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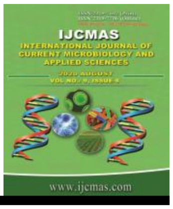

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Nitrogen Mineralization, Forms of Acidity and Fertility Status of a Paddy Soil as Influenced by Rice Stubble Management

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ABSTRACT

An experiment was conducted in the laboratory of department of Soil Science, Assam Agricultural University, Assam (India) during November 2018 to April 2019 to evaluate inorganic nitrogen fractions, forms of acidity and fertility status in a rice soil as influenced by rice stubble (RS) management practices through a fifteen weeks incubation period under constant moisture regime. Untreated and glyphosate-*yogurt* treated rice stubble was either incorporated or left on the surface of soil-filled (15 cm depth on 5 cm sand at the bottom) poly vinyl chloride (PVC) pipe (25 cm long and 8.44 cm diameter), mounted on tray maintaining a constant water depth of 5 cm and incubated for 105 days. Incorporation of rice stubble treated with glyphosate-*yogurt* mixture significantly increased NH_4-N in soil compared to all other treatments, but the NO_3-N in soil was affected neither by incorporation nor microbe culture spray. The variation in soil pH was not significant among the treatments except at 105 days after incubation. Incorporation of rice stubble, irrespective of glyphosate-*yogurt* treatment, significantly increased exchange acidity and total acidity in soil after 42 days of incubation. The total potential acidity in soil did not vary significantly throughout the study period. The exchangeable Ca^{2+}, Mg^{2+} and K^{+} in soil increased significantly due to rice stubble incorporation with or without glyphosate-*yogurt* treatment, but the effect was not observed for cation exchange capacity of soil. Incorporation of rice stubble significantly increased available P and K contents in soil, irrespective of glyphosate-*yogurt* treatment.

Keywords

Rice stubble, Inorganic N-fractions, Exchangeable cations, Acidification

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Introduction

The productivity of winter rice in Assam has remained static during last decade (Anonymous, 2019) contrast to increase in high yielding variety acreage and total fertilizer consumption. Application of mineral fertilizer without organic manure or recycling of crop residues strongly affects soil productivity (Singh *et al.*, 2001). The stubble management, which is left in the field till the next crop, in rice sole crop areas of the state deserves relook mainly for two reasons. First, simple and feasible rice stubble management holds key to expansion of area under oilseeds and summer pulses through crop intensification and diversification. Second, the left over stubbles are subject to little or slow decomposition until the pre-monsoon rain in April-May (Borah *et al.,* 2016b,c) and the decomposition during this period lead to substantial loss of nutrients from the soil without crop cover (Bezbaruah, 2017). The availability of winter rice stubble in Assam as per 2009 estimate was 6.29 million tones (88.9% of total rice crop residues), with a surplus of 3.75 million tonnes (Hiloidhari and Baruah, 2011). Rice straw contains about 0.6% N, 0.18% P and 1.38 % K (Mandal *et al.,* 2004) and for every tonne removal of rice straw about 5-8 kg/ha N, 1.6-2.7 kg/ha P_2O_5 and 14-20 kg/ha K_2O get lost (Dobermann and Fairhust, 2002).

Incorporation of rice straw without pre-treatment may adversely affect nutrient availability in soil and ultimately succeeding crop yield (Singh *et al.,* 1996), while in situ decomposition without pre-treatment is slow due to dry spell with low temperature (Borah *et al.,* 2016b,c). Spraying mixture of glyphosate and commercial *yogurt* on rice stubble *in situ* (Borah *et al.,* 2016 a, c) or their incorporation into soil (Bezbaruah, 2017) had significantly enhanced reduction of biomass weight and C:N ratio of the crop residues.

The major problem in the way of efficient utilization of cereal crop residues is microbial immobilization of nitrogen in soil (Mary *et al.,* 1996), reduction of oxygen content and production of toxic carbon compounds in soil. Response of crop residues incorporation to soil pH had shown contrasting results (Naramabuye and Haynes, 2006; Rosolem, 2011), mainly due to the differences in composition and types of added residues, soil properties and location (Xu *et al.,* 2006 a, b). Initial soil pH significantly affected the incorporation of crop residues with higher C: N ratio like rice and low soil pH inhibited the nitrification (Xiao *et al.,* 2013). Incorporation of rice straw *in situ* without any treatment (Tuyen and Tan, 2001) or followed by their chopping (Bailey *et al.,* 2013) or with phosphocompost and mineral fertilizer (Bhattacharjee *et al.,* 2013) had been reported to increase nutrient content, cation exchange capacity (Weber *et al.,* 2007), nitrogen availability due to acidification (Xu and Coventry, 2003) or liming effect (Conyers *et al.,* 2011) in soils.

Carbon or nitrogen mineralized after incorporation of residues had been studied under both laboratory conditions (Vanlauwe *et al.,* 1996; Vigil and Kissel, 1991) and in field experiments (Handayanto *et al.,* 1994, Muller *et al.,* 1988). However, the predictions of mineralizable nitrogen based on measurements of nitrogen mineralization under field study were significantly worse than that under laboratory condition (Ros *et al.,* 2011). The knowledge on nitrogen mineralization with rice stubble management under controlled laboratory conditions would thus aid in formulating effective nutrient management in the succeeding crop, and efficient method for recycling of the crop residues. Accordingly, a laboratory incubation study was carried out to evaluate nitrogen mineralization, forms of soil acidity and available nutrients in soil as influenced by stubble management practices.

Materials and Methods

Location, soil and climate

The present investigation was carried out during November 2018 to April 2019 at Assam Agricultural University (26^o44′N, 94^o10′E and 91 m above MSL), Jorhat, India. The daily temperature of Jorhat decreases from November to January and then increases from February to April with an average maximum temperature of 28°C in November to 23°C in January, and then 24°C in February to 28°C in April, and with an average minimum temperature of 16°C in November to 8°C in January, and thereafter 13°C in February to 19°C in April. Bulk surface (0-15 cm) soils were collected from field after harvest of winter rice crop, air dried and ground to pass through 2 mm sieve and the processed soil was used for the incubation experiment. The soil for the experiment had a sandy clay loam texture with 56.1 per cent sand, 25.1 per cent clay having bulk density and particle density of 1.39 and 2.36 Mg/m^3, respectively.

The soil had total porosity of 41.1 per cent, maximum water holding capacity of 43.1 per cent and field capacity moisture content of 21.6 per cent (w/w). The pH of the soil was 4.6 with exchangeable acidity, total acidity and total potential acidity fractions as 0.55, 3.41 and 18.8 c mol (p^+)/kg, respectively. The lime requirement (to raise the pH to 6.4) of the soil in terms of $CaCO_3$ was 11.9 t/ha. The cation exchange capacity of the soil was 5.46 c mol (p^+)/kg soil, and exchangeable Al^{3+} content was 0.45 c mol (p^+)/kg soil. The other exchangeable cations contents were 0.17, 0.23, 1.12, 0.78 and 0.11 c mol (p^+)/kg soil for K^+, NH_4^+, Ca^{2+}, Mg^{2+} and Na^+, respectively with a base saturation of 38.6 per cent.

Experimental set up

The incubation was carried out using 25 cm long poly vinyl chloride (PVC) hollow pipe, the bottom of which was temporarily closed by fixing a woven stainless wire cloth (diameter ≤ 0.2 mm) with rubber and adhesive tape. Each PVC pipe (internal diameter 8.44 cm and wall thickness 0.28 cm) was filled with sand up to 5 cm from the bottom, followed by the processed soil to a thickness of 15 cm maintaining the dry bulk density of the soils, estimated earlier during collection of the samples. The soil-filled PVC pipes were mounted in a one litre beaker and required mass of rice stubble was applied to each column as per the treatments and incubated for 105 days. A water level of 5 cm thickness was maintained inside the beaker throughout the incubation period.

Treatments and experimental design

A mixture of glyphosate (2.05 g/L a.i.) and edible *yogurt* (5 g/L) in water was freshly prepared and used as spray solution (Borah *et al.*, 2016 a, c). Glyphosate [N-(phosphonomethyl) glycine, $C_3H_8NO_5P$] is a non-selective herbicide with a water solubility of 12 g/L at 25 ^{0}C. The edible *yogurt* was collected from the local market and used for the spray. The spray was done on 20-12-2019 using a manual operated knapsack sprayer fitted with hollow cone nozzle, with a spray volume of 550 L/ha.

After the spray the stubble was kept for one hour in the field before collection for laboratory incubation. Both the treated and untreated rice stubbles were collected from the field, immediately chopped into small pieces (2.0 to 2.5 cm) and added to the soil columns as per treatments. Accurately weighed 4.0 gram of fresh biomass (with 60.4% moisture content, w/w) was added to respective soil column for treated and untreated rice stubbles.

The mass of rice stubble to each soil column was calculated on the basis of surface area of the PVC pipe and average dry weight of stubbles in the field per unit area, taking five random samples using a 1m x 1m quadrate. Five treatments were imposed to respective columns and comprised of T_1 – without rice stubble (RS), T_2 - RS untreated and retained on the surface, T_3 - RS untreated and incorporated into soil, T_4 - RS treated (glyphosate + *yogurt*) and retained on the surface and T_5 - RS treated (glyphosate + *yogurt*) and incorporated into soil. Five sets of the columns in a completely randomized design with four replications were incubated up to 105 days of imposition of the treatments.

Sampling and soil analysis

One of the several sets maintained for the experiment was dismantled periodically for analysis of soil properties at 21, 42, 63, 84 and 105 days after imposition of the treatments. The various physical chemical properties of the soils were estimated following standard procedures (table 1).

Ammonical nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N)

The soil was extracted with 1 *N* Na_2SO_4-phenylmercuric acetate and NH_4-N and NO_3-N in the solution was estimated using a uv-*vis* spectrophotometer (Onken and Sunderman, 1977).

Available nutrients in soil

Available nitrogen in soil was determined by modified alkaline potassium permanganate method (Subbiah and Asija, 1956) and the available phosphorous in soil was determined by Bray and Kurtz (1945) No 1 method (Jackson, 1973). The available potassium in soil was determined by extracting the soil with neutral normal ammonium acetate and the potassium in the extract was determined using a flame photometer (Jackson 1973).

Statistical analysis

A one-way ANOVA was carried out to compare the means of the different treatments. When significant F-values were detected, the differences between individual means were tested using the least significant difference (LSD) test.

Results and Discussion

Soil moisture content at different days after treatments

The soil moisture content (w/w) at different days after incubation is shown in table 2. The soil moisture content was unaffected by the treatments and ranged from 27.2 to 31.6 per cent, which was 63.1 to 73.3% of the water holding capacity of the soil.

NH_4-N and NO_3-N content in soil at different days after incubation

The highest and the lowest values of NH_4-N content in soil were observed for incorporation of glyphosate-*yogurt* treated rice stubble and without rice stubble, respectively (table 3). The ammonium-nitrogen (NH_4-N) in soil significantly increased due to incorporation of *yogurt* treated rice stubble compared to all other treatments. In case of untreated rice stubble, incorporation did not affect NH_4-N content in soil throughout the incubation period.

The NO_3-N in soil was not affected by the treatments at 21 days of incubation (table 4). Thereafter, addition of rice stubble, irrespective of glyphosate-*yogurt* treatment or incorporation, increased NO_3-N in soil over without rice stubble. The effect of *yogurt* or incorporation was non-significant. However, incorporation of glyphosate-*yogurt* treated RS showed significant increase in NO_3-N content of soil compared to untreated RS without incorporation.

The low NH_4-N content and non-significant effect on NO_3-N due to rice stubble application at early period of the incubation may be attributed to immobilization of nitrogen in soil (Mohanty *et al.,* 2010). Further, as the N-mineralization is strongly dependent on C:N ratio (van Asten *et al.,* 2005; Pandey *et al.,* 2009) the process was enhanced during later part of the incubation upon reduction in C:N ratio of the substrate (Borah *et al.,* 2016a,b,c) following mineralization of organic carbon. Positive changes in the contents of NH_4-N and NO_3-N in soil due to rice straw addition were reported earlier (van Asten *et al.,* 2005; Mohanty *et al.,* 2010; Yang *et al.,* 2018). Use of cellulose degrading microbes during organic residue decomposition was reported to facilitate N-mineralization from the substrate (Mikola *et al.,* 2002). Increased mineralization of nitrogen with application of ^{15}N-labelled rice straw from pot culture laboratory experiment was reported (Takahashi *et al.,* 2003). The significantly higher NH_4-N content in soil incorporated with *yogurt* treated rice stubble was due to faster decomposition or organic matter (van Asten *et al.,* 2005).

The NO_3-N content of soils was higher than NH_4-N content up to 84 days of incubation which was reverse beyond this stage. Higher NH_4-N and NO_3-N contents in soil with rice straw retention than removal was reported (Yana *et al.,* 2018). The transient organic intermediates like acetate, propionate, or butyrate undergo simultaneous oxidation and alternative redox processes like denitrification (Kusel *et al.,* 2002). Nitrate is subjected to both assimilation and dissimilation under most oxic conditions (Tiedje, 1988). Further NO_3-N leaching takes place from top soil (0-10 cm) due to addition of rice straw during rice season under rice-wheat cropping system (Yang *et al.,* 2018). The present work was carried out with 15 cm soil column under about 70% of the water holding capacity and might have created anoxic condition at the bottom soil layer resulting in lower NO_3-N content compared to NH_4-N after 84 days of incubation. A decrease in NO_3-N content of soil following flooding (Knoblauch *et al.,* 2014), and at 90 days after incubation of rice straw compost (Latifah *et al.,* 2018) was earlier reported.

Soil reaction and forms of acidity at different days after incubation

The soil pH values for respective treatments at different stages of the incubation are shown in table 5. The soil pH was not affected by the treatments except at 105 days after incubation, where incorporation of glyphosate-*yogurt* treated rice stubble significantly decreased it compared to that without rice stubble.

Forms of acidity in soil at different days after incubation

The values for exchange acidity and total acidity in soil at various stages of the incubation are presented in Fig 1 and Fig 2, respectively. The exchange acidity in soil significantly increased after 42 days and up to 105 days of incubation due to incorporation of rice stubble, both treated and untreated compared to without rice stubble or unincorporated rice stubble (Fig 1).

Similar to exchange acidity in soil, the total acidity in soil significantly increased due to incorporation of rice stubble (both treated and untreated) over without rice stubble or both treated and untreated unincorporated rice stubble (Fig 2). However, in case of unincorporated rice stubbles, glyphosate-*yogurt* treatment increased exchange acidity in soil over untreated rice stubble after 63 days of incubation.

The total potential acidity in soil was not affected by the treatments irrespective of the stages of the incubation (table 6).

The soil pH was not affected by the treatments except at 105 days after incubation, where significant reduction was observed due to incorporation of *yogurt* treated rice stubble compared to soil without it. A decrease in pH of the medium during anaerobic fermentation of rice straw followed by increase in the later stage of the experiment was reported (Zhao *et al.*, 2014). A decrease in soil pH with rice straw application was earlier observed (Ayinla *et al.*, 2016). On the other hand, an increase in soil pH with production of various organic acids following a decrease in early stage of rice straw decomposition was also reported (Kumari *et al.*, 2008). Contrary to the changes in pH during short-term decomposition of rice straw in soil, the pH had remained unchanged or slightly increased under long-term experiments (Qin *et al.*, 2011; Saothongnoi *et al.*, 2014). The exchange acidity and total acidity of soil increased significantly due to incorporation of rice stubble, irrespective of treatment with *yogurt*. Increase in exchange acidity but decrease in total potential acidity during three months submergence was reported (Savant and Kibe, 1971). The bottom layer of the soil in the present work remained near saturation throughout the incubation which might have contributed to the observed change in exchange acidity.

Table.1 Soil properties and methods followed for their determination

Parameter	Method	Reference
Bulk density	gravimetric method using undisturbed soil core (5.4 cm dia. and 12 cm height)	Blake and Hartge, 1986
Particle density	pycnometer box	Baruah and Borthakur, 1997
Water holding capacity	Keen-Raczkowski box	Baruah and Borthakur, 1997
Soil moisture content	gravimetric method	Baruah and Borthakur, 1997
Soil pH	soil:water (1:2.5) suspension, glass electrode pH meter	Jackson, 1973
Cation exchange capacity	centrifuge method	Baruah and Borthakur, 1997
Exchangeable cations extraction	leaching the soils with 1*N* CH_3COONH_4 (pH 7.0) solution under suction	Baruah and Borthakur, 1997
Ca^{2+} and Mg^{2+}	Versenate titration method	Richards, 1954
Na^+ and K^+	flame photometer	Jackson, 1973
Al^{3+} extraction	1 *N* KCl solution	Hesse, 1971
Al^{3+} estimation	spectrophotometer	Sivasubramaniam and Talibudeen, 1972
NH_4^+	1 *N* Na_2SO_4-phenylmercuric acetate extraction and colorimetric estimation	Onken and Sunderman, 1977
Exchange Acidity	1 *N* KCl solution extraction and titration with 0.1 *N* NaOH (Sokolov, 1939)	McLean, 1965
Total acidity	1*N* CH_3COONa extraction and titration with 0.1 *N* NaOH solution	Kappen, 1934
Total potential acidity	0.5 *N* $BaCl_2$ and triethanolamine (pH 8.0-8.2) extraction, titration with 0.2 *N* HCl	Baruah and Borthakur, 1997
Lime requirement	buffer solution (pH 6.5) extraction	Shoemaker *et al.*, 1961

Table.2 Soil moisture (%) content (w/w) at different days after incubation

Treatments	**Days after incubation**				
	21	**42**	**63**	**84**	**105**
Without rice straw (RS)	29.5	30.8	28.6	27.2	29.1
RS unincorporated	27.4	31.6	28.6	27.2	29.1
RS incorporated	30.2	28.4	30.1	28.4	28.8
RS treated, unincorporated	30.5	27.8	28.2	27.6	27.2
RS-treated, incorporated	28.6	30.1	29.6	30.2	29.5
LSD$_{P=0.05}$	NS	NS	NS	NS	NS
CV %	6.3	5.8	8.3	6.8	5.8

Table.3 NH_4-N in soil at different days after incubation

Treatments	**NH_4-N (mg/kg) at days after incubation**				
	21	**42**	**63**	**84**	**105**
Without rice straw (RS)	0.25	0.29	0.31	0.56	0.77
RS unincorporated	0.28	0.32	0.36	0.87	0.95
RS incorporated	0.28	0.34	0.39	0.91	1.10
RS treated, unincorporated	0.30	0.36	0.42	0.82	1.07
RS-treated, incorporated	0.36	0.43	0.54	1.02	1.25
LSD$_{P=0.05}$	0.06	0.05	0.08	0.11	0.08
CV %	12.3	8.6	11.0	8.5	7.8

Table.4 NO_3-N content in soil at different days after incubation

Treatments	**NO_3-N (mg/kg) at days after incubation**				
	21	**42**	**63**	**84**	**105**
Without rice straw (RS)	0.45	0.48	0.46	0.58	0.54
RS unincorporated	0.44	0.56	0.69	0.77	0.85
RS incorporated	0.47	0.64	0.76	0.82	0.81
RS treated, unincorporated	0.48	0.59	0.70	0.85	0.77
RS-treated, incorporated	0.54	0.67	0.81	0.84	0.84
LSD$_{P=0.05}$	NS	0.10	0.12	0.11	0.14
CV %	9.5	11.3	10.8	8.7	10.3

Table.5 Soil pH at different days after incubation

Treatments	**Soil pH at different days after incubation**				
	21	42	63	84	105
Without rice straw (RS)	4.70	4.73	4.60	4.63	4.60
RS unincorporated	4.63	4.68	4.55	4.53	4.50
RS incorporated	4.68	4.70	4.50	4.50	4.40
RS treated, unincorporated	4.60	4.58	4.53	4.43	4.43
RS-treated, incorporated	4.63	4.58	4.50	4.40	4.38
LSD$_{P=0.05}$	NS	NS	NS	NS	0.14
CV %	3.7	5.5	1.9	4.7	4.1

Table.6 Total potential acidity in soil at different days after incubation

Treatments	**Days after treatment [c mol (p^+)/kg]**				
	21	**42**	**63**	**84**	**105**
Without rice straw (RS)	18.9	17.6	18.6	17.8	18.1
RS unincorporated	16.8	17.8	16.9	18.4	19.5
RS incorporated	17.6	18.2	18.2	20.1	18.8
RS treated, unincorporated	19.2	19.1	18.6	19.4	20.3
RS-treated, incorporated	17.8	19.5	19.3	20.0	20.5
$LSD_{P=0.05}$	NS	NS	NS	NS	NS
CV %	8.2	7.0	5.9	5.7	6.7

Table.7 Cation exchange capacity (CEC) and exchangeable cations [c mol (p^+)/kg] in soil

Treatments	**CEC and exchangeable cations at 105 days after treatment**						
	CEC	**Ca^{2+}**	**Mg^{2+}**	**K^+**	**Na^+**	**Al^{3+}**	**$*NH_4^+$**
Without rice straw (RS)	5.49	1.12	0.77	0.18	0.14	0.46	4.26
RS unincorporated	5.74	1.11	0.80	0.18	0.15	0.48	5.75
RS incorporated	5.94	1.21	0.87	0.21	0.16	0.50	6.11
RS treated, unincorporated	5.65	1.15	0.79	0.19	0.16	0.45	5.96
RS-treated, incorporated	6.23	1.24	0.88	0.22	0.15	0.52	6.37
$LSD_{P=0.05}$	0.45	0.09	0.07	0.03	NS	NS	0.64
CV %	5.8	4.8	5.5	8.6	6.6	5.1	7.4

*x 10^{-3}

Table.8 Lime requirement (LR), WHC and available nutrients in soil at 105 days after treatment

Treatments	**LR* (t/ha)**	**$^\$$WHC (%)**	**Available nutrients (kg/ha)**		
			N	**P**	**K**
Without rice straw (RS)	11.9	43.28	259.7	5.77	161.8
RS unincorporated	11.7	41.10	273.3	5.67	167.6
RS incorporated	11.8	44.90	266.6	6.24	174.8
RS treated, unincorporated	10.9	42.90	271.0	5.97	161.3
RS-treated, incorporated	12.2	46.43	278.1	6.38	182.3
$LSD_{P=0.05}$	NS	NS	NS	0.47	12.5
CV %	8.2	8.7	5.3	5.1	4.8

*To raise the pH to 6.4, $^\$$WHC – water holding capacity

Fig.1

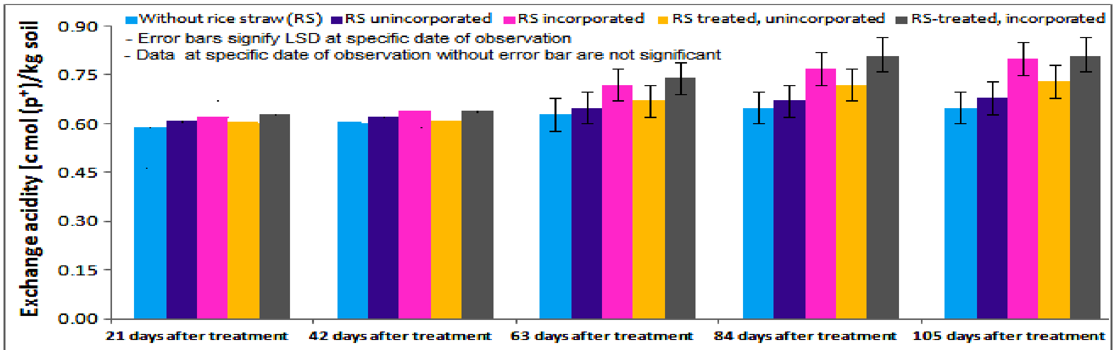

Fig 1 Exchange acidity in soil [c mol (p⁺)/kg] as influenced by stubble management at different days after treatment

Fig.2

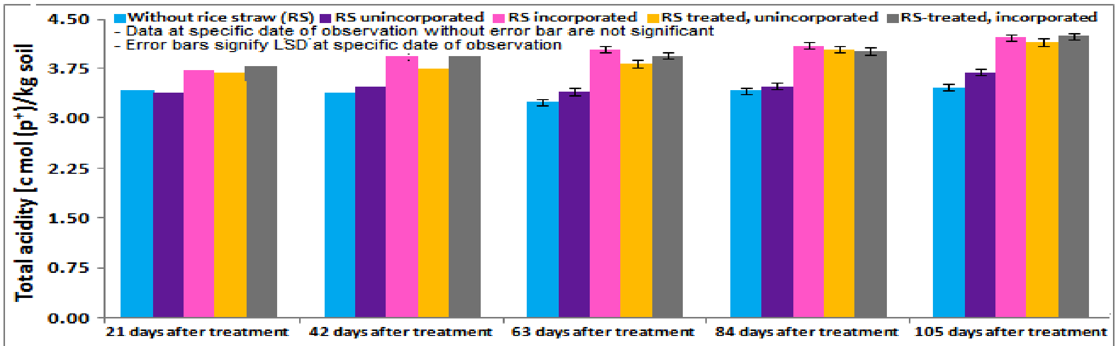

Fig 2 Total acidity [c mol (p+)/kg] in soil as influenced by stubble management at different days after treatment

Cation exchange capacity and exchangeable cations in soil

The cation exchange capacity and exchangeable cations in soil at 105 days of incubation are presented in table 7. The cation exchange capacity of soil significantly increased due to incorporation of rice stubble irrespective of glyphosate-*yogurt* treatment. The highest value was recorded for soil with rice stubble removal and the lowest for soil with incorporation of glyphosate-*yogurt* treated rice stubble. The effect of glyphosate-*yogurt* treatment was statistically not significant irrespective of incorporation or leaving stubbles on the surface.

The exchangeable Ca^{2+}, Mg^{2+} and K^{+} in soil were significantly increased due to rice stubble incorporation with or without glyphosate-*yogurt* treatment (table 7). The highest values for exchangeable Ca^{2+}, Mg^{2+} and K^{+} were recorded for incorporation of glyphosate-*yogurt* treated rice stubble, while the lowest values were recorded for soil with removal of rice stubble. Similar to cation exchange capacity, the effect of glyphosate-*yogurt* treatment was statistically not significant irrespective of incorporation or leaving stubbles on the surface for exchangeable Ca^{2+}, Mg^{2+} and K^{+} in soil. The exchangeable NH_4^{+} in soil significantly increased due to addition of rice stubble compared to their removal (table 7). The highest values for exchangeable NH_4^{+} were recorded for incorporation of glyphosate-*yogurt* treated rice stubble, while the lowest values were recorded for soil with removal of rice stubble. The effect of incorporation or glyphosate-*yogurt* treatment was not statistically significant for exchangeable NH_4^+ in soil. The exchangeable Na^+ and Al^{3+} in soil were not affected by the treatments during the incubation. The highest values for exchangeable Na^+ and Al^{3+} in soil were recorded for unincorporated untreated rice stubble and incorporation of glyphosate-*yogurt* treated rice stubble, respectively. The lowest values for exchangeable Na^+ and Al^{3+} in soil were recorded for rice stubble removal (table 7).

The cation exchange capacity (CEC), exchangeable Ca^{2+}, Mg^{2+} and K^+ significantly increased due to rice stubble incorporation with or without *yogurt* treatment. Similar results were earlier reported for CEC (Ogbodo, 2011), Ca^{2+} and Mg^{2+} (Ogbodo, 2011; Ayinla *et al.*, 2016) and K^+ (Ogbodo, 2011; Ayinla *et al.*, 2016). The increase in CEC and exchangeable Ca^{2+}, Mg^{2+} and K^+ may be attributed to corresponding increase in organic carbon contents of the soils due to enhanced decomposition of rice stubbles followed by retention of the cations in the exchange sites. The exchangeable NH_4^+ content in soil increased significantly due to addition of rice stubbles compared to without addition, irrespective of *yogurt* treatment or incorporation. Exchangeable NH_4^+ was the main pool of weakly fixed NH_4^+ in paddy soil (Matsuoka and Moritsuka, 2011) and application of rice straw significantly increased it corresponding to an increase in exchangeable NH_4^+, indicating weakly fixed NH_4^+ played as an intermediate pool between strongly fixed and exchangeable NH_4^+.

Water holding capacity, lime requirement and available nutrients in soil

The values for lime requirement (LR), water holding capacity (WHC) and available nutrients of soil at 105 days after incubation are presented in table 8.

The lime requirement and water holding capacity of the soils were not affected by the treatments.

In case of available nutrients, the available nitrogen content of soil was not affected by the treatments (table 8). The available phosphorous and potassium in soil significantly increased due to incorporation of rice stubble, irrespective of glyphosate-*yogurt* treatment. The effect of adding rice stubble with or without glyphosate-*yogurt* treatment was statistically not significant compared to without rice stubble for both available phosphorous and potassium in soil. The organic carbon content ($K_2Cr_2O_7$ wet oxidation) of the soils (data not presented here) was not affected by the treatments up to 84 days of incubation, and increased with incorporation of glyphosate-*yogurt* treated rice stubble compared to without rice stubble.

The non-significant difference in water holding capacity and lime requirement, and significant increase in available phosphorous content of soils due to stubble addition are in conformity to those reported elsewhere (Zhou *et al.*, 2002; Wei *et al.*, 2015). The significant increase in phosphorous content of soils can be attributed to the fact that phosphorous as a constituent of crop residues was mineralized and released into the soil increasing the phosphorous content in soil. The available potassium content of soil increased due to incorporation of rice stubble with or without *yogurt* treatment and conform to the results reported earlier (Li *et al.*, 2014; Zhu *et al.*, 2019). The significant increase in potassium content in soils due to rice stubble incorporation can be attributed to enhanced decomposition of the substrate.

In conclusion the decomposition of rice stubble in paddy soil under constant moisture regime had greater effect on NH_4-N than NO_3-N, exchange and total acidity than pH and selected exchangeable cations and available nutrients than cation exchange capacity. The changes in N-fractions, forms of acidity, available nutrient contents and specific biological parameters in soil during and after decomposition of rice stubble need further study in response to fertilizer, organic manure, soil amendment application and crop growth.

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