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Biophysical attributes influencing yield of summer rice in Brahmaputra valley

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ABSTRACT: The effects of biophysical attributes on summer rice yield in the Brahmaputra valley are presented by constructing a potential productivity index (PPI). PPI is the interaction of the parameters related to soil productivity and weather variability where summer rice crop is grown. Analyzing statistically the weather data of three meteorological stations representing different crop ecological scenarios and the data pertaining to summer rice yield for a duration of 29 years (1975 to 2003), it was found that summer rice yield increased fast achieving high average with less fluctuation (i.e., 1549.86 ± 403.24 kg ha^{-1}) in the Dibrugarh area of upper Brahmaputra valley during the 1990s because of cool and dry nights at the ripening period. Average potential yield of summer rice was observed highest with moderate temporal fluctuations (4764.46 ± 885.00 $kgha^{-1}$) in the Guwahati area of the central Brahmaputra valley because of ideal night temperatures and dry condition at the ripening stage. It is established that night temperature and precipitation variability are two main factors, which influence the potential as well as actual yield of summer rice in the valley.

Key words: Growth index ; Potential productivity index; Soil productivity index; Weather variability.

Temporal fluctuation of summer rice production is highly influenced by the intensity and amount of rainfall (Parthasarathy *et al.* 1992; O'Hare 1997) and wet organic soils (Masahiro 2003). Sometimes the excessive wet condition aggravates the situation further by reducing the cultivated area and yield of the summer rice (Asada *et al.* 2005). A crop growth factorology based on biophysical environment of a crop land was put forward by Subrahmanayam (1983) and Grosjean and Misserli (1988). They evaluated potential productivity of land for the provision of common biophysical base for the growth of different crops. The growing crops adjust their phenological stages and crop-duration according to available biophysical environment and consequently alter their yields. Thus, land environment has common and

interactive effects of biophysical factors on crop-growth (Singh 2003; Sharma and Kaul 2005). However, the biophysical attributes of crop-growth were used either to assess and evaluate the potential productivity of land for land use management (Grosjean and Misserli 1988) or to visualize the effects and limitation of such attributes of land in various phenological stages and physiological functioning of plant growth for crop management simulations. Most recently as reported by Chatelin *et al.* (2005), the crop growth equations were used to develop 'potential yield module' for obtaining simulated level of crop-yield using biophysical factors (water, nutrients, and crop-protection). Keeping biophysical aspects of environment in view, the present study was attempted to construct a potential productivity index (PPI) for prediction of potential yield of summer rice and to isolate the effects of biophysical attributes occurring on summer rice yield in the humid monsoon conditions prevailing in the Brahmaputra valley.

MATERIALS AND METHODS

The Study Area

The study area is situated in the North-Eastern part of India (89°42' to 95°16' E longitudes and 25°30' to 28°09' N latitudes) and receives high amount of precipitation (Das 2003; Syiemlieh and Das 2004). The humid condition (1,700 to 2,250 mm annual precipitation) and moderate temperature (20 to 29°C) of the study area provide ideal weather conditions to summer rice crop growth. Alluvial soils of gentle topography contain sufficient available N (174 to 425 $kgha^{-1}$), P (60-80 $kgha^{-1}$) and K (450 - 600 kg ha^{-1}) with slightly acidic in reaction are dominant in the valley (Deka 1996). CEC varies from 11 to 23 cmol (p^+) kg $^{-1}$ in upland alluvial soils attributing positively to the organic carbon contents (Talukdar *et al.* 2004). Moist organic soils of the valley provide a sound base for the luxuriant growth of rice during summer monsoon (May-November) when more than 70 % of the total annual rainfall precipitates with occasional floods. There is hardly any use of modern technology in the summer rice cultivation in the valley. Therefore, yield of summer rice crop is highly sensitive to such biophysical factors (Chamuah *et al.* 1996; Singh *et al.* 2006).

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Three meteorological stations representing different soil productivity zones and regional variability in weather conditions, namely, medium range of precipitation of the flood plains (Dhubri), lower range of precipitation of the central built-up plains (Guwahati) and medium precipitation of the upper built-up plain (Dibrugarh)) were selected. Monthly means of temperature and monthly totals of precipitation of summer crop-season (May - November) for 29 years (1975-2003) which were collected from Regional Office, Indian Meteorological Department, Guwahati, were used for analysis of weather variability. The summer rice yield statistics were collected from the Directorate of Economics and Statistics, Government of Assam, Guwahati.

Construction of Potential Productivity Index (PPI)

In order to simulate the effects of soil and weather conditions on yield of a particular crop, the parameters related to available soil nutrients and soil limitations for crop growth and the weather conditions pertaining to evapotranspiration (ET), potential evapotranspiration (PET), soil moisture storage (ST), thermal efficiency (TE) and photosynthetic efficiency (FE) were considered (Singh 2005). The effects of biophysical parameters on the yield of summer rice were considered to construct the PPI with the assumption that the grain yield of summer rice is an interaction of soil productivity and the following four major attributes of weather conditions.

Soil Productivity Index (SPI)

The soil suitability weights were assigned to 13 soil attributes as per their importance and contribution to soil potential for crop-growth suitability. The ideal weights for such soil attributes for optimal growth of summer rice crop have been assigned on the basis of observations in the field. The most suitable condition of each soil attributes for the summer rice yield prevalent at different soil scenarios are almost same for Dhubri, Guwahati and Dibrugarh areas in the valley (Table 1). The composite score of soil (ΣSC) and ideal composite scores (ΣSC*) for each station were calculated and finally the SPI was prepared for each simulated site in the following manner as:

$$SPI_i = (S\,SC_j / (S\,SC_j^*) \qquad \text{...........(1)}$$

j= 1,2,3,…,13 (soil attributes) and i= 1,2,3 (Meteorological stations or simulated sites)

Table 1. *Soil productivity index based on assigned weights of soil attributes*

Soil attributes	Dhubri	Guwahati	Dibrugarh	Ideal weight for summer rice growth
Surface form	0.56	0.50	0.80	0.95
Parent material	1.13	1.20	1.20	1.20
Soil depth class	1.50	1.50	1.50	1.50
Soil temperature class	1.15	1.15	1.15	1.15
pH value	1.04	1.15	0.80	0.95
Ground water depth	0.93	1.00	0.80	1.00
Surface stoniness	1.11	1.11	1.10	1.00
Slope class	1.09	1.20	0.95	1.10
Erosion class	0.92	1.48	1.00	1.10
Flooding	1.10	1.10	1.10	0.90
Particle size class	1.10	1.10	1.10	1.10
Soil fertility	1.20	0.80	0.80	1.00
Water holding capacity	1.40	1.00	1.40	1.00
Total weights	14.23	14.29	13.70	13.95
Total ideal weight for optimal rice growth (ΣSCj)	13.95	13.95	13.95	13.95
SPI = (ΣSCj/ ΣSCj*)	1.020	1.024	0.982	1.00

N.B:The classification of soil attributes follows the criteria given by the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Nagpur.
Source: Singh (2005, Tables 2 through 6).

Crop-growth Index (GI)

Crop-growth implies the direct proportion of the ratio of ET/PET (Johns and Smith 1975; McCall and Bishop-Hurley 2003; Kang *et al*. 2002 and 2003). It reflects the influence of temperature, soil moisture and evaporative demands and also a representative of the rate of transpiration and degree of biomass assimilation for crop-growth. An optimal ratio of ET/PET at the sowing time, i.e. (ET/PET)*, was calculated to make Crop-growth Index as follows:

$$GI = {}^{1}/{}_{m}\, S\{(ET/PET)/(ET/PET)^*\} \qquad \text{...........(2)}$$

Where, m is the number of time units (months in present case) in the crop season of summer rice at simulated site. Variation of GI may be attributed to ET/PET relationship especially during dry season of crop growth. The index is valid for the flooded as well as upland conditions of paddy growth. The evapotranspiration may reach upto the level of potential evapotranspiration for few months during the rice season in low lying areas of the Brahmaputra valley as ET = PET, which implies that GI = 1.00. However, the sowing and harvesting periods of the summer rice cultivation are relatively drier. So GI varies slightly during the summer rice crop-season for the areas of low land condition (Table 2).

Table 2. *Calculation of growth index (GI) of Dhubri for the year 2003*

Months	PET (mm)	ET (mm)	ET/PET	ET/PET*	GI
January	25	20	0.80	-	-
Feburary	34	31	0.91	-	-
March	40	33	0.77	-	-
April	42	39	0.93	-	-
May	43	40	0.93	0.90	1.033
June	44	44	1.00	0.90	1.111
July	46	46	1.00	0.90	1.111
August	44	44	1.00	0.90	1.111
September	40	37	0.91	0.90	1.022
October	39	29	0.74	0.90	0.822
November	35	25	0.71	0.90	0.788
December	35	20	0.57	-	-
Growth Index (GI)	-	-	-	-	0.998

N.B.: PET and ET are calculated using Thornthwaite and Mather's (1957) Conversion tables. Likewise the values of GI for other stations were also calculated.

Water Availability Index (WAI)

It is largely dependent on the proportion of soil moisture storage (ST) at specific field capacity (FC) as W= (ST/FC) and its minimum requirement for the optimal growth of a particular crop (W*), which varies temporally within the crop-season (Prashar and Hagan 1970; Doorenbos and Pruitt 1977; Thakur and Spehia 2006). For instance, summer rice needs W= (0.90 ± 0.05) during vegetative growth and W= (0.70 ± 0.10) during ripening stage (Singh, 2003). Thus, the index is given below:

$$WAI = 1/m\ S(W/W^*) \qquad ....(3)$$

W and W* both vary over time during the crop-season (Fig 1).

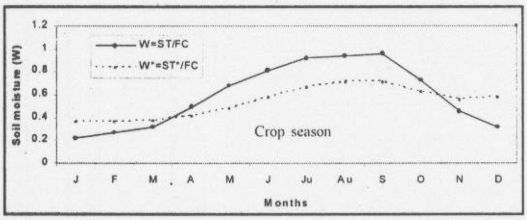

Fig. 1. *Monthly variation in water availability for summer rice in Brahmaputra valley*

Photosynthetic Efficiency Index (FEI)

The measurements based on day length and insolation (photo period) are considered for computation of FEI. When the duration of photosynthetic efficiency during vegetative growth (tc-tf) (that includes the duration of initiation growth phase at the time of inflorescence emergence) is shorter, the degree of efficiency of radiation used in the process of photosynthesis to reproduction is higher and *vice-versa* (McCall and Bishop-Hurley 2003). A ratio of total crop-season duration, D, with the duration of vegetative growth period (tc-tf) is a representative of the use of photosynthetic efficiency by plants. FEI, is also dependent on the ideal time duration of vegetative growth period, i.e., (tc-tf*), while (tc-tf) varies in different soil and weather conditions (Singh *et al.* 2006). Thus, photosynthetic efficiency index is written as:

$$FEI_i = [\{D/(tc-tf)\}/\{D/(tc-tf^*)\}]$$

and simplifying it, we get

$$FEI_i = [(tc-tf^*)/(tc-tf)] \qquad ....(4)$$

Where, tc is constant pertaining to sowing time duration, i.e. 15 days from the sowing time and tf* indicates an ideal flowering/earing time. The value of tf* is considered as 100 days for the ideal flowering of summer rice in the Brahmaputra valley (Singh *et al.* 2006).

Thermal Efficiency Index (TEI)

It is indication of a prevalent temperature for accelerating different processes of plant-growth. It is used in the form of degree - days to define phenological development or duration of growth stages (Singh 2003). In the present case, the index is constructed to convert temperature into monthly heat index, H_j using Thornthwaite's heat conversion equation as $H_j = (T^0C/5)^{1.514}$ and considering values at its three levels, namely, (i) minimum required heat index at which rice germinates when crop-growth starts and crop-growth simulation takes place, H_{jbase} as constant, (ii) monthly required (optimal) level of heat index during vegetative and reproductive growth phases, H_j^*, and (iii) heat index for monthly atmospheric temperature, H_j. The TEI for i[th] site of crop-growth simulation are given below:

$$TEI_i = 1/m\ \Sigma\,[(H_j - H_{jbase})/(H_j^* - H_{jbase})] \qquad ....(5)$$

Where, m is the number of time units during crop season (months for rice season), H_{jbase} is constant (i.e. $H_{jbase} = 2.856$) and H_j and H_j^* are variables (Fig. 2) (Singh *et al.* 2006).

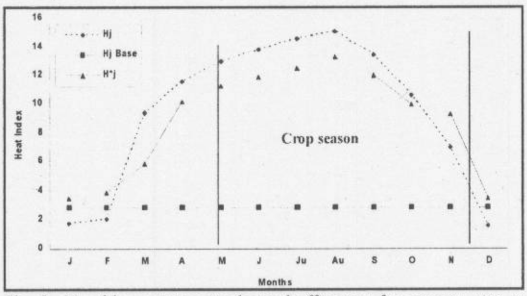

Fig. 2. *Monthly variation in thermal efficiency for summer rice in Brahmaputra valley*

Finally the assessment of potential yield of summer rice in unit term of kgha^{-1} is made by using an interactive function of the given determinants of crop-growth as explained above considering summer rice crop-season (May -November). Thus, ecological based land potential productivity index for a summer paddy (PPI) with a constant m may be written as:

$$A = m \times PPI \qquad \text{..........(6)}$$

Where, m is genetic crop-grain yield (kgha^{-1}), a constant based on cultivars and crop management (Mall and Singh, 2000). PPI is interactive function of five determinants of biophysical attributes and defined as

$$PPI = SPI \times GI \times WAI \times FEI \times TEI \qquad \text{..........(7)}$$

Monthly ET/PET and ST parameters are calculated by using Thornthwaite and Mather's (1957) conversion tables which are based on standard water balance equation (as $P = ET + \Delta ST + RO$, where ΔST = change in soil moisture and RO = runoff). The values of water holding capacity, FC as given by Regional Centre, NBSS & LUP, Jorhat were used for the calculation of monthly ST for different sites (FC= 250 mm m^{-1} for Dhubri, 200 mm m^{-1} for Guwahati and 250 mm m^{-1} for Dibrugarh stations).

RESULTS AND DISCUSSION

A genetic yield coefficient, m, value 3650 kgha^{-1} as given by ICAR, New Delhi for all three soil productivity scenarios (Prasad *et al.* 1987) is assigned to potential yield equation (6) in order to prove the variability of PPI and crop-yield. The actual yield records show sub-optimal use of biophysical parameters and lack of cultivars and land management practices. As a result, the summer rice yield in the valley is recorded marginally low from 1000 kgha^{-1} to 2200 kgha^{-1}.

In fact, there was a record progress in actual rice yield ranging from 970 to 1930 kgha^{-1}, 1030 to 2225 kgha^{-1} and 1290 to 2100 kgha^{-1} in the flood plains of Dhubri area of the lower Brahmaputra valley, Gauhati built-up area of central plains and the built-up area of Dibrugarh plains during the study period, respectively. As a result, rate of yield realization (i.e. percentage share of actual yield to potential yield) increased fairly high in the flood plains (16.3 to 44.6 %) and moderately high (3.0 to 5.0 %) especially in the Dibrugarh built-up plains during 2000-2003. The progress in rice yield and the increase in its realization rate may be either due to improvement in genetic yield coefficient over time (which was used as constant here) or because of changes in biophysical environment of the land on which the potential yield of summer rice is largely dependent.

Potential yield and weather variability have of course a close relationship. Potential yield progresses as the range of seasonal mean of minimum temperature rises while seasonal mean of maximum temperature is almost constant (about 29°C to 30°C) throughout the crop growth time. The trends of seasonal minimum temperature reveal that the fall in night temperature particularly during the vegetative growth period checks respiration and limits the biomass production of rice crop (Papadakis 1975). Such observations are found from the Dhubri flood areas where seasonal minimum night temperatures were recorded falling up to 14°C and, consequently, potential yield reduced to 3200 kgha^{-1} during the late 1990s (Fig 3).

Weather variability at the time of reproductive

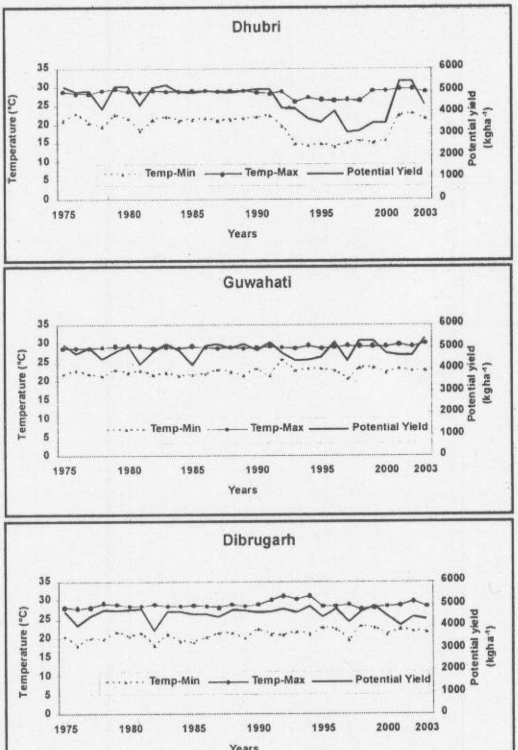

Fig. 3. *Weather variability and trend of potential yield at different sites*

phenological (especially ripening) stage is equally important which contributes more towards crop yield (Gorski *et al.* 1994; Kozyra 2004). Summer rice crop in the tropical and monsoon countries belongs in fact to the thermophytes whose development of grain size in the month of late October and November is fairly good at lower temperatures (with its less temporal fluctuation) and dry environment. Probability of ripening and drying of the rice plants in the late October till early and mid November is quite high in the entire Brahmaputra valley because normal air temperature is recorded about 20°C during the ripening time. In early to mid November, the relative humidity (RH) becomes 70-85 % with temperature of 20°C - 24°C which are considered as moderately higher than the ideal weather for grain size setting and its hardness. As a result, harvest of the summer rice plants is usually kept for drying for about a week because of the absorption of direct solar radiation.

Instead of mean temperature of the day, the drop in night temperature during the month of November influences the formation of grain size of the summer rice. It appeared that in Dibrugarh area, the summer rice yield increased and achieved an average of 1549.8 kgha^{-1} revealing the low degree of fluctuation (± 403 kgha^{-1}) during the 1990s and early 2000s because of cooler nights (13.2 ± 2.5°C) coupled with dry conditions (RH 70.2 ± 2.2%) (Table 4). Contrary to it, Dhubri area of the flood plain produced lower rice yield with its significantly high fluctuations (1243.04 ± 548.44 kgha^{-1}) because of warmer nights and high RH at night time.

Average potential yield of summer rice was recorded very high with its moderate temporal fluctuations (4764.46 ± 885.00 kgha^{-1}) in the Guwahati area of the central alluvial plains, where low precipitation conditions prevail in the old alluvial soils. The night temperatures at Guwahati station noticed ideal with its low fluctuations (16.3 ± 1.2°C), low RH in the day time (75.5 ± 3.7%) and less precipitation (4.3 mm) during the ripening time (i.e., November). In such optimal weather conditions, potential yield of summer rice progressed satisfactorily with the moderate fluctuations (Table 4).

Analysis of the trends of precipitation totals and potential yield for the entire period concluded that potential yield fluctuations were observed much smooth than the fluctuations of seasonal precipitation totals. The smooth trend of the potential yield was observed in the built up plains of the upper as well as central Brahmaputra valley, where high water retention capacity of soils exists (Fig. 4)

Table 4. *Weather variability (Mean ± SD) at ripening time of the summer rice crop (November) at different stations*

Weather Variability		Dhubri	Guwahati	Dibrugarh
1.	Daily mean temperature (°C)			
	Maximum	26.1 ± 1.3	27.4 ± 1.8	27.9 ± 2.1
	Minimum	18.2 ± 1.5	16.3 ± 1.2	13.2 ± 2.5
	Mean	22.1 ± 3.5	22.4 ± 2.2	23.3 ± 1.7
2.	Precipitation (mm)			
	Total	5.5 ± 8.3	4.3 ± 5.7	12.8 ± 8.9
3.	Relative humidity (%)			
	Morning (8:30 hrs)	85.5 ± 3.7	84.6 ± 3.4	70.2 ± 2.2
	Evening (17:30 hrs)	76.3 ± 3.9	75.5 ± 3.7	78.1 ± 1.3
	Daily differences	9.2 ± 4.8	6.1 ± 4.7	9.9 ± 5.2
4.	Actual yield (kgha^{-1})	1243.22 ± 548.44	1434.22 ± 632.45	1549.86 ± 403.24
5.	Potential yield (kgha^{-1})	4341.53 ± 1167.40	4764.46 ± 885.00	4216.07 ± 481.41

N.B: Figures are based on 13 years weather statistics (1991-2003).

CONCLUSION

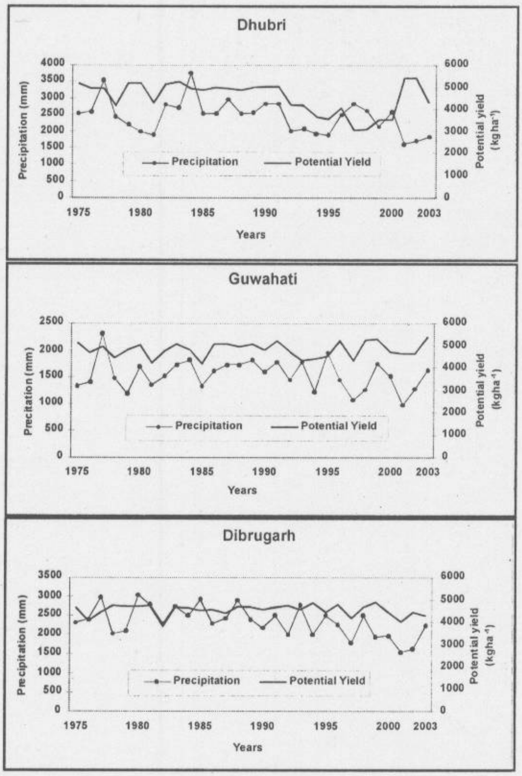

Fig. 4. *Trends of precipitation and potential yield at different sites*

The parametric description of the crop-growth model helped in simulating yield potential as function of biophysical parameters for the summer rice yield in Brahmaputra valley. It is observed that yield realization rate of summer rice is progressed as weather variability is reduced especially during the 1990s and early 2000s. Secondly, trend of potential yield of summer rice crop is highly sensitive to the attributes related to thermal efficiency. In spite of the direct influence of the variation in the mean temperature, the trend of minimum temperature during crop season was found more influential on the fluctuation in the potential yield at all sites in the valley. Lastly, the cool and dry nights with lower fluctuations at the ripening time of the summer rice crop are helpful in the development of healthy and larger grain size which increases potential as well as actual yields of the summer rice in Brahmaputra valley.

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