Comparative Performance of different types of Liming materials for Maize crop grown in Acid Soil

A THESIS SUBMITTED TO
THE ORISSA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
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MASTER OF SCIENCE IN AGRICULTURE

(SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)

By

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2014

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Dr. G.H. Santra	**Bhubaneswar**
Professor	**Date:-**

CERTIFICATE I

This is to certify that the thesis entitled **"Comparative Performance of different types of Liming materials for Maize crop grown in Acid Soil"** submitted in partial fulfillment of the requirements for the award of the degree of **MASTER OF SCIENCE IN AGRICULTURE (SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)** to the Orissa University of Agriculture and Technology is an authentic record of bonafide research work carried out by **Rahul Dev Behera** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

It is further certified that the evidence and help obtained by him from various sources during the course of investigation has been duly acknowledged.

Dr. G. H. Santra

(CHAIRMAN)
ADVISORY COMMITTEE

CERTIFICATE II

This is to certify that the thesis entitled **“Comparative Performance of different types of Liming materials for Maize crop grown in Acid Soil”** submitted by **Rahul Dev Behera** to Orissa University of Agriculture and Technology, Bhubaneswar in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE (SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)** has been approved by the student’s advisory committee and the external examiner.

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ABBREVIATIONS

Kg	kilogram
g	Gram
mg	Miligram
Meq	Milli-equivalent
m	Meter
cm	Centimeter
mm	Millimeter
tha^{-1}	Tonnes per hectare
qha^{-1}	Quintals per hectare
^{0}C	Degree centigrade
%	Percent
@	At the rate of
DAS	Days after sowing
CD	Critical difference
CV	Co-efficient of variance
Fig.	Figure

ACKNOWLEDGEMENT

This perspicuous piece of acknowledgement gives me an opportunity and proud privilege to epitomise my deepest sense of gratitude and greatfulness to my esteemed guide Dr. G. H. Santra, Professor, Department of Soil Science and Agricultural Chemistry, OUAT, Bhubaneswar for his constant supervision, Valuable guidance, keen and sustained interest, intuitive ideas, persistent endeavour and inspiring assistance renderd throughout the course of this investigation, inspite of his multifarious engagements.

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Lastly, I bow my head before the omni present sacred divine who has shown a beam of spiritual light in the darkness. I still seen his blessings to proceed further.

Bhubaneswar

Date : **Rahul Dev Behera**

ABSTRACT

A field experiment was conducted to study the "**Comparative Performance of Different Types of Liming Materials for Maize crop grown in Acid soil"** in the Village Bajpur in Khurda district of Odisha during Kharif 2013. The soil of the experimental site was strongly acidic (pH_w – 4.94) with LR- 3t $CaCO_3ha^{-1}$,EC-0.09 dSm^{-1} , OC- 5.7 g/kg. The available N, P, K, S were 169,105,143 and 17 $kgha^{-1}$ respectively. The experiment was conducted in a RBD design with 10 treatments and each treatment replicated three times. The soil was ameliorated with three sources of liming materials (Paper mill sludge @ 0.1LR, Stromatolyte @ 0.1 LR & 0.2 LR and Calcium silicate @ 0.2 LR) added with soil test dose with or without FYM @ 5 tha^{-1}. There was one treatment as absolute control and another as soil test based dose of fertilizers. The 100 % soil test based dose for maize crop (cv. Hishell) was 150-30-50-30-10-25 kg of N - P_2O_5 - K_2O -SO_4 - Borax- $ZnSO_4$ ha^{-1}.

The soil samples were collected at 7 days interval, processed and analyzed for pH, Exchange acidities, OC, CEC, Exch. Ca^{2+} and Exch. Mg^{2+} etc. The initial and post harvest soil samples were also collected and analysed for physic-chemical properties of the soil. At the harvest stage the maize cob, root and plant samples were collected and analyzed for concentration, uptake and recovery of nutrients by the crop.

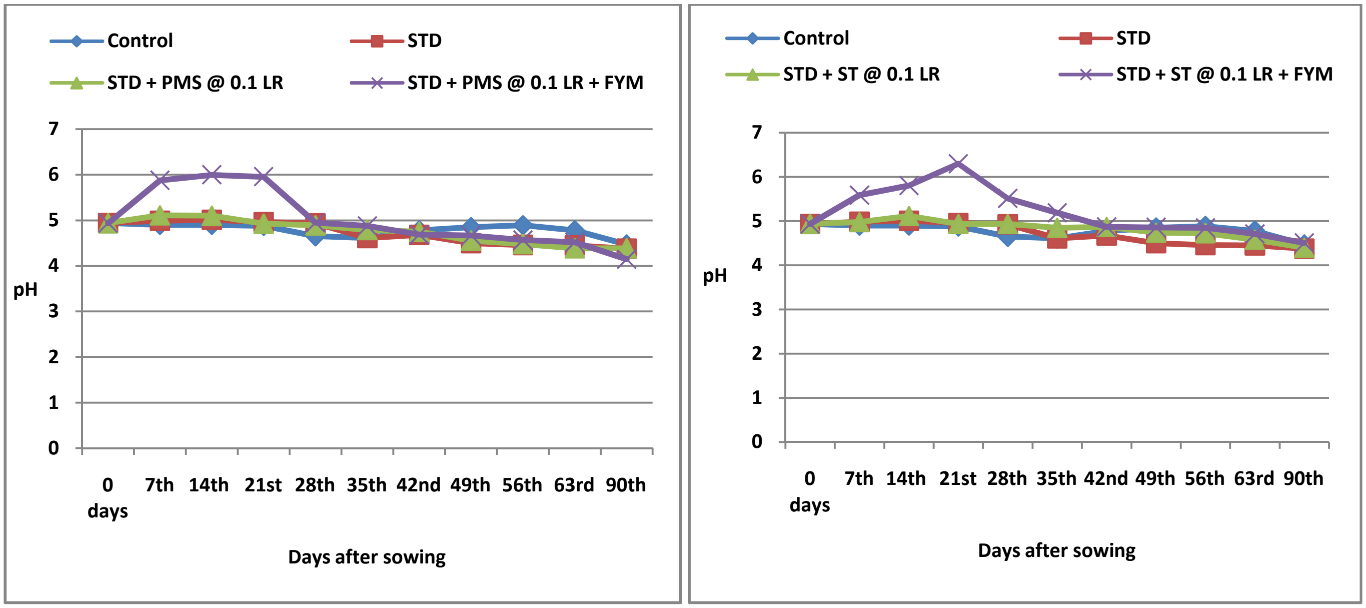
Application of liming materials irrespective of the sources neutralized soil acidity, increased from a level of 4.94 to a level ranging from 5.11 to 5.55 and maintained for 14-35 days when lone sources were used. Combined use of liming materials with FYM increased the pH to a level ranging from 5.65-6.08, which was maintained for a period of 28-49 days after application. The acid neutralizing efficiency of liming materials followed the order: ST @ 0.2 LR >CS @ 0.2 LR > PMS @ 0.1 LR> ST @ 0.1 LR.

The grain yield of Maize increased by 21.4 - 44 % when the liming materials were applied alone with fertilizers but when mixed with FYM increased to a range from 46 – 78.6 % over STD (22 q/ha).The yield performance of the lone sources of liming materials followed the order : ST@ 0.2 LR > CS @ 0.2 LR > PMS @0.1 LR > ST @ 0.1 LR. When applied with FYM the sources followed the order: ST@ 0.2 LR > PMS @0.1 LR > CS @ 0.2 LR > ST @ 0.1 LR.

The recovery of N by Maize crop increased from 19 – 27 %, when liming materials are used alone, but from 26 – 36 % when used with FYM. The APR increased from 32 – 47 % when lone sources of liming materials were used, but with FYM increased from 42 – 66 %.Similarly AKR increased from 24 – 44 % with lone sources but with FYM from 42 – 55 %.The ASR increased from 10.2 – 17.4 % with lone sources, but from 18.4 – 28.7 % when applied with FYM.

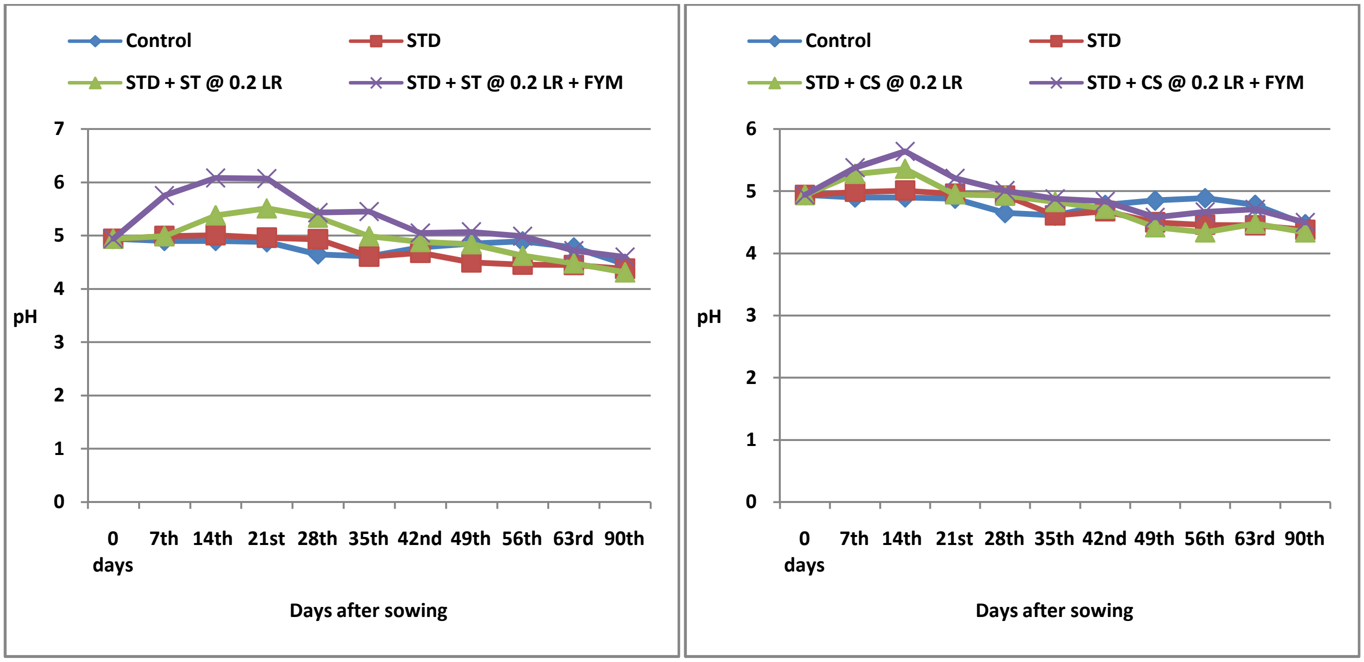
Irrespective of the liming materials used in maize crop production, the soil turned acidic. The OC content, available P and K status decreased, where as the available S & N status in soil increased by the harvest of the crop.

Fig-4.1 : Change in soil reaction due to the application of liming materials with or without FYM



(a) Paper mill sludge @ 0.1 LR

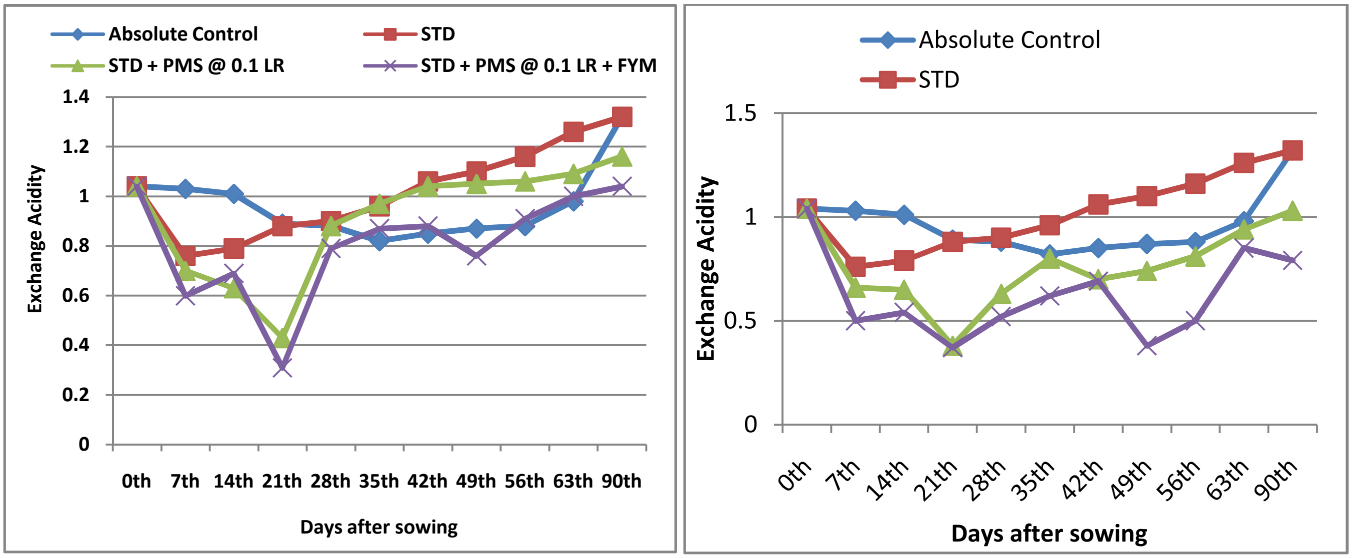
(b) Stromatolyte @ 0.1 LR



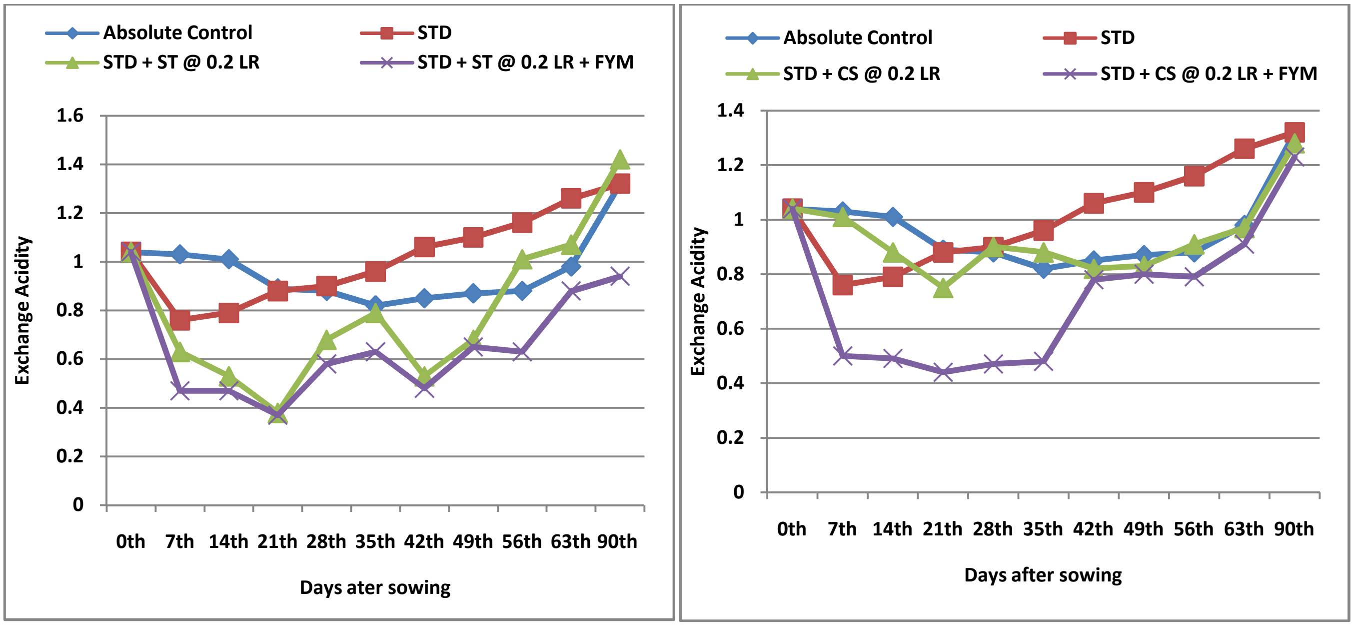
(c) Stromatolyte @ 0.2 LR

(d) Calcium silicate @ 0.2 LR

Fig-4.2 : Change in Exchange acidity due to the application of liming materials with or without FYM

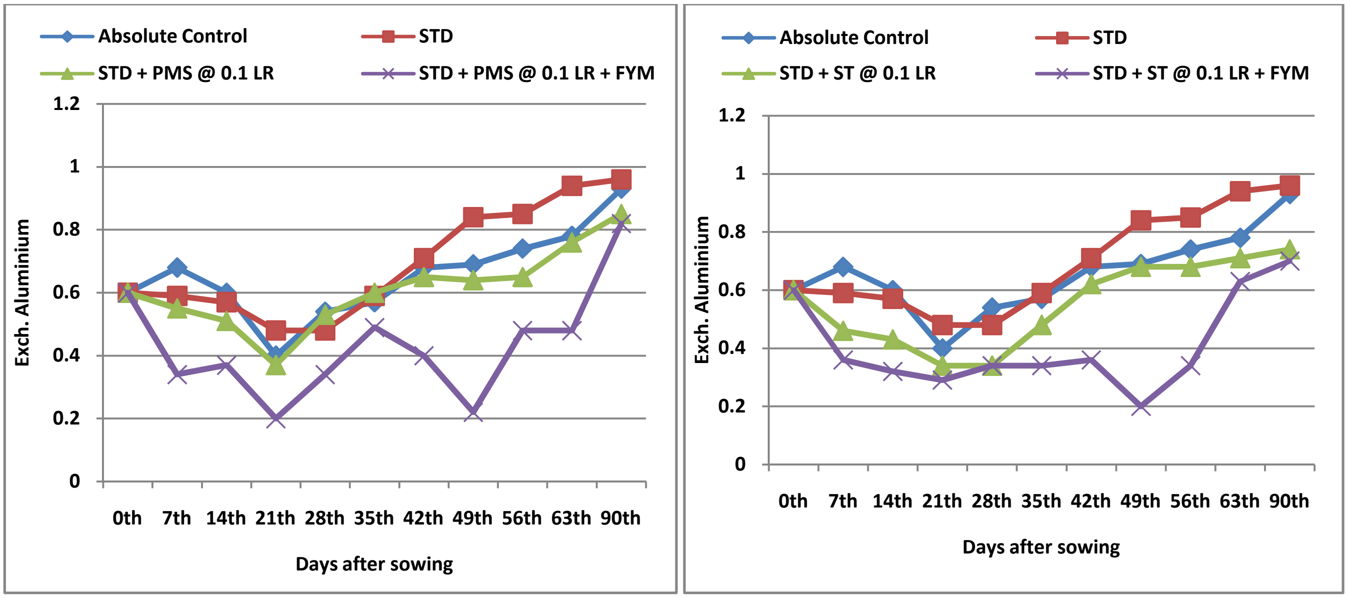


(a) Paper mill sludge @ 0.1 LR **(b) Stromatolyte @ 0.1 LR**



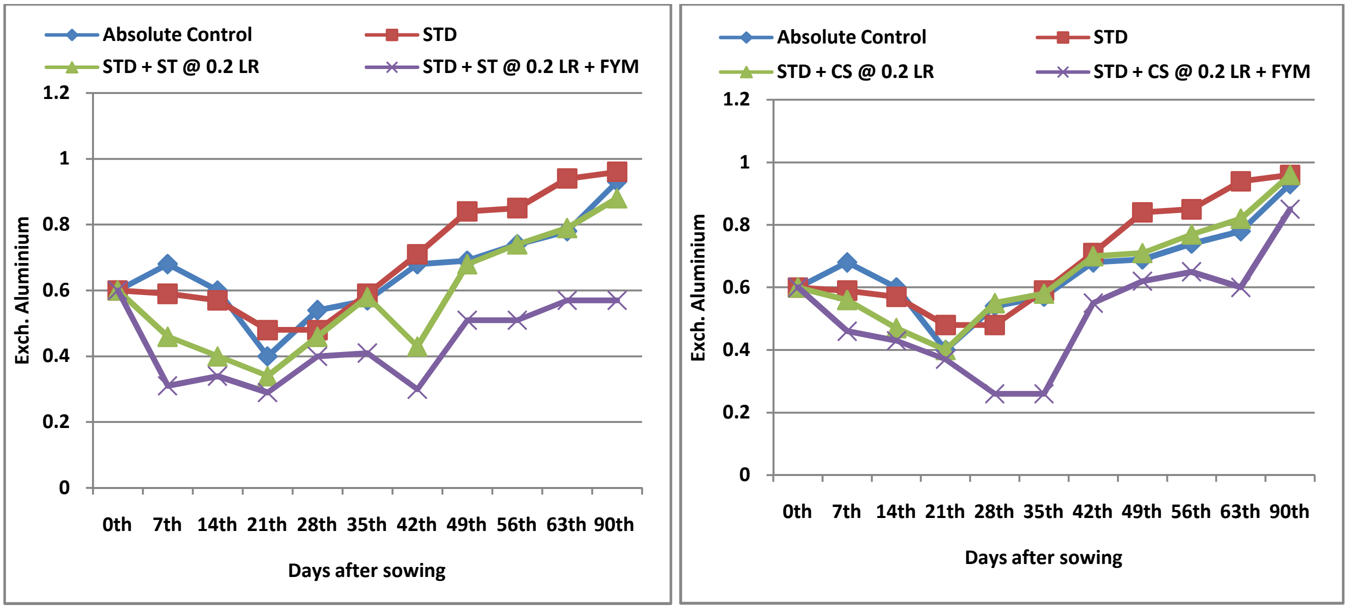
(c) Stromatolyte @ 0.2 LR **(d) Calcium silicate @ 0.2 LR**

Fig-4.3 : Change in Exchangeable aluminium due to the application of liming materials with or without FYM



(a) Paper mill sludge @ 0.1 LR

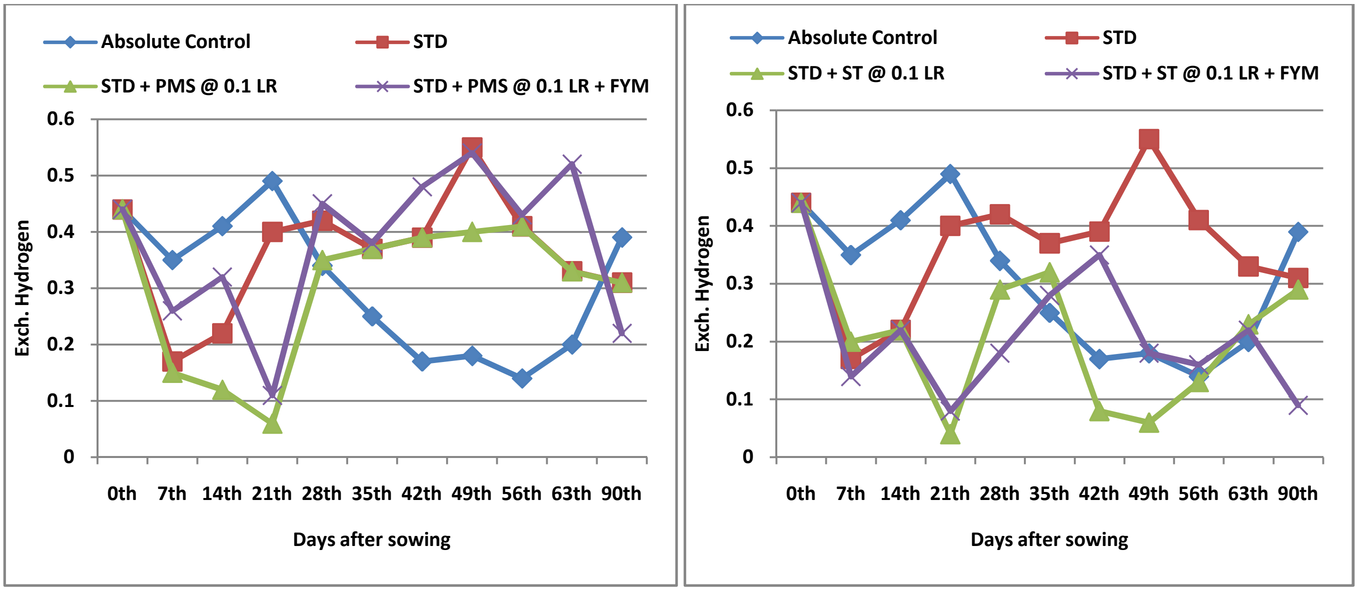
(b) Stromatolyte @ 0.1 LR



(c) Stromatolyte @ 0.2 LR

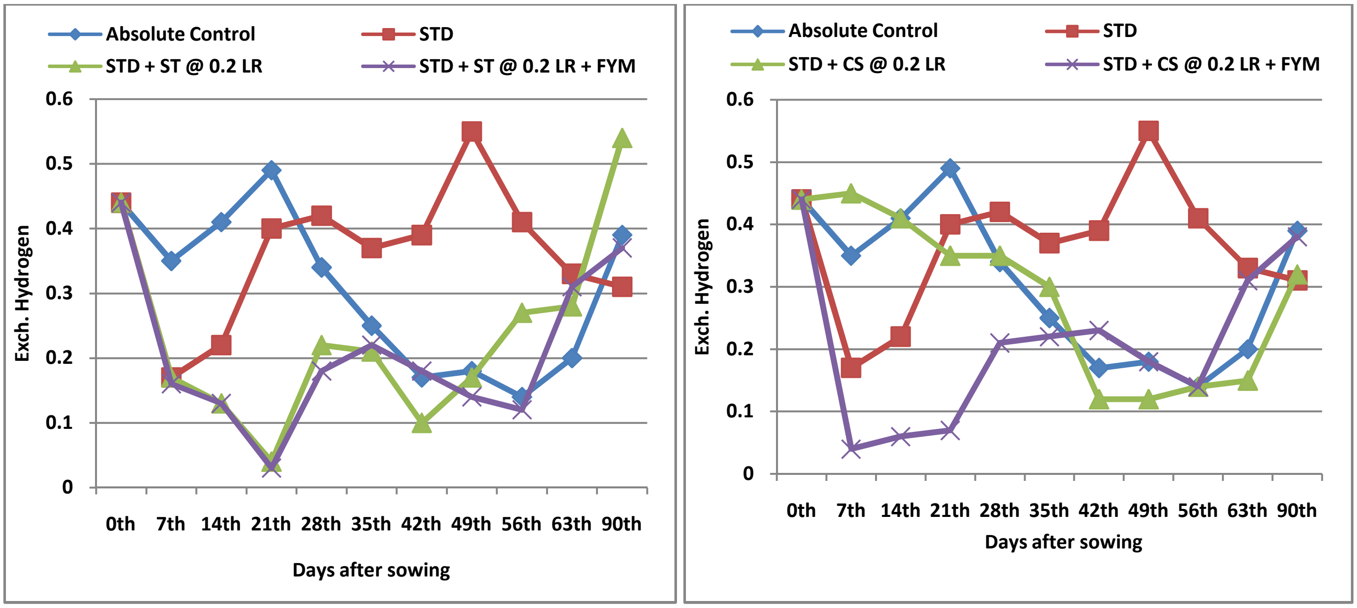
(d) Calcium silicate @ 0.2 LR

Fig-4.4 : Change in Exchangeable Hydrogen due to the application of liming materials with or without FYM



(a) Paper mill sludge @ 0.1 LR

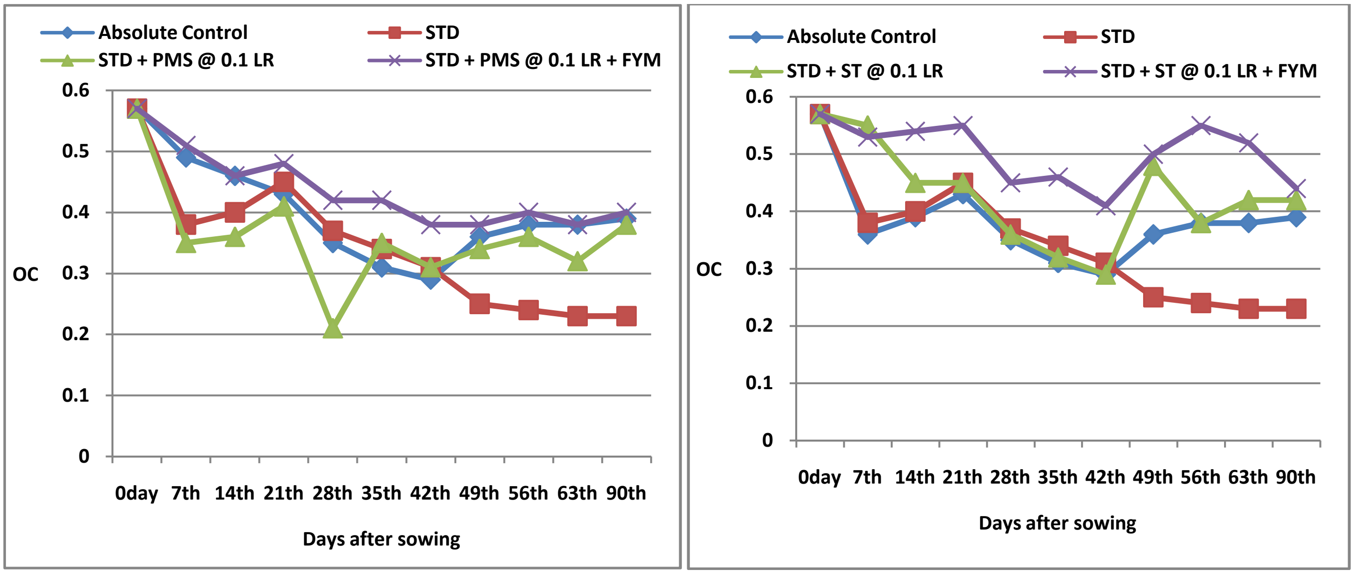
(b) Stromatolyte @ 0.1 LR



(c) Stromatolyte @ 0.2 LR

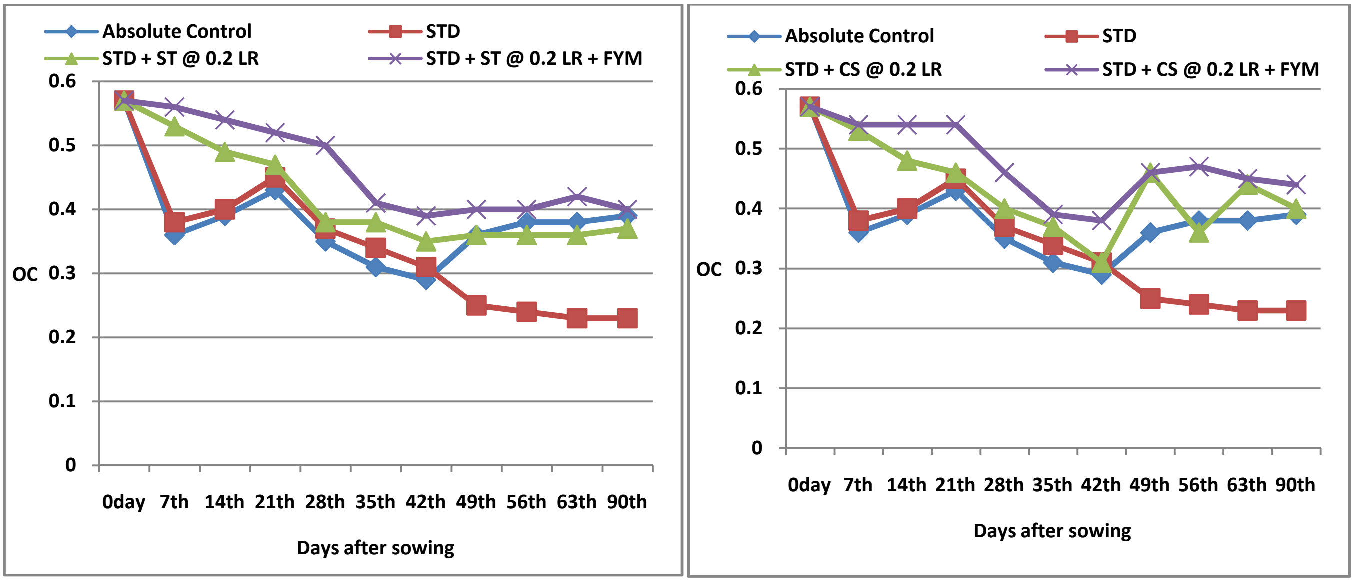
(d) Calcium silicate @ 0.2 LR

Fig-4.5 : Change in Organic Carbon status in soil due to the application of liming materials with or without FYM



(a) Paper mill sludge @ 0.1 LR

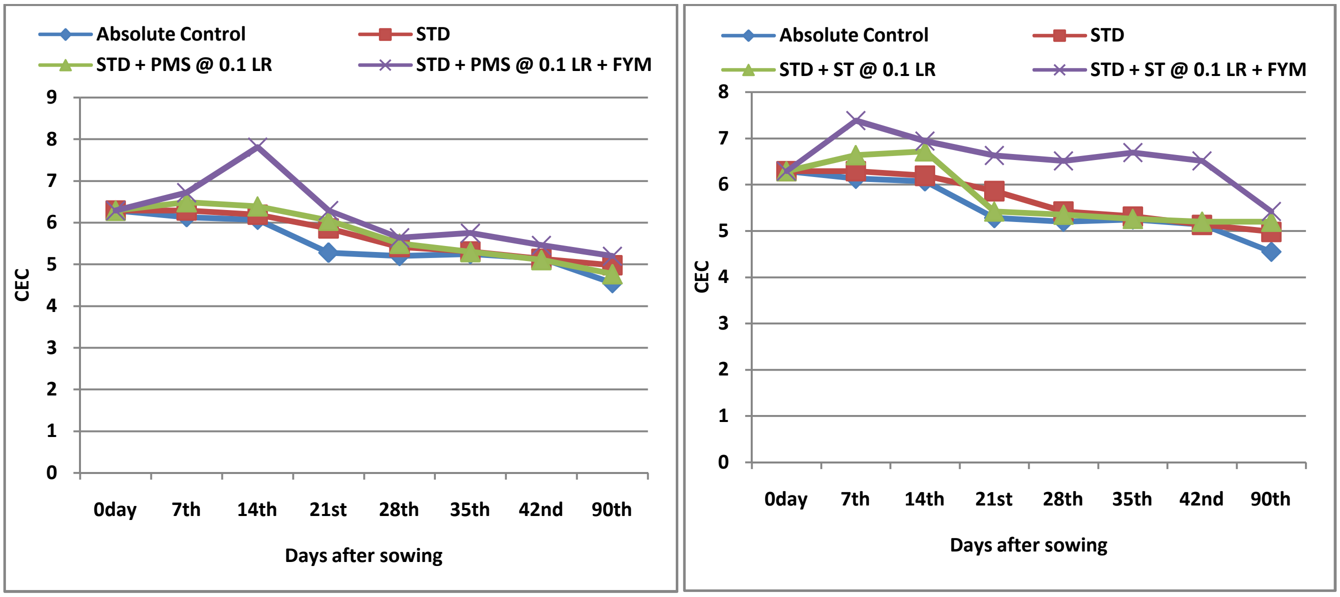
(b) Stromatolyte @ 0.1 LR



(c) Stromatolyte @ 0.2 LR

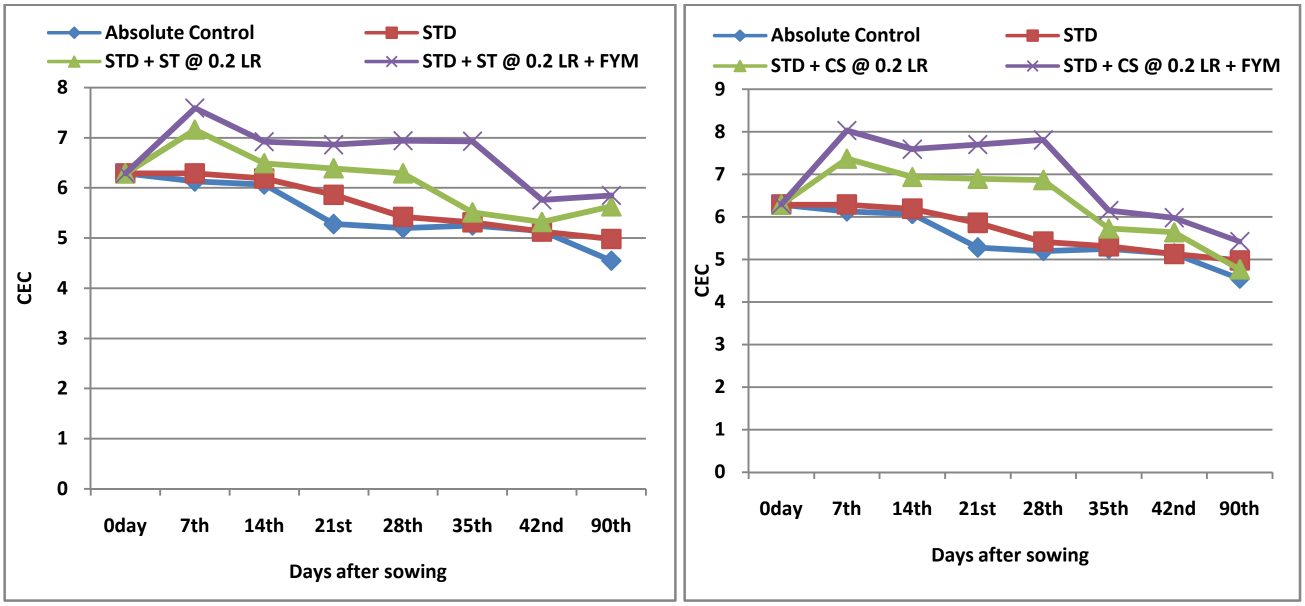
(d) Calcium silicate @ 0.2 LR

Fig-4.6 : Change in Cation Exchange Capacity of soil due to the application of liming materials with or without FYM



(a) Paper mill sludge @ 0.1 LR

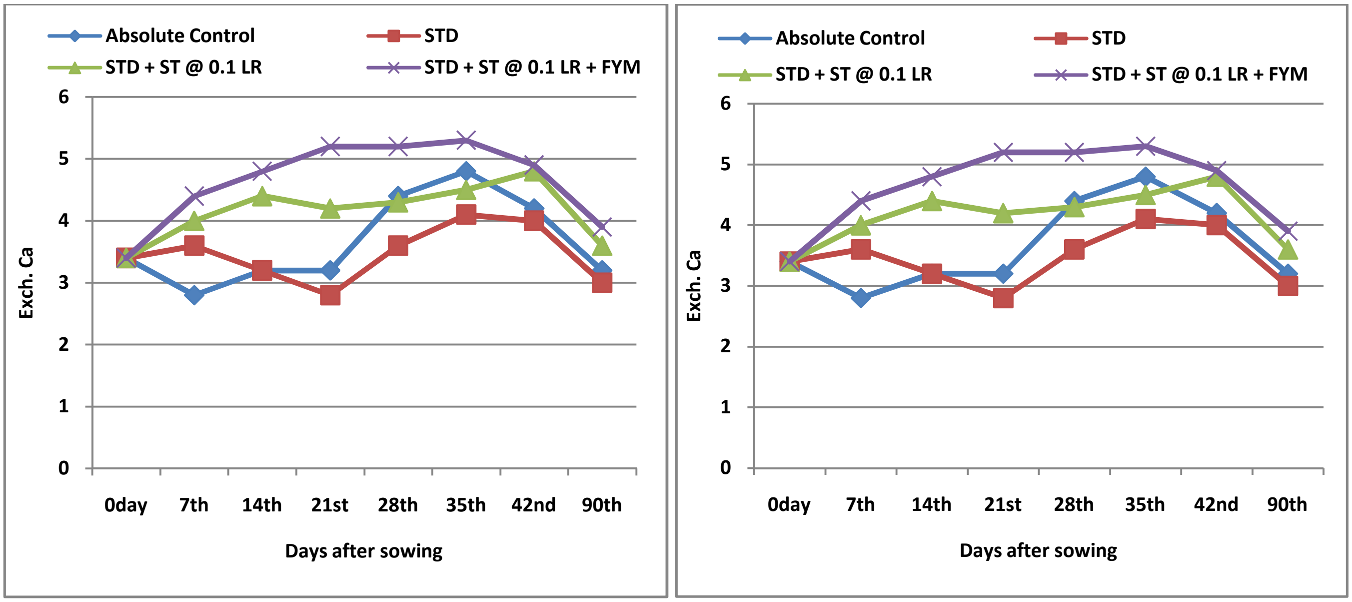
(b) Stromatolyte @ 0.1 LR



(c) Stromatolyte @ 0.2 LR

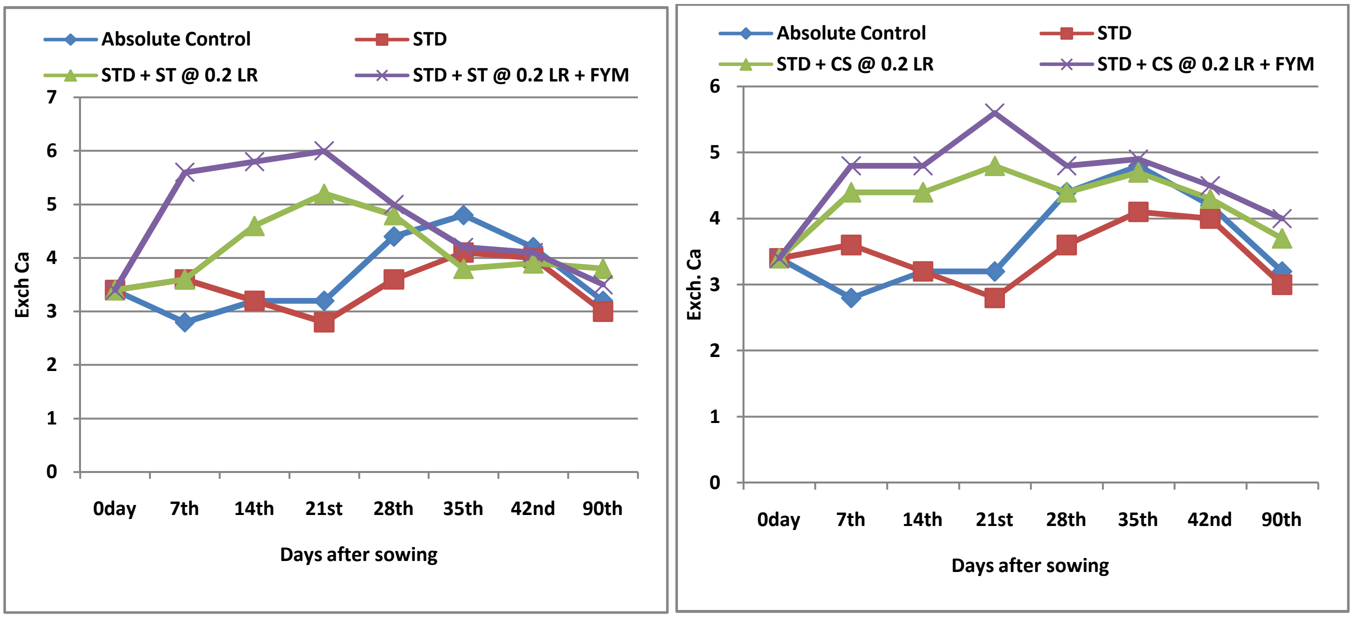
(d) Calcium silicate @ 0.2 LR

Fig-4.7 : Change in Exchangeable Calcium in soil due to the application of liming materials with or without FYM



(a) Paper mill sludge @ 0.1 LR

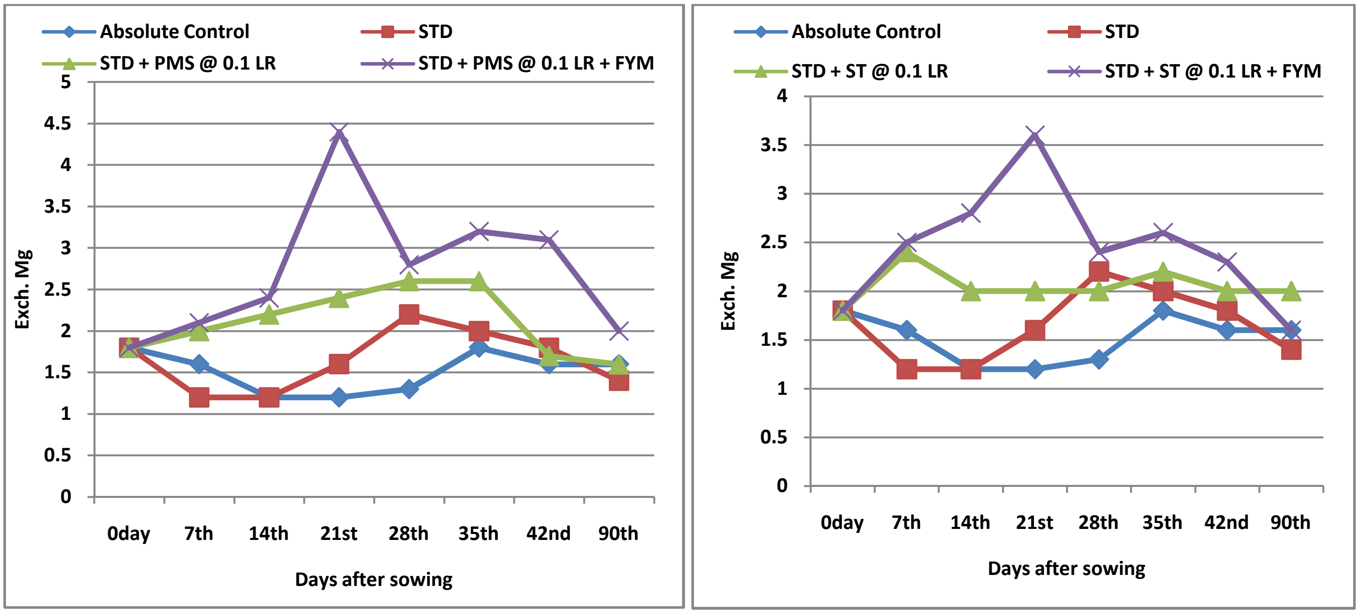
(b) Stromatolyte @ 0.1 LR



(c) Stromatolyte @ 0.2 LR

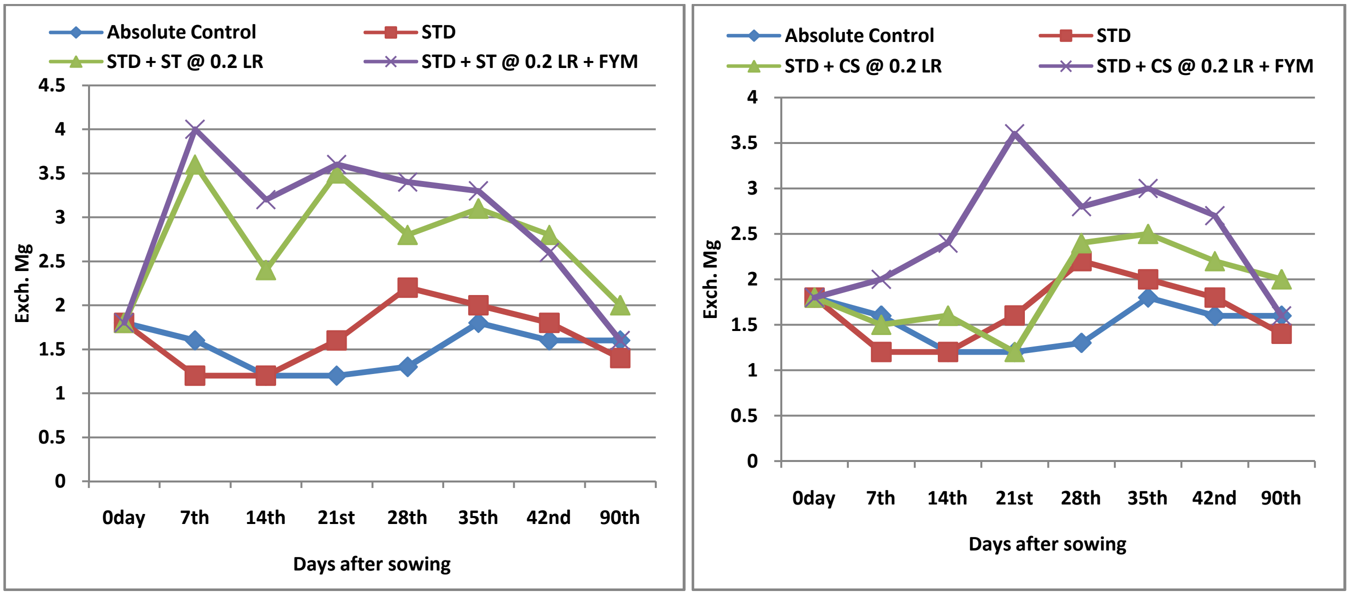
(d) Calcium silicate @ 0.2 LR

Fig-4.8 : Change in Exchangeable Magnesium in soil due to the application of liming materials with or without FYM



(a) Paper mill sludge @ 0.1 LR

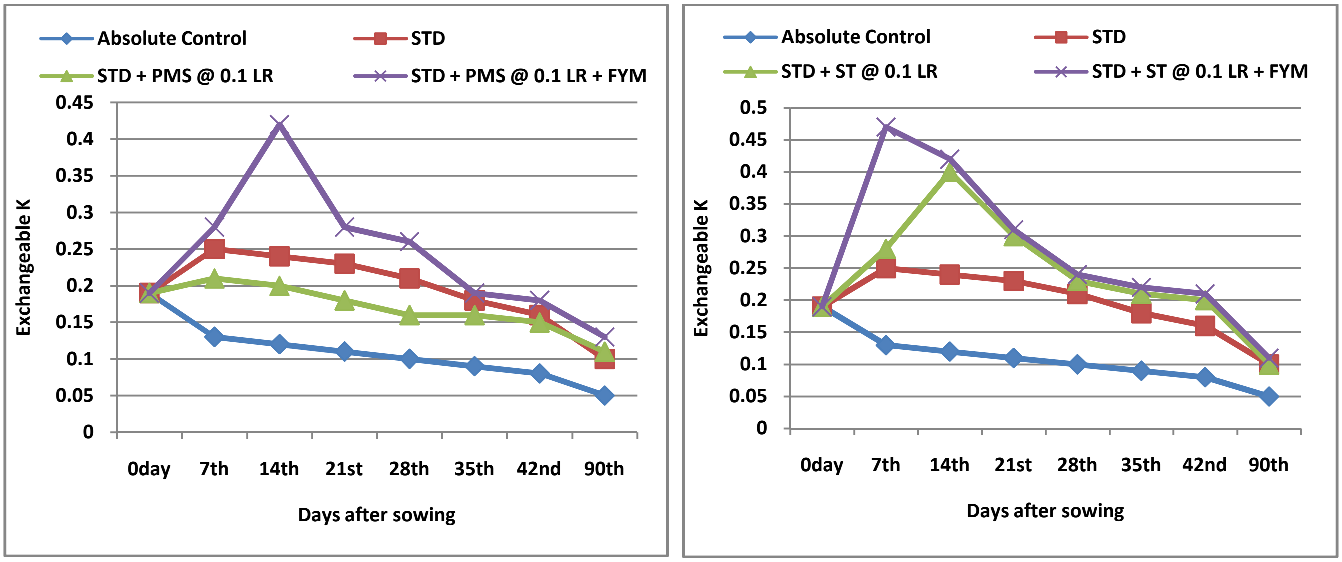
(b) Stromatolyte @ 0.1 LR



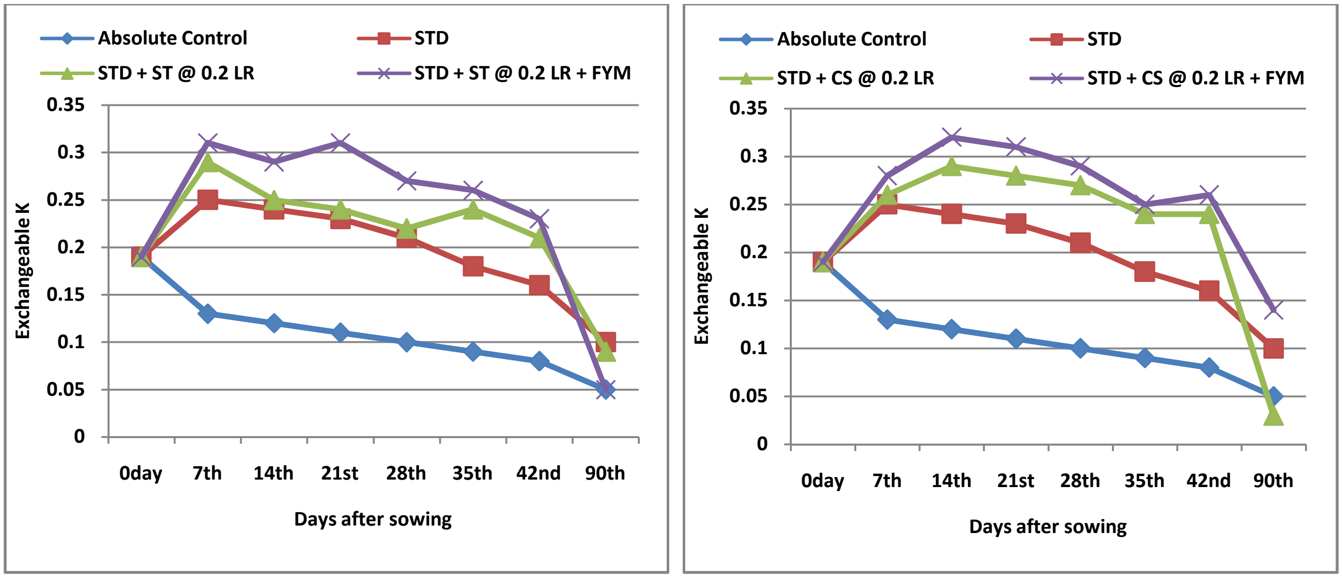
(c) Stromatolyte @ 0.2 LR

(d) Calcium silicate @ 0.2 LR

Fig-4.9 : Change in Exchangeable Potassium in soil due to the application of liming materials with or without FYM



(a) Paper mill sludge @ 0.1 LR **(b) Stromatolyte @ 0.1 LR**



(c) Stromatolyte @ 0.2 LR **(d) Calcium silicate @ 0.2 LR**

Fig-4.10 : Chlorophyll content (SPAD Value) at different growth stage

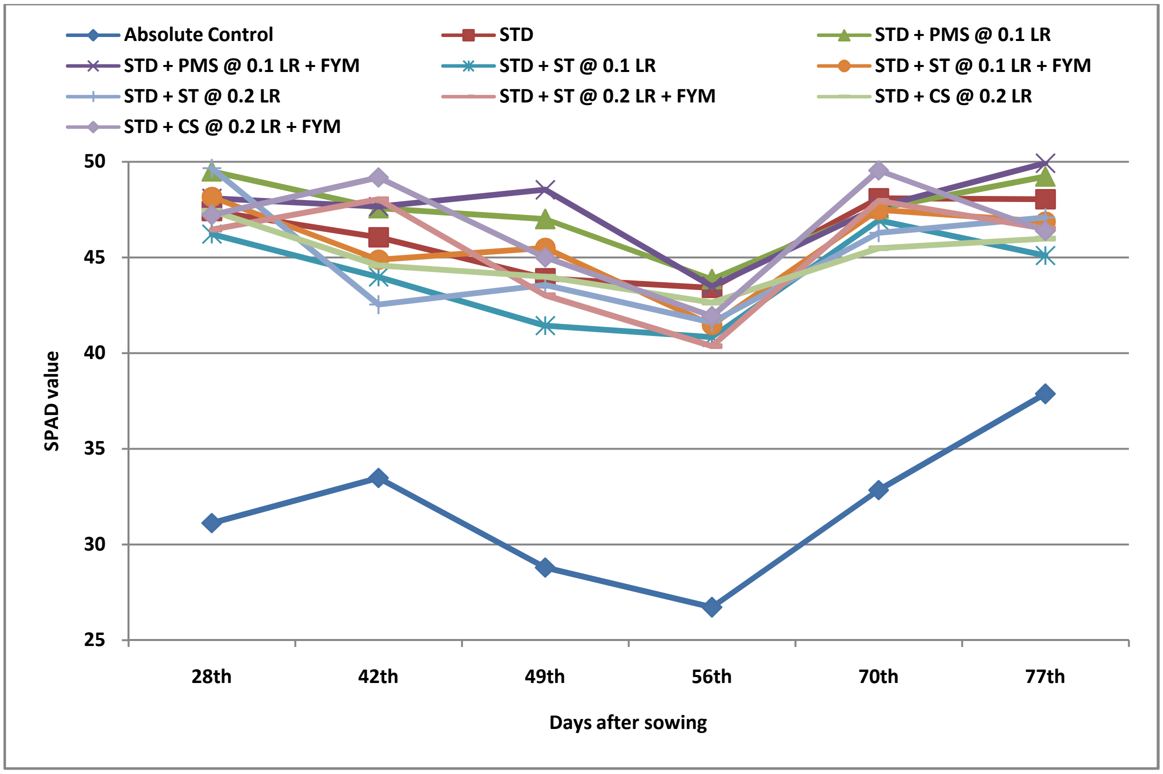


Fig-4.11 : Plant height(cm) at different growth stage

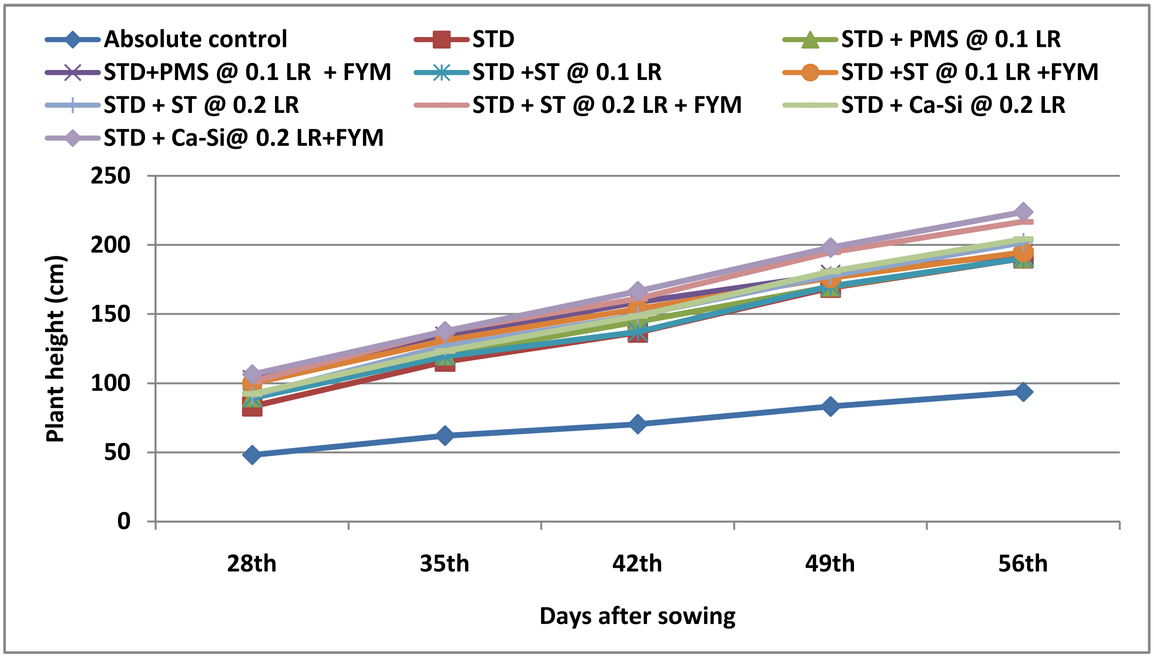


Table-4.3 : Root characteristics of Maize crop as influenced by different Liming materials

Treatments	Root length (cm)	Root dry wt (g)	Root volume (cc)	Root density (g/cc)
Absolute Control	15	0.83	10	0.08
STD	26	4.76	30	0.14
STD + PMS @ 0.1 LR	33	7.45	50	0.15
STD + PMS @ 0.1 LR + FYM	45	16.56	100	0.17
STD + ST @ 0.1 LR	30	9.80	50	0.19
STD + ST @ 0.1 LR + FYM	34	11.99	60	0.20
STD + ST @ 0.2 LR	53	8.29	40	0.20
STD + ST @ 0.2 LR + FYM	62	10.99	50	0.22
STD + CS @ 0.2 LR	31	6.07	35	0.18
STD + CS @ 0.2 LR + FYM	38	7.83	40	0.20
CD (P=0.05)	**2.8**	**1.8**	**3.8**	**0.098**

Fig-4.12 : Root length of maize crop as influenced by different liming materials

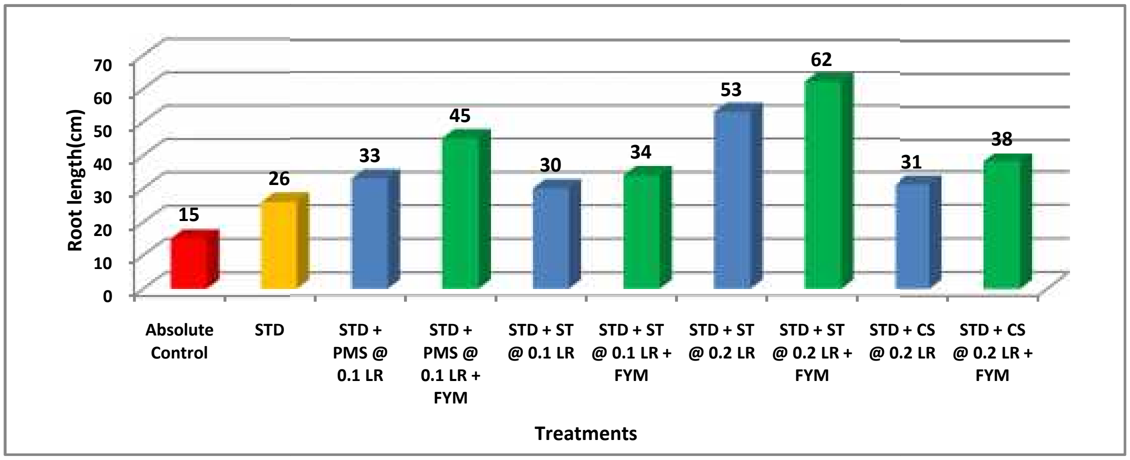


Fig-4.13 : Root volume of maize crop as influenced by different liming materials

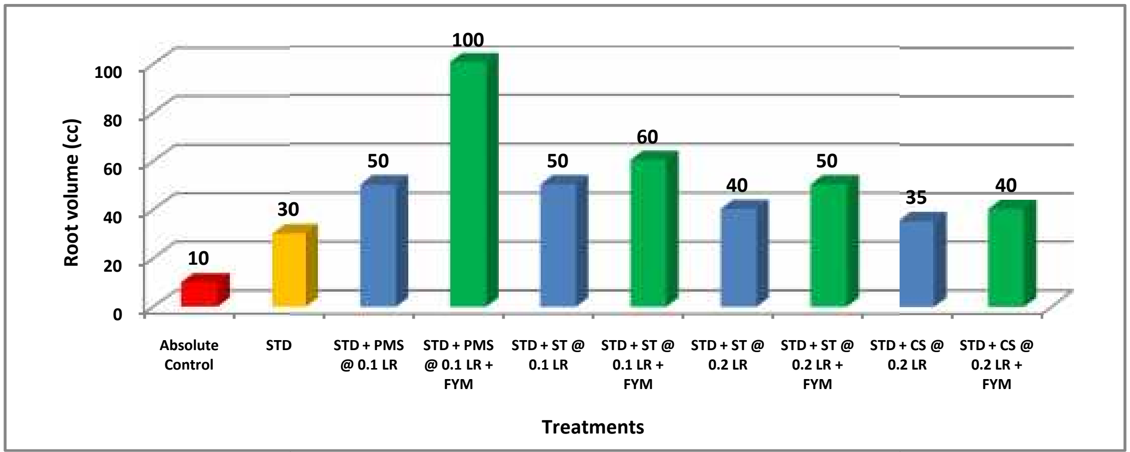


Table-4.4 : Maize cob characteristics as influenced by the different liming materials

Treatments	Cob length (cm)	Cob diameter (cm)	Seeds/Cob (g/Cob)
Absolute Control	11.0	10.2	22.8
STD	15.2	12.4	54.7
STD + PMS @ 0.1 LR	17.1	13.6	66.0
STD + PMS @ 0.1 LR + FYM	17.6	13.9	75.4
STD + ST @ 0.1 LR	16.2	13.5	60.4
STD + ST @ 0.1 LR + FYM	16.6	13.6	66.0
STD + ST @ 0.2 LR	16.5	13.6	68.7
STD + ST @ 0.2 LR + FYM	16.9	13.9	74.9
STD + CS @ 0.2 LR	15.8	13.0	68.0
STD + CS @ 0.2 LR + FYM	16.4	13.8	74.0

Fig-4.14 : Cob length of maize crop as influenced by different liming materials

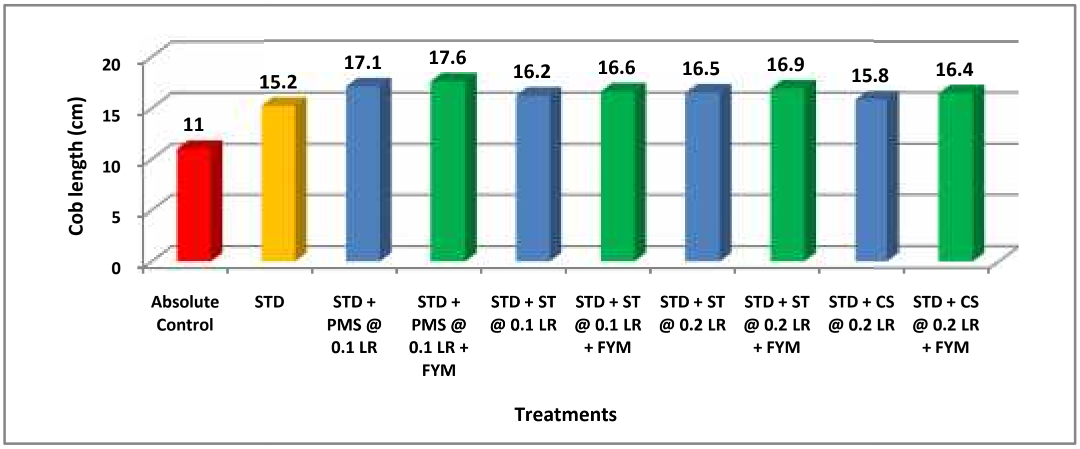


Fig-4.15 : Seeds Cob^{-1} of maize crop as influenced by different liming materials

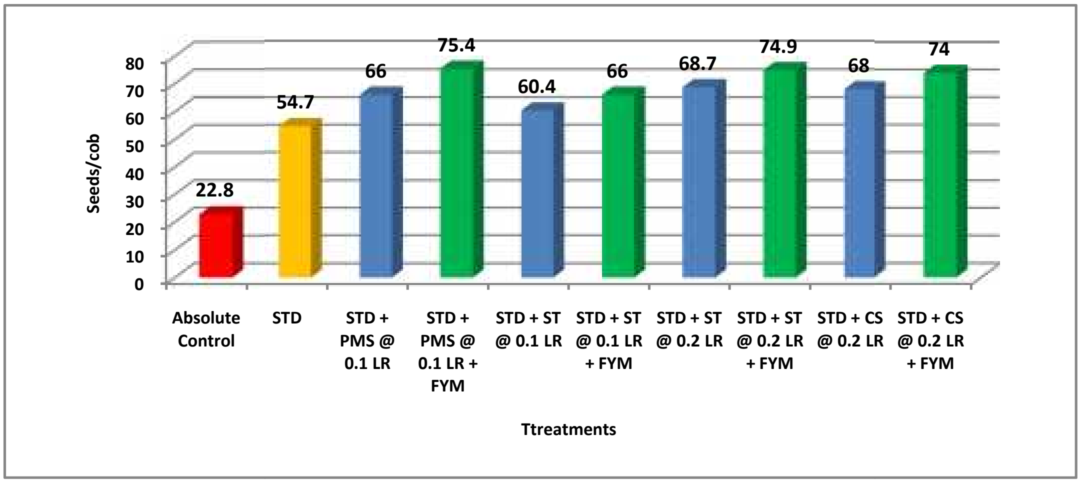


Table-4.5 : Maize productivity under the influence of integrated use of lime sources and FYM

Treatments	Grain	Stover	Rachis	Spathe	Root	Total Biomass
	(q/ha)					
Absolute Control	11.3	9.4	2.7	2.9	0.1	26.4
STD	22.0	18.2	6.5	5.0	0.5	52.2
STD + PMS @ 0.1 LR	27.0	22.9	6.4	8.6	0.8	65.7
STD + PMS @ 0.1 LR + FYM	37.7	31.0	7.6	7.4	1.7	85.4
STD + ST @ 0.1 LR	26.7	21.7	5.5	4.8	1.1	59.8
STD + ST @ 0.1 LR + FYM	32.0	25.4	5.8	6.6	1.2	71.0
STD + ST @ 0.2 LR	31.7	26.4	6.1	6.8	1.1	72.1
STD + ST @ 0.2 LR + FYM	39.3	31.3	6.7	8.1	1.4	86.8
STD + CS @ 0.2 LR	30.3	24.4	6.0	6.4	1.2	68.3
STD + CS @ 0.2 LR + FYM	37.7	29.1	7.1	8.2	1.6	83.0
CD (P=0.05)	**3.97**	**5.13**	**1.19**	**1.03**	**---**	**9.02**
CV(%)	**7.9**	**11.8**	**11.5**	**11.8**	**---**	**7.9**

Fig-4.16 : Grain and Stover yield of maize crop as influenced by different liming materials

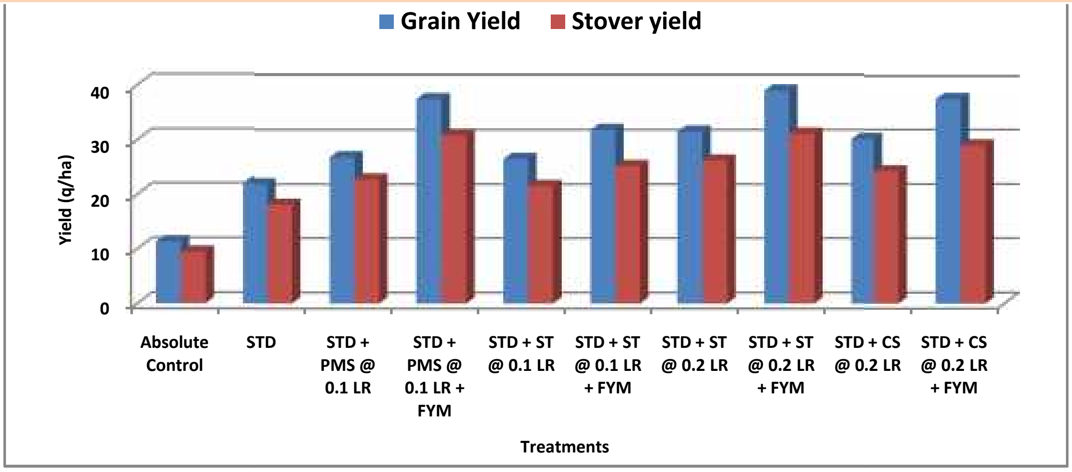


Fig-4.17 : Total biomss of maize crop as influenced by different liming materials

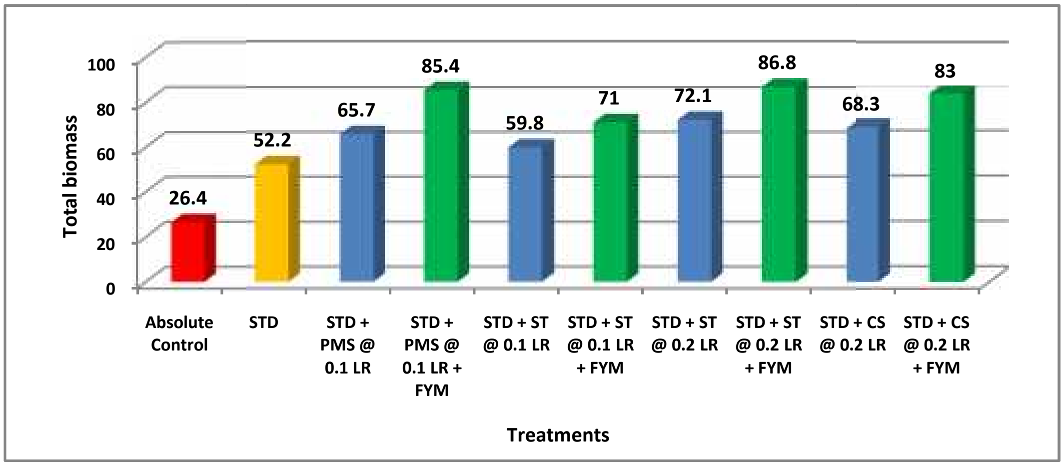


Fig-4.18 : Grain : Straw ratio of maize crop as influenced by different liming materials

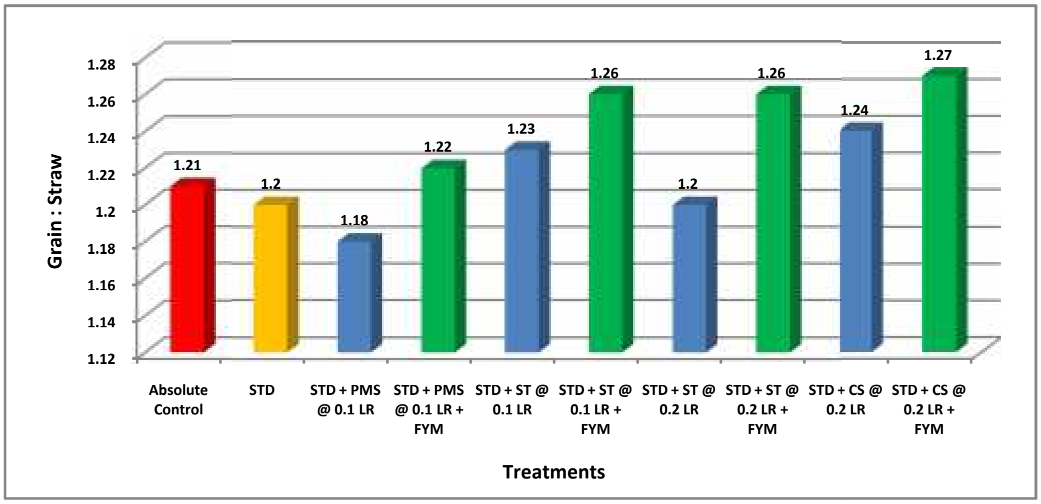


Fig-4.19 : Harvesting Index of maize crop as influenced by different liming materials

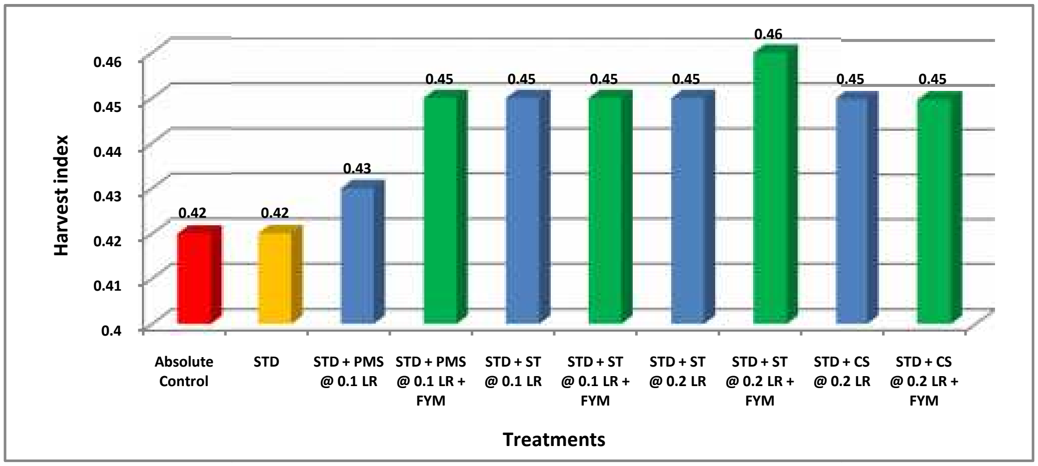


Fig-4.20 : RAE of maize crop as influenced by different liming materials

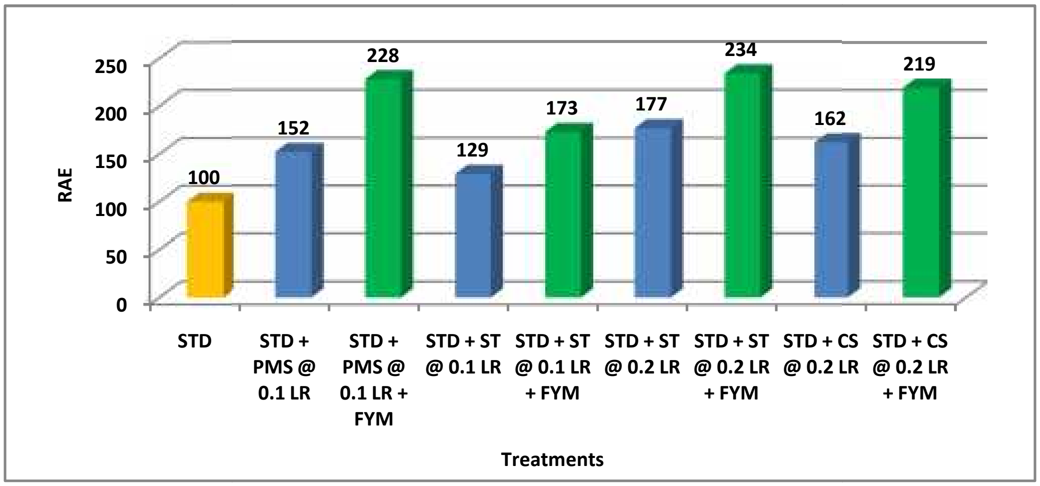


Table-4.6 : Concentration, uptake and recovery of the Nitrogen as influenced by application of different liming materials

Treatments	Concentration(%)			Uptake(kg/ha)				ANR
	Grain	Stover	Root	Grain	Stover	Root	Total	(%)
Absolute control	1.41	0.34	0.58	15.7	5.1	0.06	20.9	----
STD	1.55	0.38	0.85	34.2	11.4	0.43	45.9	17
STD + PMS @ 0.1 LR	1.33	0.44	0.97	35.9	16.6	0.77	53.3	22
STD+PMS @ 0.1 LR + FYM	1.42	0.45	1.05	52.8	20.1	1.82	74.8	36
STD +ST @ 0.1 LR	1.43	0.32	1.01	38.2	10.0	1.13	49.4	19
STD +ST @ 0.1 LR +FYM	1.38	0.38	1.02	44.3	14.5	1.23	59.9	26
STD + ST @ 0.2 LR	1.40	0.38	1.06	44.5	14.9	1.16	60.7	27
STD + ST @ 0.2 LR + FYM	1.30	0.40	1.23	51.4	18.9	1.77	71.9	34
STD + Ca-Si @ 0.2 LR	1.32	0.31	1.21	40.0	11.6	1.49	53.1	22
STD + Ca-Si@ 0.2 LR+FYM	1.48	0.34	1.23	54.9	15.1	1.97	71.9	34
CD(P=0.05)	**0.16**	**6.63**		**8.58**	**3.38**	**0.28**	**9.66**	

Fig-4.21 : Apparent Nitrogen Recovery by maize crop as influenced by application of different liming materials

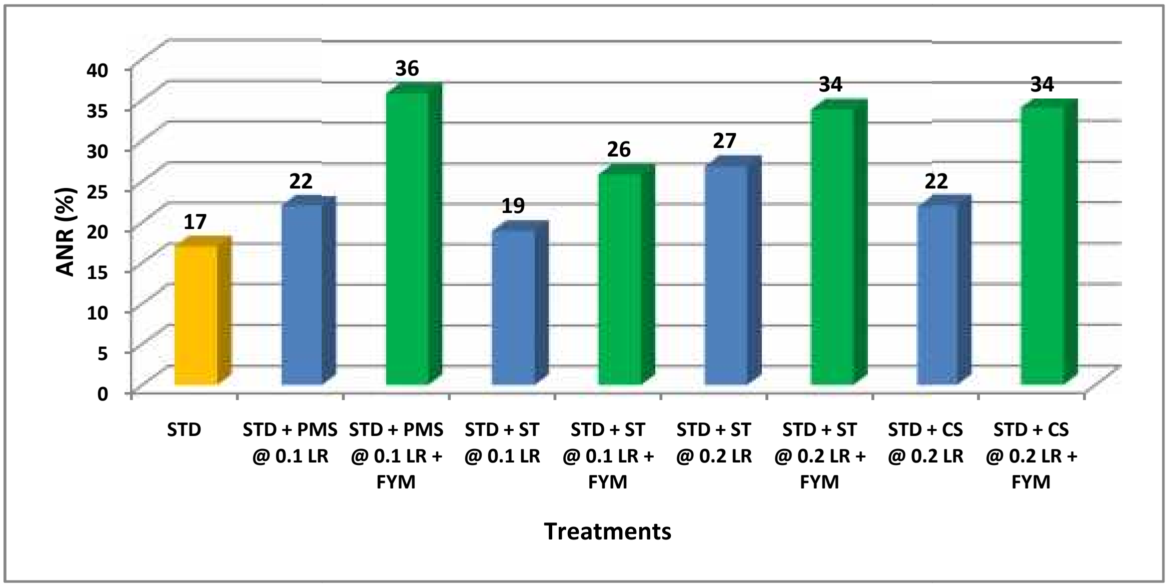


Table-4.7 : Concentration, uptake and recovery of Phosphorus as influenced by the application of different liming materials

Treatments	Concentration(%)			Uptake(kg/ha)				APR
	Grain	Stover	Root	Grain	Stover	Root	Total	(%)
Absolute control	0.29	0.03	0.06	3.3	0.9	0.01	4.2	----
STD	0.31	0.05	0.08	6.7	1.3	0.04	8.1	26
STD + PMS @ 0.1 LR	0.26	0.05	0.08	7.1	2.0	0.07	9.2	34
STD+PMS @ 0.1 LR + FYM	0.25	0.06	0.09	9.4	2.5	0.16	12.1	57
STD +ST @ 0.1 LR	0.28	0.04	0.05	7.3	1.4	0.06	8.8	31
STD +ST @ 0.1 LR +FYM	0.27	0.05	0.08	8.5	1.7	0.09	10.2	42
STD + ST @ 0.2 LR	0.28	0.05	0.06	8.9	1.9	0.07	10.9	47
STD + ST @ 0.2 LR + FYM	0.27	0.06	0.09	10.7	2.6	0.13	13.4	66
STD + Ca-Si @ 0.2 LR	0.26	0.05	0.09	8.0	2.0	0.11	10.1	41
STD + Ca-Si@ 0.2 LR+FYM	0.28	0.06	0.13	10.5	2.4	0.21	13.1	64
CD(P=0.05)	**4.58**	**1.07**		**1.52**	**0.42**	**1.63**	**1.48**	

Fig-4.22 : Apparent Phosphorus Recovery by maize crop as influenced by application of different liming materials

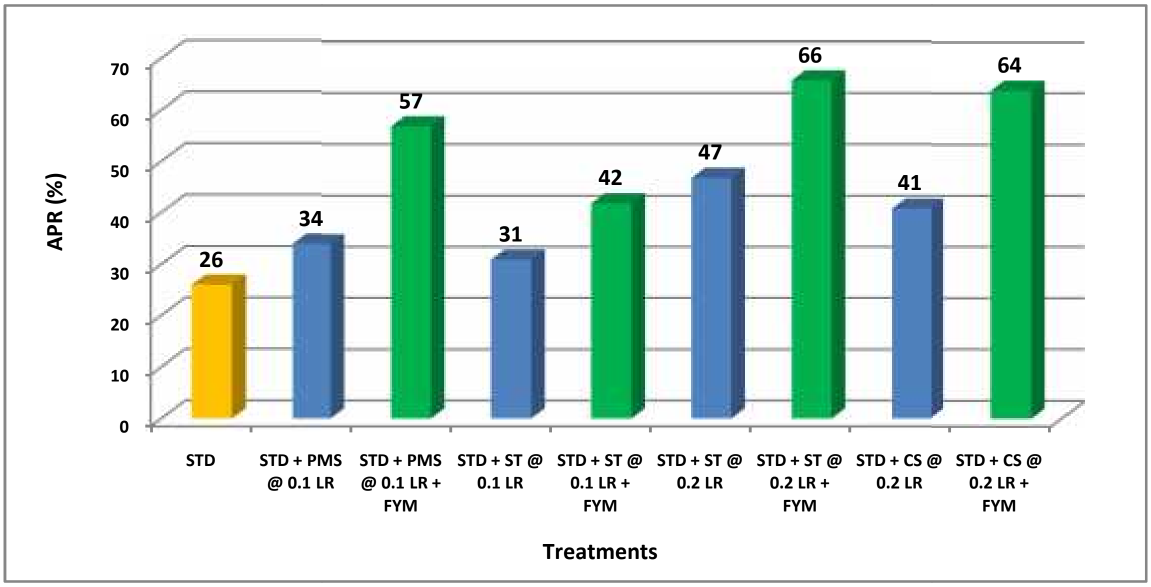


Table-4.8 : Concentration, uptake and recovery of the Potassium as influenced by application of different liming materials

Treatments	Concentration (%)			Uptake (kg/ha)				AKR
	Grain	Stover	Root	Grain	Stover	Root	Total	(%)
Absolute control	0.36	0.39	0.31	4.1	6.0	0.03	10.1	----
STD	0.37	0.35	0.40	8.1	10.5	0.20	18.8	22
STD + PMS @ 0.1 LR	0.33	0.38	0.41	8.9	14.5	0.33	23.6	34
STD+PMS @ 0.1 LR +FYM	0.32	0.43	0.45	11.8	19.6	0.77	32.2	55
STD +ST @ 0.1 LR	0.33	0.32	0.44	8.8	10.4	0.49	19.7	24
STD +ST @ 0.1 LR +FYM	0.32	0.42	0.52	10.2	16.0	0.62	26.9	42
STD + ST @ 0.2 LR	0.36	0.38	0.44	11.3	15.3	0.49	27.0	42
STD + ST @ 0.2 LR + FYM	0.32	0.39	0.52	12.8	18.1	0.75	31.5	54
STD + Ca-Si @ 0.2 LR	0.34	0.40	0.43	10.2	14.8	0.53	25.5	39
STD + Ca-Si@ 0.2 LR+FYM	0.32	0.44	0.60	11.9	19.4	0.96	32.2	55
CD(P=0.05)	**0.08**	**0.12**	**---**	**1.58**	**4.66**	**7.93**	**4.70**	**----**

Fig-4.23 : Apparent Potassium Recovery of maize crop as influenced by application of different liming materials

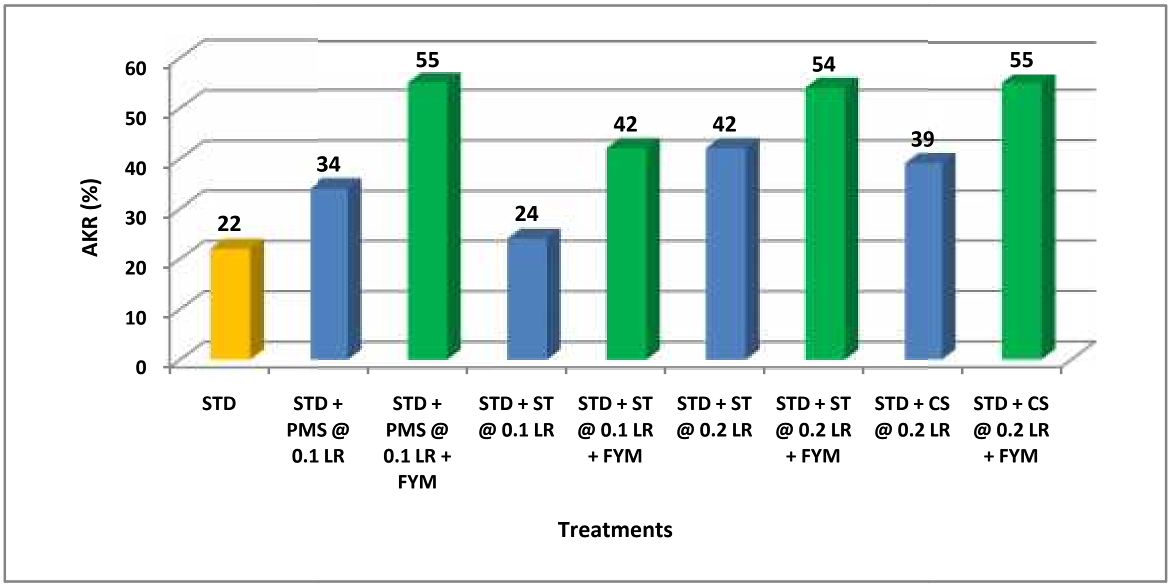


Table-4.9 : Concentration, uptake and recovery of the Sulphur as influenced by application of different liming materials

Treatments	Concentration (%)			Uptake (kg/ha)				ASR
	Grain	Stover	Root	Grain	Stover	Root	Total	(%)
Absolute control	0.06	0.058	0.03	0.6	0.9	0.01	1.5	----
STD	0.05	0.055	0.07	1.0	1.6	0.04	2.7	6.2
STD + PMS @ 0.1 LR	0.05	0.054	0.06	1.4	2.0	0.05	3.5	10.3
STD+PMS @ 0.1 LR + FYM	0.06	0.06	0.07	2.2	2.8	0.12	5.1	18.4
STD +ST @ 0.1 LR	0.07	0.068	0.05	1.8	2.2	0.06	4.1	13.3
STD +ST @ 0.1 LR +FYM	0.08	0.075	0.06	2.5	2.8	0.08	5.4	19.9
STD + ST @ 0.2 LR	0.06	0.07	0.07	2.1	2.7	0.07	4.8	16.9
STD + ST @ 0.2 LR + FYM	0.07	0.082	0.09	2.7	3.6	0.12	6.4	25.1
STD + Ca-Si @ 0.2 LR	0.07	0.075	0.07	2.1	2.7	0.08	4.9	17.4
STD + Ca-Si@ 0.2 LR+FYM	0.08	0.088	0.10	3.0	3.9	0.16	7.1	28.7
CD(P=0.05)	**0.005**	**0.006**	**0.006**	**0.39**	**0.42**	**0.05**	**0.41**	

Fig-4.24 : Apparent Sulphur Recovery of maize crop as influenced by application of different liming materials

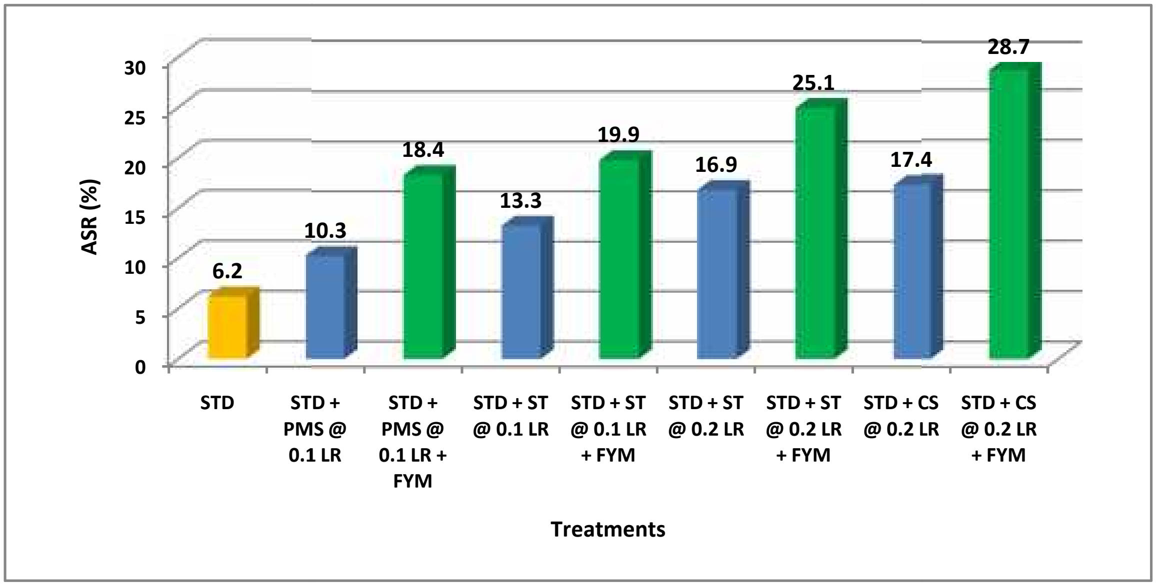
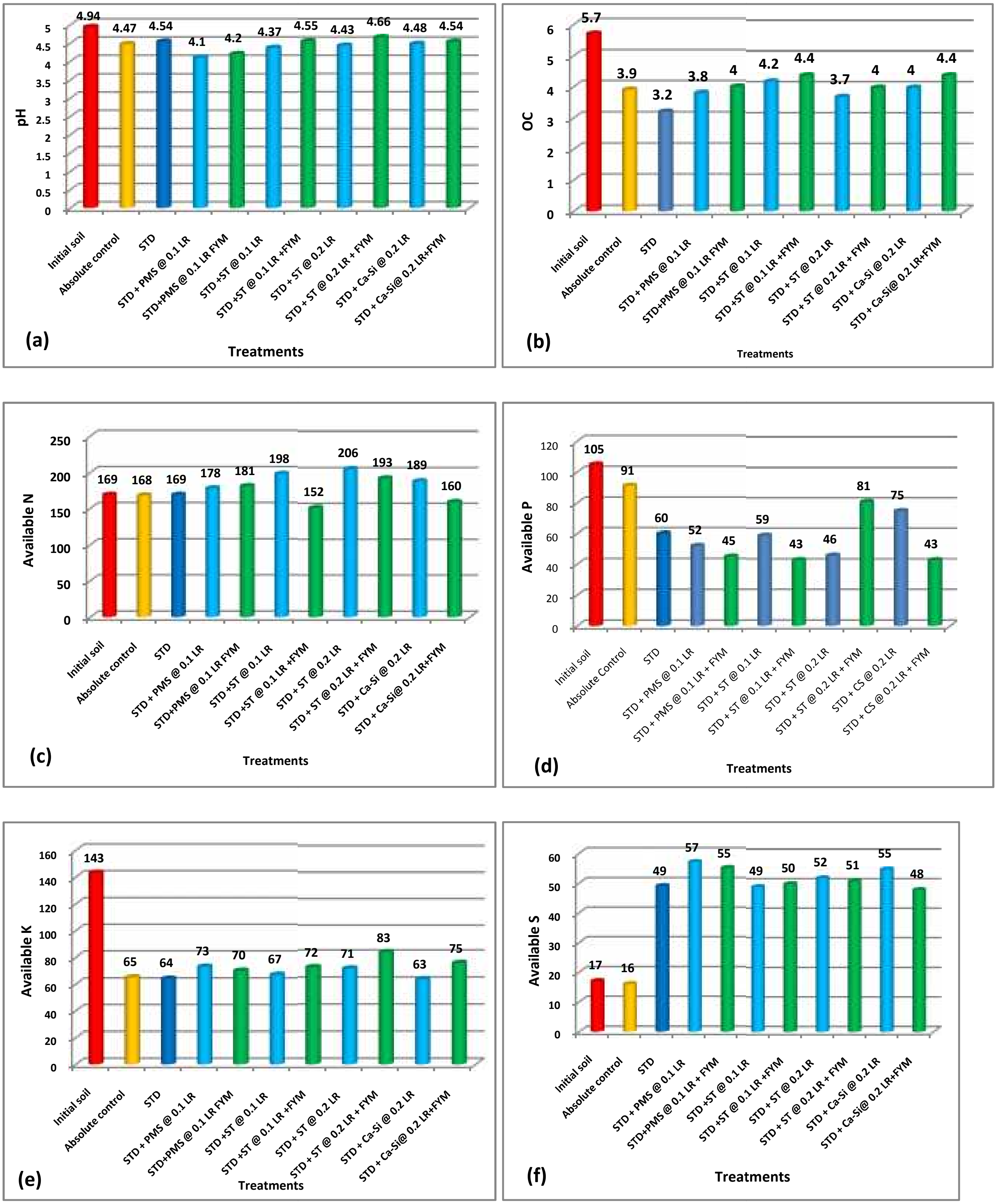


Fig-4.25: Change in soil properties in the post harvest soil



(a) pH, (b) Organic carbon, (c) Available N, (d) Available P,(e) Available K, (f) Available S

INTRODUCTION

In India, out of 328 mha of total geographical area 87.7 mha is subjected to degradation of various kinds, producing less than 20 per cent of its potential capacity (Motiramani, 1971). Approximately 100 mha of land suffer from soil acidity, out of which 51 mha is under forests and 49 mha under cultivation, of which 25.9 mha have pH less than 5.6 and 23.07 mha have pH value between 5.6 and 6.5 (Sarkar, 2002).In Odisha, the acid soils occupy nearly 70 per cent of the total cultivated area (Mitra *et al*,2002). Entire upland (46 %) and major part of the medium lands (30 %) are under acidic. About 21.2 per cent of the acid soil (pH >5.5) is strongly acidic in nature. Out of 30 districts, in 15 districts more than 70 per cent of soils are acidic (Cuttack, Kendrapada, Jagatsinghpur Jajpur,Koraput,Khurda,Nawarangpur,Malkangiri,Dhenkanal,Puri,Rayagada,Mayurbhanj,Nayagarh,Anugul, Kandhamal), 8 districts soils are between 50 to 70 per cent acidic (Jharsuguda,Ganjam, Gajapati,Baragarh, Sambalpur,Sundergarh,Boudh,Deogarh) and rest 7 districts less than 50 per cent of soils are acidic (Bhadrak, Balasore,Kalahandi, Keonjhar, Sonepur,Bolangir, Nuapada).

The acidic soils develop physical, chemical, nutritional and biological constraints for crop production in terms of soil crusting (affecting seed germination), high infiltration rate, low water holding capacity, high permeability, low pH, low cation exchange capacity (due to dominance of 1:1 type of clay), low base saturation (16-67 %), high Al, Fe and Mn saturation percentage, high P fixing capacity (92 %) (Pattanayak and Misra, 1989), poor availability of essential plant nutrients like Ca, Mg, P, Mo, B and Si, poor microbial activity and biologically mediated nutrient transformation processes, poor N_2 fixation due to poor *Rhizobial* activity etc.

Restoration of lost basic cations, amelioration of acidity, supplymentation of different nutrients as per crop requirement, judicious use of chemical fertilizers, proportionate use of organics can help managing acid soils. Liming of acid soil is the way to raise pH, base status, cation exchange capacity, inactive Al, Fe and Mn in soil solution and reduce P fixation (Panda and Koshy,1982 Misra *et al*.,1989, Sahu and Patnaik, 1990, Mishra and Pattanayak, 2002).

To meet the calcium demands as well as to create favourable environment for uptake of other essential nutrients and higher crop yields, liming is an important management option in acid soils. Liming is the addition of any compound containing calcium or calcium plus magnesium to the acid soils that are capable of reducing the acidity of the soil. The main aim of soil liming is to neutralize acidic inputs and recovering the buffering capacity to the soil (Ulrich, 1983).

Liming materials that have potential use in agriculture include organic liming material (Fly ash, Wood ash, organic residue of various crops etc.), inorganic or naturally occurring liming materials including pure limestone, dolomite and stromatolytic limestone and different industrial waste like paper mill sludge, basic slag, gypsum, cement kiln waste, pressmud etc. In the state of Odisha there is large deposit of high grade limestone. These are used for steel industry. Their cost is very high and this cannot be used in agriculture sector Although , research regarding use of limestone and dolomite as acid soil ameliorant has proved their effectiveness in reducing soil acidity and enhancing crop growth, but large quantity of liming materials are generally required for amendment. Liming on the basis of lime requirement data is highly expensive and not cost effective. For many subsistent farmers the high cost of lime prevents their use in agriculture.(Panda, 2009)

Therefore, liming practice should be less expensive and be available within easy reach of farmers besides its suitability. Research has shown that several industrial byproducts and organic residues, which are potential lime sources, can be used if available at an affordable distance. Such materials includes converter slag from steel industries (Torkashvand Ali, *et al*, 2007), Paper mill sludge (Panda, 1987; Sahu and Mitra, 1996; Sahu and Nanda, 1998; Pattanayak *et al.*, 2011), cement kiln waste and precipitated $CaCO_3$ from fertilizer industries (Panda and Das, 1971), which have been successfully used as soil amendments. These materials have comparable performance with limestone and dolomite in raising soil pH neutralizing acidity and increasing available P content of acid soils. In this context, attention has given for the possible exploitation of a natural source of liming materials known as "Stromatolytic Limestone", which is a low grade limestone with high silica content with limited industrial importance and contains 28.32% CaO, 12% MgO and 0.5% P_2O_5 (Misra, 2004 and Pattanayak, 2013). The total reserve of this limestone in Odisha is about 40Mt. Hence, the purpose of the present investigation is to evaluate the "**Comparative performance of different types of liming materials for Maize crop grown in Acid soil**" with following objectives :

To study the influence of liming materials on :-

1) Physico-chemical properties of the soil.
2) Crop growth and yield of maize crop.
3) Nutrient uptake and recovery by the test crop.
4) Post-harvest properties of soil under the influence of liming practice.

REVIEW OF LITERATURE

2.1 Soil acidity

Theoretically, soil acidity is largely associated with the presence of hydrogen and aluminum ions in exchangeable forms (Brady, 2001). Thus, the higher concentrations of these ions in soil solution, higher is the acidity. Most acid soils have been found to be low in fertility, have poor physical, chemical, and biological properties. Generally, soils have natural buffering capacity by which they are able to resist changes in soil pH upon marginal increases in their acidity or alkalinity (Black, 1968). This natural buffering ability of soils, however, varies from region to region as the parent materials and the unconsolidated soil strata differ greatly in their physico-chemical properties. The buffering capacity of soils, regardless of the location is, however, attenuated when soils are continuously exposed to processes that lead to soil acidification. Soil acidity develops from a combination of natural and anthropogenic processes. Naturally, soil acidity develops gradually over time as part of the soil development process and other natural phenomena.

2.2 Chemistry of soil acidity

In acid soil regions precipitation exceeds the evapotranspiration and hence leaching is predominant causing loss of bases from the soil. When the process of weathering is drastic the subsoil, and in many cases, the whole profile become acidic. In these soils, the concentration of H^+ ions exceeds that of OH^- ions. For long it has been considered by soil scientist that the soil acidity is owing to exchangeable H^+ ions only. These soils contain large amounts of soluble Al, Fe and Mn. Water is also a source for small amount of H^+ ions. A large portion of the H^+ ions present in soil remain adsorbed by clay complex as exchangeable H^+ ions. These exchangeable H^+ ions dissociate into free H^+ ions. The degree of ionization and dissociation into soil solution determines the nature of acidity. The free H^+ ions create the active acidity which account for the pH. The exchangeable H^+ ions are reasons for the potential or reserve acidity. The adsorption of H^+ ions by soil colloids takes place by two processes (Bolt, 1976) *viz.* non-selective and preferential adsorption. Clays adsorb H^+ ions by non-selective process. On the negatively charged surface they accumulate as a swarm of counter positive ions. On the other hand, organic colloids exhibit preferential adsorption of H^+ ions. The organic compounds contain acidic groups that are highly selective for association with protons. These are difficultly exchangeable with other cations (Bolt, 1976).

Mukherjee and Chatterjee (1942, 1945) adduced the evidence of dominance of Al in soil acidity in early thirties. Most clay particles interact with H^+ ions. Hydrogen saturated clay undergoes a spontaneous decomposition. The hydrogen ion penetrates the octahedral layer and replaces the Al atoms. The Al released is then adsorbed by the clay complex and an H-Al- complex is formed rapidly. The trivalent aluminum hydrolyses to monomeric and polymeric hydroxyl-aluminum complex (Chernov, 1947) made of units such as $Al(OH)_2^+$ and $Al(OH)^{2+}$, or to forms representing intermediates degrees of neutralization. Aluminium may precipitate as solid phase gibbsite [$Al(OH)_3$] whenever the solubility product of this mineral is exceeded. The hydrolysis reactions of the monomers can be represented as

$Al(H_2O)_6^{3+} + H_2O = Al(OH)(H_2O)_5^{2+} + H_3O^+$

$Al(OH)(H_2O)_5^{2+} + H_2O = Al(OH)_2(H_2O)_4^+ + H_3O^+$

$Al(OH)_2(H_2O)_4^+ + H_2O = Al(OH)_3(H_2O)_3^0 + H_3O^+$

$Al(OH)_3(H_2O)_3^{+0} + H_2O = Al(OH)_4(H_2O)_2^- + H_3O^+$

Each reaction is driven to the right by consumption of hydronium (H_3O^+) ions through reaction with added or indigenous OH^- ions. Successive hydrolysis reactions are associated with solutions of successively higher pH. The $Al(OH)_5^{2+}$ ion is of minor importance and exits over only a narrow pH range of 4.0 to 5.0. The $Al(OH)_5^{2+}$ ions occur only at pH value above those common to soils. The Al^{3+} ion is predominant below pH 4.7, $Al(OH)^{2+}$ between pH 4.7 and 6.5, $Al(OH)_3^0$ between pH 6.5 nad 8.0, and $Al(OH)_4^-$ above pH 8.0 solid phase $Al(OH)_3$ precipitates throughout the pH range covered, whenever its solubility product is exceeded. Each hydrolysis reaction liberates hydrogen ions and lowers the solution pH unless a source of hydroxyl ions is present.

The active species of naturally occurring ions bound to the clay are H and Al. The KCI-Extractable Fe has minor role in soil acidity compared to Al . Humic acid, heavy metal hymetamalonic acid, fulvic acid and humus contribute to acidity in various ways. The total acidity of the soil extracted by $BaCl_2$ –TEA comprises pH dependent acidity and exchange acidity. The pH dependent acidity (variable charge) calculated as the difference between total and exchange acidity increased linearly with increasing free Fe_2O_3+Al_2O_3 plus organic carbon in soil (Misra *et al.*, 1989).

2.3 Sources of soil acidity

2.3.1 Leaching due to Heavy Rainfall

Generally acid soils are common in all regions where rainfall or precipitation in high enough to leach appreciable bases from the surface soils and relatively insoluble compounds of Al and Fe remains in soil. The nature of these compounds are acidic and its oxides and hydroxides react with water and release Hydrogen ions in soil solution and soil becomes acidic. Besides when the soluble bases are lost, the H^+ ions of the carbonic acid and other acids developed in the soil replace the basic cations of the colloidal complex. As the soil gets gradually depletes of its exchangeable beses through constant leaching, its gets desaturated and becomes increasingly acid.

$$CO_2 + H_2O = H_2CO_3$$

$$H_2CO_3 + CaCO_3 = Ca(HCO_3)_2$$

2.3.2 Rocks and Minerals

Soils originating from acidic parent materials lead to the development of acidic soils. These parent materials are over saturated wiyh free quartz (SiO_2>66%). The major minerals in soils are quartz, feldspar, and oxides of Al and Fe. The soils developed from these parent rocks and minerals contain low amount of basic elements e.g. Ca^{2+} and Mg^{2+}.

2.3.3 Humus and Other Organic Acids

Humus materials in soils occur as a result of microbial decomposition of organic matter and contain different functional groups like carboxylic (-COOH), phenolic (-OH) etc. which are capable of attracting and dissociating hydrogen ions. During organic matter decomposition, humus, organic acids and different acid salts may also be produced and also concentration of CO_2 increased. The increased concentration of CO_2, hydrolysis of acid salts and various organic acids combinedly increased the total acidity of soil.

2.3.4 Aluminosilicate clay minerals and sesquioxides

The aluminosilicate clay minerals are considerd to be layer minerals, two or three layer silicate clays typified by Kaolinite (1:1) and montmorillonite (2:1), which contribute to soil acidity by way of holding on to H^+ and Al^{3+} ions to neutralize the negative charge on them. The negative charge arises from (i) isomorphous substitution within Al octahedral and Si tetrahedral layers of higher valence cations with lower valence ones of identical ionic size, and from (ii) the dissociation of protons from the exposed hydroxyl groups of bound water of constitution, both of which are structural components of the crystal lattice leading to the development of the negative charges, which naturally depends on pH of the surrounding soil solution.

The sesquioxides (hydrous oxides of Fe and Al), particles of clay sized dimensions may also contribute to the pool of pH dependent negative charges in soil. The following equations depict how silicate clays and sesquioxides give rise to pH dependent charges in soil.

2.3.5 Acid Forming Fertilizers

The use of ammonium sulphate $(NH_4)_2SO_4$ and ammonium nitrate, NH_4NO_3 increases soil acidity. Ammonium (NH_4^+) ions from $(NH_4)_2SO_4$ when applied to the soil replace calcium

.

(Ca^{2+}) ions from the exchange complex and the calcium sulphate ($CaSO_4$) is fromed ans finally leached out.

$$(NH_4)_2SO_4 \longrightarrow 2NH_4^+ + SO_4^{2-}$$

$$2NH_4^+ + SO_4^{2-} + Ca\ (Clay) \longrightarrow CaSO_4 + 2\ NH_4\ (Clay)$$

$$2\ NH_4\ (Clay) + 3O_2 \longrightarrow 6H\ (Clay) + 2HNO_3$$

Besides, basic portion of ammonium sulphate, $(NH_4)_2SO_4$ is NH_4^+ and it undergoes biological transformation in the soil and form acid forming nitrate (NO_3^-) ions. Similarly, sulphur also produce acid forming sulphate (SO_4^{2-}) ions through oxidation.

2.3.6 Aliminium and Iron Polymers

The Al^{3+} ions displaced from clay minerals by cations are hydrolysed to monomeric and polymeric hydroxyl aluminium complexes. Hydrolysis of the monomeric hexaquo aluminium or ions forms are illustrated by the following stepwise reactions with the liberation of hydronium ion (H_3O^+) and lower soil pH. Each successive step occurs at a higher pH.

2.3.7 Carbon dioxide

Carbon dioxide in soil is produced from many sources. Decaying of organic matter, root and microbial respiration produce CO_2. This CO_2 by reacting with water in soil produce weak acid called carbonic acid. This is the same acid that develops, when CO_2 in the atmosphere reacts with rain water in the form of acid rain. Organic matter decomposition also produces several other organic weak acids to make the soil acidic slowly over a long period of time.

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

2.4 Productivity constraints of acid soils

Acid soils pose many limitations to crop growth by way of toxic effects of acidity and of certain nutrient elements and restrictions on availability of certain other nutrients.

2.4.1 Deficiency of major nutrients

The acid soils of india are generally poor in available nutrients owing to the adverse effect of soil acidity, low base saturation, microbial and nutrient imbalances (Mandal *et al*., 1975; Mandal, 1976; panda and Koshy, 1982; Tripathi *et al*.,1982; Singh *et al*., 1983; Mandal, 1984).

Nitrogen : The organic matter and N status of acid soils show extreme variation depending upon the nature of vegetation and intensity of organic matter decomposition.

Except the brown forest soils, the other group of acid soils of Orissa are low in organic matter and total N status (Panda and Nanda, 1985). Total N content of broad acid soil groups of Orissa varied from 0.027 to 0.093 % and C/N ratio from 8:1 to 13.7:1(Patra, 1987).

Phosphorus : Availability of both native and applied water soluble P are low because of high P fixation capacity of acid soils. Most of red and lateritic acid soils of Odisha are low in available P (Bray’s 1P : 1.3 to 5.9 ppm) although their total P_2O_5 content is quite adequate ranging from 0.08 to 0.35 % (Panda and Mishra, 1969). High P fixation has been observed in lateritic soils of Odisha (Sahoo,1985), in Sikkim (Gupta and Prasad,1983), in Kerala (Madhu Soodhan and Padmaja, 1983), in Bihar (Ghose *et al*., 1997).

Potassium : Potassium status of acid soil is characterized by extreme variation with differences in parent material composition and the degree of weathering of K-bearing minerals. Mandal (1976) reported K fixing capacity to vary from 0 to 17 %. The magnitude of K adsorption was higher in clayey soils rich in organic matter than in other (Kumar, 1990). Roy (1987-88) has indicated high percentage of upland soils of Bihar to be low in K. Most of the laterite soils of Odisha have low K fixation capacity. Much of K is lost owing to leaching (Misra and Misra, 1979).

2.4.2 Deficiency of secondary nutrients :

Ca and Mg deficiencies are key limitations to plant growth in many kind acid soils, especially in highly leached, sandy soils. With increasing soil acidity, Al and Mn replace exchangeable Ca and Mg, and in soils with low CEC the resultant low levels of Ca and Mg may cause deficiency problems with some crops (Foy 1984; Fageria *et al.*,1991). Crops remove between 20 and 150 kg Caha^{-1} and 10 to 80 kg Mgha^{-1} (Sanchez, 1976). The availability of Ca and Mg to plants is influenced by the percentage Ca and Mg saturation, the total Ca and Mg supply, the concentration of Ca and Mg in the soil solution, and by the presence of ions such as Al^{3+} and Mn^{2+}, which inhibit Ca^{2+} and Mg^{2+} absorption. While inadequate soil Ca level in the topsoil are noticeably manifested on plant growth, inadequate Ca levels in the subsoil may be invisible (Adams, 1984). For root growth, Ca deficiency is discernible by the death of the meristematic root tissue. Because of the incapability of plants to translocate Ca within the phloem tissue, roots, cannot grow in a soil zone that is Ca deficient (Adams, 1984).

Absolute Ca deficiency is difficult to identify within the acid soil complex except in the most highly leached acid soils with low CEC (Foy, 1984; Kamprath & Foy, 1985). This is because the levels of Ca required for essential growth functions are so low as to approach those of micronutrients (Wallace *et al*., 1966), therefore the majority of the Ca in soils and in plants serves as an exclude or detoxifier of other elements, such as Al and heavy metals that might otherwise be toxic (Foy, 1992). While absolute deficiencies of Ca have been attributed to possible Al-Ca antagonism rather than to low Ca supply per se, recent evidence suggests that Ca deficiency can be a worse growth-limiting factor than Al toxicity (Foy, 1992). This is because some of the acid soils can be particularly low in exchangeable Ca without a concurrent level of soluble Al (Spain *et al*., 1975).

Magnesium deficiency may limit plant growth on acid, sandy, highly leached soils having low CEC values and possibly high Al saturations. The uptake of Mg is antagonized with Al and Ca for exchange sites, it is often deficient in the topsoil because of acidification, or because of application of large quantities of soluble Ca. Thus, limiting to near neutrality with calcitic lime in acid soils low in available Mg can exacerbate Mg deficiency, so can application of high levels of K (Kamprath & Foy, 1985). The critical Mg saturation levels have been reported as 5 to 10 % of CEC, with a Mg/K ratio of at least 0.5 (May land & Grunes, 1979).

2.4.3 Toxicity problems

Aluminium Toxicity

Al toxicity is the major limiting factor for plant productivity on many acid soils (Kinraide, 1991). In the tropics, Al toxicity has been identified as a major constraint for the production of maize (Zea mays L.), sorghum (Sorghum bicolor) and rice (Oryza sativa) (De La Funete-Martinez & Herrera-Estrella,1999). The most easily recognized symptom of Al toxicity is the inhibition of root growth, and this has become a widely accepted measure of Al stress in plants. The root system of plants severely affected by Al toxicity is often collaroid in appearance, with many stubby lateral roots and no fine branching (Kamprath & Foy, 1984; Delhaize & Ryan, 1995; Kochain,1995). The toxic effect of Al on roots has a clear effect on plant metabolism by decreasing mineral nutrition and water absorption. Aluminium has been shown to interfere with cell division in plant roots ; inhibit the respiratory activity of mitochondria; increase pectin, hemicelluloses and cellulose contents of root cell walls; reduce DNA replication; decrease cell permeability by coagulating protein and inhibiting cell division ; reduce root respiration; precipitate nucleic acid by forming strong complexes; inhibit cation transport across the plasma membrane; block K^+ uptake in root hairs; interfere with uptake, transport, and use of several nutrients (P, K, Ca, Mg, Zn and Fe) and water by plants (Kamprath & Foy, 1984; Keltjens, 1990; Keltjens & Djikstra, 1990; Baligar *et al*., 1993; Delhaize & Ryan, 1995; Kochain, 1995). Therefore, crop production in acid soils is largely affected by limiting water and nutrient uptake caused by the inhibition of root growth and function that result from the toxic effects of Al, in addition to direct effects on plants, Al complexes with some nutrients such as P, reducing their availability for root uptake (Haynes & Mokolobate, 2001).

Manganese Toxicity

Excess Mn seems to affect plant tops more directly than roots. Manganese produces more definitive symptoms in plant tops than Al for a given plant, Mn accumulates in proportion to plant injury. Plant symptoms of Mn toxicity include marginal chlorosis and necrosis of leaves, and leaf puckering (Foy, 1984; 1992). In severe cases of Mn toxicity, plant roots turn brown, usually after the tops have been severely injured. Plant symptoms of Mn toxicity are often detectable at stress levels that produce little or no reduction in vegetative growth (Foy *et al*, 1978); Manganese toxicity alters the activities of enzymes and hormones in plant; causes the destruction of indole-3-acetic acid (IAA) through increasing the activity of IAA oxidase, amino acid imbalance, lower respiration rate, reversal of growth inhibition of roots caused by enhanced auxin production (Robson, 1988). Manganese toxicity is often associated with a decrease in Ca concentration of plants, and supplying additional Ca to the growth medium sometimes reduce Mn accumulation, decreases the severity of Mn induced chlorosis and alleviates growth reductions (Smith, 1979).

2.4.4 Microbial activity

Soil acidity affects not only plant growth but also the biological activity of soils. Poor microbial activity in acid soil leads to low nitrogen and sulphur availability. Absence or low counts of *Azotobacter* are recorded in acid soils (Pattanayak et al., 2008) and their nitrifying capacity was less but population of *Beijirinckia* proliferates in such soil (Subba Rao, 1983, Sharma *et al.*, 1983). Russel (1961) concluded that total microbial population is little affected by soil reaction in normal range but the activities of different groups of organisms are quite dependent in soil reaction. Bacteria are not very well active in soil with low pH. Patra (1974) working on acid soils of Odisha reported that bacterial population of soil increased on application of PMS. The increase was more pronounced with FYM (Pattanayak *et al.*, 2008).

The management of acid soils should aim at realization of production potential either adding of amendments to correct soil acidity and correct the soil abnormalities or to manipulate the agricultural practices to obtain optimum crop yield under acid soil conditions. One of the practices is to grow acid tolerant crops or varieties (Foy, 1984) and other is amelioration of acid acidity through liming (Kamprath, 1984).

2.5 Amelioration measure of acid soils

Several agricultural practices have been recommended to overcome the problem of tropical acid soil infertility. Among them, the most common and widely used method is liming, which is defined as the application of ground calcium and/or magnesium carbonate, hydroxides, and oxides aiming at increasing the soil pH, modifying its physical, chemical and biological properties (Edmeades and Ridley, 2003).

Amelioration of soil acidity through liming is a common practice (Ponnette *et al.*, 1991; Quoggio *et al.*, 1995). Besides lime, some other materials are also used as acid soil amendment, such as gypsum, phosphate rocks (Alva *et al.*, 1990; McLay and He *et a.*., 1996) and some industrial byproducts like basic slag (Bhat *et al.*, 2007), paper mill sludge (Sahu and Nanda, 1987; Pattanayak *et al.*,2011), press mud (Annual report, NAE) have been suggested. The main management practice to ameliorate acid soils is the surface application of lime and calcareous materials (Bolan *et al.*, 2003). The main aim of the soil liming is to neutralize acidic inputs and recovering the buffering capacity to the soil (Ulrich, 1983). To minimize the cost involvement in liming and to make the particle effective and efficient, Pattanayak *et al.*, (2011) suggested for application of paper mill sludge mixed with FYM and to apply below the seed zone on the day of sowing of seeds behind the plough.

The management of acid soils should aim at realization of production potential either adding of amendments to correct soil acidity and correct the soil abnormalities or to manipulate the agricultural practices to obtain optimum crop yield under acid soil conditions. One of the practices is to grow acid tolerant crops or varieties (Foy, 1984) and other is amelioration of acid acidity through liming (Kamprath, 1984).

2.6 Beneficial effects of liming

Liming is important for management of acid soils for it has considerable influence on crop yield and soil environment besides neutralizing soil acidity. The direct and residual beneficial effects of lime were reported by many workers (Prasad *et al.*, 1983; Mishra, 2002).

2.6.1 Lime as amendment and nutrient

Role of lime is dual, as soil amendment (Foy, 1984) and plant nutrient supplying material (Prasad *et al.*, 1983). It improves base saturation, effective CEC (Patiram *et al.*,1990), lime potential and increase availability of N, P, Ca and Mg in soil (Bishnoi *et al.*, 1988; Sahu and Patnaik, 1990; Pattanayak *et al.*, 2011).

2.6.2 Effect of liming on toxic elements

Iron toxicity in red and laterite rice field is a problem when the dissolved Fe in the rooting medium exceeds 300-500 ppm. Deficiencies of P, K, Ca, Mg and Si in soil induce increased uptake of Fe. Iron toxic soil treated with Udaipur rock Phosphate @ 80 kg P_2O_5/ha containing good amount of dolomite and calcite resulted in 67 and 72 per cent increased rice grain yield of resistant variety Samalai and susceptible variety Jajati over control yields of 1.5 and 0.9t/ha, respectively. Such composition of rock phosphate helped the rice plants in uptake of less Fe and more Ca compared to other P sources (Pattanayak *et al.*, 1997).Lime inactivates toxic elements like Al (Haynes, 1984; Patiram *et al.*, 1990; Verma *et al.*, 1996; Mishra, 2002), Fe, and Mn in soil solution (Bishnoi *et al.*,1988; Panda and Koshy *et al.*, 1982). The reduction in exchangeable Al and Mn probably occurs due to their precipitation as carbonates, oxides or hydroxides by liming (Prasad, 1992).

Different forms of soil aluminum, namely exchangeable, extractable and organically bound decreased with liming except amorphous Al which increased some what on liming (Sing *et al*., 2000). The increase in amorphous form of Al may be attributed to the fact that liming neutralize the Al^{3+} ions occupying exchange sites of the soil colloids by forming the amorphous oxides or hydroxides i.e. the (Al-OH) polymers which may interact with organic matter content of soil to form chelate/complex with large area known for its high adsorptive power (Sanyal *et al.*, 1995) thereby ensuring partial stabilization of former. According to Mongia *et al.*, (1998), water soluble and exchangeable Al in soil could be brought down to trace level by application of one half of LR and ¼ th level of LR. Gupta *et al.*, (1990) observed that lime application @ $20qha^{-1}$ antagonized the toxic effects of Fe and Al. Dixit *et al.*, (1993) found application of lime and K decreased the different forms of Al and Fe and acidities. Similar studies were made by Muralidharan *et al.*, (2001) to investigate the effects of lime and P application on extractable Al and Al potential in acid soils of Kerala.

Maji *et al*., (1996) observed liming neutralized exchangeable Al^{3+} to a greater extent than exchangeable H^{+} and reduced available Fe and Mn and exchange acidity in coastal acid saline soils of West Bengal. Iron and manganese contents decreased significantly due to application of zinc and liming materials like $CaCO_3$ (Mukhopadhya *et al.*, (2001). The results further indicated that such decrease in iron and manganese content has been found to be counteracted by application of higher levels of well decomposed FYM suggesting a favorable effect on release of Fe and Mn in soils. Alleviation of Al toxicity by gypsum or phosphogypsum application partly is attributed to the exchange of OH^- ions by SO_4^{2-} termed as the “self liming effect” by Reeve and Sumner (1972).

2.6.3 Effect of liming on soil physical properties

Liming of acid soil is found to improve the physical condition of soil. Barade *et al*., (1998) conducted a field experiment where liming improved soil aggregation, maximum water holding capacity and hydraulic capacity of soil. Organic manuring along with lime resulted in still better aggregation of these soils. Prasad and Singh (1980) also observed beneficial effect of liming and FYM on soil aggregation. Water stable aggregates increased from 16.8 per cent under control to 19.4 per cent with 4tha^{-1} lime and 18.6 per cent with 4tha^{-1} press mud which may be attributed to enhance flocculation of soil particles (Sewaram *et al.*, 1992).

2.6.4 Effect of liming on soil chemical properties

(a) Soil pH : An increase in soil pH is known under the many soil crop- lime situations (Bishnoi *et al.*, 1998; Gupta *et al*., 1989; Gupta *et al.*, 1990; Dixit *et al.*, 1993) and has been attributed to an increase in degree of base saturation and a decrease in exchangeable H^+ and Al^{3+} (Wikander, 1960; Bishnoi *et al.*, 1988). Sahu *et al*., (1990) observed that lime and organic matter additions in highly weathered acid and laterite soils resulted in an increase in the CEC and pH values, which are essential for higher crop productivity.

Studies made by Pradhan and Mishra (1982) showed application of paper mill sludge and organic amendments caused a rise in soil pH. By increasing lime level there was rise in soil pH (Singh *et al.*, 2000). The soil pH under lower dose or lime was comparable to that under full dose of lime which gradually decreased with time probably on account of uptake and downward movements of lime due to leaching. Similar observations were made by Gupta *et al.*, (1989).

(b) Forms of Acidity : The decrease in exchangeable acidity with liming may be attributed to the neutralization of exchangeable Al^{3+} and H^+ where as the reduction in pH dependent and total acidity would be due to neutralization of hydroxyl-Al and Fe-polymer (Mclean, 1964; Verma *et al.*, 1996). Other reasons may be that on liming Al^{3+}, Fe^{3+} and Mn^{2+} which are dominant in acid soil get reduced and consequently decrease the different forms of acidities thereby improving soil pH and base saturation (Haldar and Mandal, 1987).

2.6.5 Effect of liming on nutrient availability

Liming of acid soils has been proved to be beneficial in increasing available nutrients in acid soils.

Nitrogen (N)

Lime application increased the available N status by 22.6 per cent in acid soils of Himachal Pradesh (Bishnoi *et al.*, 1988). It was also noticed that liming benefitted the soils, already low in native available N. Pal *et al.*, (1985) conducted a laboratory experiments in alluvial acid soils of West Bengal and found available N status of soil to increase within 20 days of incubation at ¼ th or ½ dose of lime application. Subsequent studies by Behura *et al.*, (1996) found combined application of lime and fertilizers increased the available N status of soil. Increase in available N in limed soil may be an indirect effect of enhanced pH and direct effect of accelerated decomposition and mineralization of organic N (Patnaik, 1961).

Phosphorous (P)

The mechanism suggested for increased P availability due to action of lime is due to breaking of Al and Fe phosphates vis-a-vis mineralization of organic P (Mandal., 1975). Muralidharan *et al.*, (2001) conducted an experiment in acid saline soils of Kerala to show the effect to different levels of lime and P application on the available P and phosphate potential. Liming and flooding of soil resulted in a decline in available P content of soil initially and later on increased up to 60 days after transplanting (DAT) of rice. Lime levels and application of P influenced the P availability in soil at 30 DAT but only the later influences P availability at 60 DAT.

The initial decline in available P on liming is attributed to increased P adsorption (Haynes, 1982; Paliyal *et al*., 2002) because of the formation of new adsorption surfaces in soils high in exchangeable Al caused by precipitation of exchangeable Al as amorphous hydroxyl-Al polycations. A proportionate increase in available P up to 30th day, with increase in lime levels was observed by Mongia *et al*., (1998) in acid saline soils of Sundarbans (West Bengal). Application of lime or press mud @ 4 tha^{-1} increase P availability in acid soils.

Conflicting reports suggest that the prior liming of highly weathered acid soils can result in an increase, a decrease, or no change in the availability of applied phosphate. Adsorption of phosphate by amphoteric soil surfaces generally decreases slowly as the pH is raised from 4.0 to 7.0. However, in soils initially high in exchangeable Al^{3+}, liming results in the formation of new, highly active, phosphate adsorbing surfaces as the Al^{3+} ions precipitate as insoluble polymeric hydroxy-Al cation species. Thus, if an acid soil is reacted with lime and then phosphate, without intervening air drying, liming can increase phosphate adsorption. If the same limed soil is air dried before reaction with phosphate (*e.g.* adsorption isotherm studies), liming decreases phosphate adsorption. Apparently, air drying alters the surface characteristics of recently limed soils, probably by promoting the crystallization of the hydroxy-Al cation polymers as gibbsite. An important phenomenon, which is often overlooked, is that liming can increase phosphate availability by stimulating mineralization of soil organic phosphorus. However, at high soil pH values, the precipitation of insoluble calcium phosphates can decrease phosphate availability. Since Al toxicity is characterized by the inhibition of the uptake, translocation and utilization of phosphate by plants, liming often increases the utilization of soil phosphate by plants through amelioration of Al toxicity (Haynes, 1984).

Potassium (K)

Liming acid soils may either increase or decrease the availability of K. Decreasing K availability can be explained by increased fixation like NH_4^+ in acid soils. The increased CEC on liming retains more fertilizers K and other cations against leaching (Mishra and Misra, 1979). The increase in available K status of acid soils by liming (Bishnoi *et al.*, 1988; Behura *et al*., 1996) can also be explained on the basis that release of K from non exchangeable fraction to available pool gets accelerated when acid soils are limed (Kamprath and Foy, 1987; Prasad *et al*., 1987; Patiram *et al.*, 1988).

Calcium and Magnesium

Liming increases availability of Ca and Mg and their degree of saturation on soil colloids (Bishnoi *et al.*, 1988; Behura *et al.*, 1996; Pattanayak *et al*., 2011). Increasing the dose of lime resulted in an increase in exchangeable calcium of soil in Bihar (Mathur *et al.*, 1991; Prasad, 1992). Similar studies were made by Gupta *et al.*, (1989) in acid soils of Sikkim, Pradhan and Misra (1982) in acid laterite soils of Odisha and Chatterjee *et al*., (2001) in acid laterite soils of Konkan.

Sulphur

Lime application has positive influence on sulphur availability in acid soils. While studying the influence of graded doses of S in terms of SSP on maize and mustard grown in a sequence in an *Alfisol* treated with PMS at the rate of 0 and 30% LR. It was observed that the yield of maize grown first in the sequence increased up to 30 kg S/ha, where as mustard crop responded to 45 kg S/ha. Lime exerted positive influence on the yield of both the crops. (Badajena, 2003).

Micronutrients

Generally availability of all micronutrients is reduced due to liming except molybdenum but Lal and Mathur (1989) noted an increase in availability in presence of high organic matter in soils.

Molybdenum

Soil acidity exerts a regulatory effect on the behavior of molybdenum in soils. Singh and Sinha (1987) noted higher availability of Mo in Ranchi soils due to organic manuring and liming, Pal *et al.*, (1985) noted higher availability of Mo in alluvial acid soils of West Bengal owing to liming. Molybdenum availability decreased in acid soils due to exchange of MoO_4^{2-} and $HMoO_4^-$ ions on the colloids for OH^- in the solution. Verma and Jha (1970) observed that liming doubled the oxalate soluble molybdenum and increased its uptake by crops. Ebhin Masto *et al.*, (2000) reported higher availability of Mo in Srikakulam district due to application of lime.

Boron

Boron is an anoin like molybdenum but unlike molybdenum its adsorption/precipitation increases with rise in pH. Sinha and Singh (1966) reported lowering of water soluble B upon liming as well as its uptake by soybean and groundnut plants. More than 72 per cent conversion of water-soluble to insoluble form on liming acid soil was noted by Singh and Singh (1985). It appears that the major boron fixing inorganic compounds (hydroxides of Fe and Al) increases with a rise in pH and facilitates boron adsorption in high pH soils.

Cupper

An increase in concentration as well as uptake of copper has been found with increasing dose of liming materials. Organic manuring increased available copper status in acid soils due to chelation (Lal and Mathur, 1989).

2.6.6 Effect of liming on Microbial Population

Liming stimulates microbial activity leading to mineralization of organic N and fixation of atmospheric nitrogen (Raychaudhuri *et al.*, 1998). Several processes like ammonification, organic matter decomposition and nitrogen fixation are stimulated by application of lime.

The population of bacteria, actinomycetes, Azotobacter, cellulose decomposers and phosphate solubilizers increased on liming or organic manuring, whereas Fungi &

Beijerenckia proliferated in the absence of lime or FYM. Except fungi almost all other microorganisms survived in neutral to alkaline pH (Sharma *et al*., 1983). In acid soils, the activity of non-symbiotic free living bacteria, non-symbiotic free living BGA and symbiotic rhizobia could be improved by application of lime, phosphorus and molyddenum (Roy *et al*., 1985).

2.7 Dose of lime application

The economic feasibility of liming need to be evaluated before recommendation as ameliorant. When applied in higher doses, lime is lost by leaching from the top soil of light textures soils because of their low exchange capacity. Attempts were made to reduce the dose of lime one fourth to one-half of lime requirement and apply in split doses. (Tripathy *et al.*, 1982; Prasad *et al.*, 1983; Pradhan and Misra, 1985). Singh and Singh (1985); Sahu and Pal (1987) and Panda (1987) found lime dose of one-fourth of lime requirement to be optimum for getting a good crop yield. Pal and Mandal (1985) found one-fourth dose of lime to be quite sufficient in alluvial acid soils of Islampur. Patiram *et al.*, (1990) recommended lime application at the rate of 1 to 2 times exchangeable Al^{3+} to raise the pH above 5.5. Mathur *et al.*, (1991) observed that the percent net return due to liming increased with time at all levels of split doses and 0.1 LR dose was found most profitable although 0.2 LR dose was sufficient to meet the Ca requirement of crops. Sahu and Nanda (1988) recorded economic response to lime sludge applied at LR dose to variety of crops in red loam soils of Semiliguda, Odisha. Mishra (2002) from experiments on use of PMS for dicot crops recommended lime @ 0.2 LR and for monocot @ 0.1 LR preferably mixing with FYM for efficient use in *Alfisol* of Odisha.

2.8 Time and Method of Application

The rate of reaction between soil and lime depends mainly on moisture condition of soil. Under optimum moisture condition, neutralization of soil acidity may be affected to a satisfactory level in the monsoon. But if irrigation facilities are available it can be applied in Rabi season also.

Deep placements of lime were in one way found superior to surface application and application of lower doses of lime (3 to 4 qha^{-1}) in furrows at the time of sowing of crops was advocated (Mathur, 1985) for poor and marginal farmers of Chotanagpur Plateau (Bihar). Rhizosphere application of paper mill sludge (PMS) mixed with FYM has been suggested by Mishra (2002) and Pattanayak *et al*., (2011).

Pradhan and Misra (1985) advocated that the paper mill sludge, a by product of paper mills should be applied in two splits, one-half mixed with the soil one week before sowing and the rest applied 3 weeks interval in bands at 8 cm deep into soil and covered up before drilling other fertilizer used for top dressing.

2.9 Efficiency of liming material to neutralize soil acidity

The capacity of liming material to neutralize soil acidity depends upon (i) type of liming materials, (ii) fineness of liming materials.

2.9.1 Type of liming materials influencing neutralization of acidity

Materials like carbonates, oxides, hydroxide of calcium and magnesium compounds are referred as “Agricultural lime” which neutralize soil acidity (Adams, 1984). Liming materials are classified as (a) naturally occurring (b) Industrial wastes.

(a) Naturally occurring liming materials

Among the naturally occurring lime sources, calcitic, dolomitic and stromatolytic limestones are important. But the former two have industrial uses and hardly have prospects of being economically used as agricultural lime. Limestone containing more than 47 per cent CaO and above is usually preferred in the manufacturing of cement. Odisha has a limestone reserve of 1682 M tonnes. Stromatolytic limestone is a poor grade lime, which contains 28-32 per cent CaO, 12 per cent MgO and 0.5 per cent P. The algal deposits in it contribute to its P content (Panda and Mishra 1970). High silica content restricts its use in industry, hence is good for agriculture. Estimated reserve of such material is 40 M Tones in Odisha.

(b) Industrial waste

Several industrial waste such as steel mill sludge (42% CaO), blast furnace sludge from steel industries, limes sludge from paper mills (40% CaO), press mud cake from mills (33% CaO), cement kiln wastes and precipitated calcium carbonate from fertilizer factories have potential for use as soil amendments which are ecofriendly (Panda and Das, 1971; Vithal Rao *et al.*, 1970; Mishra, and Pattanayak 2002).Press mud from sugar mills using carbonation process, cement kiln wastes and precipitated calcium carbonate from fertilizer industry can be used for amelioration of acid soil successfully and economically. (Sewaram *et al.*, 1992)

2.9.1.1 Efficacy of different liming materials

Ananthanarayana *et al*., (1993) conducted an experiment in acidic soils of Shimong District (Karantaka) to study the efficiency of different liming materials in neutralizing soil acidity. It was concluded from their study that CaO, $Ca(OH)_2$ and $CaCO_3$ were effective in reducing soil acidity at a rapid rate. The rate of reaction of these materials with acid soils was maximum during the first week of application. Mussoorie rock phosphate was not effective in ameliorating the soil acidity over a period of eight weeks while dolomite, paper mill sludge and basic slag neutralize the soil acidity fairly late i.e. after two months of their application in soil.While working on the quality of liming Singh *et al.*., (1985) reported that various liming materials may be arranged in order of superiority as calcite limestone > dolomitic limestone > basic slag= burnt lime.

Relative efficiency of four sources of lime viz. limestone, dolomite, basic slag and lime sludge was compared in lateritic soil taking three successive crops of maize. When applied on equivalent basis the average relative efficiency were 100, 94,111 and 108, respectively (Panda, 1967). Panda and Das (1971) evaluated these materials at 3 levels, viz. 1000, 2000 and 3000kg $CaCO_3$ ha^{-1} and reported that lime sludge can profitably be used as amendment in light textured soils at low doses because of its faster solubility.

2.9.2 Fineness of liming materials

The effectiveness of agricultural limestones depends upon degree of finess, because the reaction rate depends on the surface area in contact with the soil (Singh *et al*., 1985). Amounts of a particular limestone fraction needed to produce a given rise in pH two years after application shows, that much less of the finer fractions than of coarser fractions is needed to achieve a certain pH, particularly at lower reference pH values (Love *et al*., 1960). Limestones with at least 50% passing through a 60 mesh screen are quite satisfactory for most agricultural purposes (Barber, 1984).

Pattanayak and Pandey (2012) while working with Stromatolyte a low grade naturally occurring lime stone recommendation of 22 mesh sieve size for its effectiveness. It could be became more reactive after 20 DAS and continued till 60 DAS.

2.10 Crop response to liming

Crops have been classified according to their relative response to liming. Mandal *et al*., (1966) grouped upland crops into three categories (i) high response group (Pigeon pea, Soybean and Cotton) (ii) Medium response group (Maize, Groundnut, Gram, Lentil, Pea) (iii) Low response group (Paddy, Potato, Small millets etc.). Under rainfed condition high responsive crops may be grown in the 1st year of liming followed by medium responsive crops in the next year/season. Low responsive crops may be grown when effect of liming is further reduced. Pradhan and Misra., (1982) conducted a field experiment to show the effect of application of paper mill sludge and organic amendments on yield of maize and horse gram. The yield of crops increased significantly over control due to lime application, particularly when applied with NPK fertilizers. 0.5 LR was significantly superior to control but at par with higher doses. The organic amendments brought about 15 per cent increases in grain yield of maize over no lime application.

Application of lime, FYM and P fertilizer source individually and combination resulted in significance in grain yield and uptake of Ca and Mg by wheat in acid *Alfisol*s of Himalayan region (Sharma *et al.*, 1994). The amelioration effect of acid soils following lime and K application increased significantly the yield of grain and straw in a wheat-soybean-linseed cropping system (Dixit *et al.*, 1993; Dixit *et al.*, 1995).

Patiram *et al.*, (1990) reported that application of dolomite limestone equivalent to two times the exchangeable Al completely eliminated the exchangeable Al and gave optimum yield of wheat and maize (Patiram *et al.*, 1989) in acid soils of Sikkim. Application of lime @ 20 and 25 qha^{-1} caused significant increase in grain yield and uptake of P, K, Ca and Mg by wheat and maize in acid soils of Nagaland (Datta *et al.*, 1983) which corroborated with the finding of Gupta *et al*., (1989).

Bhat *et al.*, (2007) reported that calcite and basic slag applied @ 1/5th LR dose than 1/10th LR dose increased the grain yield of wheat to the extent of 21.9 and 31.0 per cent over the no lime treatment, respectively. Their results further showed that increase in the yield of wheat was more with basic slag 1/5th LR than with calcite. Incorporation of organic sources of nutrients particularly FYM and poultry manure caused a further increase in yield, the magnitude being 56.2 and 60.3 per cent respectively over the no lime treatment and similar trend of change also occur in straw yield.

Legumes are more responsive to lime in acid soil. Application of limestone powder @ 2500 kgha^{-1} and lime sludge @ 1250 kgha^{-1} raised the yield of groundnut from 12.12 to 17.1 and 18.9 qha^{-1} hectare respectively in sandy loam laterite soil of Dhenkanal District of Odisha. The shelling percentage was also improved by 12 per cent due to liming (Hanson and Sahu, 1971). Dutta *et al.*, (1997-98) reported that liming up to 25 per cent LR and 50 per cent LR increased significantly the yield attribute characters, pod yield and oil content of groundnut. Chatterjee *et al*., (2001) worked on effect of lime on yield, quality and nutrient uptake by 6 groundnut varieties in an acid soils of Konkan and reported at 10, 50 and 100% LR of soils in furrows increased the dry pod yield by 15.5, 23.4 and 32.6% over the treatment receiving recommended dose of NPK fertilizer (25:50:50) alone. They also reported the increase of protein content at 100% LR by 32 per cent over no lime application. However, application of lime did not produce any significant increase in oil content.

Productivity of rice-groundnut system was found to be higher in limed soils as compared to unlimed soil (Misra *et al.*, 1990). Singh and Singh (1983) reported that liming @ 10 to 16.5 tonnes ha^{-1} in acid soils of Kumaon hills increased the dry matter yield and nutrient content of French been under green house condition. Lime application decreased concentration of Fe, Mn and Cu in shoots of mung grown in alluvial acid soils (pH 4.7) of North Bengal (Pal *et al.*, 1985), the concentration of Al and Mn in berseem decreased and that of Ca, Mg and P increased with increasing rate of liming (Tripathy *et al.*, 1883 -1984). Liming the acid soils of Himachal Pradesh increased the dry matter yield of soybean crop and also uptake of N, P, K, Ca and Mg by the crop (Bishnoi *et al.*, 1988). It was found that graded dose of lime significantly increased the soybean yield in acid soils up to a certain level of liming, beyond which higher doses were not been beneficial (Prasad *et al.*, 1985; Gupta *et al.*, 1989; Prasad *et al.*, 1992). The decrase in yield at higher level of liming might be due to imbalance of Ca and Mg concentration (Patiram, 1989). The yield of soybean was highest in acid soils of Sikkim when it was applied at the rate of 1 to 1.5 times the exchangeable Al content or 25 per cent of LR. Also liming increased the Ca uptake by plant (Patiram, 1990).

Lime application @ 3.2 tones ha^{-1} increased the yield of black gram by 13.7 per cent over no lime. Increase in lime dose from 3.2 to 6.4t ha^{-1} was ineffective in increasing the yield (Shard *et al.*, 1991).

The nodular N, seed yield and nutrient uptake by green gram crop increased significantly when the seeds were inoculated with *Rhizobium* and further by amending the soil with lime @50% LR or seed inoculation with *Rhizobium* and treated with micronutrient (Mo and Co) and soil liming (Pattanayak *et al.*, 2002). There is increase in the growth and yield of pea as recorded by the application of lime @4 ton ha^{-1} followed by FYM + NPK (Negi *et al.*, (1999-2000). Singh *et al.*, (2003) reported the effect of lime along with boron in an acid *Alfisol* of Jharkhand. They reported that the combined application of 0.05 kg B and 250 kg lime ha^{-1} gave maximum grain yield in gram which is 81.4 per cent higher than control.

Raychoudhary *et al.*, (2001) reported that liming at 2.5 tha^{-1} increased the efficiency of phosphate solublizing micro organism and increased the available P content of an acid hilly *Ultisol* of Manipur by 25.9 per cent. Liming alone increased the nodule weight per plant (71%), pod (36%) and haulm yield (37%) and their respective N uptake (51% and 91%) and P uptake (49% and 50%) respectively in pod and haulm.

MATERIALS AND METHODS

The **“Comparative performance of different types of liming materials for Maize crop grown in Acid soils”** was studied with the help of a field experiment. The materials used and the methods followed for conducting the experiment have been discussed in this chapter.

3.1 Experimental site

The field experiment was conducted in the farmer’s field during *Kharif* (2013) in the Village- Bajpur, District- Khurda. The farm is situated at N-20^0 03' $44.0^{''}$ latitude and E-85^0 17' $11.2^{''}$ longitude with an elevation of 25.5 above mean sea level.

3.2 Climate and Weather conditions

The experimental site experiences a warm and moist with hot and humid summer and mild winter. The mean minimum and maximum temperature were 22.6^0 and 32.6^0 respectively.

3.3 Treatment & their details

Three different types of liming materials were evaluated in the experiment. These were Paper Mill Sludge (PMS), Stromatolyte (ST) and Calcium Silicate (CS) . Liming materials were applied mixed with and without FYM in the field. Absolute control treatment was included without any addition of external source of nutrients. The test crop Maize (Hishell-hybrid) received 10 treatments. Each treatment was replicated three times and imposed over statistically laidout field with Radomised Block Design (RBD) in the field and have been described below.

3.4 Treatments

T_1	Absolute control	T_6	STD + FYM + ST @ 0.1 LR
T_2	Soil test based recommended dose (STD)	T_7	STD + ST @ 0.2 LR
T_3	STD + Paper mill sludge (PMS) @ 0.1 LR	T_8	STD + FYM + ST @ 0.2 LR
T_4	STD + FYM + PMS @ 0.1 LR	T_9	STD + Calcium silicate (CS) @ 0.2 LR
T_5	STD + Stromatolyte (ST) @ 0.1 LR	T_{10}	STD+ FYM + CS @ 0.2 LR

3.5 Soil charecterstics of the experimental site

A. Physical Parameters	**Value**
Sand (%)	76
Silt(%)	14
Clay(%)	10
Texture	Loamy Sand
Bulk density(Mg m^{-3})	1.75
B. Chemical Parameters	
EC(dSm^{-1})	0.09
pH_w(1:2.5)	4.94
Organic carbon (g/kg)	5.70
Available Nitrogen(kg ha^{-1})	169
Available Phosphorus (kg ha^{-1})	105
Available Potassium (kg ha^{-1})	143
Available Sulphur (kg ha^{-1})	17
Available Boron ($mgkg^{-1}$)	0.15
Available Zinc ($mgkg^{-1}$)	0.41
Cation Exchange Capacity (CEC) [cmol(p^+)kg^{-1}]	6.29
Exchangeable Ca^{2+} [cmol(p^+)kg^{-1}]	3.4
Exchangeable Mg^{2+} [cmol(p^+)kg^{-1}]	1.8
Exchangeable K^+ [cmol(p^+)kg^{-1}]	0.19
Base saturation (%)	86
Exchange Acidity [cmol(p^+)kg^{-1}]	1.04
Exchangeable Al^{3+} [cmol(p^+)kg^{-1}]	0.60
Exchangeable H^+ [cmol(p^+)kg^{-1}]	0.44
Lime requirement [t $CaCO_3ha^{-1}$]	3.2

3.6 Inputs used

(a) Fertilizers:

(i) Soil test Dose : N – P_2O_5 – K_2O – SO_4 – $ZnSO_4$ – Borax (kg/ha)

150 - 30 - 50 - 30 - 25 - 10

(ii) Sources : Navaratna (20-20-0-13), Urea, MOP, Borax and Zinc sulphate.

(b) Manure : Farmyard Manure (FYM) @ 5 tha^{-1}

*** The inputs were applied in split doses**

	N	P	K	Borax	$ZnSO_4$	FYM
Basal	20 %	100 %	25 %	50 %	50 %	100 %
1st Top (21 DAS)	50 %	x	50 %	50 %	50 %	x
2nd Top (45 DAS)	30 %	x	25 %	----	----	x

(c) Plant Protection Chemicals :

Bavistin,chlorodust,monochrotophos,phorate,seathmar etc.

3.7 Intercultural operations and plant protection measures

Intercultural operations like hoeing, weeding, earthing up, irrigation and plant protection measures were carried out as and when required to raise a good crop. Seed treatment was done with Bavistin, Chlorodust was applied @ 50 kg ha^{-1} against termite, Phorate and Monochrotopos against stem borer and Seathmar against seath blight.

3.8 Collection and Processing of Soil and Plant samples

Soil : Representative composite soil samples were collected at 7 days interval from all the treatments during crop growth period. The initial and post harvest sois were also collected. The samples were dried under shade, grined with wooden hammer and sieved through 2mm sieve. The samples were preserved in polythene bags with proper labels for analysis.

Plant : The fresh active leaf samples were collected at 30 days interval for analysis (3rd from top). At the time of harvesting stage five plants from each treatment were selected randomly (avoiding boundary line).

Root : The roots from different treatments were collected at the time of harvest of the crop. by moisturing the rhizosphere, up rooting the plants without disturbing the roots with the help of spade. The entire root and adhered soils were loosen in a bucket of water, saving the roots. Then washed thoroughly and dried. The mass (weight) and volume was estimated by water displacement method and the density was calculated.

The different plant parts like leaf,shoot,cob and roots were kept in separate envelops, washed, labeled properly and dried in hot air oven till a constant weight was recorded. Each sample was grinded separately and was used for analysis of different elements.

3.9 Method of analysis

A. Soil Analysis.

B. Plant Analysis.

A. Soil Analysis : The soil samples were analysed for different parameters following standard methods were followed.

(a) Soil texture :- The sand, silt and clay content of the soil samples were determined by Bouyoucos Hydrometer method as described by Piper (1950).

A 50 g of air dry soil was transferred in to a 500 ml beaker. To it 200 ml distilled water and 10 ml of 5 % sodium hexametaphosphate solution were added, stired by a glass rod for 5 minutes and in a mechanical stirrer for 20 minutes. The contents of the beaker was transferred without loss into a 1000 cc spoutless cylinder and volume was made up to 1 lit. A rubber pad was placed on the mouth of the cylinder and shaken it end to end for 1 minutes, the cylinder was placed on the table and the time of commencement of sedimentation was recorded. The hydrometer reading after 5 minutes and the temperature of the suspension was also noted down. The content of the cylinder was shaken again as before, placed on the table and recorded the time . The hydrometer reading and temperature were recorded just after 5 hours.

Calculation :-

% (silt + clay) = First corrected reading x 2

% clay = Second corrected reading x 2

% sand = 100 – (% silt + % clay)

% silt = % (silt+ clay) – (% clay)

The textural class of the soil was determined by placing these values in the triangular coordinate of the textural triangular diagram.

(b) Water holding capacity of soil :- The water holding capacity of the soil was determined by Keen Raczkowski box method as described by Piper (1950).

A filter paper was fitted to the perforated base of the box. It was weighed in a physical balance, the box was packed with the soil by adding small quantities at a time and tapped after each addition to ensure uniform packing. Enough soil was added to fill the box. The surplus soil was removed with a sharp knife to bring the soil in the box to the level of the top of the box. The box was tapped smartly and if necessary soil was added and leveled off once again. The box was placed with the soil in a small tray containing water to a depth of 5 cm and kept overnight. At the end of the period, the box was removed and wiped outside with filter paper and weighed it immediately (extra water was allowed to drain out). The box containing the wet soil was placed in an oven and the soil was dried at 105^0C till a constant weight was obtained. The amount of water absorbed by the filter paper was determined by taking 10 pieces of filter paper together, then weighed and saturated with water and weighed again. Thus the moisture absorbed by each filter paper can be determined.

Calculation :-

Weigh of box + filter paper = A g

Weigh of box + filter paper + oven dry soil = B g

Weigh of box + wet filter paper + saturated soil = C g

Max. water holding capacity of soil = C- (B+M)/B-A x 100

(c) Bulk density of soil :- The bulk density of experimental soil was determined by core method as described by Black (1965).

(d) Soil pH :- Soil pH was determined in 1:2.5 soil : water ratio by pH meter as described by Jackson (1973).

A 10 g of air dried processed soil sample was taken in to 50 ml plastic beaker. Distilled water of 25ml was added, stirred it intermittently and wait for half an hour. The pH of soil water suspension was checked. The electrode was washed properly before and after each measurement. The water was removed from the surface with a piece of filter paper.

(e) Exchange Acidity, Exchangeable Hydrogen (H^+) and Aluminium (Al^{+3}) :

The exchange H^+ and Al^{+3} were determined by following the methods Lin and Coleman (1980) as described by Page *et al*.,(1982).

A 10 g of test soil was taken in a 50ml plastic beaker. To it 25 ml of 1N KCl was added, stirred for 30 minutes and filtered (through Whatman no.1). Another 125 ml of same KCl solution was added to soil inside the cone of filter paper in 25 ml increments. The leachets were collected and titrated against standard NaOH using phenolphthalein indicator to know the exchange acidity. Exchangeable aluminium was determined by adding 10ml of 1N NaF to the titrand in 500 ml flask. When pink colour persisted after addition of NaF indicated the presence of Al. It was titrated against HCl till disappearance of pink colour. Simultaneously a blank sample was taken to determine the exchange acidity.

Calculation :-

Meq KCl acidity/100 g = (ml NaOH sample – ml NaOH Blank) × N × 100 / g sample

Meq KCl exch. Al/100 g = ml HCl used × N × 100 / g sample

Meq H/100 g = KCl acidity – KCl exchangeable Al

(f) Lime Requirement :-

The lime requirement of the acid soil was determined by Woodruff Buffer method.

A 10 gm of soil was taken in a plastic beaker. To this 10 ml of distilled water was added, stirred, 2 drops of $CaCl_2$ was added, pH of the soil suspension was taken with the help of a pH meter. This pH was noted as salt pH (pHs). Then 10 ml of Woodruff buffer solution was added to it, stirred and pH was measured after 30 minutes. This was called as buffer pH.

Calculation :-

L.R. to pH_s7 ($CaCO_3$ in kg/ha)= (pH of the buffer – pH of soil buffer suspension) x 10,000

Suppose liming is to be done to attain a desired pH_s^1 but not to attain $pH_s = 7$ then quantity of lime is to be calculated as follows :

$$L^1 = L\frac{p\quad 1s-p\quad 1}{7.0-p}$$

WhereL^1 = lime requirement to achieve a pH_s value less than 7.0

L = lime requirement to achieve a pH_s of 7.0

pH^1_s = soil pH_s value desired

pH_s = observed pH_s

Quantity of the liming material to be used was calculated by multiplying L or L^1 with neutralizing value.

LR= L or L^1 x 100/NV in $kgha^{-1}$.

(g) Cation Exchange Capacity of soil :-

The Cation Exchange Capacity of the soil was determined by successive extraction of soil with neutral 1N ammonium acetate as per the procedure outlined by Page *et al.,* (1982). The excess NH_4^+, adhered to the soil complex was washed twice with ethanol (80 and 90 %) and then distillation was done by Micro kjeldahl distillation method.

The exchangeable cations were estimated from the successive neutral normal ammonium acetate extractions. The Ca^{2+} and Mg^{2+} were estimated by EDTA complexometric titration method (Jackson, 1973) and K^+ by flame photometry.

(h) Organic carbon content of soil :-

The Organic carbon content of soil was determined by wet digestion procedure of Walkley and Black as outlined by Page *et al*,1982.

(i) Available nitrogen (N):-

Available nitrogen in soil was determined by alkaline $KMnO_4$ method (Subbiah and Asija, 1956).

(j) Available phosphorous (p):-

Available phosphorous in the soil was determined by Bray's 1 method (Bray and Kurtz, 1945) as out lined by page *et al*., (1982).

(k) Available potassium (K):-

Available potassium was determined by extracting the soil with neutral normal ammonium acetate solution and estimated by flame photometer.

(l) Available sulphur (S):-

Available sulphur was determined by extracting the soil with 0.15 per cent $CaCl_2$ solution and determined colorimetrically by turbidimetric method using $BaCl_2$(Chesin and Yien,1951).

B. Plant Analysis : The leaf,stem,root and grain samples were analysed for determination of N,P,K,Ca,Mg and S concentration. The methods employed are given below :

(a) Nitrogen :

Nitrogen in the processed sample was determined by Kjeldahl digestion method as described in AOAC (1960).

(b) P,K,Ca,Mg and S:

The samples were digested in diacid mixure [HNO_3 : $HClO_4$ (3:2)]. The P and S were estimated spectrophotometrically, K, flame photometrically, Ca & Mg by EDTA titration method. (Jackson,1973).

3.10 Statistical analysis :

The biometric data, nutrient uptake, cob and stover yield were recorded, compiled in appropriate tables and analyzed statistically as per the procedure prescribed for Randomised block design. To obtain the analysis of variance, standard error of means i.e., SE(m) ± were determined in all the cases, while critical difference (CD) at 5 % level of significance was estimated only in cases where 'F' test was found significant.

3.11 Emperical formulae :

(a) $\text{Per cent yield response} = \frac{\text{Yield in treatment} - \text{yield in control}}{\text{Yield in treatment}} \times 100$

(b) Relative Agronomic Efficiency (RAE) =

$$\left(\frac{\text{Total Biomass production in treatment} - \text{Total Biomass production in Absolute Control}}{\text{Totlal Biomass production in STD} - \text{Total Biomass production in Absolute Control}} \right) \times 100$$

(c) Nutrient uptake (kg ha^{-1}) = Dry matter (q/ha) x nutrient concentration (%)

(d) Apparent Recovery of Nutrient (%) =

$$\left(\frac{\text{Uptake of nutrient in desired treatment} - \text{Uptake in absolute control}}{\text{Amount of nutrient added}} \right) \times 100$$

RESULTS

In order to study the "**Comparative performance of different types of liming materials for Maize crop grown in Acid soil**" The field experiment was conducted in an acid loamy sand soil of Village Bajpur in Khurda district of Odisha with Maize as the test crop (Cv. Hishell) . The experiment was conducted in a randomised block design with 10 treatments and each treatment replicated thrice. The soil was ameliorated with three sources of liming materials (PMS @ 0.1LR, Stromatolyte @ 0.1 LR & 0.2 LR and Calcium silicate @ 0.2 LR) added with soil test based dose with or without FYM @ 5 t/ha.

Table – 4.1 : Properties of liming materials

Liming materials	Properties				
	*NV (%)	Ca (%)	Mg (%)	S (%)	Si (%)
Paper mill sludge	60	22.0	---	---	---
Stromatolyte	80	17.3	10.5	0.04	---
Calcium silicate	80	34.5	---	---	24.17

*** NV : Neutralising value**

4.1 Characteristic of experimental soil

The soil of the experimental site (Table – 4.2) was loamy sand in texture with 76 per cent sand, 14 per cent silt and 10 per cent clay with 1.75 Mg m^{-3} of bulk density. The soil was strongly acidic in reaction (pH_w 4.94). The organic carbon status was medium, i.e. 5.7 gkg^{-1} with lime requirement of 3.2 t $CaCO_3ha^{-1}$. The CEC of the experimental soil was 6.29 $cmol(p^+)kg^{-1}$ soil with 1.04, 0.60 and 0.44 $cmol(p^+)kg^{-1}$ soil of exchange acidity, acidity due to Al^{3+} and H^+ respectively. The available nitrgen, phosphorous ,potassium and sulphur in soil were 169 (low),105 (high),143 (medium) and 17 $kgha^{-1}$ (low) respectively. The available Boron and Zinc content were very low, i.e 0.15 and 0.41 $mgkg^{-1}$ soil respectively.

Table – 4.2 : Initial properties of experimental soil

A. Physical Parameters	**Value**
Sand (%)	76
Silt(%)	14
Clay(%)	10
Texture	Loamy Sand
Bulk density(Mg m^{-3})	1.75
B. Chemical Parameters	
EC(dSm^{-1})	0.09
pH_w(1:2.5)	4.94
Organic carbon (g/kg)	5.70
Available Nitrogen(kg ha^{-1})	169
Available Phosphorus (kg ha^{-1})	105
Available Potassium (kg ha^{-1})	143
Available Sulphur (kg ha^{-1})	17
Available Boron ($mgkg^{-1}$)	0.15
Available Zinc ($mgkg^{-1}$)	0.41
Cation Exchange Capacity (CEC) [cmol(p^+)kg^{-1}]	6.29
Exchangeable Ca^{2+} [cmol(p^+)kg^{-1}]	3.4
Exchangeable Mg^{2+} [cmol(p^+)kg^{-1}]	1.8
Exchangeable K^+ [cmol(p^+)kg^{-1}]	0.19
Base saturation (%)	86
Exchange Acidity [cmol(p^+)kg^{-1}]	1.04
Exchangeable Al^{3+} [cmol(p^+)kg^{-1}]	0.60
Exchangeable H^+ [cmol(p^+)kg^{-1}]	0.44
Lime requirement [t $CaCO_3ha^{-1}$]	3.2

4.2 Effect of liming materials on soil reaction during crop growth period

The initial soil pH was 4.94. The soil was strongly acidic in reaction. During crop growth period in control treatment the soil pH continued to decrease gradually till the harvest of the crop, which attended a level of 4.47 by the harvest of crop.(Fig-4.1.a, Appendix-1).

Upon addition of inorganic fertilizers alone (STD), the soil pH increased to a level of 5.01 by 14th DAS, there after decreased continuously till the harvest and attended the pH level of 4.38. Combined application of fertilizers and PMS @ 0.1 LR, raised the pH to a level of 5.11 by 7th DAS and maintained higher pH compared to STD alone up to 56th DAS, there after decreased (increased acidity) to the pH level of 4.39 by the harvest of the crop. Combining FYM application @ 5 tha^{-1} with STD and PMS @ 0.1 LR, helped in raising the pH from 4.94 to 5.88 by 7th DAS, 6.0 by 14th DAS, maintained high pH up to 21 days decreased there after gradually maintaining all along higher pH (even though acidic) compared to STD + PMS, except at harvest (pH 4.15),(Fig-4.1.a, Appendix-1).

The low grade lime stone (Stromatolyte – ST) when applied @ 0.1 LR mixed with STD raised the pH to 5.12 by 14th DAS, there after decreased the pH till the harvest of the crop, but maintained high pH than STD + PMS + FYM. Combined application of FYM with ST @ 0.1 LR helped raising the initial pH from 4.94 to 6.30 by 21st DAS, maintained for another 15 days (35 DAS) decreased there after till the harvest of crop but the pH remained above that due to STD + ST without FYM (Fig-4.1.b, Appendix-1).

Double the dose of stromatolyte was effective in maintaining higher pH (5.34) than ST @ 0.1 LR up to 28th DAS, decreased there after maintaining higher pH than ST 0.1 LR up to 49th DAS. After 49th DAS the soil pH decreased indicating development of more acidity by the harvest of crop .

The effectiveness of ST applied @ 0.2 LR further increased by its combined application with FYM, which raised the pH to a level of 6.08/6.07 by 21st DAS and maintaining a pH level of 5.43 to 5.07 up to 49th DAS, decreased there after till crop harvest and all along higher pH was maintained than rest of the sources.(Fig-4.1.c, Appendix-1). The industrial by product Calcium silicate when applied @ 0.2 LR with STD, initially acted slowly, raised the pH to a level of 5.36 by 14th DAS, decreased there after. However, when applied mixed with FYM attended maximum pH level of 5.64 by 14th DAS, a level of pH ranging from 5.21 to 5.01 up to 28th DAS, decreased there after maintaining higher pH compared to STD + CS @ 0.2 LR. (Fig-4.1.d, Appendix-1).

4.3 Exchange Acidity in soil under the influence of addition of liming materials during crop growth period

The initial exchange acidity in soil was 1.04 cmol(P^+)kg^{-1} . Seven days after sowing of Maize seeds in absolute control treatment, this acidity remained at 1.03 cmol(P^+)kg^{-1}, there after decreased with crop growth, intercultural operations and water source from rain water (dilution effect) up to 35th DAS. There after gradually increased and attended a level of 1.32 cmol(P^+)kg^{-1} soil by the harvest of the crop (Fig-4.2.a, Appendix-2).

In STD treatment, due to addition of external sources of nutrients; namely Urea, DAP and MOP temporarily decreased the acidity during 7 to 14 DAS, there after continued to increase gradually and attended a level of 1.32 cmol(P^+)kg^{-1} by the harvest of the crop. Soil amelioration measure with the adiition of paper mill sludge (PMS) when used with STD, neutralized the acidity (both H^+ and Al^{3+} ions), raised the pH, neutralized acidity to a level of 0.70 cmol(P^+)kg^{-1} soil, which further decreased to a level of 0.43 cmol(P^+)kg^{-1} soil by 21st DAS, there after increased gradually and attened a level of 1.16 cmol(P^+)kg^{-1} soil by the harvest of the crop.

Integrating organic addition through FYM helped alleviating the soil acidity condition through its buffering action, brought down exchange acidity to 0.6 cmol(P^+)kg^{-1} soil level by 7th DAS and lowest level of 0.31 cmol(P^+)kg^{-1} soil by 21st DAS, increased there after gradually and attended a maximum of 1.04 cmol(P^+)kg^{-1} soil level (initial stage) by the harvest of the crop. During entire growing period the exchange acidity remained below the acidity levels achieved through the use of STD either alone or more specifically with PMS application (Fig-4.2.a, Appendix-2).

The acid neutralization efficiency of stromatolyte (ST) applied @ 0.1 LR dose was better than the PMS applied @ 0.1 LR. The acid neutralization efficiency of ST further increased and brought down the acidity to a level of 0.5 cmol(P^+)kg^{-1} soil by 7th DAS, attended a minimum level of 0.28 cmol(P^+)kg^{-1} soil by 21st DAS, There after gradually increased with crop growth till the harvest of crop. This source of liming material helped maintaining lower acidity level throughout growing period compared to PMS particularly when added with FYM. (Fig-4.2.b, Appendix-2) .

Double dose of ST, when added with STD alone, neutralized soil acidity both H^+ and Al^{3+} ions raised the pH , maintained lower acidity upto 49th DAS, increased there after, reached maximum of 1.42 cmol(P^+)kg^{-1} soil by the harvest of the crop.

The effectiveness of ST applied @0.2 LR, further increased, when applied mixed with FYM, maintaining lower acidity (low H^+ and Al^{3+} ion conc, Table-4.4) throughout the growing season, specially upto 56th day of growth (Fig-4.2.c,Appen.-2).

The calcium silicate (CS) when applied @ 0.2 LR was not effective as PMS or ST when applied with STD. Very slowly it started neutralizing the protons (H^+ ions), Al^{3+}

ions, ultimately the exchange acidity attending a minium level exchange acidity of 0.75 cmol(P^+)kg^{-1} soil by 21st DAS, and increased there after till the harvest of crop.

However when applied mixed with FYM, effectively neutralized the protons (H^+ ions), Al^{3+} ions, ultimately the exchange acidity, raised the pH quickly, as a result of which the exchange acidity of 0.5 cmol(P^+)kg^{-1} soil was achieved by 7th DAS, further lower down acidity up to 28th DAS, increased there after gradually and attended the maximum of 1.23 cmol(P^+)kg^{-1} of soil by the harvest of the crop. All along lower level acidity was maintained in soil compared to STD + CS @ 0.2 LR (Fig-4.2.d,Appendix-2).

In general, PMS with STD was most effective up to **21st DAS**, STD + PMS + FYM up to **28th DAS**, STD + ST @ 0.1 LR/0.2 LR up to **49th DAS**, and STD + ST @ 0.1 LR/+ FYM up to **56th DAS**, the STD + CS @ 0.2 LR up to 21st DAS and STD + CS @ 0.2 LR + FYM up to **28th DAS**.

4.4 Change in acidity due to Aluminium and Hydrogen during crop growth period

The change in acidity due to aluminium and hydrogen in soil due to application of liming materials have been presented in Appendix-3and 4 respectively.

Before application of liming materials, the acidity due to H^+ and Al^{3+} were 0.44 and 0.60 cmol(P^+) kg^{-1} soil.In control treatment only the H^+ ion acidity decreased and acidity due to Al^{3+} increased gradually during crop growth period.

In the treatment where inorganic fertilizers were applied alone decrease in acidity due to H^+ and Al^{3+} ions were observed up to 35th DAS and continued to increase till the harvest of the crop.

Integrated use of PMS @ 0.1 LR, neutralised the acidity due to H^+ and Al^{3+} up to 28th DAS, there after do not persist in the system to neutralise acidity as a result acidity increases. Combined application of FYM and PMS helped neutralising acidity due to H^+ up to 21st DAS and acidity due to Al^{3+} up to 63rd DAS, increasing the efficiency of PMS (Fig-4.3.a and Fig-4.4.a).

The low grade limestone Stromatolyte when applied @ 0.1 LR, continued to neutralise H^+ acidity till the harvest of crop and maintained at a lower level all along compared to initial status. At the same time acidity due to Al^{3+} neutralised partially up to 35th DAS, increased there after.

Combined application of FYM and ST @ 0.1 LR increased the effectiveness of liming material by restricting loss of Calcium and other basic materials, neutralised the acidity and maintained at lower level throughout the growing period. So also the acidity due to Al^{3+} was also neutralised considerably brought down to 0.34 cmol(P^+) kg^{-1} soil level by 56th DAS, increased there after (Fig-4.3.b and Fig-4.4.b).

Increasing the dose of Stromatolyte to 0.2 LR dose effectively neutralised protons (H^+) for entire growing period and Al^{3+} ions up to 42nd DAS. Combining FYM and ST @ 0.2 LR effectively maintained both H+ ions and Al^{3+} ions at lower level compared to the initial status for the entire crop growing period (Fig-4.3.c and Fig-4.4.c).

The industrial finished product ready to use calcium silicate applied @ 0.2 LR initially reacted slowly, effectively brought down the level of H^+ well below the initial level for entire growing period. At the sametime, the acidity due to Al was controlled up to 35th DAS, increased there after. Integration of FYM with calcium silicate enhanced the efficiency for another 7 days i.e, up to 42nd DAS by effectively lowering the activity of H^+ and Al^{3+} ions in the rhizosphere (Fig-4.3.d and Fig-4.4.d).

In general it was observed that use of liming materials were very much effective in neutralising the acidity due to H^+ and brought down to lower manageable level well below the initial level for entire crop growth period. At the same time the acidity due to Al^{3+} ions were brought down below initial level up to 28th DAS by PMS @ 0.1 LR, 35th DAS by ST @ 0.1 LR, 42nd DAS by ST @ 0.2 LR, 35th DAS by CS @ 0.2 LR.

Combining FYM application increased the effectiveness of liming materials further, by maintaining H^+ ions concentration well below the initial level of 0.44 cmol(P^+) kg^{-1} soil throughout the growing period and at the same time Al^{3+} ion acidity up to 63rd DAS by PMS, 56th DAS by ST @ 0.1 LR, 90th DAS by ST @ 0.2 LR and 42nd DAS by CS @ 0.2 LR.

4.5 Change in Organic Carbon status in soil during crop growth period

The data relating to change in organic carbon status under the influence of fertilizers, lime and manure application have been presented in Fig-4.5.a,b,c,d and Appendix-5 respectively.

The initial organic carbon in soil was medium in status. (5.7gkg^{-1} soil). Crop growth without addition of external source of nutrients exhibited depletion of organic carbon status in soil throughout the growing period. Crop growth with soil test based fertilizers application maintained still lower organic carbon status in soil compared to control treatment (Fig-4.5.a).

Integration use of lime sources with STD of fertilizers for maize crop did not help in raising the organic carbon status in soil till the harvest of the crop. Combined use FYM with fertilizers and lime sources, though maintained higher level of organic carbon during crop growth period over other treatments which had not received FYM, continued to decrease till the harvest of crop (Fig-4.5.a,b,c and d).

4.6 Cation Exchange Capacity (CEC) of soil under the influence of lime, fertilizer and manure application

The information relating to change in CEC in soil during crop growth period under the influence of input addition have been presented in Fig-4.6.a,b,c,d and Appendix-6 respectively.

Initial CEC in soil was 6.29 cmol$(p^+)kg^{-1}$ soil . It had increased in limed and FYM amended treatments (ranging from 6.64 to 8.03), remained same in STD but decreased in absolute control treatment after 7 DAS, there after decreased gradually till the harvest of the crop. Up to 35th DAS the limed treatments maintained higher CEC than unlimed one. Further manure treatments maintained higher CEC compared to unmanured ones, all along the crop growth period.

The lime source PMS @ 0.1 LR maintained higher CEC 6.39 cmol$(p^+)kg^{-1}$ of soil up to 14th DAS and highest of 6.49 cmol$(p^+)kg^{-1}$ soil by 7th DAS. The ST @ 0.1LR recorded highest CEC of 6.72 cmol$(p^+)kg^{-1}$ by 14 DAS decreased there after. It's double dose recorded highest CEC of 7.16 cmol$(p^+)kg^{-1}$ soil at 7 DAS and maintained higher CEC compared to initial status by 21st DAS, decreased there after.The CS @ 0.2 LR recorded highest CEC of 7.37 cmol$(p^+)kg^{-1}$ at 7th DAS, maintained higher CEC compared to initial status by 28th DAS.

Combined use of FYM with PMS maintained higher CEC up to 21st DAS (7 days more compared to PMS alone)(Fig-4.6.a), ST @ 0.1 LR with FYM, achieved highest CEC of 7.38 by 7th DAS and higher CEC compared to initial up to 42nd DAS (Fig-4.6.b). When double dose of Stromatolyte was used with FYM, highest CEC of 7.59 cmol$(p^+)kg^{-1}$ soil was achieved by 7th DAS and higher CEC continued up to 35th DAS, decreased there after (Fig-4.6.c). The CS @ 0.2 LR with FYM, recorded highest CEC of 8.03 cmol$(p^+)kg^{-1}$ soil by 7th DAS, all time higher CEC values compared to other sources up to 28th DAS, decreased there after (Fig-4.6.d).

4.7 Exchangeable Calcium in soil under the influence of application of agro-inputs

The exchangeable Ca status in soil under the influence of liming, manuring and fertilization practice have been presented in Fig-4.7.a,b,c,d and Appendix-7. Before experimentation the exchangeable Ca in soil was 3.4 cmol$(p^+)kg^{-1}$ soil.

The exchangeable calcium under controlled condition, decreased its status at the beginning with a small increase at mid stages of crop growth and decreased to words at the harvest stage (Fig-4.7.a). Similar trend of exchangeable Ca status was observed with the application of STD, where its status decreased maintained below the level in absolute control under each treatment (Fig-4.7.a) . On the other hand application of PMS @ 0.1 LR, ST @ 0.1/0.2 LR and CS @ 0.2 LR continued to supply Ca and maintain higher exchangeable Ca status till the harvest of crop compared to the status without their application (Fig-4.7.a,b,c and d).Combining FYM application with lime sources maintained still higher status of Ca in the exchange complex compared to their lone sources throughout the growing period of the crop.(Fig-4.7.a,b,c and d)

4.8 Exchangeable Mg in soil

The informations on dynamics of Mg in the soil exchange complex have been presented in Fig-4.8.a,b,c,d and Appendix-8.

Its status in initial stage was almost half (53 %) of the exchangeable Ca. The Mg in the soil exchange complex continued to decrease till the harvest of the maize crop in absolute control as well as in STD treatments (Fig-4.8.a).

Supplimentation of Mg through liming sources helped maintaining high exchangeable Mg status in the soil covering majority of times of the growing of maize,however decreased towards the crop harvest. Combined use of FYM with liming materials prevented quick loss of Mg from exchange complex and helped maintaining higher status till the harvest of the crop, inspite of crop removal (Fig-4.8.a,b,c and d).

4.9 Exchangeable K in soil

The exchangeable K status in soil under the influence of different liming materials have been presented in Fig-4.9.a,b,c,d and Appendix-9.

Initially it was 0.19 $\text{cmol}(p^+)\text{kg}^{-1}$ soil, decreased continuously till the harvest of the crop in control treatment. Its addition through fertilizer continued to maintain higher status up to 28th DAS, decreased there after. Under soil ameliorated condition particularly lime sources with FYM maintained higher status of exchangeable K in soil 21 DAS, gradually decreased there after. Among the exchangeable cations, K was next in abundance to Ca and Mg.

4.10 Growth parameters of maize under the influence of liming materials during crop growth period

4.10 (A) Chlorophyll content :

The photosynthetic activity (chlorophyll content) of maize crop under the influence of application of different liming materials have been presented in Fig-4.10 and Appendix-10.

The photosynthetic activity was measured by SPAD cholorophyll meter. The values recorded at six growth stages starting from 28th DAS till 77th DAS. At 28th DAS stage the SPAD values in the leaf varied between 31.13 and 49.50, which increased and maintained between 33.48 and 49.19 at 42nd DAS, there after decreased invariably in all the treatments and maintained between 28.8 and 48.54, further decreased by 56th DAS where it was maintained between 26.72 and 43.86, there after increased to the level varying between 32.85 and 49.55 at 70th DAS, there after either increased or maintained in the most of the treatments between 37.87 and 49.93 at 77th DAS (Fig-4.10). The average recorded SPAD value in different treatments varied between 31.8 and 47.56. At all stages the absolute control treatment recorded lowest SPAD values. The FYM integrated treatments maintained higher SPAD values than FYM untreated one. However use of liming materials did not influence the recorded SPAD values much in the crop (Appendix-10).

4.10 (B) Plant height under the influence of different liming materials

The maize crop heights recorded at different growth stages have been presented in Fig-4.11 and Appendix-11.

The height of the crop continued to grow at differential rates under different treatments. The height ranged from 48.1 to 106.5 cm, from 62.1 to 137.7 cm, from 70.4 to 166.7 cm, from 83.2 to 198.2 cm and from 93.73 to 223.9 cm at 28th, 35th, 42nd, 49th and 59th DAS, respectively. The average crop height varied between 71.5 and 66.6 cm (Appendix-11) and the growth rate between 1.28 cmday^{-1} and 2.98 cmday^{-1}, lowest with control and highest with STD + CaSi @ 0.2 LR + FYM (Appendix-12).

Integrating PMS @0.1 LR, ST @ 0.1 LR, ST @ 0.1 LR and CS @ 0.2 LR with STD resulted in 3.0, 2.0, 7.3 and 8.0 per cent increase in plant height compared to the average height due to STD of 139.1 cm. Further integration of FYM with STD and lime sources increased the plant height by 7.3, 9.2, 9.1 and 11.2 per cent compared to the height due to respective lime sources (Appendix-11).

The growth rate of the crop differed from treatment to treatment and from day to day. Growth rate of the crop was 1.77 cmday^{-1} at 28th DAS in absolute control treatment which increased to 2.98 cmday^{-1} with STD,still higher with liming materials when used either alone or more with FYM ranging from 3.19 to 3.8cmday^{-1} (Appendix-12).

The growth rate increased irrespective of the treatments up to 49th DAS except in control and decreased there after to a range of 1.67 to 4.0 cmday^{-1} in 56th DAS. All along the growing period integrated use of inputs had recorded positive influences (Appendix-12).

4.11 Root characteristics of maize crop under the influence of application of liming materials.

At harvest, the root length, their weight, volume, and calculated density have been presented in Table-4.3,Plate-2.

The root length of the maize crop under the influence of different liming materials varied significantly between 15 and 62 cms, lowest with no nutrient control and highest with the integration of STD + ST @ 0.2 LR + FYM (Table-4.3,Fig-4.12).

Application of liming materials with STD resulted in 27, 15.2, 10.4 and 19 per cent increase compared to the root length of 26 cm due to STD alone. Integrating FYM application with liming materials further influenced the root growth which as 36, 13.3, 17.0 and 22.6 per cent higher compared to the root length due to respective liming materials.

Root weight : The root weight of maize crop under the influence of different lime integrated treatments varied significantly between 0.83 and 16.5 g plant^{-1}.

Root volume : The volume of roots under individual treatments ranged from 10 cc (lowest in control) to 100 cc (STD + PMS @ 0.1 LR + FYM). There was significant influence of application of liming materials and their combined use with FYM and STD on root volume (Fig-4.13).

Root density : As a result of variation in root weight (mass) and volume of maize crop due to the application of liming materials either alone or with FYM, their density varied between 0.08 and 0.22 g/cc.

4.12 Maize cob characteristics under the influence of soil amelioration with liming materials.

The characteristics of the economic part of maize crop i.e, cob, its length, diameter , seeds weight cob^{-1} have been presented in Table-4.4,Plate-3.

Application of different liming materials for amelioration of acid soils when added with or without FYM influenced the cob charecteristics in terms of its length (Fig-4.14), its diameter and seed weight cob^{-1} (Fig-4.15) which varied between 11.0 and 17.6 cm, 10.2 and 13.9 cm, 22.8 g and 75.4 gcob^{-1} respectively. Lowest values were recorded with the cobs produced form absolute control treatment and highest values with STD + PMS @ 0.1 LR + FYM. On an average liming of soil and their mixing with FYM resulted in 4 to 11 per cent increase in cob length, 4.8 to 12.1 per cent in their diameter and 10.4 to 38 per cent increase in seed weight cob^{-1} compared to the length, diameter and seed weight cob^{-1} of 15.2, 12.4 and 54.8 gcob^{-1} due to STD respectively. Combined use of FYM with individual liming materials recorded positive influence.

4.13 Maize productivity under the influence of integrated use of lime and FYM frtilizers

4.13(A) Grain yield :

The grain yield of maize crop varied significantly between 11.3 and 39.3 qha^{-1} (Table-4.5,Fig-4.16), lowest due to control and highest due to STD + ST @ 0.2 LR + FYM. There was 49 per cent yield loss in maize grain yield when grown with out addition of external source of nutrients (-STD). Soil ameliorating with PMS @ 0.1 LR resulted in 23 per cent yield increase (27 qha^{-1}) with ST @ 0.1 LR by 21.4 per cent (26.7 qha^{-1}), with ST @ 0.2 LR by 44 per cent (31.7 qha^{-1}) and with CS @ 0.2 LR by 37.7 per cent (30.3 qha^{-1}) compared to 22 qha^{-1} due to STD alone.

Combined use of FYM @ 5 tha^{-1} with PMS increased the grain yield by 40 per cent (37.7 qha^{-1}) over PMS alone (27.0 qha^{-1}). Similarly mixing FYM with ST @ 0.1 LR by 20 per cent (32.0 qha^{-1}), ST @ 0.2 LR with FYM by 24 per cent (39.3 qha^{-1}) and CS @ 0.2 LR with FYM by 22 per cent (37.0 qha^{-1}) over ST @0.1 LR,ST @ 0.2 LR and CS @ 0.2 LR. Combined use of FYM with liming materials increased the usefullness of the liming materials (Table-4.5).

4.13(B) Stover yield :

The stover production of maize under different ameliorated treatments were less than the grain yield which varied between 9.4 and 31.3 qha^{-1} and followed similar trend as that of grain yield (Table-4.5,Fig-4.16).

The grain to stover ratio in maize crop indicated that, the FYM integrated treatments maintained higher ratios than the FYM unintegrated treatments (Fig-4.18).

The rachis of maize cob (after grain separating) under different treatments varied between 2.7 and 7.6 qha^{-1}. The spathe (covering the cob) content also varied between 2.9 and 8.6 qha^{-1}. The root mass of the crop also exhibited differences under the influence of lime and FYM treatment, which varied between 0.1 and 1.7 qha^{-1}. All the INM treatments under study recorded higher HI than unintegrated one (Fig-4.19).

The total biomass production of maize crop significantly Varied between 26.4 and 86.8 qha^{-1} under the influence of lime,FYM and fertilizers applications. Individual input had significant influence on biomass production (Table-4.5,Fig-4.17). Considering the efficiency of STD in biomass production taken as 100, the performance of other integrated treatments varied between 129 and 234 (Fig-4.20). The performance of different treatments can be arranged as follows :

STD (100)< STD + ST @ 0.1 LR (129) < STD + PMS @ 0.1 LR (152) < STD + CS @ 0.2 LR (162) < STD + ST @ 0.1 LR + FYM (173) < STD + ST @ 0.2 LR (177) < STD + CS @ 0.2 LR + FYM (219) < STD + PMS @ 0.1 LR + FYM(228) < STD + ST @ 0.2 LR + FYM (234).

4.14 Concentration, uptake and recovery of the nutrients as influenced by addition different liming materials

4.14(A) Nitrogen :

The concentration N in different maize plant parts and uptake through these parts have been presented in Table-4.6.

Its concentration of N in grain was more (ranging from 1.30 to 1.55 %) than through stover (ranging from 0.31 to 0.44 %) and than through roots (ranging from 0.58 to 1.23 %). So also the N uptake through grain was more (ranging from 15.7 to 54.9 kgha^{-1}) than stover (ranging from 5.1 to 20.1 kgha^{-1}) than through roots (ranging from 0.06 to 1.97 kgha^{-1}). The total uptake under different treatments varied significantly between 20.9 and 74.8 kgha^{-1}, lowest with control and highest with STD + PMS @ 0.1 LR + FYM.

Application of STD based inorganic nutrients significantly increased N uptake by the crop. Combined application of liming materials with STD though increased N uptake but not significantly higher than STD alone, except for ST @ 0.2 LR. However, integrating FYM application with STD and lime sources significantly increased N uptake even compared to N uptake due to STD + lime sources, indicating the importance of organic integration in improving efficiency of liming materials.

The recovery added by maize crop increased from the level of 17 to 36 per cent (Fig-4.21). Liming of acid soil improved the recovery of N ranging from 5 to 10 per cent over the recovery due to STD (17 %). The lime sources followed the order : ST @ 0.2 LR > CS @ 0.2 LR = PMS @ 0.1 LR > ST @ 0.1 LR. Integrating FYM application with liming materials further increased the recovery of N ranging from 7 to 11 per cent. The combinations followed the order : PMS @ 0.1 LR = CS @ 0.2 LR > ST @ 0.2 LR = ST @ 0.1 LR

4.14(B) Phosphorus :

The data relating to the concentration of P and its uptake through maize crop have been presented in Table -4.7.

The concentration of P in maize grain was more (from 0.25 to 0.31 %) than its root (from 0.05 to 0.13 %) than the stover (from 0.03 to 0.06 per cent).

The uptake through grain was more (from 3.3 to 10.7 kgha^{-1}) than stover (from 0.9 to 2.6 kgha^{-1}) than the roots (from0.01 to 0.21 kgha^{-1}). The total uptake varied significantly between 4.2 and 13.4 kgha^{-1}, lowest with control and highest with STD + ST @ 0.2 LR.

With the application of soil test based inorganic fertilizers there was significant influence on P uptake, but with the application of liming materials with STD, the P uptake increased significantly with ST @ 0.2 LR and CS @ 0.2 LR not with PMS 0.1 LR or ST @ 0.1 LR. However combined application of FYM with the sources significantly increased P uptake except with ST @ 0.1 LR.

The recovery of P by maize crop increased from a level of 26 to 66 per cent. (Fig-4.22) Integrating application of ST @ 0.1 LR with STD increased P recovery by 5 per cent, PMS @ 0.1 LR with STD by 8 per cent, CS @ 0.2 LR with STD by 15 per cent and ST @ 0.2 LR with STD by 21 per cent compared to that of STD alone. Integrating FYM application with lime sources increased the recovery further (ST @ 0.1 LR by 11 %, ST @ 0.2 LR by 19 % both PMS @ 0.1 LR and CS @ 0.2 LR by 23 %).

4.14(C) Potassium :

The data related to potassium concentration and uptake by Maize crop have been presented in Table- 4.8.

The concentration of K in maize root was more (ranging from 0.31-0.60%) than its stover (ranging from 0.32-0.44%) than its grain (ranging from 0.32 to 0.37%. But its uptake through stover was more (ranging from 6.0-19.4 Kg/ha) than its grain(ranging from 4.1- 12.8 Kg/ha) and roots (ranging from 0.03-0.96%) .

The total uptake varied significantly between 10.1 and 32.2 kg/ha. The uptake of K was significantly influenced by the application of STD compared to control.

Integrating use of ST @ 0.2 LR and CS @ 0.2 LR with STD significantly increased the K uptake but not the PMS or ST @0.1 LR. However, combining FYM application with STD and lime sources significantly increased K uptake by maize crop compared to FYM.

The recovery of K by maize crop increased from a level of 22 per cent with STD only to a level of 55 per cent STD + PMS @ 0.1 LR / CS @ 0.2 LR + FYM (Fig-4.23).

The recovery of K with integrated use of ST @ 0.1 LR with STD increased only by 2 per cent, 12 per cent with PMS, 17 per cent with CS @ 0.2 LR and 20 per cent by ST @ 0.2 LR. Due to FYM integration with STD+Lime sources, the recovery per cent further increased by 12 per cent with ST @ 0.2 LR , 16 per cent with PMS@ 0.1 LR..

4.14(D) Sulphur :

The data related to sulphur nutrition of maize have been presented in Table-4.9.

There are not much difference in the distribution of S in maize grain, stover and roots. In the grain it was 0.05-0.08, in stover from 0.055-0.088 and in root from 0.03-0.1 per cent . The removal through stover was more (ranging from 0.9-3.9 Kg/ha.) than grain (ranging from 0.6-3.0 Kg/ha) and roots (ranging from 0.01-0.16 Kg/ha). The total uptake varied significantly between 1.5 and 7.1 Kg/ha. Application of STD of fertilizers either alone or or with liming materials or more specifically with FYM significantally influenced S uptake by the crop. The apparent recovery of applied S by maize crop increased from a level of 2.2 to 8.8 per cent. Integrated use of fertilizers, Lime sources and FYM acted positively for recovery (Fig-4.24).

4.15 Concentration and Uptake of Calcium as influenced by different liming materials

In maize crop more of Ca was analysed from its stover (ranging from 0.12 to 0.19%) than from grain (ranging from 0.10-0.17%) and least in roots (ranging from 0.08-0.10%) (Table-4.10).

Its uptake through stover was more (ranging from 1.9-9.0Kg/ha.) than grain (ranging from 1.1-6.4 Kg/ha) and root (ranging from 0.01-0.16 kg/ha) .

The total uptake varied between 3.1 and 12.8 kg/ha. Fertilizering crop increased Ca uptake by the crop compared to control . Even its uptake increased by combining both liming materials and FYM (Table-4.10).

4.16 Concentratin and uptake of Magnesium as influenced by different liming materials

More Mg was analysed from maize roots (ranging erom 0.16-0.29 %) than grain (ranging from 0.07-0.10 %) and stover (ranging from 0.05-0.09%) . The Mg in maize root was even more than the Ca in the root (Table-4.11). The uptake of Mg through stover was more (ranging from 0.8-3.8 kg/ha) than grain (ranging from 0.8-3.9 kg/ha) and root (ranging from 0.02-0.51 kg/ha). The total Mg uptake varied between 1.7 and 7.5 kg/ha. The use of soil test based fertilizers either alone or its integration with liming materials and particularly FYM increased Mg uptake by the crop (Table-4.11).

Table-4.10 : Concentration and Uptake of Calcium as influenced by different liming materials

Treatments	Concentration(%)			Uptake(kg/ha)			
	Grain	Stover	Root	Grain	Stover	Root	Total
Absolute control	0.10	0.12	0.08	1.1	1.9	0.01	3.1
STD	0.11	0.16	0.09	2.4	4.7	0.05	7.1
STD + PMS @ 0.1 LR	0.09	0.17	0.07	2.6	6.6	0.06	9.3
STD+PMS @ 0.1 LR + FYM	0.10	0.17	0.08	4.1	8.0	0.14	12.2
STD +ST @ 0.1 LR	0.17	0.18	0.08	3.1	5.6	0.09	8.8
STD +ST @ 0.1 LR +FYM	0.12	0.19	0.09	3.9	7.3	0.12	11.4
STD + ST @ 0.2 LR	0.14	0.18	0.07	4.3	6.9	0.08	11.3
STD + ST @ 0.2 LR + FYM	0.16	0.19	0.10	6.4	9.0	0.14	12.2
STD + Ca-Si @ 0.2 LR	0.13	0.16	0.08	3.9	6.3	0.07	10.3
STD + Ca-Si@ 0.2 LR+FYM	0.14	0.17	0.09	5.0	7.6	0.16	12.8

Table-4.11 : Concentration and Uptake of Magnesium as influenced by different liming materials

Treatments	Concentration(%)			Uptake(kg/ha)			
	Grain	Stover	Root	Grain	Stover	Root	Total
Absolute control	0.07	0.05	0.16	0.8	0.8	0.02	1.7
STD	0.08	0.06	0.17	1.7	1.6	0.09	3.4
STD + PMS @ 0.1 LR	0.08	0.07	0.19	2.2	2.9	0.15	5.3
STD+PMS @ 0.1 LR + FYM	0.09	0.08	0.29	3.2	3.8	0.51	7.5
STD +ST @ 0.1 LR	0.09	0.06	0.17	2.5	1.9	0.19	4.6
STD +ST @ 0.1 LR +FYM	0.10	0.09	0.18	3.9	3.6	0.21	7.6
STD + ST @ 0.2 LR	0.07	0.06	0.25	2.3	2.3	0.27	4.9
STD + ST @ 0.2 LR + FYM	0.08	0.08	0.28	2.9	3.4	0.40	6.7
STD + Ca-Si @ 0.2 LR	0.07	0.07	0.27	2.2	2.8	0.33	5.3
STD + Ca-Si@ 0.2 LR+FYM	0.08	0.08	0.28	3.0	3.1	0.45	6.6

4.17 Post harvest soil properties

The post harvest soil properties after Maize have been presented in Appendix-14.

Soil reaction:

Initial soil was strongly acidic in reaction (pH 4.94) Post harvest soil reaction indicated that irrespective of the treatments the soil reaction turned more acidic (drop in pH), ranging from 4.10 to 4.66 (Fig-4.25,a).

Organic Carbon:-

Initial organic carbon was medium in status . It had also decreased under each treatment irrespective of FYM application ranging from 3.2 to 4.4 kgha^{-1} (Fig-4.25,b).

Available N status:

Its status was low initially, remained under low status after the harvest of the crop, but showed some increasing trend under all treatments except in control, STD + ST @ 0.1LR +FYM, STD + CS @ 0.2 LR+FYM treatments (Fig-4.25,c).

Bray's-1 available Phosphorous:

The Bray's 1 P status in intial soil was high (105 kgha^{-1}). Twenty five per cent less was recommended. The crop removed considerable amount of P under different treatments.

The post harvest soil P status even through decreased but maintained higher level irrespective of the treatments varying between 43 and 91 kgha^{-1} (Fig-4.25,d).

Availale Potssium:

The initial K status was medium in status. After crop production , inspite of K addition through fertilizers its status decreased and maintained a much lower level ranging from 63-83 kg/ha (Fig-4.25,e).

Available sulphur:

Its status was low initially. Therefore it was applicated through fertilizers from external source except in control. Inspite of crop removal higher sulphur status has been maintained in all the treatments varying between 16 and 57 kgha^{-1} (Fig-4.25,f).

DISCUSSION

The **"Comparative performance of different types of liming materials on maize crop grown in Acid soil"** was studied with the help of farmers field experiment in the village Bajpur in Khurda districts. The liming materials used in experiment include: paper mill sludge (PMS), stromatolyte (low grade naturally occurring stone) and industrially processed source calcium silicate (CS). The PMS was applied @ 0.1 LR for monocot crop maize as per earlier recommendation of the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Bhubaneswar. The indigenous source Stromatolyte was collected from Nabarangapur district of Odisha. No field evaluation was not conducted with this source, it was decided to evaluate this new material with two doses, i.e @ 0.1 LR and @ 0.2 LR . The 3rd source calcium silicate was granular in nature received from USA, through Harsco India Ltd, Hyderabad. It was tested with one dose, i.e @ 0.2 LR. The neutralizing value of these sources followed the order : PMS (60 %) < Stromatolyte (80 %) = Calcium Silicate (80 %): Based on Ca content , the sources followed the order : CS (34.5 %) > PMS (22.0 %) > ST (17.3 %). The Stromatolyte source contained 10.5 % Mg and 0.04 % S. The CS source also contained silicon of 24.17 per cent.

Depending upon the nature and fineness of the different liming materials the effectiveness varies. Generally the liming materials are either calcitic ($CaCO_3$), dolomitic {$Ca,Mg(CO_3)_2$} or mixture of both . Some times calcium silicate also act like liming materials. All these are sparingly soluble in pure water, but become soluble in water containing CO_2 . Greater is the partial pressure of CO_2 in the system, the more soluble is the liming material, Such situation is encountered in soils having high organic matter content (Pattanayak,2014). The liming material provide conjucate bases of weak acids like

CO_3^{2-}, hydroxide (OH^-) and silicate (SiO_3^{2-}). These conjugate bases are anions that are capable of consuming (reacting with) H^+ to form weak acids (such as water) as per the following reactions :

$$CO_3^{2-} + 2H^+ \longrightarrow CO_2 + H_2O$$

$$(CaCO_3 + H_2O + CO_2 \longrightarrow Ca(HCO_3)_2 \longrightarrow Ca^{2+}\ [\text{Cation Exch. site}] + HCO_3^- + OH^-).$$

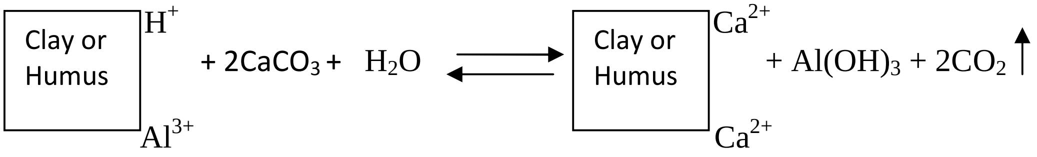
$$H^+\ (\text{soil solution}) + OH^- \longrightarrow H_2O$$

$$H^+\ (\text{soil solution}) + HCO_3^- \longrightarrow H_2O + CO_2\uparrow$$

The oxide sources of lime i.e CaO and MgO form hydroxy ions in water.

$$CaO + H_2O \longrightarrow Ca(OH)_2 \longrightarrow Ca^{2+} + 2OH^-$$

The PMS is expected to react in acid soils in the following manner :

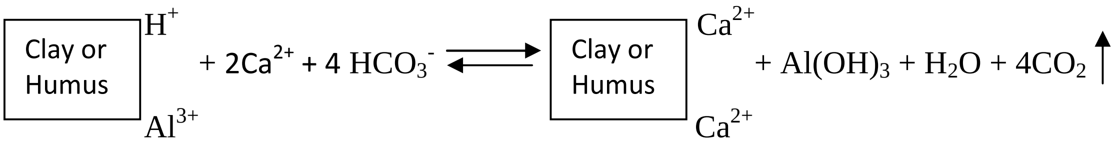


$$\boxed{\begin{matrix}\text{Clay or}\\ \text{Humus}\end{matrix}}\begin{matrix}H^+\\ \\ Al^{3+}\end{matrix} + 2CaCO_3 + H_2O \rightleftharpoons \boxed{\begin{matrix}\text{Clay or}\\ \text{Humus}\end{matrix}}\begin{matrix}Ca^{2+}\\ \\ Ca^{2+}\end{matrix} + Al(OH)_3 + 2CO_2\uparrow$$

The dolomitic lime stone function more effectively than $CaCO_3$. The Stromatolyte source being dolomitic lime is expected to react in the following manner :

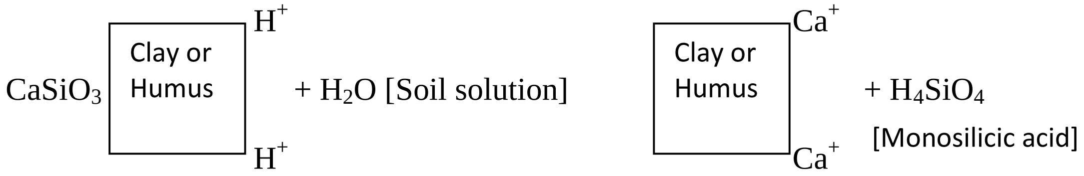
$$CaMg(CO_3)_2 + 2H_2O + 2CO_2 \rightleftharpoons Ca + 2HCO_3^- + Mg + 2HCO_3^-$$

The caicium and Magnesium bicarbonates are much more soluble than carbonate, so the HCO_3^- formed is quite reactive with the exchangeable and the residual soil activity. The Ca^{2+} and Mg^{2+} replace H^+ and Al^{3+} ions on the exchange complex , increase base saturation and neutralize acidic cations.



$$\boxed{\begin{matrix}\text{Clay or}\\ \text{Humus}\end{matrix}}\begin{matrix}H^+\\ \\ Al^{3+}\end{matrix} + 2Ca^{2+} + 4\ HCO_3^- \rightleftharpoons \boxed{\begin{matrix}\text{Clay or}\\ \text{Humus}\end{matrix}}\begin{matrix}Ca^{2+}\\ \\ Ca^{2+}\end{matrix} + Al(OH)_3 + H_2O + 4CO_2\uparrow$$

The possible reaction of $CaSiO_3$ in acid soil is as follows :



$$CaSiO_3\ \boxed{\text{Clay or Humus}}\begin{matrix}H^+\\ \\H^+\end{matrix}\ + H_2O\ \text{[Soil solution]} \qquad \boxed{\text{Clay or Humus}}\begin{matrix}Ca^+\\ \\Ca^+\end{matrix}\ + H_4SiO_4\ \text{[Monosilicic acid]}$$

The mono silicic acid complexes with toxic Al^{3+} and Al hydroxy species from non toxic alumino silicate and hydroxy amino silicate compounds, which precipitate at root zone.

The consequences of liming of acid soils are (i) neutralization of proton (H^+) and raising pH (ii) precipitation of Al^{3+} ions as $Al(OH)_3$ at higher soil pH values ultimately neutralization of acidity (Pattanayak and Pandey,2013) (iii) improves base saturation and CEC (iv) reduce phosphate fixation and increase P availability (v) influence N mineralization and increase N availability (vi) keep k in available mode for plants (vii) micro-nutrients availability is moderated (toxic levels to non toxic levels Fe,Mn,Zn and Cu), a better growing environment for crops to grow (Mishra,2004, Pattanayak,2013).

In the present investigation crop production without any nutrition or amelioration measure brought down the pH (Fig-4.1.a) or increased soil exchange acidity (Fig-4.2.a), acidity due to Al (Fig-4.3.a), acidity due to H^+ (Fig-4.4.a),decreased CEC (Fig-4.6.a), exchangeable Ca (Fig-4.7.a), exchangeable Mg (Fig-4.8.a) and exchangeable K (Fig-4.9.a). All these unfavourable growing environment lead to poor crop growth, low chlorophyll content (Fig-9), 95 % less plant height compared to the plant height of 139.1 cm due to STD (Fig-10), with low growth rate, low yield (11.3 qha^{-1}), significantly less nutrient uptake compared to other fertilized and well managed crop. Removal of basic cations resulted in decrease in pH, increased acidity and all unfavourable growing environment to produce lowest yield.

Similar was the findings of crop fertilized with soil test based inorganic nutrients without any ameliorative measure against soil acidity aggravated acidity (Fig-

4.2.a), both due to Al (Fig-4.3.a) and H^+ ions (Fig-4.4.a) after 21 DAS. Before 21 DAS due to addition of fertilizers (Navaratna, Urea and MOP) and dilution effect from rain water prevented pH drop and decreased acidity in the rhizosphere. However due to increased crop demand after 21 DAS removed more of basic cationic nutrients [drop of exchangeable Ca(Fig-4.7.a), Mg(Fig-4.8.a) and K (Fig-4.9.a] rendered soil to be more acidic compared to absolute control (drop in pH, Fig-4.1.a, increased exchange acidity, Fig-4.2.a, acidity due to Al^{3+}, Fig-4.3.a, acidity due to H^+ ion, Fig-4.4.a, decreased CEC of soil, Fig-4.6.a till the harvest of the crop).

Attempt to ameliorate the soil with PMS @ 0.1 LR when applied with STD neutalised (decreased) exchange acidity (Fig-4.2.a), decreased acidity due to Al^{3+} (Fig-4.3.a), decreased acidity due to H^+ ions (Fig-4.4.a), raised the soil pH more than that under STD (Fig-4.1.a) and maintained it up to a period of 14 to 21 DAS, decreased there after till the harvest of the crop as crop growth continued. With crop growth demand for exchangeable Ca (Fig-4.7.a), Mg (Fig-4.8.a) and K (F-g-4.9.a) increased. The demand was met through the PMS and supplied fertilizer source. The increase in CEC in soil (Fig-4.6.a) and maintainance of higher level of exchangeable Ca, exchangeable Mg and exchangeable K up to 28th DAS, and decreased there after till the crop harvest was indicative of the fact.

Ameliorating the acid soil with stromatolyte @ 0.1 LR effectively neutralized acidity due to H^+ (Fig-4.4.b) up to 49th DAS, acidity due to Al^{3+} up to 35th DAS (Fig-4.3.b) and exchange acidity up to 21 DAS (Fig-4.2.b) and maintained higher pH than initial status up to 28th DAS (Fig-4.1.b). This source of liming material could maintain higher CEC than PMS source up to 14 DAS (Fig-4.6.b), higher exchangeable Ca up to 21st DAS (Fig-4.7.b) and exchangeable Mg (Fig-4.8.b) and K (F-g-4.9.b) through out growing period . Inspite of higher crop demand for basic cations, higher exchangeable Ca, Mg and K status was maintained till the crop harvest due to their supplymentation through the supplied source.

Soil amelioration with double dose of stromatolyte (ST @ 0.2 LR) could neutralized partially the acidity due to H^+ ions up to 35th DAS (Fig-4.4.c), acidity due to Al^{3+} ions up to 35 DAS (Fig-4.3.c), maintained lower level of exchange acidity up to 49th DAS (Fig-4.2.c) and higher soil pH compared to ST source applied @ 0.1 LR (Fig-4.1.c). All along the double dose of stromatolyte maintained higher CEC than ST applied @ 0.1 LR and higher level of CEC compared to initial stage up to 28th DAS (Fig-4.6.c) and decreased there after . Removal of basic cations through crop uptake (may be some due to leaching), with decrease in soil organic carbon status in soil (Fig-4.5.c) the CEC decreased. The double dose of stromatolyte (ST @ 0.2 LR) was more effective than 0.1 LR dose in managing acidity and raising the pH for better crop growth.

The calcium silicate source of lime even though had high neutralizing value (80 %) but reacted slowly at the beginning, was able to maintain lower level of H^+ ion concentration till the harvest of crop (Fig-4.4d), acidity due to Al^{3+} effectively lower level compared to initial stage up tp 35th DAS (Fig-4.3.d). As a result of this the exchange acidity remained at lower level compared to the initial state till 63rd DAS (Fig 4.2.d) but higher pH than initial soil pH up to only 21st DAS (Fig 4.1.d). As the lime source continued to react in soil, the exchangeable Ca (Fig-4.7.d) and Mg (Fig-4.8.d) remained at higher level than initial level but the increased CEC status was maintained up to 28th DAS, decreased there after till the harvest of the crop. Such decrease in CEC may be attributed to the decreasing status of organic carbon (Fig-4.5.d).

Addition of FYM @ 5tha^{-1} with lime sources and soil test based fertilizers, through its buffering action on soil reaction, protection and preservation of basic cations like Ca^{2+}, Mg^{2+} and K^+ from possible chances of losses through leaching under open textured soil conditions; and complexing ability with Al^{3+} ions have played important role in management of acid soil.

Irrespective of the lime sources and their doses, combined application of FYM could brought down the level of Al to lower level compared to the treatments without FYM application throughout the growing period by complexing with the exchangeable Al^{3+} (Fig-4.3.a,b,c,d) but the level of H^+ ion continued to be at higher level with FYM application compared to that of without FYM (Fig-4.4.a,b,c,d). As a result of this the exchange acidity decreased with FYM application and was maintained at lower manageable level.(Fig-4.2.a,b,c,d). Therefore higher pH was maintained all along the growing period compared to the pH under no FYM added condition (Fig-4.1.a,b,c,d).

Addition of FYM helped maintaining higher organic carbon content in the soil compared to the soil without its irrespective of the lime sources (Fig-4.5.a,b,c,d) throughout the growing season. Such increase in organic carbon content in soil maintained higher level of exchangeable Ca (Fig-4.7.a,b,c,d) and Mg (Fig-4.8.a,b,c,d) inspite of their crop removal. These things have also been reflected in maintenance of higher CEC compared to without FYM (Fig-4.6.a,b,c,d).

The average growth rate of maize crop in absolute control treatment was 1.72 cm day^{-1} with the application of soil test based fertilizers it increased to 3.26 cm day^{-1} (90% higher). Integrating lime sources with STD increased it by 4 % with PMS, 3.8 % by ST @ 0.1 LR, 9.0 % by ST @ 0.2 LR and 8.6 % by CS @ 0.2 LR. Combining FYM application with PMS, ST @ 0.1LR, ST @ 0.2 LR and CS @ 0.2 LR increased the growth rate by 8.6,7.4,9.0 and 12.0 per cent, respectively. Better growing environment interms of reduced acidity, increased availability of Ca, Mg, K and other nutrients helped achieving better growth rate of the crop with ameliorated soil condition.

The beneficial function of fertilizers application, its integration with lime sources and further combination with FYM was not only reflected on growth on above ground portion but also on under ground portion i.e root. The increase in root length due to integrated use of lime sources with STD varied widely; with PMS @ 0.1 LR by 27 per cent, with ST @ 0.1 LR by 15 per cent ,with ST @ 0.2 LR by 104 per cent, with CS @ 0.2 LR by 19 per cent, combined use of FYM increased the root length further ranging from 13 to 36 per cent.

Not only the root length, but also root weight, their volume and density were influenced by soil amelioration measure with lime sources and more positively by combined use of FYM.(Table-4.3). Similar results of positive impact of liming on root grown were also reported by Onwuka *et al* (2009),Fageria and Baligar (2004).

The proper inorganic nutrition of crop coupled with acid soil amelioration measures with lime sources and further with organic source FYM, not only produced bigger sized cobs which could accommodate more grains compared to no fertilization and no amelioration measure was indicative of better growing environment for higher production with INM practice (Table-4.4). The results corroborate the findings of Dierolf *et al* (1997), Pattanayak and Mishra, 2002.

The positive influence of proper crop nutrition, soil amelioration with inorganic (lime) and organic (FYM) ameliorants not only restricted to the growth of the maize plant, root and cob characteristics, but also the biomass production of maize including grain, stover, rachis and spathe production(Table-4.5). Under the system of integrated nutrient management, constraints for production were taken care to provide optimum growing environment for maize crop to produce as per the treatment specificity.Based on the efficiency of lone lime sources on maize grain production, the sources can be arranged as ST @ 0.1 LR (21 %) < PMS @ 0.1 LR (23 %) < CS @ 0.2 LR (37.7%) < ST @ 0.2 LR (44 %). Combined application of organic ameliorant (FYM) with lime sources influenced grain production differently, where the sources can be arranged in order : ST @ 0.1 LR (20 %) < CS @ 0.2 LR (22 %) < ST @ 0.2 LR (24 %) < PMS @ 0.1 LR (40 %). These results indicate that combined use of inorganic and organic ameliorants are essential for better yield. There is scope for increasing efficiency of the lime sources, particularly the indigenous source i.e stromatolyte. Earlier Pattanayak and Pandey (2012) reported for the application of Stromatolyte @ 0.1 LR with FYM of 22 mesh sieve size for better effectiveness. But the test was conducted under close system (Pot experiment).These results are in aggrement with the results reported by Mishra and Pattanayak (2002), Mishra, 2004, Sharma and Sarkar (2005).

Crop production under optimum growing environment (through crop growth) utilizes the inputs/resources efficiently. Where constraints remains, the inputs are inefficiently utilized which are reflected in production. In the present study soil ameliorants both inorganic (lime) and organic (FYM) influenced the growth of maize crop for uptake of N,P,K,S,Ca and Mg. Under ameliorated soil condition the uptake of nutrients increased as a result the 17 per cent N recovery with STD increased to 22 per cent with PMS @ 0.1 LR, 19 per cent with ST @ 0.1 LR, 27 per cent with ST @ 0.2 LR and 22 per cent with CS

@ 0.2 LR. Organic amelioration increased ANR by another 14,7,7,12 per cent with PMS, ST @ 0.1 LR, ST @ 0.2 LR and CS @ 0.2 LR sources.

Recovery efficiency for P was most influenced by amelioration practice from 26 to 66 per cent, for K from 22 to 55 per cent and for S from 6.2 to 28.7 per cent. Soil amelioration measures almost doubled the uptake of Ca (from 7.1 to 12 8 kgha^{-1}) and Mg (from 3.4 to 6.6 kgha^{-1}). The better utilisation of Ca by the test crop under soil ameliorated condition and its influence on maize crop growth was reported by Nkana *et al* (1998), Ojeniyi *et al* (1999), Pattanayak (2013).

As maize is one exhaustive crop for soil, inspite of fertilizer, lime and FYM addition, due to removal of nutrients (mostly basic) the soil had turned acidic, due to frequent intercultural operations facilitating carbon oxidation process had resulted in depletion of organic carbon status. Post harvest available N status decreased in control where it was not added. Its status either maintained or increased in rest of the treatments compared to initial, but these were under low status of ratting.

Available P status was high initially less was recommended for the crop. Inspite of crop removal the P status was being maintained at higher level.

The available K status indicates warning for its management (Appendix-14). Initially the status was medium. Irrespective of treatments its status had decreased drastically due to crop removal and may be due to some loss through leaching. This warrents for its careful judicious management.

The available S status was low initially in control treatment, its status had decreased because of crop removal without supplementation. In rest of the treatments, its supplementation through complex fertilizer (20-20-0-13). Due to its less uptake through crop (1.5 to 7.1 kgha^{-1}) and recovery was <29.0 per cent, higher status was maintained in post harvest soil.

SUMMARY

The "**Comparative performance of different types of Liming materials for Maize crop grown in Acid Soil**" was studied with the help of farmers field experiment in the village Bajpur in Khurda district during *Kharif* (2013). The soil of the experimental site was loamy sand in texture, strongly acidic in reaction (pH_w : 4.94), EC 0.09 dSm^{-1}, OC content of 5.7 gkg^{-1} soil, available N,P,K and S of 169,105,143 and 17 $kgha^{-1}$ respectively. The B was 0.15 $mgkg^{-1}$ and Zn of 0.41 $mgkg^{-1}$ soil. The CEC was 6.29 $cmol(p^+)kg^{-1}$ with exchangeable Ca and Mg of 3.4 and 1.8 $cmol(p^+)kg^{-1}$ soil. The acidity due to exchangeable H^+ and exchangeable Al^{3+} were 0.60 and 0.44 $cmol(p^+)kg^{-1}$ soil. The exchange acidity was 1.04 $cmol(p^+)kg^{-1}$ soil. The lime requirement to raise pH to 6.5 was 3 t $CaCO_3ha^{-1}$.

The soil test report revealed that the soil related constraints for maize crop production were from (i) soil acidity, (ii) poor soil structure (open/coarse textured), nutrient imbalance like (iii) low available N, (iv) low sulphur (S), (v) low available B and Zn, (vi) high available P etc.

Due attention was given for recommendation of soil test based inorganic fertilizers correcting nutrient deficiencies. The recommended dose for maize crop was 150-30-50-30-10-25 kg of N - P_2O_5 - K_2O -SO_4 - Borax- $ZnSO_4$ ha^{-1} respectively. The test crop maize received ten different treatments namely : (i) Absolute control, (ii) STD, (iii) STD + Paper mill sludge @ 0.1 LR, (iv) STD + PMS @ 0.1 LR + FYM, (v) STD + Stromatolyte(ST) @ 0.1 LR, (vi) STD + ST @ 0.1 LR + FYM, (vii) STD + ST @ 0.2 LR, (viii) STD + ST @ 0.2 LR + FYM, (ix) STD + Calcium silicate (CS) @ 0.2 LR , (x) STD + CS @ 0.2 LR + FYM. The three sources of liming materials were applied as basal in the rhizosphere below the seed zone either alone or mixed with FYM as per the treatment

specificity. The 100 % P, 20 % N and25 % K, 50 % borax and $ZnSO_4$ were applied as basal, 50 % N and K, 50 % Borax and $ZnSO_4$ were 1st top dressed at 21 days after sowing and rest 30 % N and 25 % K were 2nd top dressed after 45 DAS. At seven days interval rhizospheric composite soil samples were collected, analysed for change in pH, OC, nature of acidity, CEC, exchangeable cations. The post harvest soil samples were analysed for soil reaction, organic carbon, and status of available nutrients. The grain, stover, root samples of maize crop were analysed for their concentration, uptake and recovery.

The liming materials upon application to soil when used with FYM their efficiency increased interms of neutralising acidity, influencing availability of exchangeable cations (Ca^{2+},Mg^{2+} and K^{+}), increasing CEC and raising pH of acid soil. The PMS @ 0.1 LR alone maintained a soil pH of 5.1 at14 DAS, with FYM a pH level of 5.96 to 6.0 up to 21 DAS. The Stromatolyte alone @ 0.1 LR attened highest pH of 5.12 but maintained higher pH than initial up to 28 DAS, with FYM maintained for 35 DAS and attending the highest pH value of 6.30. Its double dose alone raised the pH 4.94 to 5.51 and higher pH up to 35 DAS, but with FYM up to 49th DAS attending the highest level of 6.08. The calsium silicate maintained higher pH at 21 DAS, with FYM up to 28 DAS compared to initial pH of 4.94.

The maize crop recorded an average growth rate of 1.72 cm day^{-1} in absolute control, with STD 3.26 cm day^{-1} which was 9 per cent higher. Integrating lime sources with STD recorded average growth rate of maize of 3.45 cm day^{-1} which was 6 per cent higher than STD alone. Combined use of FYM with STD and lime sources further increased the growth rate by 9.6 per cent over STD with lime sources.

The positive influence of both inorganic (lime) and organic (FYM) amelioration measures were also reflected on root length, volume and density.

The grain yield of maize was almost doubled from 11.3 qha^{-1} due to absolute control to 22 qha^{-1} due to application of soil test based dose of inorganic fertilizers. On an average soil amelioration with lime sources increased the grain yield by 32 per cent compared over the yield of 22 qha^{-1} due to STD only. Integrating organic amelioration (FYM) of soil increased the grain yield by 26 per cent over the average yield of 28.9 qha^{-1} due to STD + Lime. Highest yield of 39.3 qha^{-1} was recorded with STD + ST @ 0.2 LR + FYM.

The Grain : Straw ratio varying between 1.18 to 1.76 indicated that grain yield was more than the stover yield . Comparision of relative agronomic efficiency of different treatments considering the performance of the soil test recommended dose taken as 100, different integrated treatments followed the order :

STD + ST @ 0.2 LR + FYM > STD + PMS @ 0.1 LR + FYM > STD + CS @ 0.2 LR + FYM > STD + ST @ 0.1 LR + FYM> STD + ST @ 0.2 LR > STD + CS @ 0.2 LR> STD + PMS @ 0.1 LR > STD + ST @ 0.1 LR > STD

The amelioration measure for maize crop production not only influenced the crop yield but also influenced the nutrient uptake and recovery by the crop. The amount of nutrient uptake by the crop followed the order : N > K > P > Ca > S > Mg. The 17 per cent N recovery under unameliorated condition increased to 36 per cent with amelioration. Similarly the recovery of P increased from 26 to 66 per cent, K from 22-55 per cent and S from 6.2 to 28.7 per cent.

The post harvest soil properties indicated that the soil turned acidic irrespective of the amelioration measure taken. The carbon content also decreased irrespective of the treatments. where N was not added from external source its status decreased but increased where it was applied. Irrespective of P application the status decreased but was maintained at higher level. The available K status decreased invariably in all the treatments except in control treatment. The S status in rest of the treatments increased compared to initial status in all the treatments except for control.

CONCLUSION

From the experiment on " **Comparative Performance of different types of Liming materials for Maize crop grown in Acid Soil**" following conclusions can be drawn :

1) The liming materials neutralised the activity due to H^+ and Al^{3+} and the exchange acidity to lower manageable level and raised the pH differently depending upon the neutralising value of the sources.
    a) The PMS applied @ 0.1 LR maintained higher pH up to 14 days after sowing. The Stromatolyte applied @ 0.1 and @ 0.2 LR doses maintained higher pH up to 28 and 35 days after sowing respectively. The calcium silicate source maintained higher pH up to 21 days after sowing.
    b) The effectiveness of the lime sources increased with their combined application with FYM, for PMS it was 21 days, ST @ 0.1 LR - 35 days, ST @ 0.2 LR -49 days and CS @ 0.2 LR - 28 days after sowing.
2) a) The calcium silicate source applied @ 0.2 LR and the ST @ 0.2 LR when applied mixed with FYM recorded highest average growth rate of 3.9 cm day^{-1}.

b) Inorganic (Lime) amelioration of acid soil resulted in 32 per cent higher yield compared to the yield of 22 qha^{-1} due to inorganic nutrition only.

c) Combining organic amelioration (FYM) with inorganic amelioration measure and inorganic nutrition yielded 26 per cent higher grain yield in maize crop.

d) Among the lime sources Stromatolyte applied @ 0.2 LR with STD + FYM recorded highest yield of 39.3 qha^{-1}.

3) a) Among the major nutrients, the recovery of P was maximum ranging from 26-66 % ,followed by K from 22 to 55 per cent, N from 17 to 36 per cent and sulphur from 6.2 to 28.7 per cent.

b) The maximum recoveries of major nutrients were recorded with Stromatolyte source applied @ 0.2 LR integrated with STD and FYM.

4) a) Soil turned more acidic after harvest of maize crop indicated adoption of liming practice for each crop.

b) The carbon status decreased invariably suggested insitu management of crop residues for its improvement and maintenance.

c) The status of N in soil increased with its application indicated frequent and continued application for individual crops.

d) The available P status decreased in variably but maintained at higher status which emphasized soil test based fertilizer recommendation for input saving.

e) There was drastic reduction in available K status which needs proper attention for adequate supplimentation.

f) The available S status was increased with its application.

Recommendation :

Soil test based application of inorganic nutrients after correction of soil deficient nutrients, acid soils are ameliorated with Stromatolyte @ 0.2 LR dose mixed with FYM @ 5 tha^{-1} can yield 39.3 qha^{-1} of maize grain (inspite of Philine affect during the initial stage of cob formation).

Future study :

1. Replication of the trial under optimum growing environment in different soil condition.
2. Influence of soil amelioration measure on soil and crop quality.
3. Detail study has to be conducted using Stromatolyte along with other possible source of liming materials.

REFERENCES

Adams, F. (1984) Soil Acidity and Liming. 2nd Edn (*Madison. WI: Amer. Soc. of Agronomy*)

Ananthanarayana, R and Hanumantharaju, T.H. (1993) Efficacy of Different Liming Materials in Neutralizing Soil Acidity. *J. Indian Soc. Soil Sc*. **41** (3): 603-605.

Annual Progress Report (2010-2011) Niche Area of Excellence, *Management of Acid Soils for Sustainable Crop Production*. Department of Soil Science and Agricultural Chemistry, OUAT.

AOAC (1960), Official Methods of Analysis Of the Association of Official Agricultural Chemists, pp 12-13. Association OF Official Agricultural chemists,Washington.

Badajena, B. (2003) Lime and sulphur response of maize-mustard croppimg sequence grown in an *Alfisol*. *Thesis submitted to Orissa University of Agriculture and Technology*, Bhubaneswar, Orissa.

Barade, M.D and Chavan, K.N. (1998) Liming Induced Changes in Charactristics of Fluventic Ustropepts of Konkan. *J. Indian Soc. Soil Sci*. **46**(1): 5-8.

Barber, S.A. (1984) Liming Material and Practices. *F. Adams (E.d), Soil Acidity and Liming, 2nd edn. (Madison, WI: Amer. Soc. Agron.*)

Behura, S., Sahoo, B. N. and Pradhan, N.K. (1996) Reclamation of Chromite Overburden. *J. Indian Soc. Soil Sci.* **44**(2): 313-316.

Bhat, J.A., Mandal, B. and Hazra, G.C (2007) Basic slag as a liming material to ameliorate soil acidity in *Alfisols* of Sub-tropical India. *American-Eurasian Journal of Agriculture and Environmental Science*, 2 (4): 321-327.

Bishnoi, S.K., Tripathy, B.R and Sharma, P.K. (1988) Studies on Liming of Acid Soils of Himachal Pradesh. *J. Indian Soc. Soil Sci*. **36 :** 257-263.

Black, C.A. (1968) *Soil plant-relationships*. John Willey and Sons, Inc. New York, London. Sydney. pp. 792.

Black, C.A. (1969) Methods of Soil Analysis. Part 2. *Am. Soc. Agron.* Medison, Wisconsin, U.S.A.

Bolan, N.S, Adriano,D.C. and Curtin, D. (2003) Soil acidification and liming interactions with nutrients and heavy metal transformation and bioavailability. *Advances in Agronomy*, 78: 215-272.

Bolt, G.H. and Bruggenwert, M.G.H. (1976) Adsorption of anions by soils. In: *Soil Chemistry. 2nd. Ed*. pp: 91-95.

Brady, N.C. (2001) *The Nature and Properties of Soils*. Macmillan Publishing Company.

Chernov, V.A. (1947) *On the Nature of Soil Acidity*. Academy of Science, Muscow, U.S.R., pp. 170.

Chesnin.L. and Yein, C. H. (1951) *Soil Science Soc. of Amer Proc*. 15 : 149-151.

Datta,M. and Gupta, R.K (1983) Response of wheat and maize in acid soils of Nagaland, *J. Indian Soc. Soil Sci.* **31** : 236-240.

Dierolf, T. S., Arya, L. M and Yost, R.S. (1997). Water and Cation movement in an Indonesian Ultisol. *Agron. J.* 89; 572-579

Dixit, S.P., Pritam, K and Sharma, P.K. (1993) Effect of Lime and Potassium on Soil Acidity, forms of Aluminum and Iron and yield of crops in sequence. *J. Indian Soc. Soil Sci.* **41** (3): 22.26.

Dixit, S.P. and Sharma, P.K. (1995) Effect of Lime and Potassium on Soil Acidity, forms of Aluminum and Iron and yield of crops in sequence. *J. Indian Soc. Soil Sci.* **43** (1): 78-80.

Dutta, R., Gogoi, P.K., Barman, P. and Deka, N.C. (1997-98) Effect of levels o flime and phosphorous on production of groundnut. *Legume Res.* **27**(4): 274-277 (2004).

Ebhin Masto,R., Raj, G.B., Babu, P.S and Jagachandran, K.S. (1999-2000) Effect of Liming on available phosphorus and molybdenum status of the soil after soybean. *Annals of Agricultural Research*. New Delhi, **25**(1): 164-166.

Edmeades, D.C. and Ridley, A.M. (2003) Using lime to ameliorate topsoil and subsoil acidity. In. rengal, A. (Ed.), *Handbook of Soil Acidity*. Marcel Dekker, Inc., New York, Basel, pp. 297-336.

Fageria, N.K. Baliger, V.C, Zobel, R.W (2007) Yield, Nutrient uptake and Soil chemical properties as influenced by liming and Boron application in a Notillage system. *Communication in Soil Science and Plant Analysis.* 38:8 1637-1652

Foy, C.D. (1984) In Soil Acidity and Liming (F. Adams Ed.) *Am. Soc. Agron*., Madison, USA.

Foy CD (1992). Soil chemical factors limiting plant root growth. Avd.Soil.Sci.19:97-131.

Ghosh, G.K. and Sarkar, A.K. (1997) Indices of P availability and fixation of added P in acid *Alfisols* of Chotanagpur plpateau of Bihar. *J. Indian Soc. Soil Sci.* ***45(***3*): 455-460.*

Gupta, R. K. and Prasad, R. N. (1983) *Annual report.* ICAR Research Complex (Sikkim centre), Shilong.

Gupta, R. K, Prasad, R. N. and Singh, R.D. (1989a) Evaluation of lIme Doses for Soybean-Wheat Crop Sequence on Acid Soils of Sikkim. *J. Indian Soc. Soil Sci.* ***37*** **:** 545-548.

Halder, B.R and Mandal, L.N. (1987) Effect of calcium carbonate on extractable Al content and availability of some nutrient cations in an acid soil of Assam under water logged condition. *J. Indian Soc. Soil Sci.* **35 :** 35.

Haynes, R.J. (1984) Effect of Liming on Phosphate Availability in Acid Soils. A critical review. *PI. Soil.***68** (3): 289-308.

Haynes, R.J. and Mokolobata, M.S. (2001) Amelioration of Al toxicity and P deficiency in acid soils by addition of organic residues: a critical review of the phenomena and the mechanism involved. *Nut. Cycl. Agroecosyst*. 59: 47-63.

Jackson, M. L., (1973) *Soil Chemical Analysis,* Madison, Wisconsin.

Kamprath, E.J. (1984) Soil Acidity and Liming, 2nd Edn. (Ed. Adams) Agronomy 12, *Am. Soc. of Agron.* Madison, Wisconsin.

Kochian, L.V. (1995) Cellular mechanism of aluminum toxicity and resistance in plants. *Ann. Rev. Plant Physoil. Plant Mol. Biol*. 46 : 237-260.

Kumar, B. (1990) M.Sc. (Ag.) *Thesis*, BAU, Kanke, Ranchi.

Lal, S. and Mathur, B.S. (1989) Effect of Long term manuring, fertilization and liming o crop yield and some Physico-chemcial properties of Acid soil. *J. Indian Soc. Soil Sci.* **35 :** 558.

Maji, B.and Bandhyopadhya, B.K. (1996) Effect of Liming on Yield of Safflower and Nutrient Availability in Coastal Acid Saline of Sunderbans,West Bengal. *J. Indian Soc. Coastal Agric. Res.* **14** (1 & 2) 47-51.

Mandal. S.C., Sinha H., Prasad C.R and Ali, M.A (1966). Science Cult.32:149

Mandal S.C. (1976) In: Soil Science in India. *Bull. Indian Society of Soil Science*. 14:158.

Mandal, S.C., Sinha, M.K. and Sinha, H. (1975) *Tech. BulletinNo.51*. ICAR, New Delhi.

Mandal, S.C.,(1984), In Soil Science In India .Bull. Indian Society Of Soil Science, 14:158.

Mathur, B.S., Rana, N.K., Sinha, H. and Lai, S. (1985) Lime as an effective source of fertilizer in acid red loam soils of Bihar. *J. Indian Soc. Soil Sci.* **33 :** 328.

Mathur, B.S., Rana, N.K., Sinha, H. and Lai, S. (1991) Effect of Rhizosphere Application of Lime on Crop Yield, Soil Properties, Nutrient uptake and Economic, *J. Indian Soc. Soil Sci.* **39 :** 523-529.

Mclean, E.O and Bhumbla, D.R. (1964) Aluminum in Soils: VI. Changes in pH-Dependent Acidity, Cation-Exchange Capacity, and Extractable Aluminum with Additions of Lime to Acid Surface Soils. *Soil Science Society of America Journal*. 29(4): 370-374.

Mishra, M. and Pattanayak, S.K. (2002) Response of crops to graded doses of lime amended with or without FYM in different crops grown in acid soil. Professor IFFCO chair report,OUAT,Bhubaneswar.

Misra, C. and Misra, U.K. (1979) Effect of sulphur and lime on yield and oil content of Kharif groundnut grown in an Aeric Haplauquept. *Indian Natu. Aci Aca. Proc*. **45**; 578.

Misra, U. K. and Das, N (2002) Phosphorous availability to maize as influenced by organic amendments. *J. Indian Soc. Soil Sci*. 48: 298-305.

Misra, U. K., Satpathy, S. and Panda, N. (1989) Characterization of some acid soils of Orissa 1- Nature of soil acidity. *J. Indian Soc. Soil Sci*. 37: 22-28.

Misra, U.K. (2004) Acid Soil and its Management. *Journal of the Indian Society of Soil Science*. **52**(4): 332-343.

Misra, U.K., Sahu, S.K. and Mitra. G.N. (1990) Characterization of some acid soils of Orissa-I, Nature of soil Acidity. .*J. Indian Soc. Soil Sci.* **38** ; 772.

Mongia, A.D., Singh, N.T., Mandal, L.N and Guha, A. (1998) Effect of Liming, superphosphate and rock phosphate Application to Rice on the tield and uptake of nutrients on Acid Sulphate Soils. . *J. Indian Soc. Soil Sci.* **46** (1): 61-66.

Mukherjee, J. N. and Chatterjee, B. (1942) *Indian Journal of Agricultural Science* 12: 105.

Mukhopadhya, D. and Das, D.K (2001) Effect of organic matter, lime and zinc application on the availability of Iron and Manganese in acid soils under submergence. *J. Indian Soc. Soil Sci.* **53** (1): 10-80.

Muralidharan, P and Rattan, R.K. (2001) Effect of lime and phosphorous on quality and intensity parameters of aluminum and its uptake by rice in an acid saline soil. *J. Indian Soc. Soil Sci.* **49** : 124-129.

Negi, S., Singh, R.V. and Dwivedi, O.K. (1999-2000) Effect of biofertilizer nutrient sources and lime on growth and yield of garden pea. *Legume Res.* **29**(4): 282-285.

Ojeniyi, S.O. Adetora, A.O. and Odedina, S.A. (1999). Effect of wood as on soil fertility nutrients content and yield of okra. Paper presented at horticultural society of Nigeria conference, Port Harcourt.

Onwuka, M.I.,Qsodeke, V.E. and and Ano, A.O (2009) Use of Liming Materials to reduce Soil Acidity and affect Maize growth parameter in Umudike, Southeast Nigeria, 5(2) : 386-396.

Page, A.L., Miller, R.H. and Keny, D.R. (1982) Methods of soil and plant analysis, part-2, 2nd Edn. No (9) Part in the series, *American Society of Agronomy, Inc. Soil Science Society of American Journal*. Madison, Wisconsin, U.S.A.

Pal, A.K. and Mandal, L.N. (1985) Effect of Liming on Few Chemical Properties and Nutrient status of Alluvial Acid Soils under Waterlogged Conditions. *J. Indian Soc. Soil Sci.* **33** : 36-43.

Paliyal, S.S. and Verma, T.S. (2002) Adsorption of Added Phosphorous as Influenced by Application of Lime and Gypsum in an Acid Alfisol of Himalayan Region. *J. Indian Soc. Soil Sci.* **50** : 163.

Panda, N. (1987) Acid soils of eastern India- Their chemistry and management. *J. Indian Soc. Soil Sci.* **35** : 568.

Panda, N. and Das, J.C. (1971) *Int. Symp. Soil Fert. Evaluation*, New Delhi, Part-1, pp. 7, *Soil Sci*. 81.

Panda, N. and Koshy, M.M (1982) In : Review of soil research in India, Pt-1, XII *International Congress of Soil Science*, 8-16th Feb., New Delhi.

Panda, N. and Misra, U.K (1969) Use of partially acidulated rock phosphate in Lateritic soil in India.Plant and Soil *J. Indian Soc. Soil Sci.* **39:** 353-361.

Panda, N. and Nanda, S. K. (1985) In: *Soils of India and their management*. Pp. 284.

Panda, N. (2009) Particular issues in plant production under acid soils. The Orissa scenario. Proceeding IPNI-OUAT-IPNI International Symposium, 2009. pp-137-145.

Patiram, Rai, R.N. (1988) Effects of Liming on Quality- Intensity parameters Of Potassium in some Acid Soils. J. Indian Soc. Soil. Sci. 36:402

Patiram Rai, R. N. and Singh, K. P. (1989) Liming for maize production in acid soils of Sikkim. *Journal of the Indian Society of Soil Science*. 37 : 121-125.

Patiram Rai, R.N. and Prasad, R.N. (1990) Effect of liming on aluminum and yield of wheat in acidic soil. *J. Indian Soc. Soil Sci.* **38** : 719-722.

Pattanayak, S.K and Mishra, M (2002) Response of crops to graded doses of Lime Amended with or without FYM. *Thesis submitted to Orissa University of Agriculture and Technology*, Bhubaneswar, Orissa.

Pattanayak, S.K and Misra, U.K (1989) Transformation of Phosphorous in some acid soils of Odisha. *Journal of the Indian Society of Soil Science.* 37: 455-460.

Pattanayak, S.K., Misra, U.K., Mishra, K.N and Sahu, S.K. (1997) Performance of rock phosphates under iron toxic condition applied to rice. *Ecological Agriculture and Sustainable Development vol.1, Proceedings of International Conference on Ecological Agriculture: Towards Sustainable Development*. November 15-17, 1997, Chandigarh, India.659-664.

Pattanayak, S.K., Misra, U.K., Sarkar, A.K. and Majumdar, K. (2011) Integrated Nutrient management for Groundnut and Red gram on acid soils in Odisha. *Better Crops-South Asia*,5 (1): 8-10.

Pattanayak, S.K., Mohanty, S., Mishra, K.N. and Nayak, R. K. (2008) *Technical Bulletin on “Biofertilizers for Tropical Vegetables”* AINP on Biodiversity, Biofertilizer. OUAT, Bhubaneswar, Odisha.

Pattanayak, S.K.(2013) Paper mill sludge as an Acid soil ameliorant. In Acid soils Their chemistry and management. Edited by A.K. Sarkar New India Publishing Agency New Delhi-110034

Pradhan, N. K. and Mishra, C. (1982) Effect of liming and organic soil amendments on crop yield and physico-chemical properties of an acid laterite soil. *Journal of the Indian Society of Soil Science.* 30 : 180-184.

Pradhan, N. K. and Misra, C (1985). Effects of Split Application of Liming Amendments on Grain Yield and Chemical Properties of an Acid Lateriti Soil. J. Indian Soc. Soil. Sci.33:865-69.

Prasad, B. and Singh, A.P. (1980) Changes in soil properties with long term use of fertilizer, lime and farm yard manure. *J. Indian Soc. Soil Sci.* **28** : 465.

Prasad, B. and Singh. K. D. N. (1987) Effect of continuous Application of Fertilizer, Manures and Lime on Potassium Equilibria and K Supplying Capacity of Soil. *J. Indian Soc. Soil Sci.* **35** : 748.

Prasad, B., Prasad, R. and Verma, M.K. (1983) Effectof calcium and magnesium on gram and soybean crops in acid soils. *J. Indian Soc. Soil Sci.* **32** : 229.

Prasad, B., Prasad, R. and Verma, M.K. (1985) Evaluation of some lime requirement methods for an acid soil of Bihar. *J. Indian Soc. Soil Sci.* **33** : 544.

Prasad, R. (1992) Effect of Liming on Yield of soybean and nutrient Availability in Acid soil. *J. Indian Soc. Soil Sci.* **40** : 377.

Quoggio, J.A., Gallo, P.B. and Mascarenhas, H.A. (1995) Agronomic efficiency of limestone with different acid-neutralizing capacity, under field condition. Plant-Soil Interactions at Low pH: *Principle and Management*, pp: 491-6.

Raychoudhary, M., Kumar, K and Raychoudhary, S. (1998) Lime- Rhizobium Interaction on Soybean in Kanhaplohumuet of Manipur Hills. *J. Indian Soc. Soil Sci.* **45** : 739-742.

Reeve, N. G. and Sumner, M. E. (1972) Effects of Aluminum Toxicity and Phosphorus Fixation on Crop Growth on Oxisols in Natal. *Soil Science Society of America Journal.* 34(2): 263-267

.Roy, H.K. (1987-88) *Ann. Rep. Potash Research Scheme*, BAU, Ranchi.

Russel, E.W. (1961) *Soil conditions and plant growth*. 9th ed. Longmans, London, England.

Sahu, G.C and , Patnaik, S. N. (1990) Influence of Lime and Organic Matter on pH and Ion Exchange Phenomena of Some *Alfisols*. *J. Indian Soc. Soil Sci.* **38** : 389-393.

Sahu, G.C. and Patnaik, S. (1990) Influence of lime or organic matter on pH and ion exchange phenomenon of some *Alfisols*. Journal of the *Indian Society of Soil Science* **38,** pp.154-157.

Sahu, S.K and Mitra, G. N. (1996) Acid soils of Orissa and their management in Acid soils of India, ICAR, New Delhi.

Sahu, S.K and Nanda, S.K. (1998) Paper Mill Sludge benefits the acid soils of Orissa. *Indian Farming.* ***36***(12): 21-30.

Sahu, S.K and Pal, S.S. (1987) Direct and residual effect of Paper Mill sludge and Limestone on Crop Yield under three Different Crop Rotation on an Acid Red Soil. *J. Indian Soc. Soil Sci.* **35** : 46-51.

Sanyal, S.K., Datta, S.K. and Chan, P.Y. (1995) *Soil Sci. Soc. Am. J*. **57**: 937.

Sarkar, A.K. (2002) ICAR Network Project for the year 2001-2002. *Soil Characterization and Resource Management of Acid Soil Regions for increase productivity*. Department of Soil Science and Agril. Chemistry, BAU, Ranchi.

Sarkar, A.K. and Sharma, P.D. (2005) Managing Acid Soils for Enhancing Productivity. National Resourse Management Division (ICAR), New Delhi.pp.23.

Sewaram, K., Khybri, M.L., Bhardwaj, S.P. and Gupta, O.P (1992) Effect of Lime and Pressed mud on Soil Properties and Crop Yield on Acidic Soil of Doon Valley. *J. Indian Soc. Soil Sci.* **40** : 613-615.

Sewaram, D., Khybri, M.C.; Bharadwaj, S.P. and Gupta, O.P (1992) Effect of lime and pressmud on soil properties and crop yield on acidic soil of Doon Valley. *Journal of Indian Society of Soil Science*, **40,** 613-615.

Shard, N., Bishnoi, S.K. and Azad, A.S. (1991) Effect of liming and Phosphate on the yield and Protein content of Black Gram. *J. Indian Soc. Soil Sci.* **39** : 593-594.

Sharma et.al (1999)

Sharma, N., Srivastava, L.L. and Mishra, H. (1983) Studies on microbial changes in soil as a result of continuous application of fertilizers, farm yard manure and lime. *J. Indian Soc. Soil Sci.* 30: 202-206.

Singh, R. and Singh, D.V. (1983), Effect of Lime Applied as calcitic lime stone in Acid Soil of Kumaon hills in Uttar Pradesh. J. Indin soc. Soil. Sci. 31:148.

Singh, R. and Singh, D.V. (1985) Effectiveness of liming Materials, their doses and Finess on some physiochemical properties of acidic soil. *J. Indian Soc. Soil Sci.* **33**: 218-220.

Singh, U.K . and Sanyal, S.K. (2000). Potassium and Aluminium Dynamic in Acidic Soils Under different rates of Lime Application. . J. Indin soc. Soil. Sci. 48:64-70.

Singh, R.N. and Sinha, H.K (1987) Evaluation of critical limits of available boron for soybean and maize in acid red loam soil. *J. Indian Soc. Soil Sci.* **35**: 456.

Sinha, H. and Singh, K.P. (1966) *Ranchi Univ. J. Agril. Res*. 1 : 39.

Subba Rao, N.S. (1983) *Can. J. Microbiology*. **29** : 863.

Torkashvand Ali, M. and Shahram, A.H. (2007) Converter Slag as a Liming Agent in the Amelioration of Acidic Soils. *International journal of Agriculture and Biology*, 1560-8530/2007/09-5-715-720.

Tripathy, B.R., Prasad, R.N.and Bishnoi, S.K. (1982) In *: Review of Soil Research in India, Part XII International Congress of Soil Science, Proc.* Feb., 1982, New Delhi.

Tripathy, S.B., Mannikar, N.D. and Singh, D. (1983) *J. Indian Soc. Soil Sci.* **31**: 447.

Ulrich, B. (1983) A concept of ecosystem stability and of acid deposition as driving force for destabilization

Ulrich, B. and Pankrath J. (Eds.), Effects of Accumulation of Air Pollutants in Forest Ecosystem, Proceedings of a Workshop held at Go** tingen, West Germany, May 16-18, 1982, D. Reidel Publisher Company, Dordrecht, Boston, London, pp. 1-29.

APPENDICES

Appendix-1 : Change in soil reaction due to the effect of liming materials

Treatments	Days after sowing (DAS)										
	0 days	7th	14th	21st	28th	35th	42nd	49th	56th	63rd	90th
Absolute Control	4.94	4.9	4.9	4.88	4.65	4.61	4.78	4.85	4.89	4.78	4.47
STD	4.94	4.99	5.01	4.96	4.93	4.61	4.68	4.5	4.46	4.45	4.38
STD + PMS @ 0.1 LR	4.94	5.11	5.1	4.93	4.89	4.79	4.75	4.56	4.48	4.39	4.39
STD + PMS @ 0.1 LR + FYM	4.94	5.88	6.0	5.96	4.95	4.88	4.69	4.67	4.57	4.52	4.15
STD + ST @ 0.1 LR	4.94	4.98	5.12	4.94	4.94	4.85	4.87	4.74	4.73	4.58	4.4
STD + ST @ 0.1 LR + FYM	4.94	5.59	5.81	6.3	5.52	5.19	4.87	4.86	4.85	4.71	4.51
STD + ST @ 0.2 LR	4.94	4.99	5.38	5.51	5.34	4.99	4.88	4.84	4.62	4.48	4.31
STD + ST @ 0.2 LR + FYM	4.94	5.75	6.08	6.07	5.43	5.45	5.05	5.07	4.99	4.72	4.6
STD + CS @ 0.2 LR	4.94	5.28	5.36	4.95	4.93	4.83	4.72	4.42	4.34	4.48	4.34
STD + CS @ 0.2 LR + FYM	4.94	5.38	5.64	5.21	5.01	4.88	4.84	4.58	4.67	4.71	4.5

Appendix-2 : Change in Exchange acidity due to the effect of liming materials

Treatments	Days after sowing (DAS)										
	0th	7th	14th	21th	28th	35th	42th	49th	56th	63th	90th
Absolute Control	1.04	1.03	1.01	0.89	0.88	0.82	0.85	0.87	0.88	0.98	1.32
STD	1.04	0.76	0.79	0.88	0.9	0.96	1.06	1.1	1.16	1.26	1.32
STD + PMS @ 0.1 LR	1.04	0.7	0.63	0.43	0.88	0.97	1.04	1.05	1.06	1.09	1.16
STD + PMS @ 0.1 LR + FYM	1.04	0.6	0.69	0.31	0.79	0.87	0.88	0.76	0.91	1.0	1.04
STD + ST @ 0.1 LR	1.04	0.66	0.65	0.38	0.63	0.8	0.7	0.74	0.81	0.94	1.03
STD + ST @ 0.1 LR + FYM	1.04	0.5	0.54	0.37	0.52	0.62	0.69	0.38	0.5	0.85	0.79
STD + ST @ 0.2 LR	1.04	0.63	0.53	0.38	0.68	0.79	0.53	0.68	1.01	1.07	1.42
STD + ST @ 0.2 LR + FYM	1.04	0.47	0.47	0.37	0.58	0.63	0.48	0.65	0.63	0.88	0.94
STD + CS @ 0.2 LR	1.04	1.01	0.88	0.75	0.9	0.88	0.82	0.83	0.91	0.97	1.28
STD + CS @ 0.2 LR + FYM	1.04	0.5	0.49	0.44	0.47	0.48	0.78	0.8	0.79	0.91	1.23

Appendix-3 : Change in acidity due to Aluminium in soil

Treatments	Days after sowing (DAS)										
	0th	7th	14th	21th	28th	35th	42th	49th	56th	63th	90th
Absolute Control	0.6	0.68	0.6	0.4	0.54	0.57	0.68	0.69	0.74	0.78	0.93
STD	0.6	0.59	0.57	0.48	0.48	0.59	0.71	0.84	0.85	0.94	0.96
STD + PMS @ 0.1 LR	0.6	0.55	0.51	0.37	0.53	0.6	0.65	0.64	0.65	0.76	0.85
STD + PMS @ 0.1 LR + FYM	0.6	0.34	0.37	0.2	0.34	0.49	0.4	0.22	0.48	0.48	0.82
STD + ST @ 0.1 LR	0.6	0.46	0.43	0.34	0.34	0.48	0.62	0.68	0.68	0.71	0.74
STD + ST @ 0.1 LR + FYM	0.6	0.36	0.32	0.29	0.34	0.34	0.36	0.2	0.34	0.63	0.7
STD + ST @ 0.2 LR	0.6	0.46	0.4	0.34	0.46	0.58	0.43	0.68	0.74	0.79	0.88
STD + ST @ 0.2 LR + FYM	0.6	0.31	0.34	0.29	0.4	0.41	0.3	0.51	0.51	0.57	0.57
STD + CS @ 0.2 LR	0.6	0.56	0.47	0.4	0.55	0.58	0.7	0.71	0.77	0.82	0.96
STD + CS @ 0.2 LR + FYM	0.6	0.46	0.43	0.37	0.26	0.26	0.55	0.62	0.65	0.6	0.85

Appendix-4 : Change in acidity due to Hydrogen in soil

Treatments	Days after sowing (DAS)										
	0th	7th	14th	21th	28th	35th	42th	49th	56th	63th	90th
Absolute Control	0.44	0.35	0.41	0.49	0.34	0.25	0.17	0.18	0.14	0.2	0.39
STD	0.44	0.17	0.22	0.4	0.42	0.37	0.39	0.55	0.41	0.33	0.31
STD + PMS @ 0.1 LR	0.44	0.15	0.12	0.06	0.35	0.37	0.39	0.4	0.41	0.33	0.31
STD + PMS @ 0.1 LR + FYM	0.44	0.26	0.32	0.11	0.45	0.38	0.48	0.54	0.43	0.52	0.22
STD + ST @ 0.1 LR	0.44	0.2	0.22	0.04	0.29	0.32	0.08	0.06	0.13	0.23	0.29
STD + ST @ 0.1 LR + FYM	0.44	0.14	0.22	0.08	0.18	0.28	0.35	0.18	0.16	0.22	0.09
STD + ST @ 0.2 LR	0.44	0.17	0.13	0.04	0.22	0.21	0.1	0.17	0.27	0.28	0.54
STD + ST @ 0.2 LR + FYM	0.44	0.16	0.13	0.03	0.18	0.22	0.18	0.14	0.12	0.31	0.37
STD + CS @ 0.2 LR	0.44	0.45	0.41	0.35	0.35	0.3	0.12	0.12	0.14	0.15	0.32
STD + CS @ 0.2 LR + FYM	0.44	0.04	0.06	0.07	0.21	0.22	0.23	0.18	0.14	0.31	0.38

Appendix-5 : Change in Organic carbon status in soil due to effect of liming materials

Treatments	Days after sowing (DAS)										
	0day	7th	14th	21th	28th	35th	42th	49th	56th	63th	90th
Absolute Control	0.57	0.49	0.46	0.43	0.35	0.31	0.29	0.36	0.38	0.38	0.39
STD	0.57	0.38	0.4	0.45	0.37	0.34	0.31	0.25	0.24	0.23	0.23
STD + PMS @ 0.1 LR	0.57	0.35	0.36	0.41	0.21	0.35	0.31	0.34	0.36	0.32	0.38
STD + PMS @ 0.1 LR + FYM	0.57	0.51	0.46	0.48	0.42	0.42	0.38	0.38	0.4	0.38	0.4
STD + ST @ 0.1 LR	0.57	0.55	0.45	0.45	0.36	0.32	0.29	0.48	0.38	0.42	0.42
STD + ST @ 0.1 LR + FYM	0.57	0.53	0.54	0.55	0.45	0.46	0.41	0.5	0.55	0.52	0.44
STD + ST @ 0.2 LR	0.57	0.53	0.49	0.47	0.38	0.38	0.35	0.36	0.36	0.36	0.37
STD + ST @ 0.2 LR + FYM	0.57	0.56	0.54	0.52	0.5	0.41	0.39	0.4	0.4	0.42	0.4
STD + CS @ 0.2 LR	0.57	0.53	0.48	0.46	0.4	0.37	0.31	0.46	0.36	0.44	0.4
STD + CS @ 0.2 LR + FYM	0.57	0.54	0.54	0.54	0.46	0.39	0.38	0.46	0.47	0.45	0.44

Appendix-6 : Change in CEC due to the effect of liming materials

Treatments	Days after sowing (DAS)							
	0day	7th	14th	21st	28th	35th	42nd	90th
Absolute Control	6.29	6.13	6.07	5.28	5.2	5.25	5.14	4.55
STD	6.29	6.29	6.19	5.86	5.42	5.31	5.13	4.98
STD + PMS @ 0.1 LR	6.29	6.49	6.39	6.05	5.5	5.3	5.11	4.77
STD + PMS @ 0.1 LR + FYM	6.29	6.72	7.81	6.29	5.64	5.75	5.46	5.2
STD + ST @ 0.1 LR	6.29	6.64	6.72	5.42	5.35	5.26	5.2	5.2
STD + ST @ 0.1 LR + FYM	6.29	7.38	6.94	6.63	6.51	6.69	6.51	5.42
STD + ST @ 0.2 LR	6.29	7.16	6.49	6.39	6.29	5.51	5.32	5.63
STD + ST @ 0.2 LR + FYM	6.29	7.59	6.92	6.86	6.94	6.93	5.76	5.85
STD + CS @ 0.2 LR	6.29	7.37	6.94	6.9	6.87	5.73	5.64	4.77
STD + CS @ 0.2 LR + FYM	6.29	8.03	7.59	7.7	7.81	6.15	5.98	5.42

Appendix-7 : Change in Exchangeable Calcium of soil

	Days after sowing (DAS)							
Treatments	**0day**	**7th**	**14th**	**21st**	**28th**	**35th**	**42nd**	**90th**
Absolute Control	3.4	2.8	3.2	3.2	4.4	4.8	4.2	3.2
STD	3.4	3.6	3.2	2.8	3.6	4.1	4	3
STD + PMS @ 0.1 LR	3.4	3.6	3.8	3.9	4.8	4.9	4.3	3.5
STD + PMS @ 0.1 LR + FYM	3.4	4.0	4.2	5.5	5.4	4.6	4.5	3.8
STD + ST @ 0.1 LR	3.4	4.0	4.4	4.2	4.3	4.5	4.8	3.6
STD + ST @ 0.1 LR + FYM	3.4	4.4	4.8	5.2	5.2	5.3	4.9	3.9
STD + ST @ 0.2 LR	3.4	3.6	4.6	5.2	4.8	3.8	3.9	3.8
STD + ST @ 0.2 LR + FYM	3.4	5.6	5.8	6.0	5.0	4.2	4.1	3.5
STD + CS @ 0.2 LR	3.4	4.4	4.4	4.8	4.4	4.7	4.3	3.7
STD + CS @ 0.2 LR + FYM	3.4	4.8	4.8	5.6	4.8	4.9	4.5	4

Appendix-8 : Change in Exchangeable Magnesium of soil

	Days after sowing (DAS)							
Treatments	**0day**	**7th**	**14th**	**21st**	**28th**	**35th**	**42nd**	**90th**
Absolute Control	1.8	1.6	1.2	1.2	2	1.8	1.6	1.6
STD	1.8	1.2	1.2	1.6	2.2	2	1.8	1.4
STD + PMS @ 0.1 LR	1.8	2	2.2	2.4	2.6	2.6	1.7	1.6
STD + PMS @ 0.1 LR + FYM	1.8	2.1	2.4	4.4	2.8	3.2	3.1	2
STD + ST @ 0.1 LR	1.8	2.4	2	2	2	2.2	2	2
STD + ST @ 0.1 LR + FYM	1.8	2.5	2.8	3.6	2.4	2.6	2.3	1.6
STD + ST @ 0.2 LR	1.8	3.6	2.4	3.5	2.8	3.1	2.8	2
STD + ST @ 0.2 LR + FYM	1.8	4	3.2	3.6	3.4	3.3	2.6	1.6
STD + CS @ 0.2 LR	1.8	1.5	1.6	1.2	2.4	2.5	2.2	2
STD + CS @ 0.2 LR + FYM	1.8	2	2.4	3.6	2.8	3	2.7	1.6

Appendix-9 : Change in Exchangeable Potassium of soil

Treatments	**0day**	**7th**	**14th**	**21st**	**28th**	**35th**	**42nd**	**90th**
Absolute Control	0.19	0.13	0.12	0.11	0.1	0.09	0.08	0.05
STD	0.19	0.25	0.24	0.23	0.21	0.18	0.16	0.1
STD + PMS @ 0.1 LR	0.19	0.21	0.2	0.18	0.16	0.16	0.15	0.11
STD + PMS @ 0.1 LR + FYM	0.19	0.28	0.42	0.28	0.26	0.19	0.18	0.13
STD + ST @ 0.1 LR	0.19	0.28	0.4	0.3	0.23	0.21	0.2	0.1
STD + ST @ 0.1 LR + FYM	0.19	0.47	0.42	0.31	0.24	0.22	0.21	0.11
STD + ST @ 0.2 LR	0.19	0.29	0.25	0.24	0.22	0.24	0.21	0.09
STD + ST @ 0.2 LR + FYM	0.19	0.31	0.29	0.31	0.27	0.26	0.23	0.05
STD + CS @ 0.2 LR	0.19	0.26	0.29	0.28	0.27	0.24	0.24	0.03
STD + CS @ 0.2 LR + FYM	0.19	0.28	0.32	0.31	0.29	0.25	0.26	0.14

Appendix-10 : Chlorophyll content (SPAD Value) at different growth stage

Treatments	**Days after sowing (DAS)**						
	28th	**42th**	**49th**	**56th**	**70th**	**77th**	**Mean**
Absolute Control	31.13	33.48	28.80	26.72	32.85	37.87	31.8
STD	47.43	46.06	43.92	43.42	48.1	48.05	46.18
STD + PMS @ 0.1 LR	49.5	47.57	47.0	43.86	47.56	49.24	47.46
STD + PMS @ 0.1 LR + FYM	48.09	47.66	48.54	43.49	47.65	49.93	47.56
STD + ST @ 0.1 LR	46.22	43.98	41.44	40.83	46.94	45.10	44.09
STD + ST @ 0.1 LR + FYM	48.17	44.89	45.50	41.48	47.49	46.88	45.74
STD + ST @ 0.2 LR	49.66	42.54	43.57	41.6	46.29	47.1	45.13
STD + ST @ 0.2 LR + FYM	46.45	48.05	43.02	40.37	47.96	46.51	45.39
STD + CS @ 0.2 LR	47.44	44.58	44.0	42.65	45.48	45.99	45.02
STD + CS @ 0.2 LR + FYM	47.22	49.19	45.0	41.92	49.55	46.39	46.55

Appendix-11 : Plant height(cm) at different growth stage of maize

Treatments	Days after sowing (DAS)					
	28th	35th	42th	49th	56th	Mean
Absolute control	48.1	62.1	70.4	83.2	93.73	71.5
STD	83.3	115.8	136.7	169.2	190.4	139.1
STD + PMS @ 0.1 LR	89.9	120.3	144.7	169.9	190.7	143.1
STD+PMS @ 0.1 LR + FYM	102.8	134.0	158.6	178.6	193.7	153.5
STD +ST @ 0.1 LR	89.2	119.4	137.1	170.2	190.4	141.3
STD +ST @ 0.1 LR +FYM	99.9	130.9	153.9	176.2	194.8	154.2
STD + ST @ 0.2 LR	91.0	126.6	149.0	177.9	201.9	149.3
STD + ST @ 0.2 LR + FYM	101.3	137.7	161.2	194.8	216.9	162.4
STD + Ca-Si @ 0.2 LR	92.2	123.2	148.6	180.8	204.3	149.8
STD + Ca-Si@ 0.2 LR+FYM	106.5	137.6	166.7	198.2	223.9	166.6

Appendix-12 : Plant growth rate (cmday^{-1}) at different growth stage of maize

Treatments	28th	35th	42th	49th	56th	Mean
Absolute control	1.77	1.77	1.68	1.7	1.67	1.28
STD	2.98	3.30	3.30	3.45	3.4	2.48
STD + PMS @ 0.1 LR	3.21	3.44	3.45	3.47	3.40	2.55
STD+PMS @ 0.1 LR + FYM	3.67	3.83	3.8	3.65	3.46	2.74
STD +ST @ 0.1 LR	3.19	3.41	3.42	3.47	3.4	2.52
STD +ST @ 0.1 LR +FYM	3.57	3.74	3.76	3.6	3.48	2.75
STD + ST @ 0.2 LR	3.25	3.62	3.62	3.63	3.60	2.66
STD + ST @ 0.2 LR + FYM	3.62	3.94	3.9	3.98	3.87	2.70
STD + Ca-Si @ 0.2 LR	3.29	3.52	3.54	3.69	3.65	2.68
STD + Ca-Si@ 0.2 LR+FYM	3.8	3.93	3.97	4.05	4.0	2.98

Appendix-13 : Grain straw ratio, Harvesting Index and RAE of maize crop as influenced by different liming materials

Treatments	Grain: Straw	Harvesting Index (HI)	Relative Agronomic Efficiency (RAE)
Absolute Control	1.21	0.42	----
STD	1.20	0.42	100
STD + PMS @ 0.1 LR	1.18	0.43	152
STD + PMS @ 0.1 LR + FYM	1.22	0.45	228
STD + ST @ 0.1 LR	1.23	0.45	129
STD + ST @ 0.1 LR + FYM	1.26	0.45	173
STD + ST @ 0.2 LR	1.20	0.45	177
STD + ST @ 0.2 LR + FYM	1.26	0.46	234
STD + CS @ 0.2 LR	1.24	0.45	162
STD + CS @ 0.2 LR + FYM	1.27	0.45	219

Appendix-14 : Post Harvest Properties of soil

Treatments	pH	OC	N	P	K	S
		(g/kg)	(kg/ha)			
Absolute control	4.47	3.9	164	91	65	16
STD	4.54	3.2	169	60	64	49
STD + PMS @ 0.1 LR	4.10	3.8	178	52	73	57
STD+PMS @ 0.1 LR + FYM	4.20	4.0	181	45	70	55
STD +ST @ 0.1 LR	4.37	4.2	198	59	67	49
STD +ST @ 0.1 LR +FYM	4.55	4.4	152	43	72	50
STD + ST @ 0.2 LR	4.43	3.7	206	46	71	52
STD + ST @ 0.2 LR + FYM	4.66	4.0	193	81	83	51
STD + Ca-Si @ 0.2 LR	4.48	4.0	189	75	63	55
STD + Ca-Si@ 0.2 LR+FYM	4.54	4.4	160	43	75	48
Initial soil	**4.94**	**5.7**	**169**	**105**	**143**	**17**

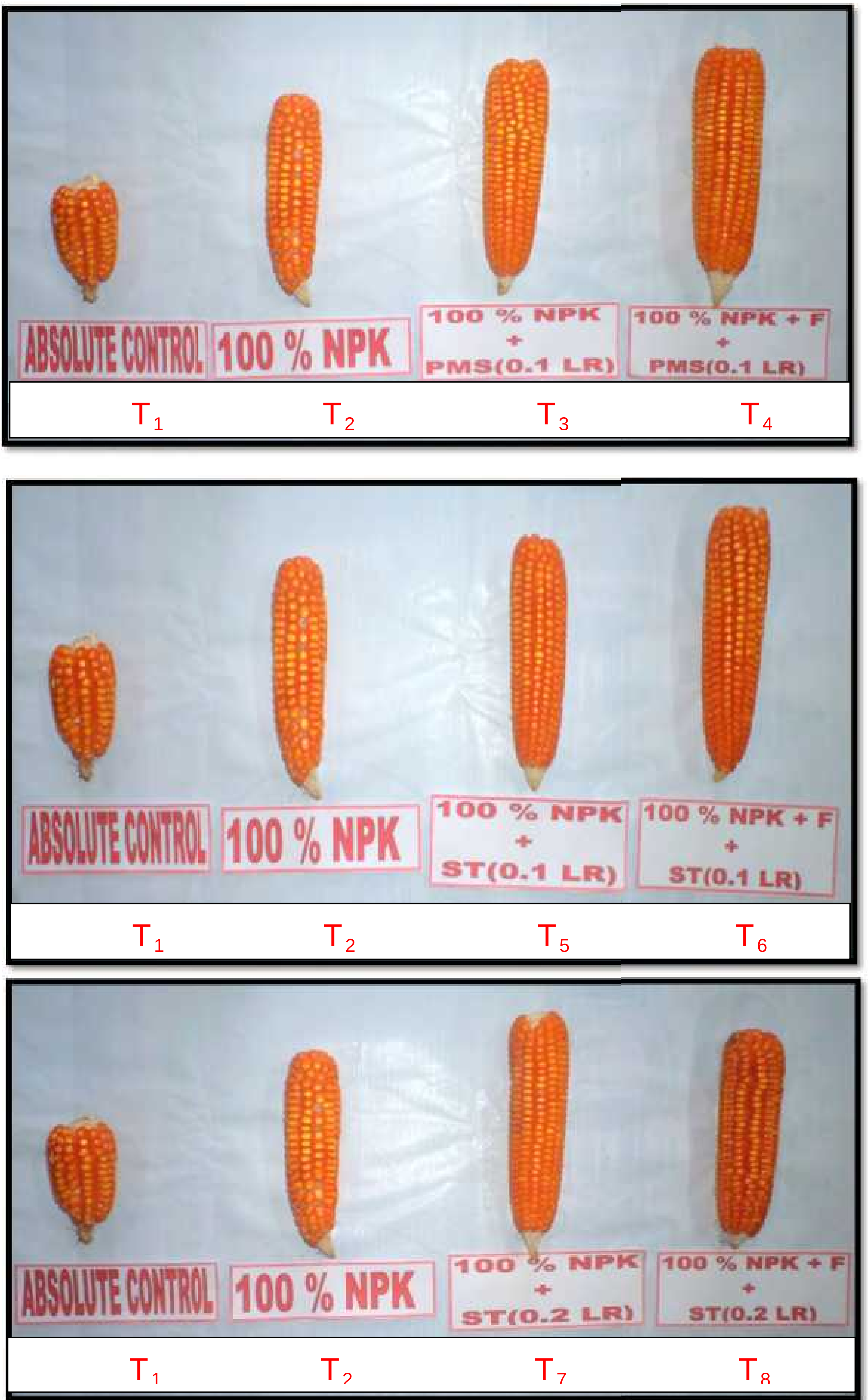
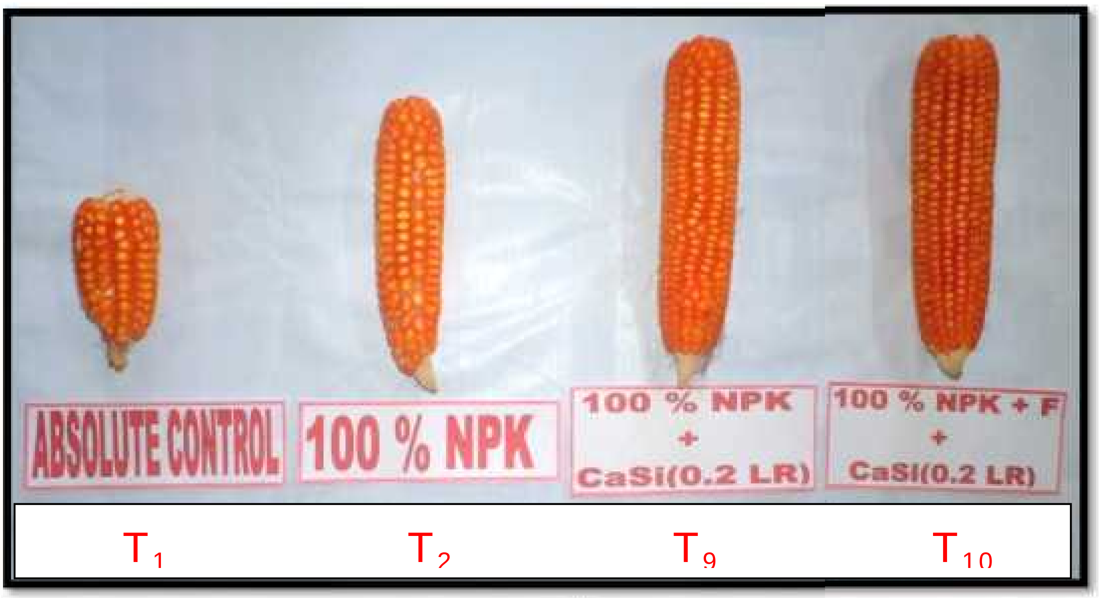
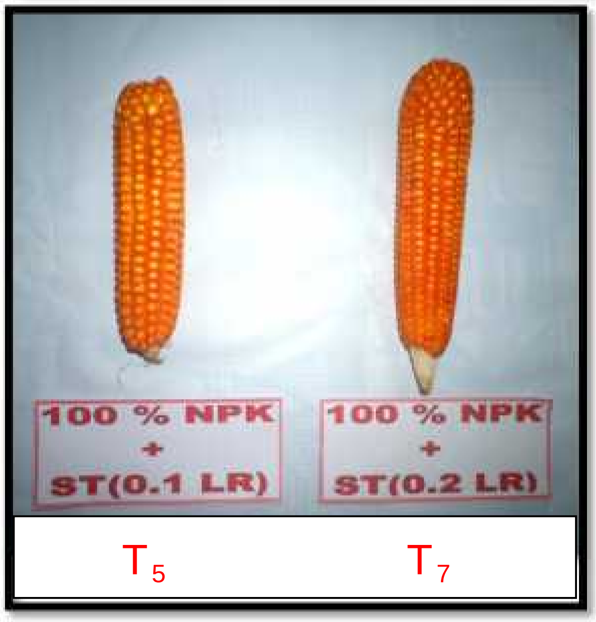
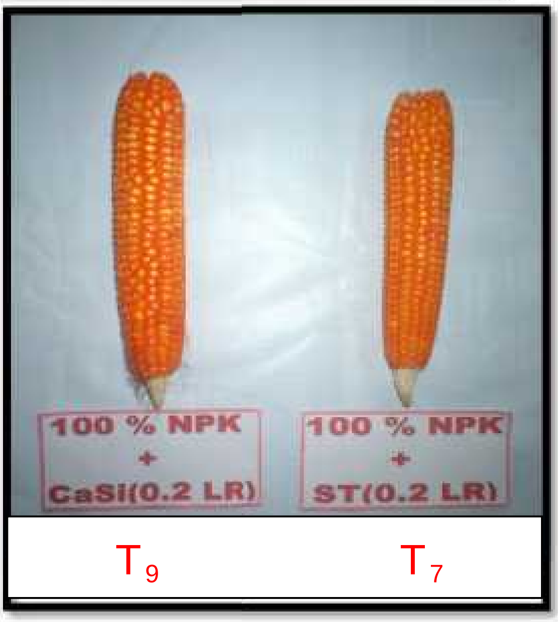
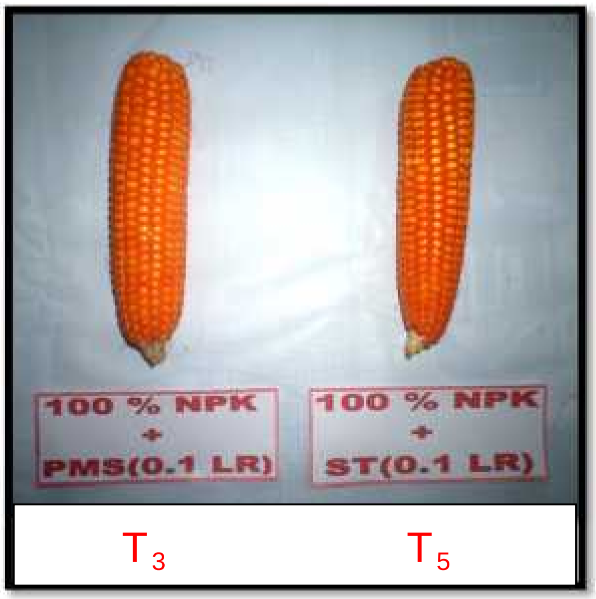


Plate-3 : Influence of liming materials on cob growth of maize at harvest stage


ABSOLUTE CONTROL
100 % NPK
100 % NPK + CaSi(0.2 LR)
100 % NPK + F + CaSi(0.2 LR)
T_1
T_2
T_9
T_{10}


100 % NPK + ST(0.1 LR)
100 % NPK + ST(0.2 LR)
T_5
T_7


100 % NPK + CaSi(0.2 LR)
100 % NPK + ST(0.2 LR)
T_9
T_7


100 % NPK + PMS(0.1 LR)
100 % NPK + ST(0.1 LR)
T_3
T_5


100 % NPK + PMS(0.1 LR)
100 % NPK + CaSi(0.2 LR)
T_3
T_9

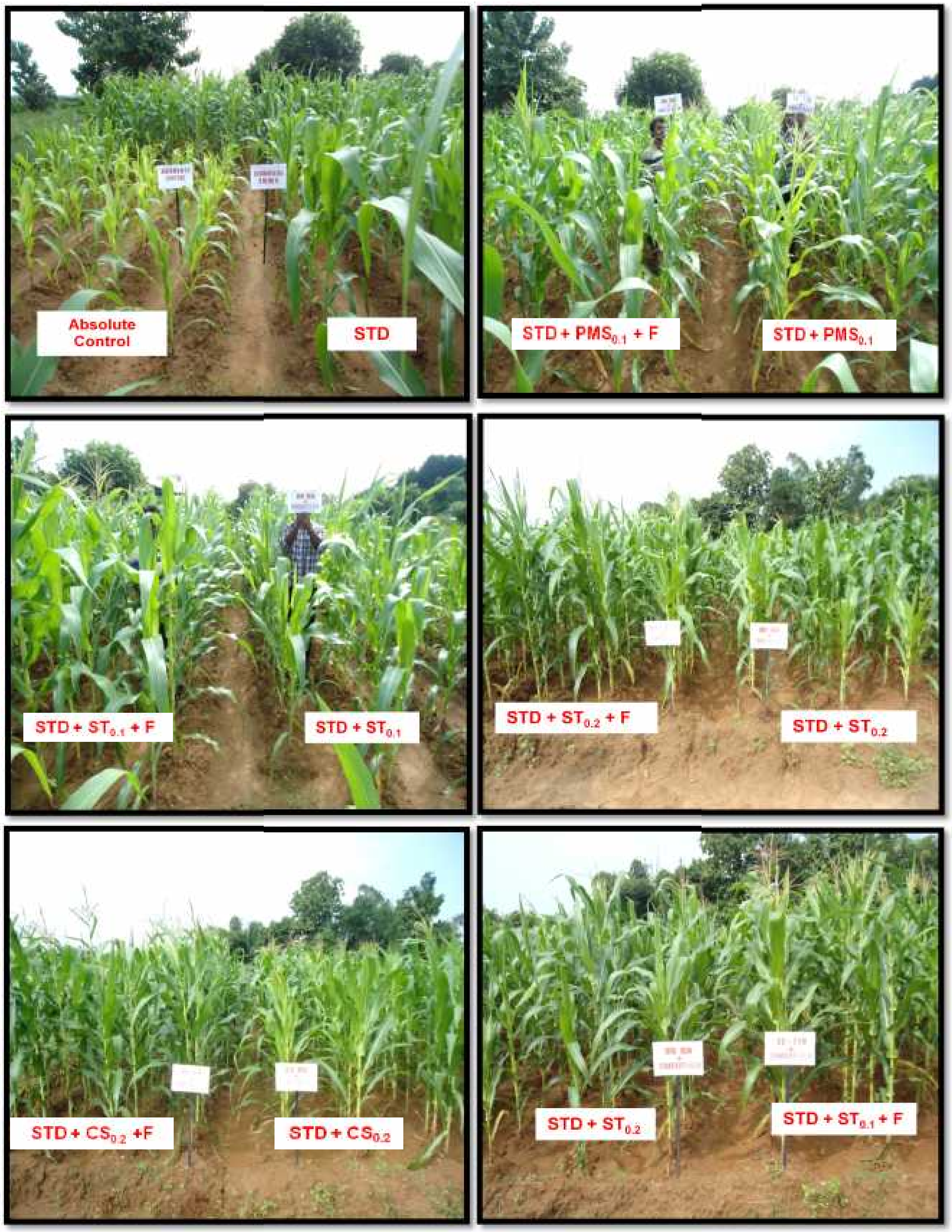
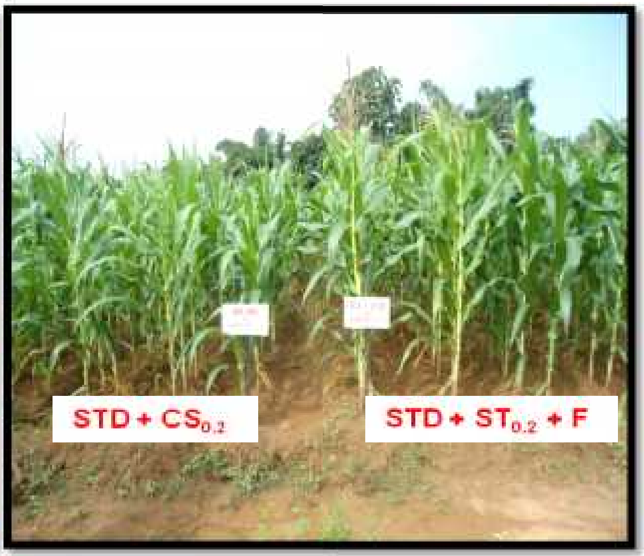
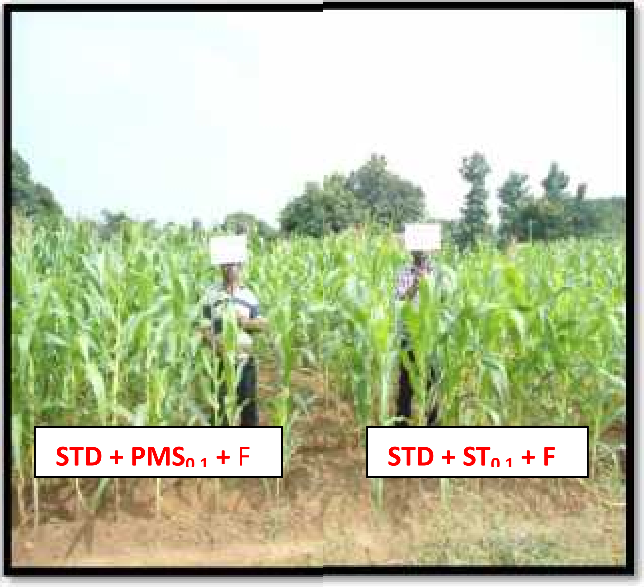


Plate-1 : Influence of liming materials on crop growth of maize

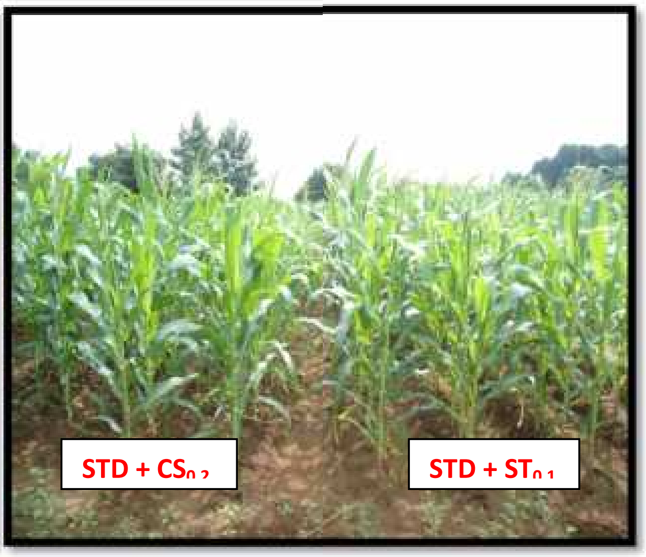

STD + PMS$_{0.1}$ +F
STD + ST$_{0.1}$

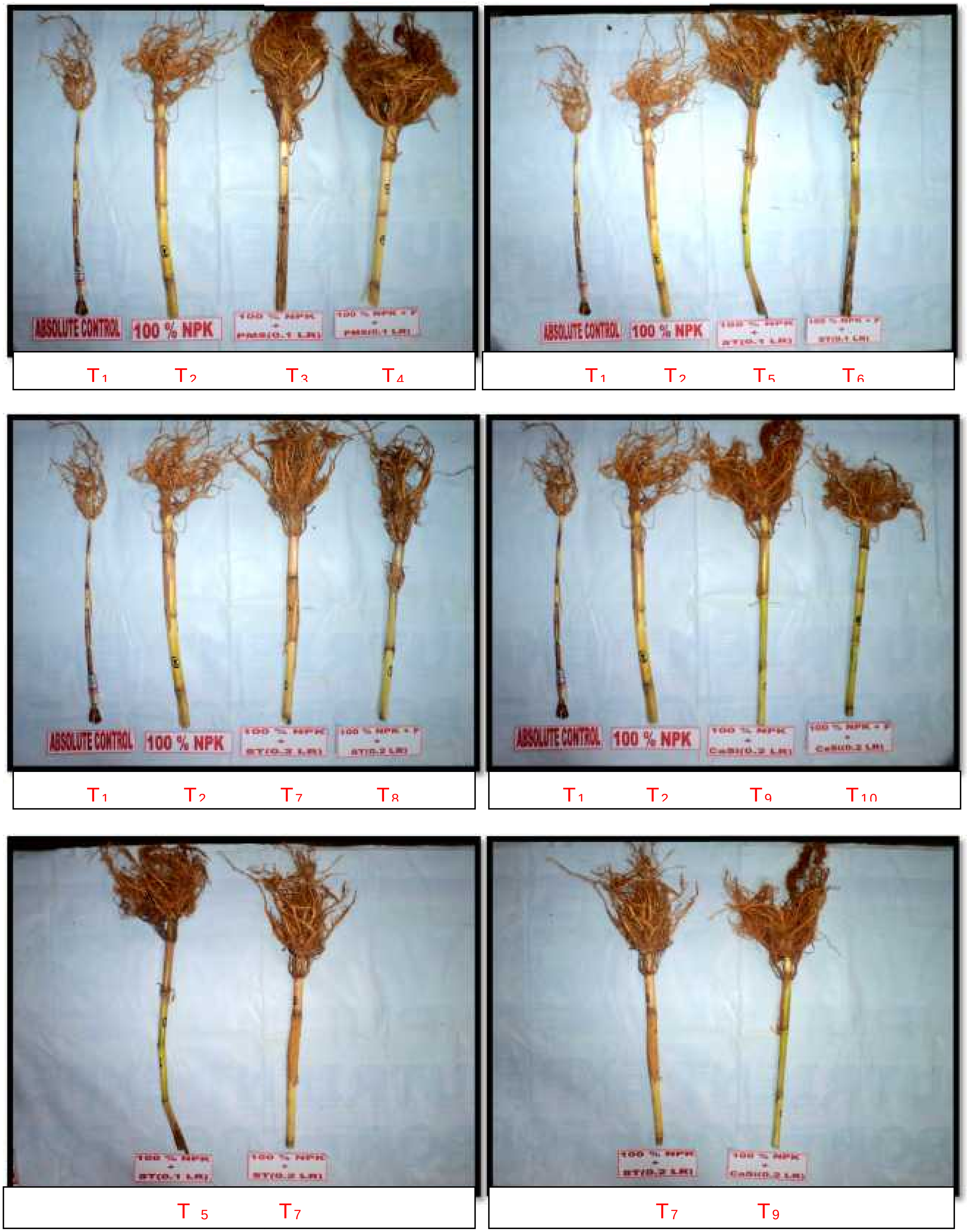

STD + CS$_{0.2}$
STD + ST$_{0.2}$ + F


STD + ST$_{0.1}$
STD + PMS$_{0.1}$


STD + PMS$_{0.1}$ + F
STD + ST$_{0.1}$ + F


STD + ST$_{0.2}$
STD + ST$_{0.1}$


STD + CS$_{0.2}$
STD + ST$_{0.1}$



T_1 T_2 T_3 T_4

T_1 T_2 T_5 T_6

T_1 T_2 T_7 T_8

T_1 T_2 T_9 T_{10}

T_5 T_7

T_7 T_9

Plate-2 : Influence of liming materials on root growth of maize at harvest stage