

Validation of traditional weed control method through common salt application in the hill region of Nagaland

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Traditionally, common salt (NaCl) is applied to control broadleaved weeds under shifting cultivation in Nagaland. The aim of the present study was to find out whether such practice is harmful to the soil. For this, an experiment was conducted on upland rice with 12 treatments, viz. control, weedy check and different doses of NaCl from 20 to 200 kg ha⁻¹. Soil samples were collected at several phases of shifting cultivation and analysed for organic carbon, available N, P, K, pH, electrical conductivity (EC), cation exchange capacity, exchangeable sodium percentage and sodium adsorption ratio. Yield and yield attributing characters were measured and economics was computed. The results revealed that soil organic carbon (SOC) increased after harvest, but decreased after one year. In contrast, available N, P and K decreased during the crop growth and post harvest period. Weedy check followed by an application of 100 kg NaCl ha⁻¹ realized the highest gross and net returns. It was observed that NaCl did not exert an undesirable influence on pH, SOC and available NPK; however, EC increased for a short time. The results were confirmed by the verification trial. The yield of rice was highest in 100 kg NaCl ha⁻¹ treatment among the treated plots. Hence, this may be recommended to control weeds under shifting cultivation.

Keywords: Common salt, direct-seeded rice, indigenous technical knowledge, shifting cultivation, weed control.

SHIFTING cultivation is commonly practised by the Nāga ethnic groups for their livelihood in the North Eastern Hill (NEH) region of India. In this form of agriculture, a part of the forest is slashed, burnt and cropped without tilling the soil, and the land is fallowed subsequently to attain the pre-slashed forest status through natural succession¹. Rice is the principal foodgrain crop in the shifting cultivation of the North Eastern hilly ecosystem. It occupies 3.51 m ha, which accounts for more than 80% of the total cultivated area of the region. The North Eastern hills account for 7.8% of the total rice area of India with 5.9%

production, having an average productivity of 1.4 t ha⁻¹ (ref. 2). In shifting cultivation rice seeds are directly sown, while in terrace and valley lands rice seedlings are transplanted. Most of the farmers grow crops on the hill without applying any synthetic pesticide. Because of intermittent occurrences of rain during the early growth stage of rice, weeds like *Digitaria sanguinalis*, *Eleusine indica*, *Borreria hispida*, *Ageratum conyzoides*, *Amaranthus viridis*, *Chromolaena odorata*, *Commelina benghalensis*, *Mimosa pudica*, etc. emerge early and grow rapidly³. This results in heavy weed infestation within a short span of time. Besides, farmers cultivate crops in the virgin forest land after clearing the native trees and shrubs. Thus, the menace of weeds is much higher than conventional cultivation. As a consequence, rice productivity in Nagaland is far lesser than that in other parts of India. Weed is one of the reasons for the poor rice yield. Research in the region reveals that weed infestation is more severe in upland condition (71%) compared to wetland (29%) condition⁴. Weed causes heavy damage to direct-seeded rice crop, which may be 5–100% (ref. 5). In general, 2,4-D Na salt is globally used to control post-emergence broadleaved weed and sedge⁶. Since farmers do not adopt synthetic pesticides, 3–4 times hand weeding is recommended during the crop growth period. But this practice incurs high labour cost. Thus, the farmers adhere to their ethnic custom of application of common salt (NaCl) for controlling weeds.

Farmers prefer NaCl to kill weeds because of its ready availability, low cost, safe use, and traditional belief. NaCl affects the plant by three modes of action: lowering of water potential, direct toxicity of Na⁺ and Cl⁻ ions, and interference with the uptake of essential nutrients². The high Na⁺:K⁺ ratio disrupts various enzymatic processes in the cytoplasm owing to the ability of Na⁺ to compete with K⁺ for the binding sites⁷. However, silica deposition and polymerization of silicate in endodermis and rhizodermis block Na⁺ influx through the apoplastic pathway in the roots of rice⁸. Thus, rice can regulate and adjust its osmotic pressure and can thrive under high salt condition. Available reports suggest that, globally NaCl is applied to control smooth crabgrass (*Digitaria ischaemum*)⁹, goose grass (*Eleusine indica*)¹⁰, sour grass (*Paspalum*

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conjugatum)¹¹, annual grass weed¹² and rip gut brome¹². Also, sea water is sprayed to control weed in turf grass¹³. As a cost-effective strategy, NaCl is mixed to reduce the rate of round-up application in oil palm plantations¹⁴. Though NaCl is not recommended as a common herbicide by the agronomists, it has the capacity to control the broadleaved weeds². Some alien weeds like *Ageratum conyzoides* and *Parthenium hysterophorus* could successfully be controlled by spraying 15–20% NaCl (ref. 15). Research findings have revealed that 150 kg ha⁻¹ NaCl may be applied to control annual broadleaved weeds in NE India¹⁶. Majority of the studies report the ability of NaCl to control weeds and its effect on rice physiology; however, its effect on the soil has not yet been studied systematically.

In view of the above facts and also to validate the application of NaCl, it was investigated whether NaCl application for upland rice is harmful to the soil. Therefore, an experiment was conducted with the following objectives: (i) to evaluate the effect of NaCl on soil properties, and (ii) to analyse the influence of NaCl on yield and growth characters of upland rice.

Methodology

Experimental details

The experiment was conducted at a farmer's field located in Medizphema (25°45.929'N, 93°53.123'E, 508 m amsl, 55% slope), Nagaland during the rainy season (June–October) of 2012. Figure 1 provides the meteorological data from January 2012 to October 2013. The mean monthly maximum and minimum air temperatures varied from 20.9°C to 33.4°C and 7.5°C to 25.5°C respectively. Total rainfall was 3011.8 mm during the experimental period. Monthly rainfall was the highest in August 2013 (476.7 mm) followed by July 2012 (366 mm). This enormous rainfall coupled with steep slope reduced salt concentration on the soil profile. The differences in timing and intensity of rainfall after salt application, and the amount and type of ground cover would affect the extent to which the salt is available on the soil surface¹².

The following 12 treatments were imposed in randomized complete block design (4 m × 4 m plots in the mid-hill across the slope) with three replications: T_0 (control: no NaCl), T_1 (manual weeding at 40 and 60 days after sowing (DAS) or weedy check), T_2 (20 kg ha⁻¹ NaCl or 2% concentration), T_3 (40 kg ha⁻¹ NaCl or 4% concentration), T_4 (60 kg ha⁻¹ NaCl or 6% concentration), T_5 (80 kg ha⁻¹ NaCl or 8% concentration), T_6 (100 kg ha⁻¹ NaCl or 10% concentration), T_7 (120 kg ha⁻¹ NaCl or 12% concentration), T_8 (140 kg ha⁻¹ NaCl or 14% concentration), T_9 (160 kg ha⁻¹ NaCl or 16% concentration), T_{10} (180 kg ha⁻¹ NaCl or 18% concentration), and T_{11} (200 kg ha⁻¹ NaCl or 20% concentration), and they were

applied at 45 and 75 DAS. NaCl was applied as foliar spray through a flat fan nozzle using water as a carrier at the rate of 500 l ha⁻¹. Rice (cv Bhalum 3; 130–140 days duration) seed (60 kg ha⁻¹) was dibbled in June 2012. Traditional practices were followed to raise the crop under rainfed condition, i.e. no application of fertilizer and farmyard manure.

Soil analysis

Surface soil samples (0–15 cm depth) were collected at different phases of shifting cultivation (Table 1). The samples were dried, ground and passed through a 2 mm sieve and analysed for sand, silt and clay contents (hydrometer method)¹⁷, pH and electrical conductivity (EC; in 1:2.5 soil:water suspension), oxidizable organic carbon¹⁸, alkaline-KMnO₄ extractable nitrogen¹⁸, available phosphorus¹⁸, available potassium using 1 N NH₄Ac (ref. 18) and cation exchange capacity (CEC)¹⁹. Two different criteria were used to measure soil salinity, viz. sodium adsorption ratio (SAR) with a reported threshold of 12 (cmol kg⁻¹)^{0.5} and exchangeable sodium percentage (ESP) with a reported threshold of 15% (ref. 20). SAR and ESP of the soil samples were measured using laboratory tests as described by the Soil Survey Staff²¹ and calculated as follows:

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{(\text{Ca}^{2+} + \text{Mg}^{2+})/2}}, \quad (1)$$

where SAR is in (cmol kg⁻¹)^{0.5} and Na⁺, Ca²⁺, Mg²⁺ are the measured exchangeable Na⁺, Ca²⁺ and Mg²⁺ respectively (cmol kg⁻¹).

$$\text{ESP} = \left(\frac{\text{Na}^+}{\text{CEC}} \right) \times 100, \quad (2)$$

where Na is the measured exchangeable Na (cmol kg⁻¹) and CEC is in cmol kg⁻¹.

To establish the relationship between ESP and SAR, a typical linear regression model was used

$$Y = k_0 + k_1X, \quad (3)$$

where Y is the dependent variable, i.e. ESP of soil, X the independent variable, i.e. SAR of soil and k_0 , k_1 are the regression coefficients.

Yield and economics

Three sites in each plot were sampled using 1.0 sq. m quadrat for yield at harvest stage and averaged. The straw and panicles were air-dried for a week, and then

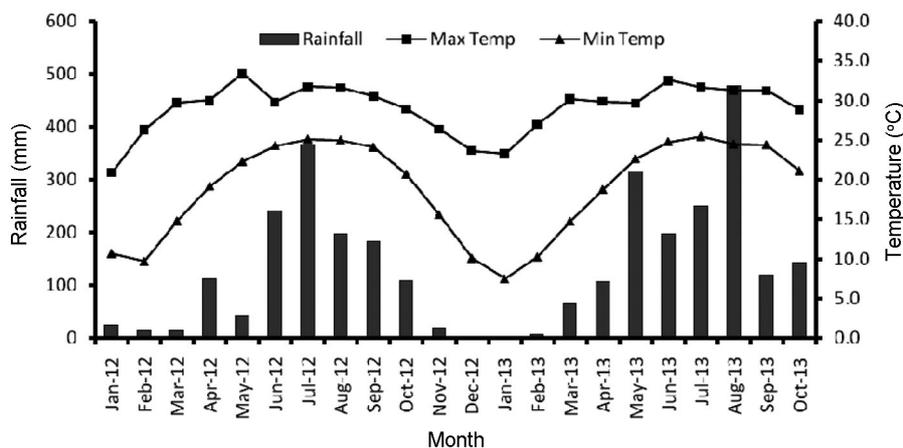


Figure 1. Weather parameters during the experimental period.

Table 1. Details of the soil samples collected at different phases of shifting cultivation

Phase	Abbreviation	Date	Remarks
Virgin forest	VF	14 October 2011	Undisturbed forest land. The forest was cut during the last week of October–first week of November 2011.
Before burning	BB	9 March 2012	The leftovers twigs of trees were dried.
After burning	AB	2 April 2012	The whole area was burnt and the field was covered with ash.
Before sowing	BS	29 May 2012	Just before the sowing of rice. Sowing was done on 3 June 2012.
Standing crop	SC	17 August 2012	At 75 DAS, which is 30 days after first application of NaCl and just before the application of the second dose.
After harvest	AH	10 October 2012	At 130 DAS, which is 55 days after the second application of NaCl.
One year after harvest	AY	10 October 2013	The land was bare and sparsely covered with bushy vegetation.

cleaned and sun-dried. The grain yield was reported at 14% moisture and straw yield on the oven-dry weight basis. This gave the yield in kilogram per plot, and then the net plot yield ($t\ ha^{-1}$) was calculated.

The cost of cultivation, gross return, net returns and benefit : cost (B : C) ratio of different treatments were worked out based on the prevailing market price. Net return (Indian National Rupees (INR) ha^{-1}) and B : C ratio were worked out using the following formulae

$$\text{Net return (INR } ha^{-1}\text{)} = \text{Gross return (INR } ha^{-1}\text{)} \\ - \text{cost of cultivation (INR } ha^{-1}\text{)}.$$

$$\text{Benefit : cost ratio} = \frac{\text{Gross return (INR } ha^{-1}\text{)}}{\text{total cost of cultivation (INR } ha^{-1}\text{)}}.$$

Verification trial

A verification trial was conducted to test the validity of the results from the main experiment before recommending for adoption by the farmers. For this, the experiment was repeated in the same location during 2013–14. The soil samples after harvest were tested for soil salinity parameters.

Statistical analysis

The analysis of variance method for randomized complete block design (RCBD) was followed to analyse the difference among treatment means²². The significance of different sources of variation was tested for the error mean square of Fisher Snedecor's *F* test at probability level ($P \leq 0.05$). In the summary tables of the results, the standard error of mean (SEM) and least significant difference (LSD) to compare the difference among the means have been provided.

Results and discussion

Initial properties of the soil

Table 2 shows that pH is low (4.81 ± 0.21) in soils of virgin forest (VF). It decreases to a small extent (4.19 ± 0.07) before burning and increases to a large extent (6.05 ± 0.09) after burning. The first decrement was due to the released organic acids from the decomposition of leftover twigs. Further increment could be attributed to the basic cations added from the ash of the leftover twigs. However, in all the cases the soil remained acidic ($pH < 7$) and this acidic soil condition helped in controlling

Table 2. Initial properties of soil samples collected at different phases of shifting cultivation

Parameter	VF	BB	AB	BS
pH (1 : 2.5 soil : water)	4.81 ± 0.21*	4.19 ± 0.07	6.05 ± 0.09	5.01 ± 0.04
Electrical conductivity (dS m ⁻¹)	0.049 ± 0.008	0.052 ± 0.008	0.104 ± 0.004	0.067 ± 0.001
Organic carbon (%)	2.30 ± 0.19	1.92 ± 0.10	1.69 ± 0.11	1.55 ± 0.10
Available N (kg ha ⁻¹)	87.81 ± 9.58	137.98 ± 16.59	282.24 ± 17.27	258.14 ± 15.44
Available P (kg ha ⁻¹)	8.38 ± 1.12	8.99 ± 1.38	39.37 ± 1.68	34.94 ± 1.32
Available K (kg ha ⁻¹)	43.54 ± 7.21	91.88 ± 17.62	336.12 ± 51.69	279.62 ± 22.56

*Mean ± standard error of mean ($n = 3$). VF, Virgin forest; BB, before burning; AB, after burning; BS, before sowing.

weeds using NaCl (ref. 2). Not much change was noted in EC (dS m⁻¹) of VF and before burning (BB) soil samples. However, EC increased almost twice after burning (0.104 ± 0.004 dS m⁻¹) compared to that before burning (0.052 ± 0.008 dS m⁻¹). The soil organic carbon (SOC) decreased with the advance of phases of shifting cultivation. This may be attributed to gravitational movement of clayey substances from experimental plots (slope 55%). Related studies in two grasslands in central California, USA, showed that the sediments transported on the steeply sloped landscapes and the average organic carbon erosion rate from convex slopes varied from 1.4 to 8 g C m⁻² year⁻¹ (ref. 23). After cutting of VF, the soil temperature increased. This may induce more microbial activities. The increased microbial activities may promote higher rate of decomposition of organic matter and less accumulation of SOC (1.92 ± 0.10%) in soil before burning. Decomposed leaves and twigs did not significantly contribute to SOC (measured at 0.5 mm sieved soil). SOC (1.69 ± 0.11%) decreased by a large amount after burning of surface residues. Available N, P and K content increased with the advance in phases of shifting cultivation. The soil trapped the released volatile nitrogenous compounds (ammonia) in acidic soil after burning. This increased available N from 137.98 ± 16.59 kg ha⁻¹ (BB) to 82.24 ± 17.27 kg ha⁻¹ (AB). Availability of P in the soils increased by 4–6 times from 8.99 ± 1.38 kg ha⁻¹ (BB) to 39.37 ± 1.68 kg ha⁻¹ (AB). This was due to the increase in pH after burning. These findings contradict those of Arunachalam²⁴, who reported that available-P, total Kjeldahl nitrogen, ammonium-N and nitrate-N decreased as the duration of cultivation increased under shifting cultivation. However, the present study also supported the addition of K to the soil from the ashes²⁵, an increase in soil pH (ref. 25) and a decrease in SOC²⁴. The content of N, P, K, pH, EC, SOC decreased by a small amount before sowing (Table 2).

Effect on soil

Temporal variation of soil nutrient status after application of different rates of NaCl (Table 3) showed that the largest amount of SOC was recorded with no NaCl (T_0), 140 kg ha⁻¹ (T_8) and 100 kg ha⁻¹ (T_6) NaCl treated plots in standing crop (SC), after harvest (AH) and one year

after harvest (AY) samples respectively. Treatments showed no clear trend; however, samples showed temporal variations with the phases of shifting cultivation. SOC increased after harvest (1.72–2.50%), which again decreased in AY samples (0.94–1.82%), even lower than SC samples (1.42–2.00%), with the exception of treatment T_5 . The first increment was due to the addition of carbon into the soil through root exudates, and the latter decrement after a year was due to loss by soil erosion in abandoned fields. Application of NaCl induced localized sodicity and consequent solubilization of SOM exaggerated potential SOC loss²⁶. However, the effect of NaCl on SOC was not clearly visible in the present experiment, even though there was a significant difference in exchangeable Na content in the experimental soil (Table 4). This could be due to the lesser extent of sodicity (0.049–0.170 meq 100 g⁻¹ Na) and salinity (0.070–0.120 EC), which was not sufficient to influence SOC content. Available N, P and K decreased continuously during the crop growth period as well as the post-harvest period. The first decrement was due to crop removal and the decrement during the latter period was due to soil loss by erosion.

Salt concentration as measured by EC showed that EC increased significantly with NaCl-applied plots (T_2 – T_{11}) over control (T_0), and weedy check (T_1) as visible in the SC samples (collected after a month of first application of NaCl; Figure 2a and b). This increment was due to the application of NaCl in the salt-treated plots. The trend remained the same after application of NaCl twice, as shown by the EC value of AH samples. However, the EC value increased 1.28–1.40 times compared to that in SC samples. EC could be best fitted to the exponential equation given below (eq. 4). It indicates that by increasing the dose of NaCl, Y (electrical conductivity) would increase exponentially.

$$Y = ae^{bC}, \quad (4)$$

where C is the dose of NaCl (kg ha⁻¹), and a , b are constants. The present findings show that the value of a ranges from 0.0408 to 0.0963, and b from 0.0005 to 0.0012. The rate (change in EC per unit change in dose of NaCl) could be obtained by differentiating eq. (4)

$$dY/dC = abe^{bC}. \quad (5)$$

Table 3. Temporal variation of soil nutrient status after different rates of common salt (NaCl) application

Treatment	Organic carbon (%)			Available N (kg ha ⁻¹)			Available P (kg ha ⁻¹)			Available K (kg ha ⁻¹)		
	SC	AH	AY	SC	AH	AY	SC	AH	AY	SC	AH	AY
Control (<i>T</i> ₀)	2.00	2.28	1.28	254.02	250.88	191.30	31.21	27.81	14.23	265.44	241.64	226.07
Weedy check (<i>T</i> ₁)	1.81	1.98	1.28	254.02	213.25	185.02	34.59	28.57	8.67	241.38	226.31	182.00
NaCl application (kg/ha)												
20 (<i>T</i> ₂)	1.75	2.19	1.07	272.83	225.79	175.62	28.06	21.68	9.40	254.24	228.03	190.79
40 (<i>T</i> ₃)	1.42	2.05	1.37	254.02	250.88	166.21	30.12	19.02	10.27	244.16	218.12	209.61
60 (<i>T</i> ₄)	1.65	2.04	0.94	244.61	213.25	181.89	27.58	14.19	7.85	151.76	150.47	141.23
80 (<i>T</i> ₅)	1.56	2.20	1.61	313.60	260.29	172.48	33.26	16.40	10.55	284.14	247.63	215.04
100 (<i>T</i> ₆)	1.87	2.28	1.82	288.51	241.47	147.39	25.28	15.55	12.90	247.52	186.59	185.64
120 (<i>T</i> ₇)	1.48	2.42	1.28	254.02	200.70	125.44	34.71	17.68	9.66	243.04	137.76	119.45
140 (<i>T</i> ₈)	1.66	2.50	1.37	235.20	222.66	159.94	33.50	19.34	8.90	193.48	187.15	185.92
160 (<i>T</i> ₉)	1.99	2.18	1.37	247.74	238.34	134.85	35.37	27.82	11.26	183.12	117.04	111.72
180 (<i>T</i> ₁₀)	1.63	1.77	1.56	279.10	254.02	144.26	27.58	16.48	11.67	196.45	192.86	175.84
200 (<i>T</i> ₁₁)	1.52	1.72	1.41	304.19	254.02	156.80	36.53	23.81	8.45	235.54	221.03	146.72
SEM	0.04	0.03	0.05	2.20	2.37	2.37	0.37	1.88	1.24	6.52	4.90	5.17
LSD (<i>P</i> ≤ 0.05)	0.11	0.10	0.14	6.45	6.96	6.96	1.10	5.52	7.09	19.14	14.38	15.17

SC, Standing crop; AH, after harvest; AY, one year after harvest.

Table 4. Temporal variation of sodium (Na), potassium (K), calcium + magnesium (Ca + Mg), exchangeable sodium percentage (ESP), and sodium adsorption ratio (SAR) status after different rates of NaCl application

Treatment	Na meq 100 g ⁻¹			K meq 100 g ⁻¹			Ca+Mg meq 100 g ⁻¹			ESP (%)			SAR (cmol k g ⁻¹) ^{0.5}		
	SC	AH	AY	SC	AH	AY	SC	AH	AY	SC	AH	AY	SC	AH	AY
Control (<i>T</i> ₀)	0.058	0.058	0.006	0.276	0.258	0.303	5.733	6.284	6.091	0.953	0.876	0.095	0.034	0.033	0.003
Weedy check (<i>T</i> ₁)	0.061	0.064	0.015	0.390	0.373	0.208	5.749	6.764	7.777	0.982	0.888	0.190	0.036	0.035	0.008
NaCl application (kg/ha)															
20 (<i>T</i> ₂)	0.079	0.088	0.018	0.260	0.218	0.290	6.394	5.827	8.025	1.177	1.439	0.220	0.044	0.052	0.009
40 (<i>T</i> ₃)	0.082	0.094	0.018	0.249	0.239	0.279	6.069	6.666	8.836	1.284	1.349	0.200	0.047	0.052	0.009
60 (<i>T</i> ₄)	0.088	0.097	0.079	0.172	0.161	0.173	5.807	6.542	5.948	1.455	1.426	1.277	0.052	0.054	0.046
80 (<i>T</i> ₅)	0.091	0.110	0.082	0.324	0.283	0.246	7.584	8.208	5.472	1.141	1.274	1.417	0.047	0.054	0.050
100 (<i>T</i> ₆)	0.094	0.113	0.091	0.212	0.213	0.283	6.627	6.808	6.559	1.361	1.580	1.317	0.052	0.061	0.050
120 (<i>T</i> ₇)	0.100	0.113	0.094	0.157	0.136	0.277	7.409	6.551	3.428	1.310	1.658	2.485	0.052	0.062	0.072
140 (<i>T</i> ₈)	0.110	0.116	0.100	0.221	0.214	0.212	5.736	6.671	5.554	1.806	1.653	1.714	0.065	0.063	0.060
160 (<i>T</i> ₉)	0.122	0.119	0.107	0.134	0.097	0.209	7.145	7.584	6.684	1.645	1.523	1.524	0.064	0.061	0.058
180 (<i>T</i> ₁₀)	0.125	0.131	0.107	0.224	0.220	0.201	7.651	7.849	3.026	1.560	1.598	3.196	0.064	0.066	0.087
200 (<i>T</i> ₁₁)	0.128	0.140	0.110	0.269	0.252	0.168	8.603	8.208	5.323	1.421	1.628	1.957	0.062	0.069	0.067
SEM	0.003	0.003	0.002	0.008	0.017	0.004	0.185	0.193	0.199	0.006	0.007	0.009	0.001	0.001	0.001
LSD (<i>P</i> ≤ 0.05)	0.008	0.009	0.006	0.023	0.051	0.012	0.543	0.565	0.584	0.017	0.019	0.025	0.002	0.002	0.002

SC, Standing crop; AH, after harvest; AY, one year after harvest.

Since the value of *b* is very small compared to *a* (eq. (5)), primarily *a* governs the rate (*dY/dC*). The samples can be arranged as AH > SC > AY on the basis of the value of *a*. The change in EC per kg of NaCl was more when applied twice, and enough time was not available for rain to wash away the common salt from the soil. Actually, the rice-growing period falls during the peak rainfall period (both pre-monsoon and monsoon) of the region, which does not allow the salt to become available on the soil surface for longer periods¹². pH showed no clear trend, however, the average value in AH (4.5), SC (4.17) and AY (4.31) samples indicated that the soil regained its initial acidity (Figure 2c). Release of organic acids in the rhizosphere and loss of basic cations by plant uptake, soil erosion and leaching were the potential reasons for such acidity retrieval.

The application of NaCl significantly increased Na levels in the soil from 0.018 to 0.140 meq Na 100 g⁻¹ (Table 4). The Na concentration (0.061–0.064 meq 100 g⁻¹) in weedy check (*T*₁) was statistically similar to that (0.058 meq 100 g⁻¹) in control (*T*₀) in the SC and AH samples. In all NaCl-treated plots, Na concentration increased in AH (0.088–0.140 meq 100 g⁻¹), which again decreased in AY (0.018–0.110 meq 100 g⁻¹), even lesser than its content in SC (0.079–0.128 meq 100 g⁻¹). Similar findings were reported by Tozer *et al.*¹² in New Zealand. On the contrary, weedy check (*T*₁) recorded the largest K content in samples collected during SC (0.390 meq 100 g⁻¹) and AH (0.373 meq 100 g⁻¹) phase. However, application of 20 kg NaCl ha⁻¹ (*T*₂) recorded the highest amount of K (0.290 meq 100 g⁻¹) in the AY samples (Table 4). Unlike the Na content in treated soils, K content

showed no definite trend. The amount of Ca + Mg ranged from 5.736 to 8.603 meq 100 g⁻¹ in the SC samples, 5.827 to 8.208 meq 100 g⁻¹ in the AH samples and 3.026 to 8.025 meq 100 g⁻¹ in the AY samples (Table 4). The ESP was much less in control (T₀, 0.095–0.953 meq 100 g⁻¹) and weedy check (T₁, 0.190–0.982 meq 100 g⁻¹) than in the NaCl-treated samples (Table 4). Likewise, SAR increased by the application of NaCl in all stages of salt application. However, control (T₀, 0.003 meq 100 g⁻¹), weedy check (T₁, 0.008 meq 100 g⁻¹) and application of NaCl @ 20 kg ha⁻¹ (T₂, 0.009 meq 100 g⁻¹) and 40 kg ha⁻¹ (T₃, 0.009 meq 100 g⁻¹) showed statistically similar effects in the AY samples. This indicates that the application of NaCl up to 40 kg ha⁻¹ (T₃) would not affect a SAR in the long run. The relationship between ESP and SAR can be derived as follows (Figure 3)

$$ESP = 0.038 SAR - 0.000 \quad (R^2 = 0.892), \quad (6)$$

$$ESP = 0.040 SAR - 0.001 \quad (R^2 = 0.931), \quad (7)$$

$$ESP = 0.028 SAR + 0.006 \quad (R^2 = 0.956). \quad (8)$$

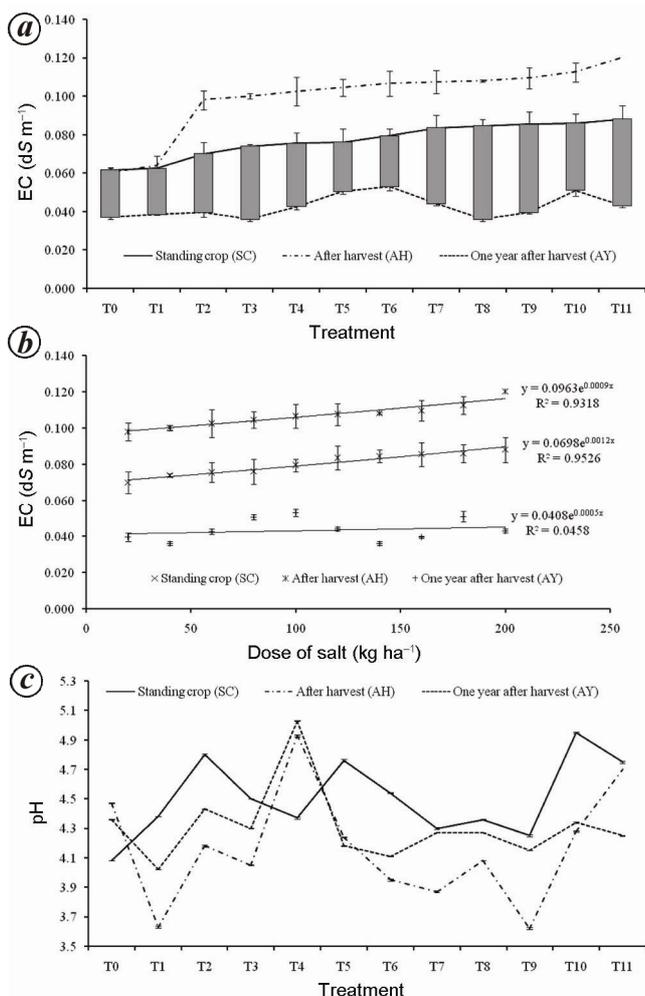


Figure 2. Effect of NaCl application on (a, b) electrical conductivity (EC) and (c) pH of the soil.

The samples applied with no or low concentration of NaCl (up to 40 kg ha⁻¹) had less ESP and SAR compared to higher rate of application (60 kg ha⁻¹) as observed in the AY samples. Although all the regression equations showed a linear type ($Y = mX \pm c$) of relationship between ESR and SAR, the constant m and c were of different magnitude. Analyses of the variance of these three temporal data showed that they represented three different populations. Since the means of ESP and SAR of these three samples were statistically different (Table 4), the regression equations for ESP and SAR in different stages of sampling were also statistically different. Proportionality coefficients (m) for the relationship between ESP and SAR could be compared to the exchange constant of the Gapon equation. Since the proportionality coefficient for the first two equations is almost close

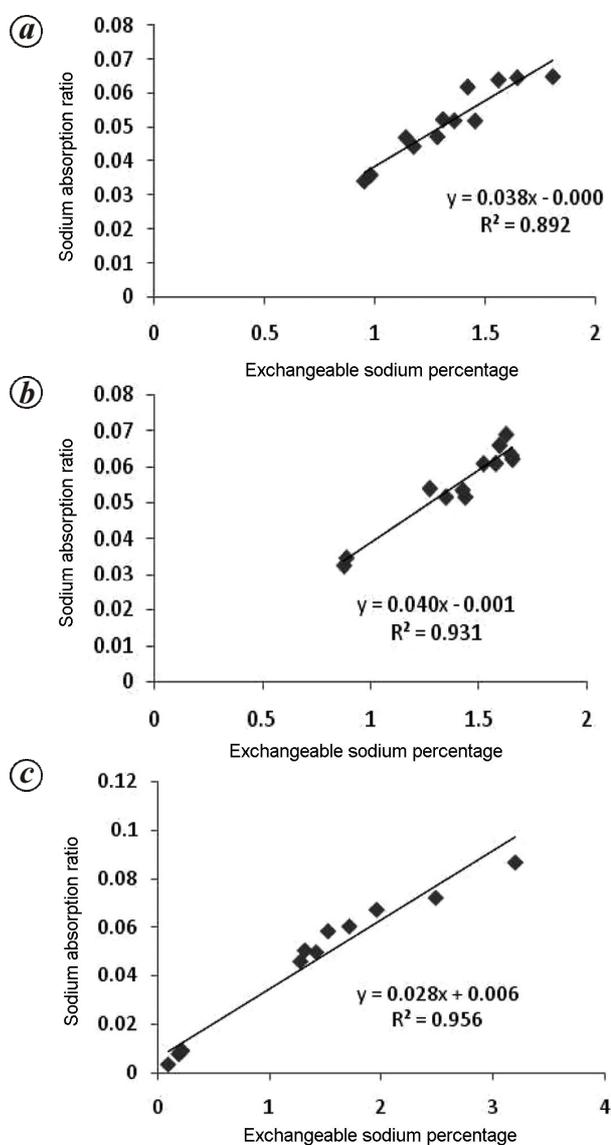


Figure 3. Exchangeable sodium percentage as a function of sodium absorption ratio for soil sample collected in (a) standing crop, (b) after harvest, (c) one year after harvest.

Table 5. Yield and economics of NaCl application in upland rice under shifting cultivation

Treatment	Grain yield (t ha ⁻¹)	Straw yield (t ha ⁻¹)	Gross return (× 10 ³ INR ha ⁻¹)	Net return (× 10 ³ INR ha ⁻¹)	Benefit: cost ratio
Control (<i>T</i> ₀)	1.51	2.02	33.28	17.73	1.14
Weedy check (<i>T</i> ₁)	2.16	3.03	48.02	27.47	1.34
NaCl application (kg/ha)					
20 (<i>T</i> ₂)	1.63	2.31	36.32	19.22	1.12
40 (<i>T</i> ₃)	1.70	2.55	38.25	20.85	1.20
60 (<i>T</i> ₄)	1.80	2.67	40.40	22.70	1.28
80 (<i>T</i> ₅)	1.90	2.68	42.24	24.24	1.35
100 (<i>T</i> ₆)	2.00	2.86	44.57	26.27	1.44
120 (<i>T</i> ₇)	1.98	2.61	43.46	24.86	1.34
140 (<i>T</i> ₈)	1.91	2.20	40.96	22.06	1.17
160 (<i>T</i> ₉)	1.86	2.17	39.93	20.73	1.08
180 (<i>T</i> ₁₀)	1.83	2.10	39.19	19.69	1.01
200 (<i>T</i> ₁₁)	1.80	2.03	38.50	18.70	0.94
SEM	0.05	0.08	1.13	0.63	0.03
LSD (<i>P</i> ≤ 0.05)	0.15	0.22	3.32	1.83	0.10

Price of rice grain = INR 18,000 t⁻¹. Price of straw = INR 3000 t⁻¹.

(0.038 and 0.040), but lesser in AY samples (0.028), a unit increase in SAR would result in an increase in ESR at a lesser rate compared to first two cases. This difference in the proportionality coefficients is due to the build-up of organic matter as induced by leftover crop residues (Table 3). Due to its preferential adsorption of divalent cations, an increase in organic matter would decrease the proportionality coefficient for Na with respect to Ca and Mg. Moreover, the loss of clay of surface soil due to shifting cultivation (average clay content being 48.4% in SC samples and 42.4% in AH samples) resulted in the exposure of coarser soil underneath. The lesser clay content (40.4%) in the AY samples resulted in considerable reduction in Na adsorption.

Effect on yield and economics of upland rice

The weedy check and NaCl-applied treatments realized 42.9 (*T*₁), 7.9 (*T*₂), 12.4 (*T*₃), 19.0 (*T*₄), 25.6 (*T*₅), 32.2 (*T*₆), 30.9 (*T*₇), 26.2 (*T*₈), 22.7 (*T*₉), 20.8 (*T*₁₀) and 19.0% (*T*₁₁) increment in grain yield over control (*T*₀; Table 5). Weedy check (*T*₁), followed by application of 100 kg NaCl ha⁻¹ (*T*₆) produced the highest grain and straw yield over control (*T*₀, Table 5). However, the mean grain yield in 100–160 kg ha⁻¹ NaCl-applied treatments (*T*₆–*T*₉) was statistically at par. The increase in yield could be attributed to the increase in the number of tillers and dry matter along with a decrease in chaffy grains in weed-controlled plots. Actually, broadleaved weed species are highly sensitive to salinity. These species can be controlled by NaCl application²⁷. In Odisha, this practice has shown 60% effectiveness in controlling weeds²⁸. Another reason could be salt tolerance of rice, since it mobilizes its food reserves (polysaccharides) into the growing regions to exert tolerance against salt application. Once

the polysaccharides are mobilized, they are converted into monomers, i.e. sucrose, fructose and glucose that are readily transportable to the sites where they are required for growth. Actually, these soluble monomers could regulate the osmotic pressure of the cells²⁹. Application of NaCl recorded an increase in yield, but the trend followed the law of diminishing returns. The yield increased to its largest value at *T*₆ and thereafter decreased in all other treatments (*T*₇–*T*₁₁). A similar study showed that, application of NaCl up to the rate of 150 kg ha⁻¹ recorded more yield¹⁶. In another experiment³, application of 150 kg ha⁻¹ NaCl recorded better performance of growth characters and yield than 50 and 100 kg ha⁻¹ NaCl. In the present study, application of NaCl @ 100–160 kg ha⁻¹ produced statistically similar grain yield of rice.

Economic analyses were conducted to check the best among the statistically similar treatments in terms of yield. Gross return, net return and (B : C) ratio were also significantly influenced by the increase in unit level of application of NaCl up to 100 kg ha⁻¹ (*T*₆), but decreased thereafter (Table 5). Weedy check (*T*₁) followed by application of 100 kg NaCl ha⁻¹ (*T*₆) recorded the highest gross return (INR 48.02 and 44.57 × 10³ ha⁻¹) and net return (INR 27.47 and 26.27 ha⁻¹), which was 44.3, 33.9% and 54.9, 48.2% higher than no NaCl application (*T*₀), respectively. Application of NaCl @ 100 kg ha⁻¹ (*T*₆) recorded the highest B : C ratio (1.44), which indicated that it is one of the best weed management strategies for making higher profit. The gross and net returns were higher in weedy check (*T*₁). However, this treatment incurred higher cost of cultivation and was associated with poor B : C ratio due to increase in labour cost. A similar study revealed that between the level and time of application, NaCl @ 150 kg ha⁻¹ applied at 30 DAS recorded the largest B : C ratio³.

Table 6. Sodium, potassium, calcium + magnesium, ESP and SAR status after different rates of NaCl application during verification trial

Treatment	Na (meq 100 g ⁻¹)	K (meq 100 g ⁻¹)	Ca + Mg (meq 100 g ⁻¹)	ESP (%)	SAR (cmol kg ⁻¹) ^{0.5}
Control (T_0)	0.055	0.248	6.897	0.761	0.030
Weedy check (T_1)	0.061	0.327	6.012	0.951	0.035
NaCl application (kg/ha)					
20 (T_2)	0.070	0.232	6.698	1.000	0.038
40 (T_3)	0.082	0.259	5.659	1.370	0.049
60 (T_4)	0.082	0.156	5.955	1.327	0.048
80 (T_5)	0.082	0.266	8.252	0.958	0.041
100 (T_6)	0.097	0.208	7.694	1.219	0.050
120 (T_7)	0.106	0.151	8.144	1.256	0.052
140 (T_8)	0.122	0.221	6.250	1.846	0.069
160 (T_9)	0.137	0.168	6.695	1.956	0.075
180 (T_{10})	0.186	0.212	7.602	2.321	0.095
200 (T_{11})	0.187	0.246	8.567	2.080	0.090
SEM	0.003	0.006	0.198	0.002	0.001
LSD ($P \leq 0.05$)	0.009	0.017	0.582	0.005	0.002

Verification trial

Table 6 shows the sodium, potassium, calcium + magnesium, ESP and SAR status after different rates of NaCl application in the samples after harvest during verification trial. Application of NaCl significantly increased Na levels in the soil from 0.070 to 0.187 meq 100 g⁻¹. Na concentration in control (T_0 , 0.055 meq 100 g⁻¹) and weedy check (T_1 , 0.061 meq 100 g⁻¹) was lesser than in the treated plots. Unlike the Na content in treated soils, K content showed no definite trend. The amount of Ca + Mg ranged from 6.659 to 8.567 meq 100 g⁻¹. The ESP was less in control and weedy check than in NaCl-treated samples. Likewise, SAR increased with the application of NaCl. The ESP and SAR increased slightly at 18–20% NaCl compared to the effect in the first year. Hence care must be taken in repeated application of NaCl at higher doses to avoid harmful effects in the long run.

Conclusion

Shifting cultivation is practiced as a combination of 1–2 years of cropping and 8–9 years of fallow period in a 10-year cycle across this region, because the productivity of the crops reduces after one year (as grown without fertilization). From the present study, the following conclusions may be drawn: (i) Application of NaCl does not exert much influence on pH, SOC and available NPK, i.e. on soil fertility parameters, but EC is increased for a short period. (ii) Application of common salt does not show any harmful effect on the yield of rice under acid soil condition of Nagaland. The yield of rice reaches a maximum with the application of 100 kg NaCl ha⁻¹ (10%). Among the treated plots, weedy check has the highest net profitability, but this treatment has practical difficulties because of the steep slope and low

B : C ratio. (iii) Considering the B : C ratio and ease in the method of application, 100 kg NaCl ha⁻¹ may be recommended for controlling weeds in upland rice for this region.

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