



PREDICTING SUMMER RICE YIELD BASED ON BIOPHYSICAL AND TECHNOLOGICAL PARAMETERS ON MONSOON LANDS OF BRAHMAPUTRA VALLEY, INDIA

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ABSTRACT

A deterministic approach for the crop grain yield function that follows reciprocity law of diminishing return to fertilizer use is adopted to simulate the effects of biophysical dynamics and fertilizer use for summer rice yield in the Brahmaputra valley. Variations in the potential yield of rice, a frontier parameter of the yield function, and the parameter related to reproductive yield which acts as a coefficient of Fertilizer Use Efficiency (FUE) are assessed by using the biophysical attributes of land (soil and weather) in terms of Potential Productivity Index (PPI) for paddy crop growth as sub-model of the function. The model and sub-models were parameterized with collecting monthly precipitation and temperature statistics over 15 (1975-1990) years of seven meteorological stations located in the Brahmaputra valley, the soil texture data of three major soil types (new alluvial, old alluvial and piedmont) and the statistics relating to summer rice yield and fertilizer use for different areas for a period of 28 (1975 - 2003) years from various Government agencies. Grain yield of summer rice increases at a constant rate as PPI increases. However, the intensive use of fertilizer diminishes its (rice yield) rate in a specific biophysical scenario because of decreasing FUE in presently employed yield function.

Keywords: Potential productivity index, fertilizer use efficiency, reproductive yield, grain yield function. © 2006 AAAE

1. INTRODUCTION

Numerous studies on the perspective of sustainable agricultural production systems suggest that the carrying capacity of such systems is not only linked with its biophysical and techno-economic conditions but also with the environmental evaluation, i.e., more concerned with the environmental stress (Stankey, 1982; Smit and Brklacich, 1989; Smit et al., 1991; Cai Yunlong and Smit, 1994; Atkinson and Mckinley, 1997; Webster, 1997; Zhen and Routray, 2003). In order to understand and analyze sustainable crop production systems, the plant - soil - atmosphere relationship has been described by considering crop systems in the form of crop yield model development. Early attempts to develop a plant simulation model in order to explain physiological processes such as photosynthesis, transpiration, respiration, distribution of dry matter among plant organs, water absorption by roots and carbohydrate assimilation especially during the late 1950s is credited to DeWit (1958) who first added knowledge of transpiration of total water use and yield simulation. He and his associates determined later on the available carbohydrate for plant growth (DeWit et al., 1969). Crop specific

models developed for cotton such as SIMCOT (Duncan, 1972), GOSSYM (Baker et al., 1972; Eye et al., 1984; Reddy et al., 1985), for wheat growth and yield (O'Leary et al., 1985), CERES-wheat (Otter and Ritchie, 1985; Ritchie, 1986; Bell and Fisher, 1994), WTGROW (Aggarwal et al., 1994), WAVES (Zhang and Dawes, 1998; Kang et al., 2002 and 2003) and DeciBle software (Chatelin et al., 2005) and for simulation of potato growth (Fishman et al., 1985) analyzed the crop growth simulation in order to examine the physiological processes, phenological events and stages and environmental stress. Such crop growth models generally contain an empirical base with experimentation and are site- as well as crop-specific. Simultaneously, the crop growth and agricultural sustainability were analyzed by developing a weather-crop yield model considering climatic variability for wheat and sugar beet yields (Gorski and Spoz-Pac, 1989; Mall and Singh, 2000; Gorski and Gorska, 2003).

A Normalized Differential Vegetative Index (NDVI in unit less index) was also used for the crop growth assessment following two-dates remotely sensed data of NDVI around the time of maximum green leaf bio-mass growth. Such index was employed

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to assess grain yield of a particular crop like winter wheat (Manjunath and Totdar, 2004), dry season rice yield (Shrestha and Naikset, 2003) and maize yield (Kiniry et al., 2004). This index shows an ultimate aggregated grain yield without considering its seasonality effects because of technique constraints. It does not have the ability to isolate the effects of different biophysical as well as technological attributes on yield growth.

On the other hand, the agriculture resource use and resource-policy analyses were pursued to develop a variety of classical and neo-classical models analyzing the agro-ecological and technological efficiency of such crop systems. Spillman's (1922, 1933) exponential yield function and Ferrell's (1957) agricultural production function are the best examples to measure technological efficiency of crop output. Stochastic modeling was also considered by agricultural scientists to isolate the effects of technological factors on crop yield through the use of error term of production distribution (Aigner et al., 1977; Subash et al., 2004). Such modeling misses the parameters relating to crop ecology and land suitability.

A correct estimation of crop yield is not only the function of biophysical attributes but also technological parameters of crop-growth especially the agricultural crops which give better grain yield under 'created' soil environment through the use of seed-fertilizer technology. Physiological models as cited above have some limitations. First, the biophysical attributes are considered as explicit factors of crop growth in these models and hence the role of predicting grain yield of a crop is largely dependent on physiological and phenological characteristics of the crops under controlled experimentation. Secondly, the weather-soil complexity of a piece of land where crop is grown determines the potential productivity and yield reproduction for a particular crop. This is not reflected in the existing models barring a few notable exceptions, in which biophysical potential of land is considered as explicit factor. Biophysical environment of a piece of land varies spatially and changes over time. Economically less developed countries do not have extensive facilities of such experimentation to develop the model parameters. Thus, lack of adequate data for full applicability of the model is another dimension to parameterize such models (Diaz-Solis et al., 2003). Having reviewed thoroughly the development of crop-simulation models for integrating environmental and technological factors of agricultural production, Anbumozhi et al. (2003)

realized that an interactive crop simulation model was needed to optimally utilize the agro-environmental resources of a particular scenario/site. It indicates the deficiency in literature on the construction of an integrated model to estimate crop yield in which the effects of biophysical and technological yield factors may be isolated.

An effort is, therefore, made here (a) to use an integrated grain yield model to estimate grain yield of summer rice on monsoon lands, (b) to parameterize the grain yield model and to simulate the grain yield of summer rice for different biophysical scenarios, and (c) to predict long range effects of the use of fertilizer on summer rice yield. The main features of the present research are the estimation of rice yield, the description of structure and parameters of the model and the evaluation of the performance of each of the form of sub-models, that comprise rice yield prediction. The model is based on data that are easily available from secondary sources of any part of the globe and is capable to evaluate the long-range effects of ecological dynamics on reproductive growth and potential yield under different biophysical conditions of crop. It would be a good decision tool for regional decision makers (government as well as non-governmental agencies) and individual rice producers at the farm level, to accurately estimate the optimal rice yield pattern especially for the monsoon lands of Brahmaputra valley (India) where highly variable precipitation, temperature and use of fertilizer limit the growing seasons, its length and grain yield of rice crop.

2. DESCRIPTION OF THE STUDY AREA

The Brahmaputra valley, in the northeastern part of the great plains of India, is surrounded by the Bhutan and Arunachal Himalayas in the north, the Meghalaya plateau in the south, and the Patkai and Naga Hills in the east. It is comprised of longitudinal fertile plains of about 56,300 sq. km., extending 800 km in length from east to west with a varying width of 60-100 km. (89°42' to 95°16' E longitudes and 25°30' to 28°09' N latitudes). It is a gentle plain of less than a half percent surface gradient varying with elevations from 32m to 135m above m.s.l. (Fig. 1). Dominance of rice grown especially in summer season (May-October) in the valley is a specific feature of its cropping pattern because of high precipitation due to the direct effect of the southwest monsoon, shifting of Inter Tropical Convergence Zone (ITCZ) and

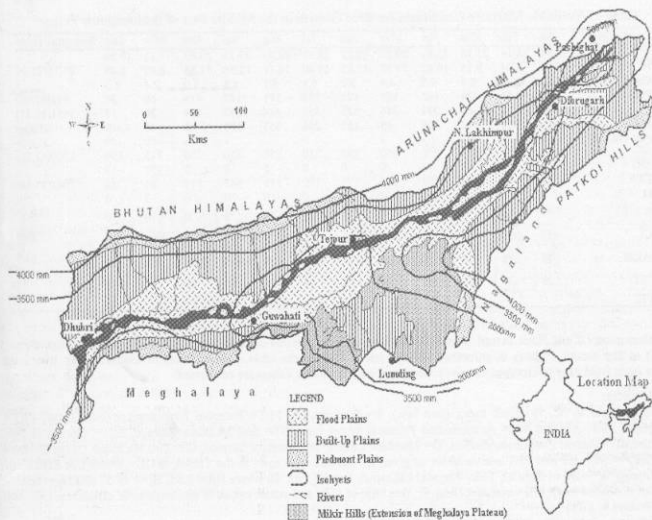


Fig. 1: Crop Ecological Scenarios in Brahmaputra valley

orographic rain (Starkel, 1972; O'Hare, 1977). The valley has different alluvial soils with high nitrogen varying from 0.013 to 0.135% in new alluvial and from 0.034 to 0.166% in the old alluvial soils, medium availability of phosphorous and potassium (800-1000 kg ha^{-1} and 450-600 kg ha^{-1} respectively) and slightly acidic in reaction ($\text{pH} = 5.5$) as analyzed by Assam Agricultural University, Jorhat (c.f. Deka, 1996). Cation Exchange Capacity (CEC) of the topsoil varies from 3.0 to 12.0 $\text{cmol(P}^+) \text{ kg}^{-1}$ in flood plains and 11.0 to 23.3 $\text{cmol(P}^+) \text{ kg}^{-1}$ in the upland soils. It is positively related with organic carbon that attributes to the organic matter contents (Talukdar et al., 2004). However, loss of organic carbon through erosion is observed (NBSS and LUP, 1999). Significant seasonal and regional variations in Evapotranspiration (ET),

Potential Evapotranspiration (PET) and atmospheric conditions are main reasons of the areal variations of rice yield. The average annual precipitation, of which more than 85.0% is received during the summer (April-October) when Precipitation (P) exceeds PET, is recorded at about 2,000 mm (Table 1). Such conditions of high precipitation, when soil water content reaches above 90% of its field capacity throughout the monsoon season ($W = 0.90$), are favorable for paddy growth. Annual precipitation varies from 4,480 mm at the Pasighat station in the upper part of the Brahmaputra valley to 1,210 mm in the lower-middle part at the Luming station with significant temporal variations of about 25% to 30% in the monsoon season during the last 26 years (1975-2001) (Das, 2003; Syiemlieh and Das, 2004).

Table 1: Available Moisture Conditions for Rice Growth in the Middle Part of Brahmaputra Valley

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Seasonal Total
T°C	16.30	18.14	21.58	23.81	26.22	28.37	28.57	28.73	27.73	25.57	21.33	17.20	-
H	5.98	7.04	9.15	10.62	12.29	13.85	14.00	14.11	13.38	11.83	8.99	6.49	93.31(73.96)
Unadj PET	1.1	1.6	2.4	3.2	4.4	5.0	5.1	5.1	4.8	4.0	2.4	1.3	-
PET	30	42	74	103	153	172	179	171	147	119	66	36	941(82.62)
P	20	32	62	211	246	323	385	324	252	121	26	17	1651(82.47)
P-PET	-10	-10	-12	108	93	151	206	153	105	2	-40	-19	710(-)
Acc Pot WL	-69	-79	-91	-	-	-	-	-	-	-	-40	-59	-
ST	188	181	173	250	250	250	250	250	250	250	213	196	1500(61.20)
ΔST	-8	-7	-8	77	0	0	0	0	0	0	-37	-17	-
ET	28	39	70	103	153	172	179	171	147	119	63	34	941(83.64)
D	2	3	4	0	0	0	0	0	0	0	3	2	0
S	0	0	0	0	0	73	135	74	2	0	0	0	284(-)
GI	.953	.955	1.000	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.00	.98	1.05
WUE	.78	.75	.79	1.00	1.05	1.05	1.05	1.05	1.05	1.05	.80	.82	1.05
TEI	.29	.39	.58	.73	.88	1.03	1.04	1.05	.98	.84	.57	.34	.97
FEI	-	-	-	-	-	-	-	-	-	-	-	-	1.11

NB:

All values except T and H are in mm. Water balance budget is prepared by considering water holding capacity in root-zone of soil as 250 mm/m. Figures in parentheses in the last column of the table show % share to annual values. Rice crop season starts from May to October for which weather variability index values are calculated.

Abbreviations:

T= Temperature in °C, H= Heat Index (unit less), P= Precipitation, PET= Potential Evapotranspiration, Unadj PET= Unadjusted PET, Acc Pot WL= Accumulated Potential Water Loss, ST= Soil Moisture Storage, ΔST= Change in Soil Moisture, ET= Actual Evapotranspiration, D= Moisture Deficit, S= Moisture Surplus, GI= Growth Index (Eqn. 7 where (ET/PET)*= .950, ET and PET are variables as given in 4th and 10th rows in the Table), WUE= Water Use Efficiency (considering W*= .95 in Eqn. 8), TEI= Thermal Efficiency Index (Eqn. 10 where Hjb= 2.85, Hj*= 13.57 and Hj= variable as given in second row), FEI= constant (Eqn. 9, the ratio of ideal and actual values of photosynthetic efficiency, i.e., 100 days/90days = 1.11)

Sources:

T and P data for 20 years averages (1975-1995) have been collected from Regional Tea Research Centre, Toklai (Jorhat District) which is centrally situated in Brahmaputra valley and other values are calculated by using conversion tables prepared by Thornthwaite and Mather (1957).

Variable rainfall in the crop system of the valley poses a fundamental challenge to the formation of different soil ecology by flooding and transportation of alluvial from upper reaches of Arunachal Himalaya to the lower flood zone in flood plains. Soil texture is, therefore, different in the build up alluvium of the central longitudinal parts from moist soils of piedmont locally called tarai. Generally, the rice is grown in two seasons, summer and winter, because of much less seasonal variability in temperature with sufficient soil moisture in dry winters. The summer rice yield rate gradient follows the precipitation and the use of chemical fertilizer gradient in different soils (Deka, 1996). Irrigation is not required for summer rice and, consequently, there was reduction in net irrigated area from 7.03% to 3.31% in the valley during the 1990s

(Sharma, 2003). High Yielding Varieties of Seeds (HYVs) namely the IR-8, IN-1 and Monohar Sali locally developed varieties of rice which are resistant to high amount of precipitation are grown but are confined spatially only in the middle parts of the valley (Bhagabati et al., 2001). Under such environmental conditions, the summer rice yield is highly sensitive to biophysical and 'created' soil environment through the use of chemical fertilizers not only in Brahmaputra valley but also in most of the South and South-East Asian countries

3. MODEL DESCRIPTION

Rice yield prediction is formulated as an integrated model, namely, the grain yield function

developed linking sub-models to simulate the temporal changes occurring in rice yield (Y in kg ha^{-1}) and fertilizer use efficiency (FUE in reproductive yield kg ha^{-1} per kg ha^{-1} use of fertilizer and, thus, it is unit less index). In order to relate summer rice yield to biophysical attributes and the effect of fertilizer, we used the 'frontier yield function' $Y = f(x)$ which includes a frontier parameter called maximum possible yield as controlled by the biophysical conditions of land (Singh, 1994, 2000). It is based on reciprocity law of diminishing return to fertilizer doses and tested in different biophysical conditions for the summer rice yield responses to fertilizer use and application of HYVs in the flood areas of the Brahmaputra valley (Singh, 2000). The function $f(x)$ integrates carrying capacity of environment of a specific biophysical scenario/site that is defined here as a parameter of model in terms of its maximum attainable (or potential) grain yield (A in kg ha^{-1}) and the effect of fertilizer use (X in kg ha^{-1}). Parameter A changes as the biophysical condition of a scenario/site changes, while FUE is linked with the yield-growth efficiency subject to fertilizer use. The difference between potential grain yield and actual grain yield ($A-Y$), called 'yield gap' by many scientists (Kumar, 1986; Varadarjan, 1986), is defined here as 'potential productivity' because it is largely dependent on water and salt stress and nutrients supply for a particular crop in crop systems. Biophysical factors of a particular scenario thus determine the level of potential grain yield of a particular crop; A . Weather conditions of such scenario are highly variable over time. Weather dynamics is, thus, a basic feature of the model. Mathematical expression of grain yield model is given as:

$$Y = A [1 + B(X)^{-1}]^{-1} \quad \dots(1)$$

Where Y is actual grain yield (kg ha^{-1}), A is constant if it is considered for one point of time otherwise variable over time, B (in kg ha^{-1}) is another constant which denotes reproduction of grain yield and $B(X)^{-1}$ is FUE, i.e., maximum response of yield reproduction attainable from different doses of fertilizer use, X (Singh, 2000). Solving equation (1), one gets:

$$\text{FUE} = B(X)^{-1} = [(A-Y)/Y] \quad \dots(2)$$

It refers to potential productivity of crop per unit of grain yield. Crop growth is only possible in the condition when potential productivity of land is enough to use and, consequently, the potential grain

yield level is higher than the actual yield ($A > Y$). This condition, $(A/Y) > 1.0$, refers to the Intensity of Yield Reproduction (IR in unit less index) that equals to $(1 + BX^{-1})$. Its reciprocal form $(\text{IR})^{-1}$ then refers to a parameter of Potential Resistance (PR). PR varies from zero to unity and shows the strain on land environment. It is closely linked with efficiency to technological inputs like the effects of use of fertilizer and irrigation in yield function (Subash et al., 2004). Grain yield responses to fertilizer use become weaker when fertilizer use is intensified in the presently employed yield function because the first order differentiation of Eqn. (1) shows that

$$dY/dX = (-) [B \cdot A (1 + BX^{-1})^{-2} X^{-2}] \quad \dots(3)$$

Optimal use of fertilizer in the function is determined by equating the decreasing yield responses to fertilizer use with increasing level of stress on land environment as $dY/dX = k(\text{PR})$ where k is proportionality constant to maintain the consistency between potential grain yield, A , and yield reproduction, B . It (k) equals (A/B) with the condition that $k > 0$. Solving this equality for X in the function, one gets the level of optimal fertilizer use:

$$X^* = 1/2 \{ [B^2 + (4BA/k)]^{0.5} - B \} \quad \dots(4)$$

Where, A and B are defined coefficients of the yield function.

3.1 Yield-growth Sub-model

Inherent mechanism of yield growth of summer rice is largely dependent on two conditions: (i) seasonal variations in weather conditions and, therefore, potential productivity influences crop grain yield (Y in kg ha^{-1}), and (ii) annual variations in the use of fertilizer, X . Photosynthetic efficiency during vegetative growth, efficiency of solar radiation and soil water effect during growth season are major biophysical parameters of seasonal variations to assess maximum green bio-mass growth (Hunt, 1977; McCall and Bishop-Hurley, 2003). Review on vegetative growth holds that precipitation effectiveness and thermal efficiency were major growth factors during early period of plant growth predictions (Thorntwaite, 1931) which were used later in terms of transpiration rate (DeWit, 1958; Hanks et al., 1969; Das, 2000 and 2001; Kang et al., 2002 and 2003). The process of photosynthesis, environmental conditions of ET and PET and Soil Moisture Storage (ST) are considered recently as

major determinants of crop grain yield (Johns and Smith, 1975). Under the conditions of high precipitation, the rice growth is largely influenced by the conditions of ET and PET. At high environmental PET demand of about 180 mm per month (i.e. approximately 6.00 mm day⁻¹) with very high rainfall (P>PET) (Table 1), the maximum green leaf biomass growth of summer rice in Brahmaputra valley is optimal at the time of its inflorescence emergence during last week of August to mid September. We used potential grain yield of summer rice, A as an interactive function of a set of crop growth determinants forming an ecologic-based land potential productivity index, PPI, with a constant, m, as

$$A = m \times X \text{ PPI} \quad \dots(5)$$

Where, m refers to genetic potential yield productivity in kgha⁻¹ for cultivars and crop yield management under non-stress condition and PPI is defined as interactions of five indexes as reflected below,

$$\text{PPI} = \text{SPI} \times \text{GI} \times \text{WUE} \times \text{FEI} \times \text{TEI} \quad \dots(6)$$

with the following notations of given terms.

SPI refers to Soil Productivity Index (i.e. unit less index) prepared to consider geomorphic, textural and fertility status of various soils and their relative weights (Table 2). The soil weight scheme is given in detail somewhere else (Singh, 2005).

GI is plant Growth Index, which refers to the average of relative crop-growth factors for the summer months (May- October) when paddy is grown as

$$\text{GI} = 1/n \sum \{(ET/PET) / (ET/PET)^*\} \quad \dots(7)$$

Where, ET/PET is monthly vegetative growth factor and (ET/PET)* is its value at sowing time to make relative weights for each month up to n for total duration of crop season, i.e., 6 months (May to October).

WUE is Water Use Efficiency index for determining the role of soil moisture in the process of assimilation of water in photosynthesis for vegetative growth. Level of available water in the soil that is $W = ST/FC$ where soil moisture storage ST per unit of field capacity, FC, was calculated for each month of rice season. The optimal level of water requirement for the proper crop growth for each month, W*, is obtained by maximizing the growth function subject to

available soil water, $d(ET/PET)/dW = 0$. The water use efficiency index is thus expressed as

$$\text{WUE} = 1/n \sum (W/W^*) \quad \dots(8)$$

Where, n = 6 in number time unites as months of summer rice crop-season.

FEI refers to Photosynthetic Efficiency Index during vegetative growth defined as the smaller the duration of initial and vegetative growth phases (t_0-t_f) when flowering period of growth, t_f , is over, the greater is the efficiency of radiation use in the process of photosynthesis to reproduce the green leaf biomass, and *vice versa* (McCall and Bishop-Hurley, 2003). A ratio of total duration of crop-season, D (in days), to the duration of vegetative growth phase (t_0-t_f in days) is photosynthetic efficiency. Photosynthetic efficiency index is a relative term written as

$$\text{FEI} = \left\{ \frac{D / (t_0-t_f)}{D / (t_0-t_f)^*} \right\} = \left\{ \frac{(t_0-t_f)^*}{(t_0-t_f)} \right\} \quad \dots(9)$$

Where, (t_0-t_f)* is an ideal value of photosynthetic efficiency in which t_f * for summer rice flowering duration is considered 100 days in Brahmaputra valley.

TEI refers to Thermal Efficiency Index which is an indicator of a receipt of heat for accelerating different processes of plant growth. Since thermal efficiency, TE, is a function of three levels of heat indexes (H) depending directly on temperature based on the Thornthwaite's 'base- variable and power-constant' that is $H = (T^{\circ}C/5)^{1.514}$. These levels of heat index are named as (i) the monthly mean value of the heat index, H_j , (ii) the minimum required temperature at which seed germinates and crop growth starts called base (or threshold) heat index as constant, H_{jb} , and (iii) the monthly optimal level of heat index for crop growth during vegetative as well as reproductive phases of growth, H_j^* . The thermal efficiency index, TEI, may thus be written as

$$\text{TEI} = 1/n \sum \left\{ \frac{(H_j - H_{jb})}{(H_j^* - H_{jb})} \right\} \quad \dots(10)$$

Where n= number of months during summer paddy crop season. Several studies indicate that the base temperature for the summer rice crop is estimated to be 10°C ($H_{jb} = 2.856$) and maximum 33°C ($H_{jmax} = 17.4096$) but not to exceed 42°C ($H_j = 25.0818$) in the range of optimal temperature varying from 25°C in May to 30°C in June-July (vegetative growth phase) and 28°C ($H_j = 13.5755$) in

Table 2: Description of Soil Characteristics, Precipitation Ranges and Location of Stations in the Study Area

Soil Characteristics Description and Range Conditions	
(A) Flood Plains (New Alluvial Soils):	
S=level, D=very poor, E=very slight, F=severe to moderate (Cs=2-5%, Fs=25-30%, Si=40-60%, Cl=5-15%), Silty loam and coarse loam soils, (W=0.90)(pH=5.25, N=450-530 kg ha ⁻¹ , P ₂ O=500-850 kg ha ⁻¹ , K ₂ O=515-694 kg ha ⁻¹), SPI= 1.11 (good productive soils).	
A1: Low Precipitation Range (500 to 2000 mm annually, average 1500 mm)	Tezpur station (26°40'N – 92°40'E, 79m msl, P=1900 mm): Hot humid, hyperthermic, FC = 250 mm/m.
A2: Moderate Precipitation Range (2000 to 3500 mm annually, average 3000 mm)	Dhubri station (26°01'N – 89°59'E, 35 m msl, P=2800 mm): Hot humid, hyperthermic, FC = 250 mm/m.
A3: High Precipitation Range (3500 to 5000 mm annually, average 4500 mm)	(range condition does not prevail in study area).
(B) Built-up Plains (Old Alluvial Soils):	
S=very gentle, D=imperfect, E= slight, F=slight (Cs=10-20%, Fs=25-40%, Si=45-60%, Cl=2-6%), Fine loamy soil (W=0.83)(pH=5.63, N=520-730 kg ha ⁻¹ , P ₂ O=1250-1700 kg ha ⁻¹ , K ₂ O=582-734 kg ha ⁻¹), SPI= 1.59 (Excellent productive soils)	
B1: Low Precipitation Range (500 to 2000 mm annually, average 1500 mm)	Guwahati station (26°03'N – 91°40' E, 55m msl, P= 1720 mm): Hot humid, hyperthermic, FC=200 mm/m.
B2: Moderate Precipitation Range (2000 to 3500 mm annually, average 3000 mm)	Dibrugarh station (27°28'N – 94°55'E, 106 m msl, P=2600 mm): Hot per humid, hyperthermic, FC = 250 mm/m.
B3: High Precipitation Range (3500 to 5000 mm annually, average 4500 mm)	(range condition does not prevail in study area)
(C) Piedmont Plains (duars, terai and red soils):	
S=gente, D=moderately well, E=moderate, F=slight (Cs=30-40%, Fs=25-40%, Si=10-25%, Cl=2-7%) Sandy loam and red soils (W=0.90)(pH=5.22, N=300-350 kg ha ⁻¹ , P ₂ O=980-1250 kg ha ⁻¹ , K ₂ O=515-790 kg ha ⁻¹), SPI= 0.81 (poor productive soils)	
C1: Low Precipitation Range (500 to 2000 mm annually, average 1500 mm)	Lumding station (25°45'N – 92°55'E, 149m msl, P=1210 mm): Hot moist sub-humid, hyperthermic, FC= 200 mm/m.
C2: Moderate Precipitation Range (2000 to 3500 mm annually, average 3000 mm)	North Lakhimpur station (27°14'N – 94°07'E, 102 m msl, P=3200 mm): Hot humid, hyperthermic, FC=200 mm/m.
C3: High Precipitation Range (3500 to 5000 mm annually, average 4500 mm)	Pasighat station (28°02'N – 95°21'E, 274 m msl, P=4480 mm): Hot sub-humid, hyperthermic, FC=200 mm/m.

NB:

Fertility classes recommended for Brahmaputra valley soils as

- (1) Phosphate (P₂O) and Potash (K₂O) requirements: High > 2000 kg ha⁻¹; Medium 1500 – 2000 kg ha⁻¹; Low < 1500 kg ha⁻¹.
- (2) Nitrogen (N) requirement 100-150 kg ha⁻¹ for optimal crop growth.

Abbreviations:

(1) Soil Fertility Status: N= Nitrogen contents, P₂O= Total Phosphate, K₂O= Total Potash.

(2) Mechanical Fraction (in % on 0-30 cm layers): Cs= Coarse sand 2.0 mm particle size, Fs= Fine sand 0.2 mm, Si= Silt .02 mm and Cl= Clay .002mm soil particle size, W= Field capacity moisture (in unit term) during paddy growing season, FC= Field capacity, P= Average annual precipitation.

(3) Physical Characteristics: S= Soil slope, D= Drainage, E= Soil erosion, F= Flooding, msl= above mean sea level.

Sources:

Soil Surveys 1967-68, Tocklai Occasional Scientific Papers No. 5 and 9, Tea Research Association, Tocklai, Jorhat; NBSS & LUP (1999); Chamuah et al. (1996); Gangopadhyay et al., (1998); Talukdar et al. (2004).

October at the time of harvest (reproductive phase). Brahmaputra valley receives an ideal range of temperature distribution during the summer rice season with its insignificant fluctuation of only 2°C (Table 1).

3.2 Fertilizer Use Efficiency Sub-Model

FUE greatly depends on available potential productivity limiting A and Y parameters of the function (Eqn. 2). Since B is constant in the yield function for specific biophysical scenario, FUE (i.e. $B(X)^{-1}$ in the yield function) diminishes with decreasing rate as use of fertilizer intensifies because X acts reciprocally in Eqn. (2). Maximum response of yield reproduction, B, varies if A varies over time.

Soils of Brahmaputra valley contain sufficient moisture but are moderate in their fertility status. Nitrogen rich soils are available in the valley (Table 2). Nitrogen added fertilizer reduces the number of plant species and insects (biodiversity) in the soils (Stiling, 2002). Potassium (K_2O_3) and Magnesium (Mg) available in the soil are important yield determining factors. Displacement of Mg by K_2O_3 in the plant's uptake reduces growth rate of green biomass of the plant in its resulting sub-optimal Mg contents in soils (Grimme et al., 1977). Deficiency of available (replaceable) magnesium and phosphate are found in the soils of Brahmaputra valley (Talukdar et al., 2004). Such deficiencies are minimized by the use of phosphate-based fertilizers to optimize grain yield function $Y(x)$, which follows asymptotic yield increase as Grimme et al. (1977) experience from experimental plot data. The application of fertilizer affects soil environment in the form of utilizing potential productivity of land. It means that FUE is the function of PPI and X, which is to be analyzed in the present research. Solving main Eqn. (1) of the model for FUE (that is, $B X^{-1}$), one must find

$$FUE = \{[(mY^{-1}) \cdot PPI] - 1.0\} \quad \dots(11)$$

and

$$d(FUE)/d(PPI) = mY^{-1} \quad \dots(12)$$

These equations expressed that FUE increased constantly at mY^{-1} rate. At higher level of grain yield, the increase in FUE became slower when m was considered as constant.

3.3 Model Validation

Once the structure of grain yield function is in order, the coefficients A and B that characterize the

presently employed model need to be estimated; considering the static form of the model as given in Eqn. (1) and adopting goodness-of-fit criterion based on 'least square' method. Collecting statistics of summer rice yield and fertilizer use of 118 farmers belonging to the central part of Brahmaputra valley, the model parameters were estimated and found that the model was valid for predicting grain yield of the summer rice in the valley with an insignificant Mean Standard Error of predicted yield at its 0.05 significant level (d.o.f.= 116) and higher coefficient of determinant ($R^2 = 0.9832$) (Singh, 2000). However, the dynamic form of the model, when A is considered as variable, was interpreted by using the calculated values of potential grain yield determinants as described in the preceding section of the sub model. PPI values in response to biophysical attributes were calculated using Eqns (5) through (10) to simulate the effects of potential productivity of land. Weather statistics of 15 years (1975-1990) were used for the purpose.

4. RESULTS AND DISCUSSIONS

4.1 Estimation of Summer Rice Yield

We estimated model parameter A by calculating PPI for summer rice season (as defined in Eqns. 5 and 6). Collecting monthly mean temperature (T in °C) and monthly precipitation totals (P in mm) for seven meteorological stations for 15 years (1975-1990) reported by the Indian Meteorological Department, the monthly Heat index, ET, PET, ST and Surface Runoff as necessary parameters of crop growth used in the model were calculated by using Thornthwaite and Mather's (1957) conversion tables that are based on standard water balance equation (as $P = ET + \Delta ST + RO$, where, ΔST = change in soil moisture and RO = runoff). Such tables provide information about the Unadjusted PET computed with the help of Heat Index and Temperature (see section 3.1e), the PET computed by multiplying Unadjusted PET with correction factor that is based on mean possible monthly duration of sunlight at different latitudes, and the moisture retained in the soil at the end of period of negative (P - PET). It was calculated through the computation of Accumulated Potential Water Loss to know the soil moisture storage, ST, depending upon water holding capacity of the different types of soils (Table 1). Values of water holding (field) capacity, FC, given in Table 2, were used in calculation of monthly ST values for different ecological scenarios in the study area.

We calculated SPI values for Eqn. (6) based on soil description and soil surveys conducted by the Regional Centre, National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Jorhat, the Assam Agriculture University and Tea Research Association, Jorhat for different scenarios and sites in Assam (NBSS&LUP, 1999; TRA, 1967-68). Soil slope, drainage, particle size, erosion and soil reaction, and soil fertility status are considered as major soil characteristics to measure their relative weights and to construct a soil productivity index for the purpose (Singh 2005).

Since rice growers use traditional rice seeds (i.e. locally named as *Sali*) and plant it when available soil moisture is more than 95% to field capacity ($W = .95$), the summer rice is grown without irrigation with an ideal soil moisture availability of $W = .90$ throughout the vegetative growth period. Soil productivity, plant growth factor ET/PET, photosynthetic efficiency and thermal efficiency are major determinants of potential grain yield, A. There is hardly any water deficiency to limit the rice crop growth. A significant amount of surplus moisture in the form of surface Runoff (RO) was recorded during summer rice season in Brahmaputra valley. However, monthly soil moisture variation is also considered in operation of Eqn. (6) in addition to above cited determinants.

The constant m in Eqn. (5) was set to an average genetic potential productivity grain yield for all simulated scenario as $3650 \text{ kg ha}^{-1} \text{ year}^{-1}$ as predicted by the National Demonstrations Projects (Mathur and Gupta, 1985; Prasad et al., 1987) for the state of Assam particularly for the years 1978-79. Annual variability of PPI to finally show the weather effects on A in Eqn. (5) is calculated for different scenarios. Similarly, summer rice yield data of the districts falling in each scenario were collected from Directorate of Economics and Statistics, Government of Assam, Guwahati for the corresponding years. Such grain yield data were based on crop-cutting experiments conducted at the time of the harvest period by selecting the site of the sample by the Directorate of Agriculture (DoA), Government of Assam, Guwahati involving its Agriculture Office at the district level based on stratified random sampling of intensity of cropping. Error on yield estimates by the DoA at the district level was not quoted, although as per the discussion with the Director, it was expected to be 5% error at the district level estimation at the time of stratification. The statistics related to the use of chemical fertilizers for the same district for all corresponding years were also collected from the DoA, Government of Assam, and Guwahati. The state

level averages of fertilizer were used for all scenarios before 1988-89 because of the non-availability of district-wide fertilizer statistics. However, statistics showed that the fertilizer use was noticed much lesser (less than $5.0 \text{ kg ha}^{-1} \text{ year}^{-1}$) for all the crops grown before the green revolution period. Crop-wise fertilizer statistics were not available in government records; it was available season-wise. Since rice is a dominant *kharif* (summer) season crop, approximately a two-thirds share of fertilizer use during *kharif* season was consumed by summer rice crop as discussed with the Director of Agriculture and rice growers during the field visits. On the same proportion, the figures of fertilizer consumption for summer rice were computed to use them in the model.

4.2 FUE in Different Ranges of PPI and Soil Productivity

In order to present long-term changes in FUE under the conditions of variable biophysical parameters, PPI, as well as classified range conditions of fertilizer consumption, X in different soil productivity status, SPI, we calculated the values of reproductive grain yield, B and fertilizer use efficiency FUE inserting the values of A as calculated by Eqn. (5) and the observed values of Y and X into the model (Eqn. 1). The values of these parameters were then classified for different ranges of Potential Productivity Index (PPI). PPI is influenced more by soil conditions than precipitation due to sufficient water availability for crop-growth and almost a similar range of monthly temperature throughout the crop growth season in the study area.

At a moderate range of PPI (0.844 to 1.679), FUE occurred unrestricted until PPI range reached to 1.798 to 2.166 especially in excellent productive soils (SPI = 1.59) (Table 3). Similar tendencies of FUE were observed in good productive as well as poor productive soils. Productive soils have higher PPI with its wider ranges and, consequently, the higher potential grain yield is noticed in excellent productive soil in the valley. As the index value of potential productivity declined with its shrinking ranges from excellent productive soils to poor productive soils in the valley, the reproductive yield also declined with declining FUE (Table 3). Increasing fertilizer doses in rice cultivation diminished FUE in all PPI scenarios. More details about changes in FUE rate would be given in the proceeding section of the present discussion. However, it is obvious that the level of reproductive grain yield was always marked very high at high range of fertilizer use (above 2.5 kg ha^{-1}) within

the specific PPI ranges in all cases. Contrary to it, FUE showed negative relationship with fertilizer use. The highest reproductive yield of about 28.21 kgha⁻¹ was demonstrated by the model in the high range of fertilizer use in excellent productive soils with very high potential grain yield of about 6370.10 kgha⁻¹ (Table 3). However, FUE occurred highest (a reproduction of 7.91 kg of rice at one kg use of fertilizer) in the higher range of PPI (1.798 to 2.166) in excellent productive soils at a lower range of fertilizer use. On the whole, the level of reproductive yield, B, varied from 28.21 kgha⁻¹ in excellent productive soils to 0.41 kgha⁻¹ in poor productive soils of very low range of PPI.

Setting $k = 571.97$ as it is ratio of the mean of A with B and inserting A and B values for different range conditions of PPI into Eqn. (4), the values of optimal fertilizer use were calculated. Optimal fertilizer rate is more influenced by reproductive yield, B because B acts in Eqn. (4) in two ways, namely, the squared term as well as multiplier manners with A. Highest optimal level of fertilizer use (8.55 kgha⁻¹) was recorded in the case of excellent productive soil areas of the highest reproductive yield (28.21 kgha⁻¹) in the valley. It diminishes as the value of reproductive yield decreases. Contrary to it, the optimal limits to fertilizer use were marked very low ranging from 0.8 kgha⁻¹ to 3.76 kgha⁻¹ in the poor productive soils of low PPI where reproductive yield and FUE levels are also low (Table 3).

4.3 Simulating the Effects of Potential Productivity of Land (PPI) and Fertilizer Use (X)

The model is capable in presenting changes in reproductive yield, potential grain yield and crop-growth in different scenarios. Effects of PPI and fertilizer consumption on the probabilities of grain yield and FUE were simulated by setting model's parameters as $m = 3650$ kgha⁻¹, $X = 3.5$ kgha⁻¹ for its different trails by changing the value of yield reproduction: $B = 0, 1, 2, \dots, 5$. The effect of potential productivity index on grain yield, Y, was observed by using Eqn. (1) and setting its parameter $m = 3650$ with variable PPI for A (Table 4). Increasing PPI increases the grain yield of summer rice at a constant rate because of replacement of A in Eqn (1) as $A = m$. PPI (Eqn. 5), that provides the following form.

$$Y = \{[m(1.0 + \text{FUE})^{-1}] \cdot \text{PPI}\} \quad \dots(13)$$

It implies that grain yield is a linear function of PPI and yield increases at a constant rate of

$\{m(1.0 + \text{FUE})^{-1}\}$ if FUE is considered as constant because

$$dY/d(\text{PPI}) = m / \{1.0 + B(X)^{-1}\} \quad \dots(14)$$

Where, $B(X)^{-1} = \text{FUE}$

It is widely accepted that the soils rich in mineral and high organic carbon in the scenario of different genotypes and use of HYVs of rice increase its grain yield (Slaton, et al. 2005, Chettri and Mondal 2005). It increased constantly in the presently employed yield function also (Eqn. 13). It is more interesting that the related parameter of reproductive yield, B, acts in the denominator in yield rate responses to PPI Eqn. (14) that limits the growth rate of the rice yield. Increasing the reproductive yield of rice crop increased FUE at its constant rate by way of uptake of more minerals and nitrogen from the soils to maintain rice plant growth. Nitrogen deficiency in the soil must have happened at higher levels of reproductive yield as Chatelin et al. (2005) also observed in their study of crop management simulation. It was noticed in the study area when grain yield results were simulated at different levels of B (Fig. 2), the yield rates of the rice crop in the valley area, consequently, observed to be declining with its decreasing rate as reproductive yield was increased (Table 4).

PPI has a direct impact on FUE as implied in Eqn. (11). Setting the parameters to this equation as $m = 3650$ kgha⁻¹ and constant value of Y that equals 500 kgha⁻¹ to 3000 kgha⁻¹ with an interval of 500 kgha⁻¹ for subsequent trials with variable PPI, the FUE increased constantly 1.825 times as PPI was increased at 1000 kgha⁻¹ of grain yield level. Such a rate of increase became slower at higher levels of grain yield in the yield growth system as it was recorded 1.2166 times at grain yield level of 1500 kgha⁻¹ (Fig. 3). It was further noticed that increasing levels of genetic yield had a positive effect on FUE, since m acted as the numerator in the Eqn. (13) of FUE rate subject to PPI. On the other hand, FUE diminishes much faster in the early phase of fertilizer use and becomes slower at higher levels of the consumption of fertilizer. The degree of concavity of FUE curve increases as reproductive yield increases in yield function. Thus, the level of FUE is observed much higher at higher reproductive yield (Fig. 4) Simulating effects of fertilizer use on grain yield at different PPIs (from 0.5 to 4.0 for subsequent trials) by setting $m = 3650$ kgha⁻¹, $B = 6.3814$ in Eqn. (1), the grain yield function follows the law of diminishing return; yield increases with its decreasing rate as fertilizer use is.

Table 3: Analysis of variance for quality of feed index based on three factors factorial split-split experiment design

Range Conditions	A (kg ha ⁻¹)	FUE (BX ⁻¹)	B (kg ha ⁻¹)	X*(kg ha ⁻¹)	Fertilizer use (kg ha ⁻¹)	
Excellent Productive Soil (SPI=1.59)						
FUE= 5.577, B= 12.322	6370.11	3.86	28.21	8.548	12.7 > X > 2.5	n= 7
1.798 < PPI < 2.166	6186.81	4.96	7.08	5.900	2.5 > X > 1.0	n= 3
n= 14	6243.73	7.91	1.61	2.973	1.0 > X > 0.0	n= 4
FUE= 4.332, B= 9.507	5469.51	3.01	20.51	7.103	16.6 > X > 2.5	n= 9
0.844 < PPI < 1.798	4499.62	3.18	5.71	4.420	2.5 > X > 1.0	n= 5
n= 20	5444.10	6.80	2.30	3.668	1.0 > X > 0.0	n= 6
Good Productive Soil (SPI=1.11)						
FUE= 3.173, B= 7.089	4501.66	2.10	13.23	5.546	12.7 > X > 2.5	n= 1
1.076 < PPI < 1.233	4348.37	3.19	5.88	4.364	2.5 > X > 1.0	n= 8
n= 13	4367.35	4.23	2.15	3.117	1.0 > X > 0.0	n= 4
FUE= 3.052, B= 5.977	4360.41	3.15	8.94	4.918	16.6 > X > 2.5	n= 6
0.924 < PPI < 1.220	4107.09	2.61	4.25	3.794	2.5 > X > 1.0	n= 6
n= 17	3520.73	3.39	2.74	2.959	1.0 > X > 0.0	n= 5
Poor Productive Soil (SPI=0.81)						
FUE= 2.144, B= 4.499	-	-	-	-	12.7 > X > 2.5	n= 0
0.842 < PPI < 0.899	3267.80	1.52	7.26	3.763	2.5 > X > 1.0	n= 9
n= 17	3254.92	2.76	1.74	2.345	1.0 > X > 0.0	n= 8
FUE=2.296, B= 3.665	3360.91	1.58	6.40	3.717	16.6 > X > 2.5	n= 8
0.821 < PPI < 0.877	3180.09	2.00	3.54	3.006	2.5 > X > 1.0	n= 5
n= 15	3284.99	3.31	1.05	1.986	1.0 > X > 0.0	n= 2
FUE= 1.024, B= 1.611	2584.93	1.10	3.93	2.685	9.9 > X > 2.5	n= 4
0.171 < PPI < 0.861	1349.44	0.29	0.41	.799	2.5 > X > 1.0	n= 5
n= 12	1652.76	1.67	0.49	.970	1.0 > X > 0.0	n= 3

N.B.: For FUE, Eqn. (2) and for Optimal Fertilizer Use, X*, Eqn. (4) in which, k= 571.97 as constant and A and B given values are used

Table 4: Values of Fertilizer Use Efficiency and Rice Yield Rate for their Different Reproductive Yield Levels

Reproductive Yield (B)	FUE (BX ⁻¹)	FUE rate (dFUE/dB)	Rice yield rate (dY/dPPI)	Differences in rice yield rate
0	0.00000	-	3650.00	-
1	0.28571	0.28571	2838.90	811.10
2	0.57143	0.28571	2322.72	516.18
3	0.85714	0.28571	1965.39	357.33
4	1.14286	0.28571	1703.33	262.06
5	1.42857	0.28571	1502.94	200.39
6	1.71429	0.28571	1344.73	158.21
7	2.00000	0.28571	1216.66	128.07
8	2.28571	0.28571	1110.87	105.79
9	2.57143	0.28571	1022.00	88.87
10	2.85714	0.28571	946.23	75.77
11	3.14285	0.28571	881.04	65.19
12	3.42857	0.28571	824.19	56.85

Note: For FUE and dY/dPPI, Eqns. (12) and (14) are used. Notations: m= 3650, PPI= 1.0, X= 3.5 and B= 0,1,2,...,5.

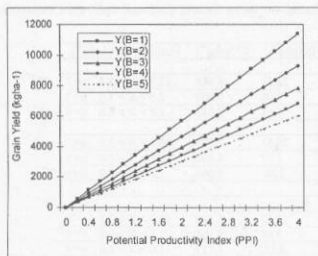


Fig. 2: Grain Yield Responses to PPI at Different Reproductive Yield Levels

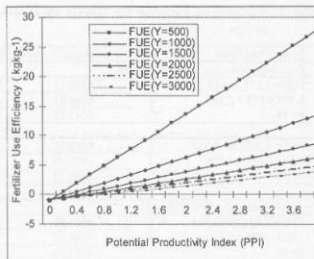


Fig. 3: Fertilizer Use Efficiency Responses to PPI at Different Grain Yield Levels

Table 5: Optimal values of Yield Function at Different Potential Productivity Index

Potential Productivity Index (PPI)	Potential Grain Yield (A in kg ha^{-1})	Optimal Fertilizer Use (X^* in kg ha^{-1})	Optimal Grain Yield (Y^* in kg ha^{-1})
<i>Poor Productive Soil</i>			
0.0	0	0	0
0.2	730	1.095	106.507
0.4	1460	1.954	342.279
0.6	2190	2.693	649.870
0.8	2920	3.348	1004.868
<i>Good Productive Soil</i>			
1.0	3650	3.944	1394.182
1.2	4380	4.493	1809.825
1.4	5110	5.006	2246.498
1.6	5840	5.489	2700.472
1.8	6570	5.946	3169.005
2.0	7300	6.381	3650.011
<i>Excellent Productive Soil</i>			
2.2	8030	6.797	4141.858
2.4	8760	7.197	4643.243
2.6	9490	7.582	5153.104
2.8	10220	7.953	5670.563
3.0	10950	8.313	6194.884
3.2	11680	8.662	6725.442
3.4	12410	9.000	7261.701
3.6	13140	9.330	7803.200
3.8	13870	9.652	8349.534
4.0	14600	9.964	8900.351

Note: For Potential Grain Yield, A, Eqn. (5) and for X^* , Eqn. (4) are used. Notations: $m=3650$, and $B=6.3814$, $k=571$.

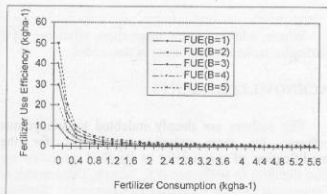


Fig. 4: Fertilizer use efficiency responses to fertilizer consumption at different reproductive yield levels

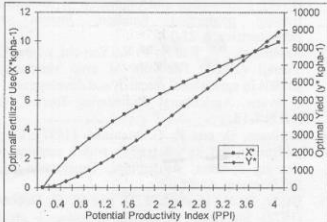
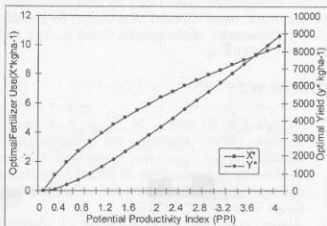


Fig. 6: Optimal yield responses to potential productivity index

increased. Increasing the degree of yield curve is directly related to increase in PPI. At higher PPIs in the scenario of good weather and soil conditions, the grain yield increase is observed much faster even at lower level of fertilizer use (Fig. 5). It shows fast increase in optimal yield at higher PPIs.

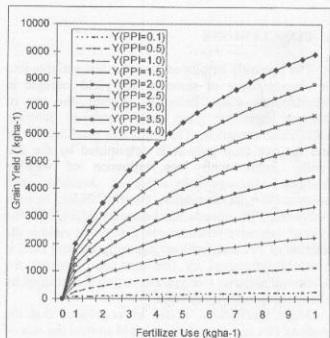


Fig. 5: Grain yield of summer rice subject to fertilizer consumption at different

Potential Productivity Indexes (PPI ranges are classified as 0.1-0.75 for Poor Potential Productivity Scenario, 0.75-1.75 for Good Potential Productivity Scenario and 1.75 - above for Excellent Potential Productivity Scenario in the Brahmaputra valley)

In order to show the spectrum of optimal values of yield function for different scenarios of biophysical environment, the parameters B and k of the optimal fertilizer use Eqn. (4) were set at their mean values of $6.3814 \text{ kg ha}^{-1}$ and 571.97 respectively to calculate the optimal fertilizer use for different trials of PPI. Then such optimal fertilizer quantities were inserted into the yield function (Eqn. 1) to get the optimal grain yield at different PPIs (Table 5). It was found that in the scenario of poor soil productivity where PPI varies from 0.17 to 0.80, the levels of optimal fertilizer use were marked 1.090 to 3.348 kg ha^{-1} which were able to produce optimally an amount of $1004.87 \text{ kg ha}^{-1}$ of grain yield. Contrary to it, the optimal values of fertilizer use were observed more than 6.797 kg ha^{-1} with the optimal yield of more than 4142 kg ha^{-1} of summer rice in the excellent soil productivity with good weather conditions rating 2.20 and above values of PPI in the valley (Table 5). However, the trend of optimal fertilizer use increases with decreasing rate as potential productivity of land increases. As a result, the curve of optimal yield responses to PPI follows convexity in its nature (Fig. 6). It means the yield function acts much faster at a higher PPI.

5. CONCLUSIONS

The presently employed model offers insights into the characteristics of summer rice yield increase in Brahmaputra valley, India. In general, the use of fertilizer alters the grain yield trends in different biophysical scenarios. The potential productivity of land for rice crop growth is determined by the soil fertility index with less influence of weather conditions because of sufficient available soil moisture ($W = .95$) throughout the rice season. In such conditions, PPI extends the boundary of FUE in the areas of extensive fertilizer use. Since rice yield is the function of PPI and fertilizer consumption and FUE is inversely influenced by fertilizer use intensity, the increase of summer rice yield is largely determined by potential productivity of land.

More specifically, it can be concluded that the levels of PPI and reproductive yield control the rate of increase of rice yield. Nitrogen deficiency in soils at higher levels of reproductive yield limits the rice yield rate which diminishes with a decreasing rate as reproductive yield increases. In different PPI ranges under different soils conditions, FUE as well as reproductive yield are counted much higher in excellent productive soils. It (FUE) decreases as fertilizer use is intensified in the operation of rice crop production. Increasing PPI accelerates fast the yield function. As a result, the level of optimal yield in response to PPI increases with its increasing rate (convex spectrum). Yield function thus integrates reproductive yield, FUE and PPI for the management of summer rice cultivation in Brahmaputra valley.

Generally speaking, these results do suggest the effects of biophysical dynamics on the grain yield of the rice crop with a prediction of potential biophysical rice yield. Yield realization and simulated yield trends over time may be other dimensions for further discussion. It is a matter of classification of concerned observations and predicted crop yield. It is obvious that the presently employed model is fully capable to predict summer rice yield in monsoon as well as humid tropical lands. The model may be used for different crops with slight modifications in the weight scheme at the time of constructing its biophysical parameters. Many technological inputs such as $X_1, X_2, X_3, \dots, X_m$ may also be used by modifying the structure of the model. The multi factor yield function may be written as:

$$Y = A [1.00 + B_1 X_1^{-1} + B_2 X_2^{-1} + B_3 X_3^{-1} + \dots + B_m X_m^{-1}]^{-1} \quad \dots (15)$$

Where, additive terms must show efficiency of a particular technological input in the model.

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