Identification of suitable areas for aerobic rice cultivation in the humid tropics of eastern India

D. K. Mandal*, C. Mandal, P. Raja and S. N. Goswami

National Bureau of Soil Survey and Land Use Planning, Amravati Road, Nagpur 440 010, India

In view of the depleting availability of water for agriculture, higher emission of nitrous oxide and methane from low land rice cultivation and their deleterious impact on global warming phenomenon, the present study stressed the need for cultivation of aerobic rice. The study focuses on identifying and mapping suitable sites in eastern India through computation of rice aridity index from soils and climatic data and proposing suitability criteria model and assessing potential yield. This study gains further significance since aerobic rice cultivation could improve the upland production efficiency and helps reduction of greenhouse gases.

Keywords: Aerobic rice, suitability assessment model, upland, rice aridity index.

RICE is the most important staple food fulfilling 43% of the caloric requirement of majority of the Indian population[1]. In India, out of 44 million hectares of rice cultivated area, about 50% is irrigated lowland, 35% rainfed lowland, 3% deep water rice and 12% rainfed upland[2]. The major rice grown areas are distributed in locations from 8°N to 35°N with an elevation up to 3000 m above mean sea level (msl) and is spread over different agro-ecological subregions with subhumid to humid/perhumid climate[3]. These agro-ecosystems constitute the Eastern Plains and Plateaus, sub-Himalayan West Bengal and Indo-Gangetic Plains (IGP), Tripura, Chhattisgarh, Western and Eastern Coastal areas and the Assam Valley. Irrigated low land rice is the most important agricultural ecosystem, but worldwide irrigated agriculture growth projection for 1995–2020 is in deceleration mode at the average annual growth rate of 0.6% as compared to 1.3% in the previous decade. At this snail's pace, India will add only additional 17 million hectares of irrigated area to the present 58 m ha[4]. Besides, the low land rice cultivation (LLRC) is major source of methane (CH_4) and nitrous oxide (N_2O) emissions contributing 48% and 52% respectively of total greenhouse gases emitted by agricultural sources[5]. These N_2O and CH_4 gases trap 310 and 20 times respectively more heat than CO_2. The Intergovernmental Panel on Climate Change (IPCC) has indicated an average rise of 3°C in temperature[6] causing severe shortage of water that exerts pressure on crop yield[4]. IPCC has also found proportionate increase of N_2O with the application of nitrogenous fertilizer[6]. This paradoxical food production scenario can be partly mitigated by bringing more and more upland areas under cultivation of aerobic rice in India in the near future.

The decline in yield of rice is reported mostly due to the decline in soil organic carbon (SOC) content, micronutrients status of soil, accumulation of phenolic compounds, viz. S, Fe^{2+} and S^{2-} and salinity in rice–rice system[7]. Traditional rice grown by the puddling system destroys soil aggregates and increases the fine pores causing reduction in the post-rainy crop yield of wheat and pulses. LLRC also reduces the fertilizer use efficiency due to high volatilization of nitrogenous fertilizer in the form of N_2O and CH_4 in the near anaerobic condition. Besides, it also consumes 1500–3000 litres of water to produce 1 kg of rice grain and more than 45% of the water is lost by deep percolation thereby increasing the factor productivity of rice. In view of resource depletion by the LLRC, nowadays, the following rice production systems are gaining importance. First the system of rice intensification (SRI-saturated/alternate wetting and drying method) addresses the ideal soil and agro-management condition that could improve the yield to the tune of 20–30% and second, aerobic rice[3] cultivation in upland under –20 to –40 kPa of tension that saves 20–35% of the water with good yield[5].

The rainfed upland constitutes 7.1 m ha area, of which more than 85% of eastern upland area is located in the states of Assam, Bihar, West Bengal, Orissa, Andhra Pradesh, Chhattisgarh and Uttar Pradesh[3]. The mean annual rainfall (MAR) and growing season temperature vary from 1000 to 2000 mm and 25°C to 35°C respectively. Ferruginous, non-calcareous soils occur in subhumid ecosystem and calcareous soils with dominant kaolinitic mineralogy occur in the eastern plateau. The texture varies from sandy to sandy clay loam with poor water retention capacity and poor yield (0.65 t/ha) due to poor land quality[8] and often suffers from moisture stress at varying stages of growing period[9,10].

Attempts have been made to classify the rice growing environment of south east Asia, China, Srilanka and India[11]. All these studies are either based on total rainfall or number of wet month index (WMI) or rice aridity index (RAI). The water-use efficiency, nitrogen management, biotic and abiotic stress and their implications on yield have been studied by many researchers[12–16]. The present study encompasses exploring and mapping of suitable sites for aerobic rice cultivation using RAIs in uplands of eastern India, proposing suitability criteria and assessing their yield potential through modelling.

The database consists of rainfall and evapotranspiration from 240 locations of rice growing uplands in India (Figure 1). The soil polygon database on 1 : 250,000 scale is used as a base map. The soil family association map is

*For correspondence. (e-mail: dkmandal@nbsslup.ernet.in)

associated with 2 or 3 individual soil series. The different properties of soil series such as depth and texture have been generalized to regenerate a homogeneous polygon in geographical information system (GIS) environment (Geomatica – version 10.1). The slope map is generated from a National Atlas and Thematic Mapping Organization (NATMO) physical plate. The vector polygon with an average soil properties are further grided to 1 × 1 km and generated 1° contour interval map. The final rice agro-climatic class map is generated by superimposing the data of RAI from 240 sites on the contour map along with soil depth and slope as schematically depicted in Figure 2. The point data of 240 locations of dominant rice growing upland areas of India is shown in Figure 1.

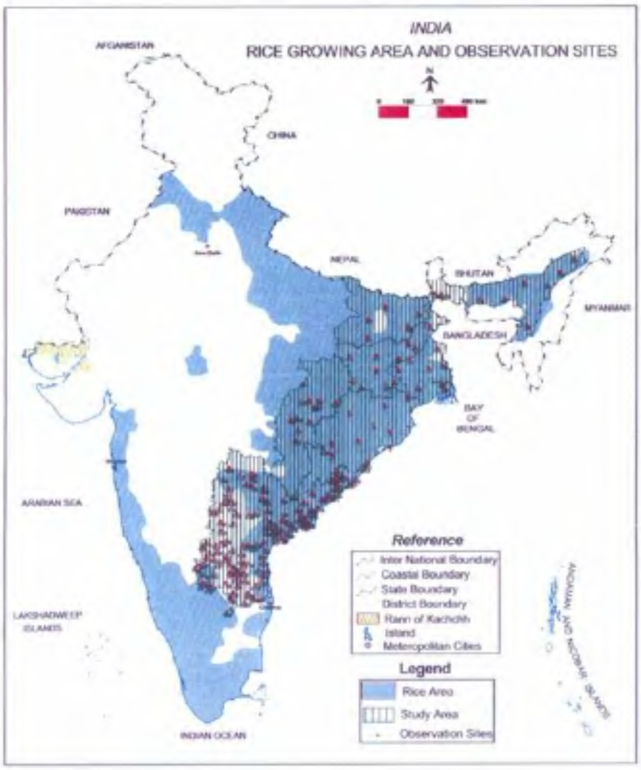

Figure 1. Rice growing and observation sites.

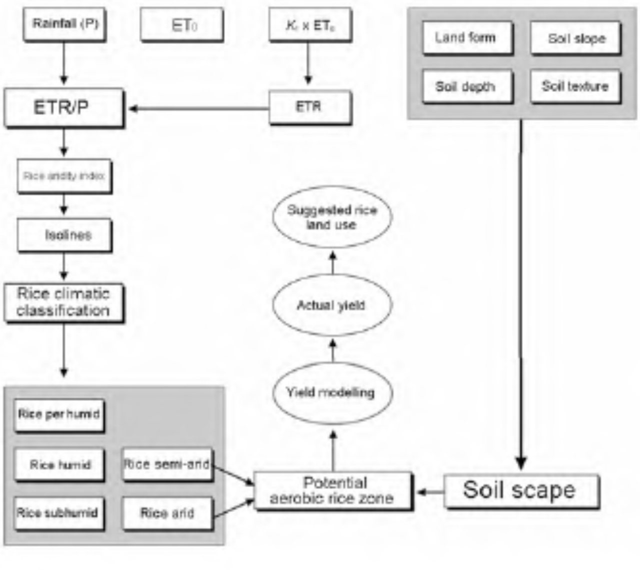

Figure 2. Aerobic rice suitability assessment model. ET_0, Reference crop evapotranspiration; K_c, Crop coefficient; ETR, rice water requirement; P, Precipitation.

The monthly rainfall and potential evaporation (Penman) data of 240 locations (Tehsilwise rain gauze) are used for RAI. This is defined as RAI = ETR/P, where ETR is the total evapotranspiration during the rice growing season and expressed as $Kc \times ET_0$, where Kc is crop coefficient and ET_0 is reference crop evapotranspiration and P the monthly precipitation. Conceptually, the RAI value of less than 0.25 indicates less than 25% of water during the rice growing season, which will be utilized for rice evapotranspiration. The index is classified and presented in Table 1.

The soil map of India[17] is used as primary data source. The point data is converted into isoline map in GIS environment using Geomatica (version 10.1) and RAI is computed and plotted. Finally, after trimming the data, the RAI map is superimposed on soil scape map to curve out the near homogeneous rice agroclimatic zones.

The yield of rice is computed from the climatological data using Natchergaele and De wit model[18]:

$$Y_m = H_i \times K\{0.36/(F \times b_o + 1 - F)b_c\}/(1/N + 0.25\ C_t),$$

where Y_m is the maximum yield, H_i the harvest index, K the correction factor related to biomass production, F the fraction of duration of day where sky is overcast (derived from radiation of sunshine or cloudiness data), b_o the maximum gross biomass production when the sky is completely overcast which is a function of latitude and time in a year, b_c the maximum gross biomass production when sky is clear, N the crop maturity days (length of growing period), C_t the correction factor for temperature and is a function of growing period and type of crop grown. Thematic maps, viz. isolines of RAI map, RAI zones map were generated in GIS environment using Geomatica, version 10.1.

In the study area, about 26.2% is covered by nearly level (<2% slope) land followed by 14% area of gently sloping (2–8%), 34.25% of moderately sloping (8–15%) and 3.9% area of steeply sloping (30–50%) land. Generally very deep to deep soils are predominant and are in

Table 1. Rice aridity index class with symbol

Rice aridity index	Rice climatic class	Symbol
<0.25	Rice perhumid	AR
>0.25 – <0.50	Rice humid	BR
0.50 – <0.60	Rice subhumid	CR
0.60 – <0.75	Rice semi-arid	DR
>0.75	Rice arid	ER

association with moderately shallow Alfisols, Inceptisols and Entisols. Rice RAI of selected observation sites is depicted in Figure 3 and the classification criteria table is presented in Table 1. Majority of the area (75%) falls under rice subhumid to rice humid climate (in terms on RAI) and mainly covers Brahmaputra Valley, Plains of Orissa, IGP of West Bengal and Bihar, parts of Chhattisgarh Plains and coastal plains of Andhra Pradesh, whereas rice arid covers 23.8% and rice semi-arid covers 21.5% of the total area.

Rice arid zones with RAI value of more than 0.75 mainly occupies coastal plains of Andhra Pradesh, upland areas of Orissa and part of IGP covering Bihar and West Bengal and Assam occupying 1.6 million hectare area (Figures 3 and 4). These areas have moderately to steeply sloping (8–15%) topography with moderately deep to deep and very deep soils. The zone receives 450–1200 mm of monsoonal rainfall (June–November) and rice evapotranspiration (ETR) during rice growing period varies from 750 to 990 mm. RAI varies from 0.75 to 2.50 and WMI (the months with ≥ 200 mm rainfall) from 1 to 3 months. The value of RAI suggests that these areas are not suitable for LLRC as more than 75% of the rainfall is required for the maintenance of rice evapotranspiration leaving less than 25% of water available for percolation and runoff requirements. However, these areas are potentially suitable for upland rice cultivation.

Rice semi-arid zone occupies the IGP covering parts of Bihar, West Bengal and Chhattisgarh Plains, hill areas of Orissa, central, northern fringes and parts of coastal areas of Andhra Pradesh covering 1.4 million hectare area representing subhumid to humid climate. RAI ranges between 0.61 and 0.75 and WMI varies from 3 to 4 months. The landform is characterized by nearly level to gentle and moderately sloping (< 2–8%) areas. The soils are mainly deep to very deep (100–150 cm) and at places moderately deep (75–100 cm). RAI values suggest that these areas are marginally suitable for LLRC as 60–70% of rainfall is used for the rice ETR. These areas are highly suitable for growing upland rice, however, pockets of low lying areas can be put under LLRC.

Rice subhumid zone occupies mainly IGP and uplands of West Bengal, Jharkhand, coastal areas of Orissa and upper reaches of Assam Valley and parts of Chhattisgarh Plains and Andhra Pradesh covering 3.8 million hectare area. The rainfall varies from 1150 to 1800 mm. RAI ranges between 0.51 and 0.61 and WMI ranges from 4 to 5 months. The slope of the land varies from gentle to nearly level (< 2–8%) and at places moderately to steeply sloping (8–30%). The depth of soil varies from deep to very deep (100 to > 150 cm) and at pockets moderately shallow to moderately deep (50–100 cm). RAI value shows that these areas are climatically suitable for cultivating upland rice (with higher water requirement) as

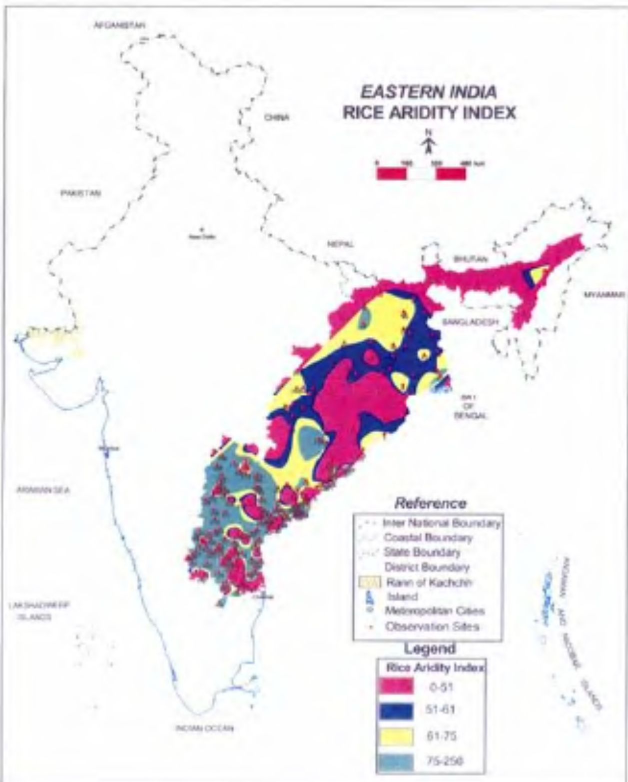

Figure 3. Rice aridity index map.

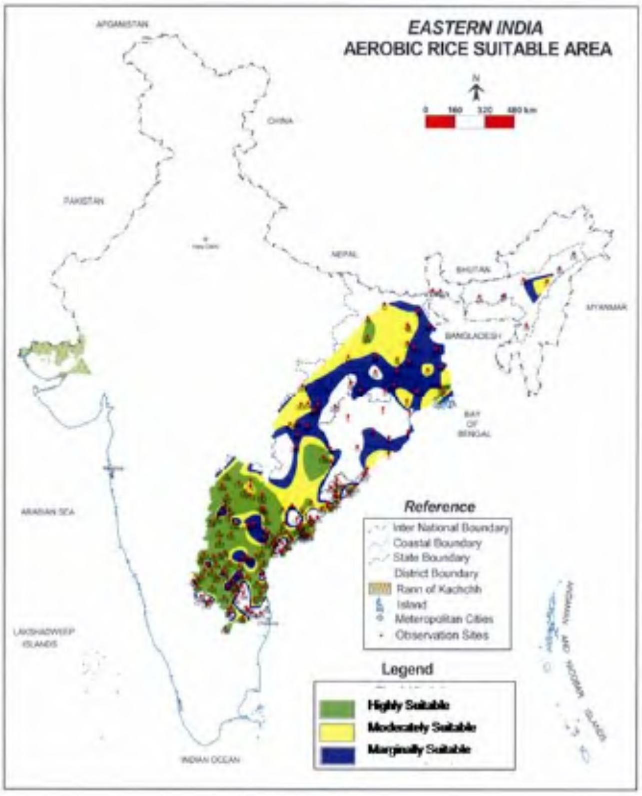

Figure 4. Aerobic rice suitable area map.

Table 2. Potential computed yield of aerobic rice

Place	Rice growing period (days)	R_s	Y_c	Y_0	R_{se}	$F = R_{se} - 0.5R_s/0.05R_{se}$	Mean temperature	Y_m (t/ha)	Present rice yield t/ha
Ranchi	110	663.9	420.7	222.4	347.8	0.057	23.7	4.76	1.01
Baripada	110	664.6	421.9	222.9	349.2	0.062	27.5	4.85	0.9
Sambalpur	110	664.9	422.8	223.7	350.9	0.066	27.7	4.84	1.27
Medinipur	110	661.4	421.9	223.1	349.4	0.067	27.9	4.03	2.07
Hazaribagh	110	652.1	420.7	220.0	347.0	0.0754	25.1	4.71	0.73
Raipur	110	646.1	422.9	223.9	351.2	0.068	26.2	4.70	0.98
Vishakapatnam	110	685.2	418.2	227.2	354.4	0.041	27.9	5.83	1.99

R_s, Solar radiation received on the earth surface (cal./cm^2/day); $Y_c = b_c$, Maximum gross biomass production in a clear day (kg/ha/day); $Y_o = b_o$, Gross biomass production in a overcast day (kg/ha/day); R_{se}, Active incoming shortwave radiation(cal./cm^2/day); Y_m, Maximum yield.

Table 3. Suitability criteria for aerobic rice (proposed)

Soil site characteristics		Rating			
		Highly suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	Not suitable (N)
Climatic regime	Mean temperature in growing season (°C)	30–34	35–38 21–29	39–40 15–20	> 40 < 15
	Total rainfall (mm)	800–900	900–1100	700–800	<700
Land quality	Land characteristics				
Oxygen availability to roots	Soil drainage (class)	Imperfectly drained	Moderately well drained	Well drained, somewhat excessively drained	Excessively drained
	Free from flooding (duration) (months)	< 1	1–2	2–3	> 3
	Depth of water (cm)	< 3	3–5	> 5–10	> 10
Nutrient availability	Texture* (class)	C, sic, cl, sicl, sc	Scl, sil, l	Sl, ls	S
	pH (1 : 2.5)	5.5–6.5	6.6–7.5 4.5–5.4	7.6–8.5	> 8.5 < 4.5
	$CaCO_3$ root zone (%)	< 15	15 to 20	21 to 30	> 30
Rooting conditions	Effective soil depth (cm)	> 40	40 to 30	20 to 30	< 20
Soil toxicity	Salinity (EC saturation extract) (dS/m)	< 3	3 to 6, 6 to 8	8–10	> 10
	Sodicity (ESP) (%)	< 15	15 to 40	40 to 50	> 50
Erosion hazard	Slope (%)	0 to 1	1–3	3–5	> 5

s, Sand; ls, Loamy sand; sl, Sandy loam; scl, Sandy clay loam; cl, Clay loam; sil, Silt loam; l, Loam; sic, Silty clay; sc, Sandy clay; c, Clay.

50–60% of the water alone is used for evapotranspiration and other 40–50% is available for percolation and runoff. These areas could be classified as moderately suitable for aerobic rice (Figures 3 and 4).

The rice production potential of the upland agro-environment has been estimated through modelling (Table 2). The data indicate that rice production potential varies from 4 to 6 tonnes which needs to be exploited through screening of appropriate aerobic rice genotypes.

The land evaluation criteria developed by FAO[19] for rainfed rice highlight the yield influencing soil site characteristics for rice production. The major soil characteristics are topography, wetness, soil texture, soil depth, soil acidity (pH), base saturation and SOC. A rainfall of more than 800 mm is suitable for rice cultivation, optimum temperature of > 12°C for seed germination and 24–36°C for optimum growth is required. Clay to sandy loam, imperfectly to moderately well drained, soil pH ranging from 4.5 to 8.2, salinity < 3 dS/m, and sodicity with a exchangeable sodium percentage (ESP) of less than 20 are required to sustain good yield. Based on analyses of agro-environment characteristics of the studied upland areas of eastern India land evaluation criteria for rainfed upland rice has been worked out and given in Table 3.

The present study has identified and mapped suitable sites for aerobic rice cultivation in eastern India. Suitability criteria model is proposed and the rice agro-environment has been further classified through computation of RAI from climatic data to harness the upland potential of India which is otherwise low productive. However, further research is needed to identify suitable aerobic rice varieties for different rice ecosystems.

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Lichenometric studies in vicinity of Pindari Glacier in the Bageshwar district of Uttarakhand, India

Santosh Joshi and D. K. Upreti*

Lichenology Laboratory, National Botanical Research Institute (CSIR), Rana Pratap Marg, Lucknow 226 001, India

The present study relates the size of the lichen thallus to the minimum age of the exposure of the surface on which it grows which consequently helps in assessment of the minimum age of the glacier retreat. The study deals with the crustose lichen *Rhizocarpon geographicum* having radial growth with a slow growth rate of 0.2 mm/year, and growing frequently in the vicinity of the Pindari Glacier. The calibrated approximate age of the surface exposed at a distance of 1 km from the glacier snout ranges from 550 to 600 years. The method is cheap, easy and applicable to date surface more than 500 years.

Keywords: Dating, lichenometry, Pindari Glacier, *Rhizocarpon geographicum*, Uttarakhand.

LICHENOMETRIC technique is useful in dating moraine ridges on recent glacier forelands in alpine regions. The method was originally developed and used by Beschel[1,2]. Glaciers are recognized as being among the most sensitive indicators of climate change, advancing substantially during climate cooling and retreating during climate warming. Lichens due to their slow growth rate and uniform growth size, help in dating the exposure time of the sequences of the rock forming glacier moraines due to retreat of the glacier thus providing the approximate time of glacier retreat. The study is based on lichen size/age correlation and lichen population distribution and involves the measurement of large specimens growing on large

*For correspondence. (e-mail: upretidk@rediffmail.com)