 to 73% were recorded with application of Zn @ 2.5 and 5 mg kg⁻¹ without and
351 with FYM respectively in comparison to no Zn control in soils of Debatoli series. However,

352 the Zn concentration in maize under all the treatments were well above the critical Zn
353 concentration of 15 to 22 mg kg⁻¹ for maize crop (Alloway, 2008) and no visual Zn deficiency
354 symptoms in plants were recorded. Mean Zn uptake values were at par for no lime, 1/10th LR
355 and 1/3rd LR with and without FYM application and it was significantly higher than Zn
356 uptake by 2/3rd LR and LR treatments in soils of both the series (Table 2, Fig. 1 d). However,
357 Zn and FYM application improved Zn uptake by maize crop in soils of both series (Fig. 1 e).
358 Addition of Zn @ 2.5 and 5 mg kg⁻¹ enhanced Zn uptake by 67 to 100 and 122 to 150%
359 respectively as compared to no Zn control in soils of Hariharapur series. Whereas, the
360 enhancements in Zn uptake were 36 to 50, 73 to 117% due to application of Zn @ 2.5 and 5
361 mg kg⁻¹ respectively as compared to no Zn control in soils of Debatoli series.

362 *3.3 Soil properties*

363 Application of lime at different rates significantly increased pH in soils of both Hariharapur
364 and Debatoli series (Table 3). With addition of graded doses of limes viz. from no lime,
365 1/10th LR, 1/3rd LR, 2/3rd LR and LR, soil pH increased from 4.58 to 7.16 (without FYM
366 addition) and from 4.89 to 7.23 (with FYM addition) in Hariharapur series and from 5.83 to
367 6.95 (without FYM addition) and from 6.04 to 7.02 (with FYM addition) in Debatoli series.

368 Application of FYM without lime increased soil pH in both  soils (Table 3). Interaction
369 effect of combined application of lime and FYM on soil pH was significant. Soil pH values
370 obtained by addition of 2/3rd LR and LR along with FYM were at par. Addition of Zn did not
371 have any effect on soil pH. Sole application of lime, FYM and Zn and their interaction did
372 not influence soil EC levels in soils of both the series (Table 3). However application of FYM
373 increased soil OC content in soils of both series. Addition of lime and Zn and their interaction
374 did not influence soil OC. 

375 *3.4 Extractable zinc in post-harvest soil*

376 Data regarding amount Zn extracted by DTPA, Mehlich 1, 0.1 M HCl and ABDTPA
377 extractants in post harvest soil are given in Table 4 and Figure 2. Perusal of data revealed
378 significant effect of individual application of lime, FYM and Zn and their interaction on
379 extracted Zn by different extractants. The amount of extracted Zn by DTPA, Mehlich 1, and
380 ABDTPA extractants decreased with increased level of lime application in soils of both the
381 series (Fig. 2 a, b, d). But addition of FYM (@ 10 t ha⁻¹) in combination of different levels of
382 lime led to marked enhancement of extracted Zn by different extractants in both the soils
383 compared to only application of different lime levels (Table 4). Application Zn at different
384 levels viz. 2.5 and 5.0 mg kg⁻¹ with and without FYM increased the concentration of
385 extracted Zn by the different extractants. The amount of Zn extracted by DTPA, Mehlich 1,
386 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
387 1.72 to 2.42 mg kg⁻¹ respectively, under different levels of lime application across FYM and
388 Zn application in soils of Hariharpur series. Whereas, the Zn extracted by DTPA, Mehlich 1,
389 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
390 2.82 to 3.36 mg kg⁻¹ respectively, under different levels of lime application across FYM and
391 Zn application in soils of Debatoli series. In both the series, the extracted Zn followed the
392 order DTPA-Zn < ABDTPA-Zn < Mehlich1-Zn < 0.1 M HCl-Zn.

393 **4. Discussion**

394 Significant increase in DMY was recorded with application of lime up to 1/3rd LR. Increase
395 in DMY with lime application up to 1/3rd LR may be ascribed to increase in soil pH and
396 positive influence on nutrient availability in soil (Tisdale, 2005). Our finding is in line with
397 the observations made by Barman et al. (2014) who reported lime application at 1/3rd LR
398 was optimum for obtaining cauliflower yield in Typic Fluvaquent soil of West Bengal, India.
399 There was reduction in DMY with lime application at 2/3rd LR and LR in soils of both the
400 series. This may be ascribed to reduced availability Zn in soil with 2/3rd LR and LR rate of

401 lime application and adverse effect on other soil properties. This needs to be verified by
402 conducting filed experiment. Increased DMY due to FYM addition may be due to positive
403 influence of on nutrient availability and uptake. Increased DMY due to Zn addition in soils of
404 Hariharapur series revealed that Zn is a limiting nutrient in this soil. It was evident from low
405 initial DTPA-Zn status (0.47 mg kg^{-1}) of this soil. Grain and vegetative tissue (stover) yield
406 of maize increased significantly with successive application of Zn up to 1 kg ha^{-1} in a Zn-
407 deficient (DTPA-Zn 0.38 mg kg^{-1}) (Critical DTPA-Zn concentration 0.80 mg kg^{-1}) Vertisol
408 of India (Behera et al., 2015). Zn addition to a soil with 0.18 mg kg^{-1} Zn enhanced wheat
409 grain yield (Cakmak et al., 2010a; Cakmak et al., 2010b). However in Debatoli series, DMY
410 response to Zn application was obtained in spite of high initial DTPA-Zn status (1.45 mg kg^{-1})
411 which needs further investigation. In contrast to our findings, Zhang et al. (2012) and
412 Wang et al. (2012) reported that zinc fertilizer application did not improve the biomass and
413 grain yields of wheat and maize in rain-fed and low Zn calcareous soils of China. This may
414 be attributed to Zn availability in soil influenced by several factors (Alloway, 2009) and
415 efficiency of the crops/genotypes to utilize available Zn in soils (Cakmak et al., 1998).

416 Addition of lime significantly reduced Zn concentration. This may be due to reduced
417 availability Zn in soil due to increased soil pH. Soil pH significantly influences Zn
418 distribution among different fractions and availability in soil (Sims, 1986; Smith, 1994) and
419 the plant uptake is primarily related with different Zn fractions (Behera et al., 2008).
420 However, FYM and Zn application improved Zn concentration in maize but not Zn uptake.
421 Application of 5 and 10 mg Zn kg^{-1} enhanced Zn concentration of navy bean shoot from
422 19.93 mg kg^{-1} to 38.12 and 54.8 mg kg^{-1} respectively (Gonzalez et al., 2008). Significant
423 increase in Zn concentration in ear leaves of spring maize, shoots of wheat and in maize and
424 wheat grains was also reported by Wang et al. (2012). Payne et al. (1988) also reported

425 increased Zn concentration in maize grain under highest ZnSO₄ application from a long-term
426 experiment.

427 Application of increased rate of lime also enhanced soil pH. Anikwe et al. (2016) also
428 reported increase in soil pH due to lime addition in an Ultisol of Nigeria. Application of lime
429 along with FYM also enhanced soil pH. This is in line with the findings of Saha et al. (2012).
430 Normally, addition of organic matter lowers soil pH by releasing H⁺ ions associated with
431 organic anions or by nitrification in an open system (Porter et al., 1980). But in contrary, it
432 may cause pH increases either by mineralization of organic anions to CO₂ and water (thereby
433 removing H⁺ ions) or because of the 'alkaline' nature of the organic material (Helyar, 1976).
434 Increase in soil pH due to addition FYM in our study may be due to operation of the second
435 mechanism. Application of lime reduced the concentrations of extractable Zn extracted by
436 DTPA, Mehlich 1 and ABDTPA extractants. Reduced availability of Zn in soil due to liming
437 has also been reported by Tlustos et al. (2006) and Vondrackova et al. (2013). It is because of
438 conversion of plant available fractions of Zn to plant unavailable fractions resulting in
439 effective immobilisation (Davis-Carter and Shuman, 1993). But application of FYM
440 improved the concentrations of extracted Zn. Addition of organic matter led to formation of
441 organic acids by microbial decomposition, which mobilize soil bound Zn and restrict the
442 fixation of soluble Zn by chelating it (Shukla, 1971; Sarkar and Deb, 1982; Tagwira et al.,
443 1992). It has also been reported by Saha et al. (1999) that application of organic matter to
444 cultivated acid soils was essential to counteract the adverse effect of lime application on Zn
445 availability. Application Zn with and without FYM enhanced the concentrations of extracted
446 Zn significantly. Rupa et al. (2003) also reported increased concentration of exchangeable
447 plus water soluble, inorganically, organically and oxide bound Zn in two Alfisols due to
448 addition of increased Zn rates. Soil pH was negatively and significantly correlated with Zn
449 concentration ($r = -0.509^{**}$, $r = -0.343^{**}$) and Zn uptake by maize ($r = -0.397^{**}$, $r = -$

450 0.326**) in both the soil series (Table 5). This revealed that increased soil pH resulted in
451 decreased Zn concentration and Zn uptake in maize and vice versa. Wang et al. (2006) also
452 recorded increased Zn concentration in *Thlaspi caerulescens* with decreased soil pH. Soil OC
453 content was positively and significantly correlated with DMY ($r = 0.221^*$), Zn concentration
454 ($r = 0.232^*$) and Zn uptake ($r = 0.294^{**}$) in Hariharpur series only. It was also positively and
455 significantly correlated with DTPA, Mehlich 1 and 0.1 M HCl extracted Zn in soils of both
456 the series. This is in line with the findings of Katyal and Sharma (1991) and Shidhu and
457 Sharma (2010). DMY was positively and significantly correlated with Zn uptake($r =$
458 0.605^{**} , 0.727^{**}) in soils of both the series.

459 Among the extractants used in this study, DTPA extracted lowest amount of Zn. This is
460 in agreement with the findings of Behera et al. (2011) who reported lowest amount of Zn
461 extracted by DTPA compared other extractants like Mehlich 1, Mehlich 3, 0.1 M HCl and
462 ABDTPA, by analysing four hundred soil samples collected from cultivated acid soils of
463 India. This may be ascribed to lower extracting power of DTPA in these soils owing to
464 reduced active sites of DTPA at lower pH values. Higher extractability of ABDTPA
465 compared to DTPA in these soils because of ABDTPA solution pH of 7.6 which allowed
466 DTPA to chelate and extract more Zn from soil. Mehlich 1 extractant which was originally
467 developed for prediction of plant available P in acidic coastal plain soil ($pH < 6.5$) with low
468 cation exchange capacity ($CEC < 10 \text{ meq/100g}$) and low organic matter (<5%), extracted more
469 amount of Zn compared to DTPA and ABDTPA extractants. Higher extractability of Zn by
470 0.1 M HCl has also been reported by Naik and Das (2010) as compared to DTPA and 0.05 M
471 HCl extracted Zn in low land rice soils. This is because 0.1 M HCl extracts Zn from freshly
472 adsorbed iron and manganese oxides, carbonates, or decomposing organic matter and Zn
473 bound with the octahedral-OH in layer silicates (Hodgson, 1963). Dilute mineral acids of pH
474 1-2 showed the greatest extracting power for extraction of Zn, followed by buffered solutions

475 of pH 7-9 containing chelating agents and buffers or very dilute acids of pH 4-5 (Misra et al.,
476 1989). Zhang et al. (2010) reported Zn extraction capacity of different extractants in the order
477 of EDTA > Mehlich 3 > Mehlich 1 > DTPA > NH₄OAc > CaCl₂ in polluted soils of rice in
478 south-eastern China. The amount Zn extracted in polluted soils of central Iran followed the
479 order Mehlich 3 > ABDTPA > DTPA > Mehlich 2 > CaCl₂ > HCl (Hosseiwgnpur and
480 Motaghian, 2015). DMY was positively and significantly correlated with Zn extracted by
481 DTPA, Mehlich 1, 0.1 M HCl and ABDTPA extractants in Hariharpur series and Zn
482 extracted by Mehlich 1, 0.1 M HCl and ABDTPA extractants in Debatoli series (Table 5). Zn
483 concentration in maize was positively and significantly correlated with Zn uptake by maize
484 and extracted Zn by different extractants in soils of both the series. Positive and significant
485 correlation coefficient values were also obtained for Zn uptake vs Zn extracted by different
486 extractants in soils of both the series. Zn extracted by different extractants in soils of both
487 series were positively and significantly correlated with each other. The values of correlation
488 coefficients ranged from $r = 0.811^{**}$ to $r = 0.937^{**}$. This indicated that the trend of
489 extraction of Zn from both the soils, by different extractants used in the study is similar. It
490 corroborates the findings of Gartley et al. (2002), Mylavapu et al. (2002) , Nascimento et
491 al. (2007) and Behera et al. (2011) who have reported the suitability of extractants like
492 DTPA, ABDTPA, Mehlich 1, Mehlich 3 and 0.1 M HCl for extraction of phyto-available Zn
493 in acids of different parts of the world. Since Zn extracted by different extractants like
494 DTPA, ABDTPA, Mehlich 1 and 0.1 M HCl, was positively and significantly correlated
495 amongst themselves and with DMY, Zn concentration and Zn uptake by maize, all these
496 extractants can be used for extraction of Zn from acid soils. However, ABDTPA extractant
497 was found to be the best extractant for extraction of Zn in acid soils as the values of
498 correlation coefficients between Zn concentration and Zn uptake by maize with extracted Zn
499 by ABDTPA extractant were highest compared to that by other extractants.

500 **5. Conclusion**

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

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687 **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	

688 *Critical concentration of DTPA-Zn is 0.80 mg kg⁻¹

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Table 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)				Overall mean
	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	
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
1/10 th LR	2.43	2.37	2.16	2.32b	2.21	2.74	2.66	2.53ef	2.43
1/3 rd LR	2.88	2.87	2.96	2.83c	2.57	2.89	3.66	2.98f	2.91
2/3 rd 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
1/10 th LR	53.3	87.4	113	84.6a	59.2	99.5	119	92.7e	88.6
1/3 rd LR	38.5	63.5	75.0	59.0b	46.3	72.8	80.0	66.4f	62.7
2/3 rd LR	27.4	52.7	60.8	47.0c	35.4	59.8	67.6	54.6g	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
1/10 th LR	0.13	0.21	0.24	0.19b	0.13	0.27	0.32	0.24g	0.22
1/3 rd LR	0.10	0.18	0.22	0.17c	0.11	0.21	0.29	0.20h	0.19
2/3 rd 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

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

Treatments	No FYM				FYM (10 t ha ⁻¹)				Overall mean
	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	
Hariharapur series									
No lime	4.56	4.57	4.61	4.58a	5.16	5.10	5.34	5.20f	4.89
1/10 th LR	4.80	5.01	4.83	4.88b	5.46	5.42	5.44	5.44f	5.16
1/3 rd LR	5.69	6.14	5.57	5.80c	5.93	6.49	5.97	6.13g	5.97
2/3 rd 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
1/10 th LR	0.14	0.10	0.10	0.12a	0.15	0.11	0.12	0.13a	0.12
1/3 rd LR	0.13	0.13	0.11	0.12a	0.12	0.10	0.14	0.12a	0.12
2/3 rd 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
1/10 th LR	0.27	0.24	0.27	0.26a	0.33	0.34	0.39	0.35b	0.31
1/3 rd LR	0.25	0.24	0.27	0.25a	0.31	0.36	0.37	0.35b	0.30
2/3 rd 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
1/10 th LR	5.93	5.88	5.94	5.92b	6.28	6.42	6.56	6.42f	6.17
1/3 rd LR	6.38	6.21	6.21	6.27c	6.44	6.57	6.58	6.53f	6.40
2/3 rd 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)								
	OC (%)								
No lime	0.23	0.22	0.27	0.24a	0.21	0.26	0.23	0.23a	0.24
1/10 th LR	0.27	0.27	0.23	0.25a	0.21	0.23	0.20	0.21a	0.24
1/3 rd LR	0.23	0.23	0.24	0.23a	0.17	0.29	0.25	0.24a	0.24
2/3 rd 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
1/10 th LR	0.22	0.22	0.21	0.22a	0.28	0.28	0.28	0.28b	0.25
1/3 rd LR	0.21	0.25	0.24	0.23a	0.28	0.26	0.29	0.28b	0.26
2/3 rd 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

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

Treatments	No FYM				FYM (10 t ha ⁻¹)				Overall mean
	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	
Hariharapur series									
No lime	0.40	1.44	2.95	1.60a	0.88	1.68	3.21	1.92f	1.76
1/10 th LR	0.40	1.24	2.30	1.31b	0.66	1.67	3.20	1.84f	1.58
1/3 rd LR	0.38	1.06	1.64	1.03c	0.61	1.62	2.68	1.64fh	1.33
2/3 rd 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
1/10 th LR	0.77	1.66	3.74	2.06b	1.17	3.20	4.88	3.08f	2.57
1/3 rd LR	0.74	1.50	3.27	1.84c	1.05	2.64	4.79	2.83gi	2.33
2/3 rd 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
1/10 th LR	0.89	2.31	4.61	2.60b	1.34	3.72	6.20	3.75fi	3.18
1/3 rd LR	0.84	2.25	4.28	2.46c	1.33	3.39	5.68	3.47gi	2.96
2/3 rd 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
1/10 th LR	0.68	1.98	3.19	1.95b	1.11	2.43	3.92	2.49f	2.22
1/3 rd LR	0.59	1.70	2.62	1.64c	1.00	2.43	3.84	2.42f	2.03
2/3 rd 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
1/10 th LR	1.30	2.32	2.93	2.18b	1.37	2.54	4.01	2.64fh	2.41
1/3 rd LR	1.08	1.94	2.91	1.98bd	1.32	2.37	3.79	2.49fh	2.24
2/3 rd 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
1/10 th LR	1.63	3.60	6.59	3.94b	2.44	4.20	6.28	4.31b	4.12
1/3 rd LR	1.51	3.44	6.12	3.69c	2.42	4.10	6.21	4.24b	3.97
2/3 rd 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
1/10 th LR	2.32	4.42	5.34	4.03b	2.75	4.70	6.93	4.79e	4.41
1/3 rd LR	2.22	4.40	6.07	4.23c	2.86	5.25	7.61	5.24f	4.74
2/3 rd 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
1/10 th LR	1.82	3.46	4.19	3.16a	1.98	3.37	5.89	3.75e	3.46
1/3 rd LR	1.61	2.77	4.60	2.99b	1.93	3.46	5.17	3.52e	3.26
2/3 rd 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

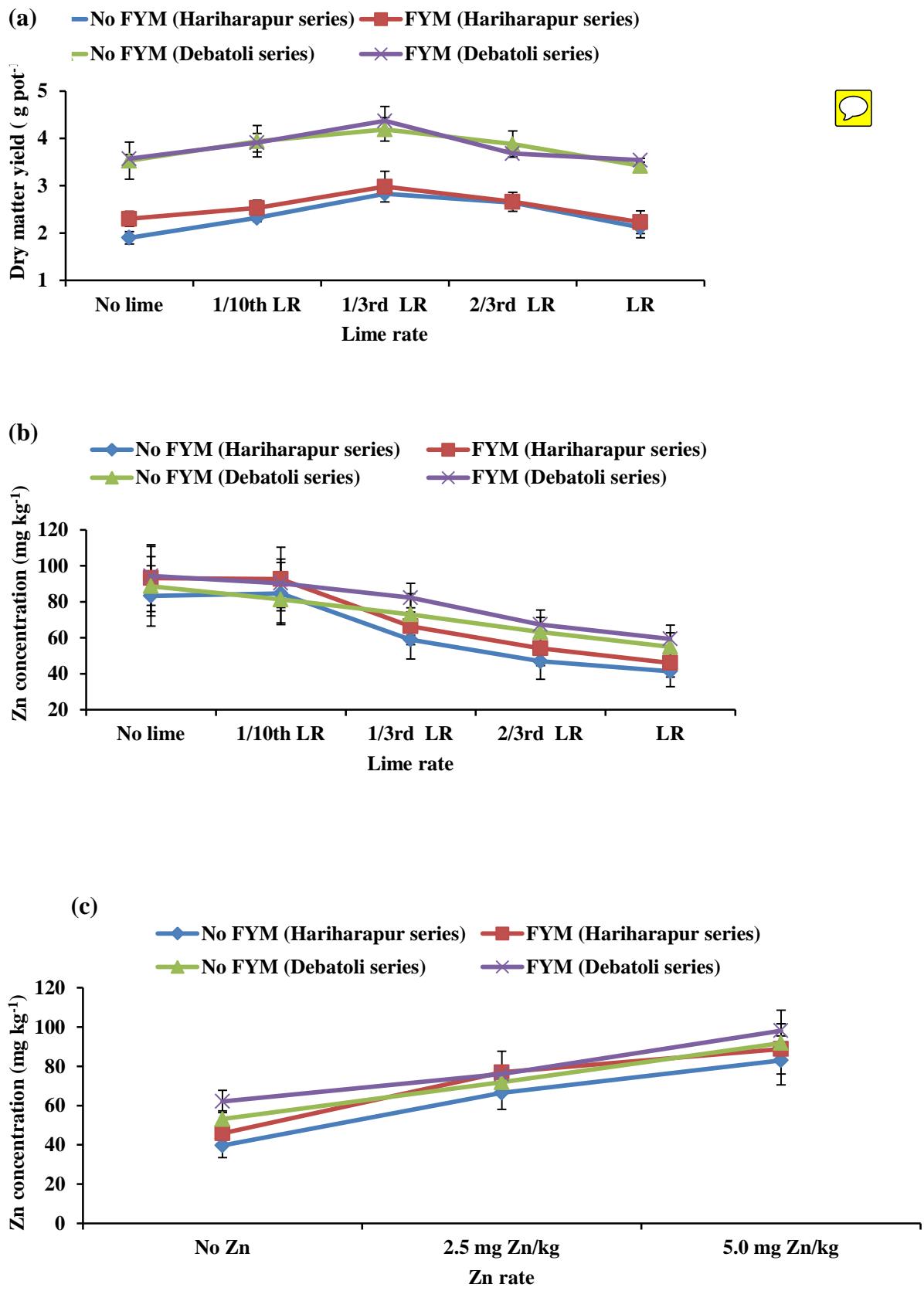
Table 5 Pearson's correlation coefficient values revealing relationship among soil properties, dry matter yield, Zn concentration, Zn uptake and extracted Zn in soils (n = 90).

	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 \pm 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 \pm SE.



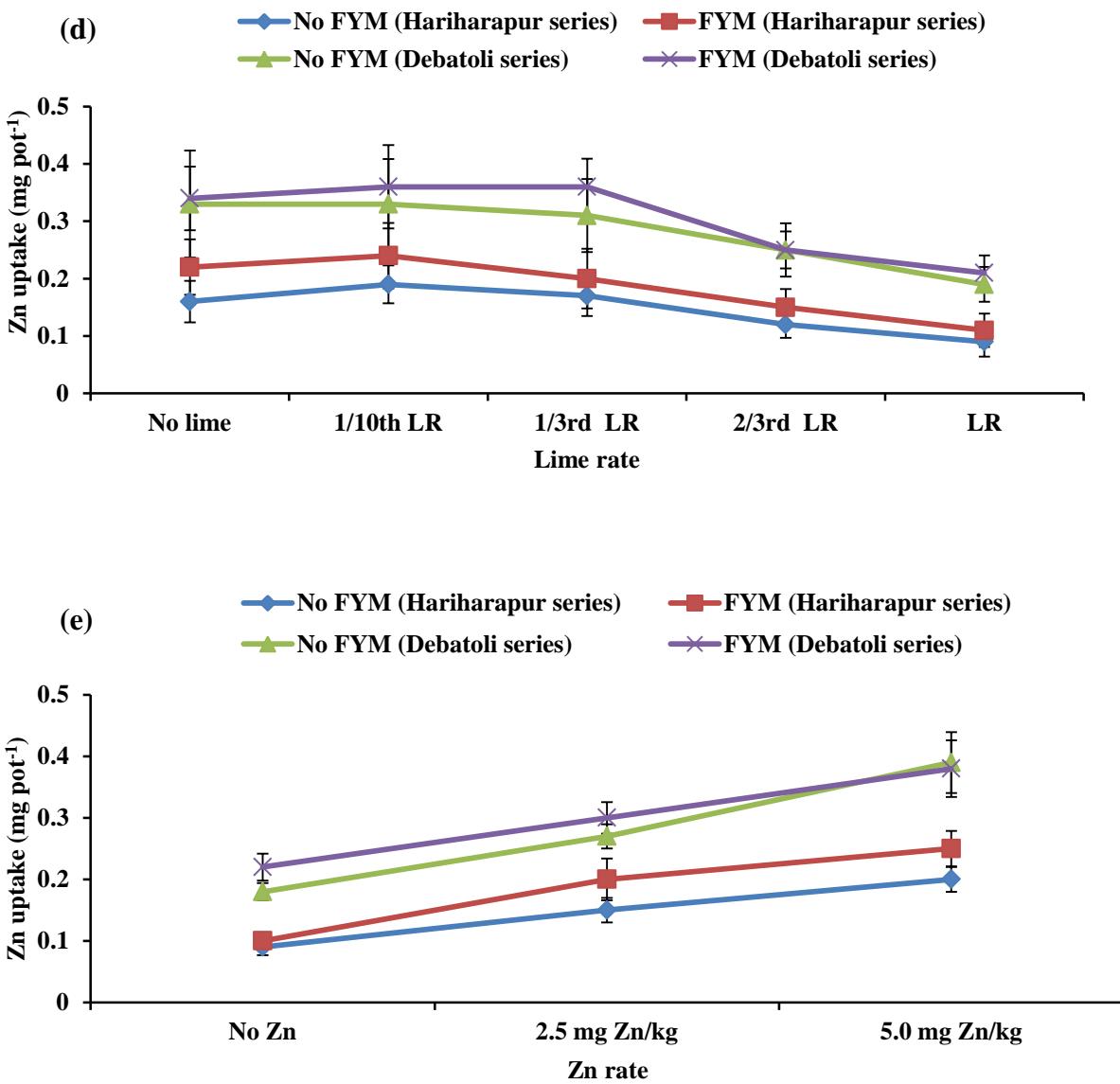
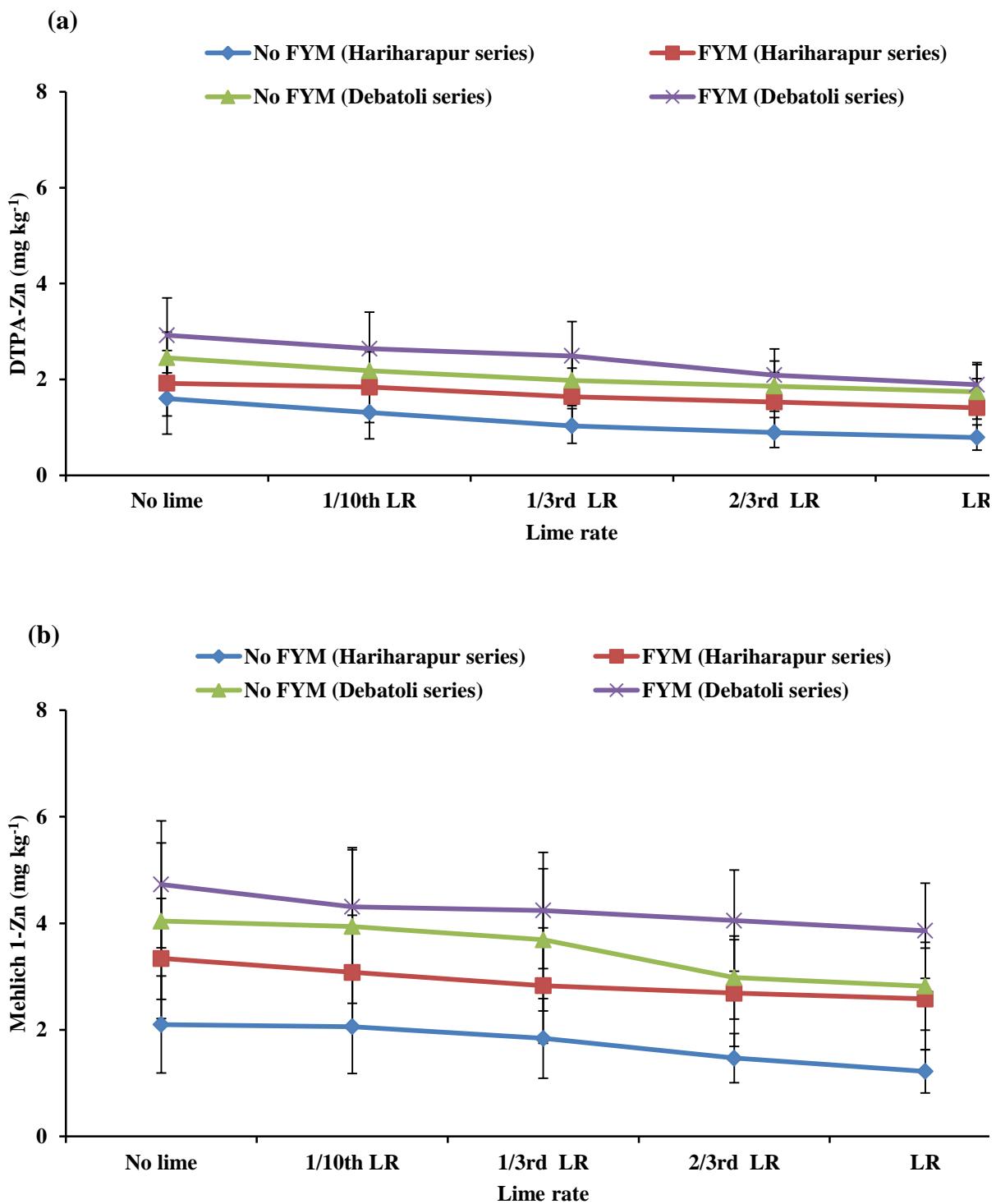


Fig. 1. Dry matter yield, Zn concentration and Zn uptake by maize as influenced by interaction of Zn application and lime rate in Hariharapur and Debatoli series. Error bars represent \pm SE.



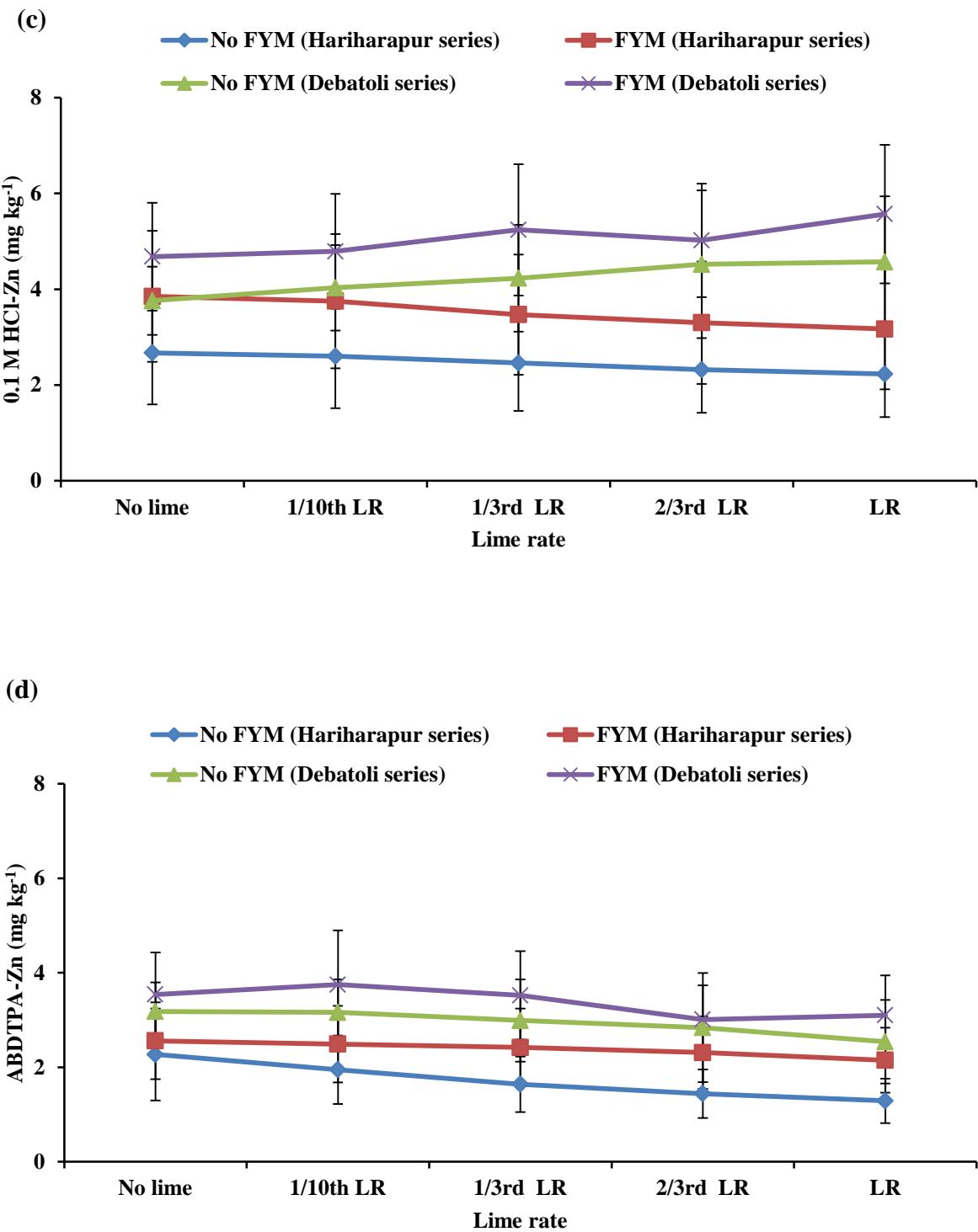


Fig. 2. Extractable Zn by different extractants as influenced by interaction of Zn application and lime rate in Hariharapur and Debatoli series. Error bars represent \pm SE.