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Understanding biophysical and socio-economic determinants of maize (*Zea mays* L.) yield variability in eastern India

Hirak Banerjee [a], Rupak Goswami [b], Somsubhra Chakraborty [b,*], Sudarshan Dutta [c], Kaushik Majumdar [c], T. Satyanarayana [c], M.L. Jat [d], Shamie Zingore [e]

[a] *Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia–741252, West Bengal, India*
[b] *IRDM Faculty Centre, Ramakrishna Mission Vivekananda University (RKMVU), Kolkata-700103, India; E-mails*
[c] *International Plant Nutrition Institute, South Asia Program, 354, Sector-21, HUDA, Gurgaon 122016, Haryana. INDIA, E-mails*
[d] *International Maize and Wheat Improvement Center (CIMMYT), CG Block, National Agricultural Science Center (NASC) Complex, DPS Marg, New Delhi - 110012, India*
[e] *International Plant Nutrition Institute, Sub-Saharan Africa Program, IFDC - East & Southern Africa Division, ICIPE Compound, Duduville–Kasarani, Thika Road, P.O. Box 30772-00100, Nairobi, Kenya*

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ABSTRACT

The aim of this paper was to investigate the key factors limiting maize (*Zea mays* L.) productivity in eastern India to develop effective crop and nutrient management strategies to reduce yield gap. A series of farm surveys was conducted in two distinct agro-ecological zones of eastern India to evaluate the importance of crop management and structural constraints for maize productivity in a range of socio-economic settings prevalent in smallholder farms. Surveys revealed yield gap and yield variations among farms across growing seasons. Lower yields of farmers were mainly associated with farmer's ethnic origin, availability of family labor, land ownership, legumes in cropping sequence, irrigation constraints, seed type, optimal plant population, labor and capital investment, and use of organic manure. These constraints varied strongly between sites as well as growing seasons. Stochastic Frontier Analysis suggested intensification of farm input use and removal of socio-economic and structural constraints for increasing efficiency in maize production. The use of multivariate classification and regression tree analysis revealed that maize yield was affected by multiple and interacting production constraints, differentiating the surveyed farms in six distinct resource groups. These farm types lend scope for introducing typology-specific crop management practices through appropriate participatory on-farm evaluation/trials. Summarily, this research indicated that interacting production constraints should be addressed simultaneously, considering the need of different farm types, if significant productivity improvements are to be achieved. This will be, however, more challenging for less endowed farms due to lack of social and financial capital to improve management intensity.A typology-specific farm support strategy may be formulated to offset this lack of entitlement among resource-poor farmers.

1. Introduction

Eastern India is one of the most populous and intensively cultivated regions in the world [1]. Farming is dominated by smallholder farmers, operating under a wide range of soil, climate, and socio-economic conditions [2], while farm resource endowment plays a potentially important role in determining profitability of cereal production systems [3]. Development of such smallholder systems is strongly constrained by limited availability of key resources such as land, plant nutrients, cash, and labor [4]. Furthermore, interactions between these limiting resources can strongly influence the efficiency with which the resources are used [5,6]. Typically, low resource availability to the farmers and low productivity of cereal crops demand that inputs, including fertilizer, should be used in an efficient manner to close yield gap and maintain farm profitability [7,8]. Realistically, recent increase in fertilizer prices in India has raised doubts about the profitability of fertilizer application in cereals [9,10].

* Corresponding author. IRDM Faculty Centre, RKMVU, Kolkata-700103, India; Tel.: +91 33 24772020, fax: +91 33 24772020.
E-mail addresses: hirak.bckv@gmail.com (H. Banerjee), goswamirupak@rediffmail.com (R. Goswami), som_pau@yahoo.com (S. Chakraborty), sdutta@ipni.net (S. Dutta), kmajumdar@ipni.net (K. Majumdar), tsatya@ipni.net (T. Satyanarayana), M.Jat@cgiar.org (M.L. Jat), SZingore@ipni.net (S. Zingore).

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In reality, recommendations on agronomic and nutrient management practices in eastern India do not consider farm resources. Consequently, these non-flexible recommendations are generally not accepted by farmers [11,12]. These problems of yield gap along with lack of site-specific nutrient management require identification of yield limiting factors in different socio-economic settings and characterization of farm typologies for targeting site-specific management interventions.

Farm typology recognizes that farmers are not a monolithic group and face differential constraints in their farming decisions based on the available resources and their lifestyle [13]. Developing the types is an essential step in any realistic evaluation of the constraints and opportunities that exists within farm households for appropriate policy interventions [14,15]. Ideally, farm typologies reflect the potential access of different households to resources for managing their crops and are typically constructed on the basis of information derived from surveys, key informant interviews, focus group discussions, and literature on bio-physical and socio-economic characteristics of the farmers. Survey questionnaires that are designed to capture bio-physical, socio-economic, and managerial aspects of farming households in an area must capture information on key variables like characteristics of the household and family structure, labor availability, main source of household income, farm land use patterns, volume of crop produce sold or bought, use of agricultural inputs, livestock ownership, links to nearby market, and production orientation [16–19].

Although maize (*Zea mays* L.) research and extension efforts in eastern India have successfully focused on coping with biotic, abiotic, and crop management constraints individually [20–22], relatively little attention has been given to the socio-economic constraints and their interaction with these factors. Understanding the relative importance of these factors to the yield gap is a necessary step to improve maize productivity. The yield gap is generally defined as the difference between actual yields and potential yield, while potential yield is the maximum yield that can be achieved in a given agro-ecological zone. Conversely, Fermont et al. [23] studied the gap between the actual and attainable yield which is the maximum yield observed in a given agro-ecological zone with a given management intensity. However, methods for assessing yield variability and productivity gaps often make use of experimental results obtained on research stations [24,25], without considering the irregularity caused by inherent and management factors under farm conditions. Close monitoring of farmers' fields to assess the impacts of climate, soil, biotic constraints, management practices, and socio-economic factors is imperative for comprehensive diagnosis of yield variability [26]. While some researchers used classical statistical methods to analyze yield variability, such as regression, correlation, principal component analysis or cluster analysis [27,28], others used simulation models to assess yield potential and yield gaps with respect to on-farm gaps [29,30]. The analysis of multiple interactions between target and explanatory variables often requires multivariate analysis and the ability to deal with non-linear relationships. Since field survey data contain continuous, discrete, and categorical variables, and are often highly skewed, a few recent studies have made use of classification and regression tree (CART) analysis to deal with such complexities [31–33]. CART categorizes groups of observations that are homogeneous in terms of target and driving variables, and can be analyzed individually and comparatively.

This study investigated the socio-economic, crop management and infrastructural factors of maize productivity in smallholder farms of selected agro-ecological zones of eastern India. The study is based on data collected from a series of farm surveys in Bankura and Malda districts of West Bengal state, which represent two distinct agro-ecological zones of the state and is representative of a large part of eastern India. Average and attainable yields for smallholder farms under current farming practices were quantified and analyzed for different crop management practices, socio-economic settings, and infrastructural variability. Lastly, farm households with a host of socio-economic and crop management variables were classified into resource groups keeping maize grain yield as the target variable for different crop seasons.

2. Materials and methods

2.1. Site description

West Bengal was chosen as a study area due to its demographic and agro-ecological characteristics, which are broadly representative of the other tropical plains of eastern India. The study comprised of two intensively populated districts of West Bengal: Malda (24°40′20"N to 25032′08"N; 88°28′10"E to 87°45′50"E) and Bankura (22° 38′N to 23° 38′ N; 86° 36′ to 87° 46′E) in the rainfed 'Old Alluvial' and 'Red and Lateritic' agro-ecological zones, respectively (Fig. 1), covering an area of 10,615 km^2. The districts were chosen on the basis of several criteria including soil type, maize growing season, and farmer resource endowment etc. The climate of Malda is rather extreme: very hot and humid throughout summer, with normal average annual rainfall of 1453 mm. The maximum precipitation occurs during the period from June to September. The climate of Bankura, particularly in the upland tracts to the west, is much drier than in eastern or southern West Bengal with normal average annual rainfall of 1400 mm. The bulk of the rainfall (80%) occurs in the months of June to September. Topography of Bankura is mainly undulating with mounds and valleys, showing different grades of laterisation process in soil formation. The population densities for Bankura and Malda are 446 and 881 inhabitant km^{-2}, respectively [34]. Additionally, total net sown area ranges from 260,000 in Bankura to 345,000 ha in Malda while the cropping intensities are 164 and 183%, respectively. These districts also represent different grades in altitude, soil types (deep clay to loamy sand), ethnic groups, and land uses which cover much of the variability found in eastern India. Notably, both districts are characterized by small farm sizes (from 0.2 to 2.0 ha). Cropping seasons in this region is broadly classified into three distinct categories namely *Pre-kharif* or summer season (March-May), *Kharif* or rainy season (June-October), and *Rabi* or winter season (November-February). Maize is gaining importance among the farmers of Malda (during *pre-kharif*, *kharif* and *rabi* seasons) and Bankura (during *kharif* season) districts. Malda holds 5th position among all maize growing districts of the state with respect to overall production (19.95 thousand t from 8.62 thousand ha). The maize acreage (172 hectares) and productivity (2.26 t ha^{-1}) are lower in Bankura than Malda district [34]. Small and marginal farmers are predominant in both the districts, the percentage being more than 80%.

2.2. Farm survey

For conducting farm surveys, two community development blocks which are smaller administrative units comprising of several villages or village clusters, were identified in each of the two selected districts for the survey (Table 1). Three villages in each of the selected blocks were chosen in consultation with the Programme Coordinators of *Krishi Vigyan Kendra* (first line extension agency of Indian Council of Agricultural Research), district agriculture officers, local NGOs, and progressive farmers (Table 1 and Fig. 1). Maize growing farmers in the villages were then selected through systematic sampling for detailed survey. The number of maize growing farmers in each village (N) was divided by fifteen (N/15 = k), the desired sample size for individual villages. Then a random number between 1 and 'k' was selected, with which 'k'

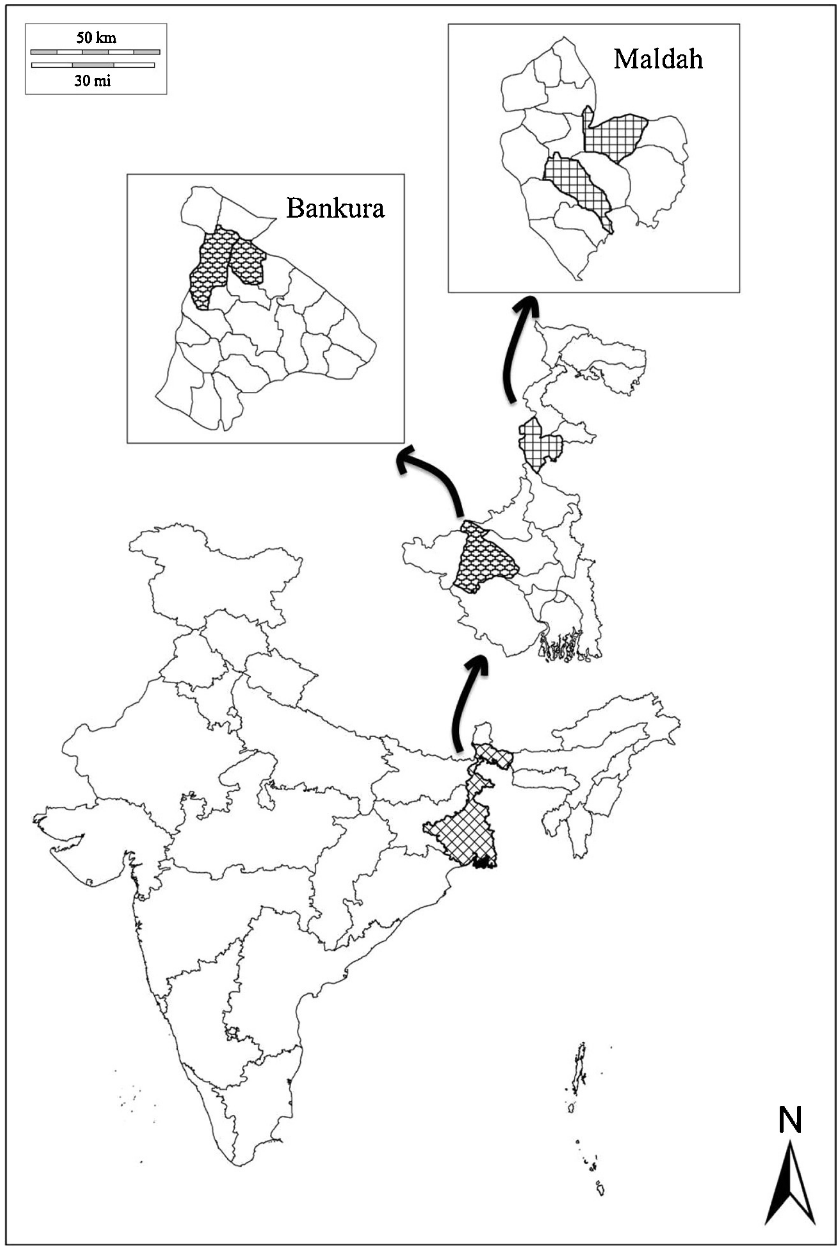

Fig. 1. Study locations in eastern India.

Table 1
Study locations in West Bengal, India.

District	Block	Village	Latitude (N) (In Degree Decimal)	Longitude (E) (In Degree Decimal)
Bankura	Chatna	Dalpur	23.34	86.91
		Kendua	23.37	86.96
		Suyarabagra	23.49	86.96
	Gangajal Ghati	Bamundiha	23.49	87.23
		Kayamati	23.39	87.05
		Shuyabasa	23.64	87.08
Malda	English Bazar	Madia	25.19	88.15
		Naraharipur	25.11	88.08
		Niyamatpur	25.05	88.19
	Gazole	Bhabanipur	25.45	88.28
		Durgapur	25.52	88.32
		Uttar Maldanga	25.35	88.21

was added incrementally to select farm households from the list of farmers prepared beforehand. However, it was difficult to maintain this equidistance of selected farmers due to the complexity of the settlement pattern and nature of cooperation received from the farmers. For example, in some villages houses were not located in a linear pattern and some farmers were more cooperative and accessible for taking part in the surveys and providing necessary information.

Pre-survey focus group discussions were done with farmers to gather basic information related to the villages such as number of households, crops grown, distance to input and output market etc. Farmers' fields were surveyed to understand the present status of maize cultivation. The information gathered in the focus group discussions and farm visits was incorporated in a structured interview schedule constructed during a day-long stakeholder consultation. The interview schedule had distinct sections such as background information and socio-economic profile, farm profile, farm asset

Table 2
Variables used in the classification and regression tree and stochastic frontier analysis.

Variables	Description
Socio-economic	
Education	Formal education received by the head of the household; Categorised as – Illiterate -0; Up to 10th – 1; Up to 12th – 2; More than 12th - 3
Farming experience	Number of years the farm family is engaged in crop cultivation Measured in years;
Ethnic origin	Ethnic identity of the farm household as per the stipulation of Government of India; Categorised as – General – 1; Scheduled Caste – 2; Scheduled Tribe – 3; Other Backward Caste – 4
Household size	Number of members in a farm family who share food from a single source; Absolute number of members in a family
Members of family working in own farm	Number of members in a farm family who work within the farm completely or partially for sustaining livelihood
Farm income	Total revenue (Indian Rupees) earned by the farm family in a year from farm-related enterprises only
Non-farm income	Income (Indian Rupees) of the farm family in a year from non-farm sources
Wage earning	Whether the farm family earns wage from working in others' farms; Yes=1; Otherwise=0
Ownership of cultivable land	Whether the farm family has own land, which is lawfully recorded; Yes=1; Otherwise=0
Farm size	Size of the homestead and owned cultivable land (ha) recorded lawfully
Livestock ownership	Number of owned cattle and small livestock with the farm family
Ownership of pond	Whether the farm family has own pond, which is lawfully recorded; Yes=1; Otherwise=0
Topography of land	Whether the land is 'level' or 'undulated' as perceived by the respondent; Level-1, Undulated =2;
Farm management	
Leguminous crop in the cropping sequence	Whether at least one leguminous crop is grown on the plot where the Maize crop was grown; Yes=1; Otherwise=0
Constraint in Irrigation	Whether irrigation is a constraint in non-Monsoon months; Yes=1; Otherwise=0
Spacing R-R	Spacing between two rows of Maize plant (cm)
Spacing P-P	Spacing between two Maize plants within a row (cm)
Seed type	Genetic nature of seed used in Maize cultivation; Composite-1; Hybrid-2; Traditional-3
Seed rate	Amount of maize seed used in cultivation plot (t ha^{-1})
Organic manure	Amount of organic sources of plant nutrient used in maize cultivation plot (t ha^{-1})
Fertilizer	Amount of inorganic sources of plant nutrient used in maize cultivation plot (t ha^{-1})
Insecticide	Amount of active ingredient of plant protection chemicals used in maize cultivation plot (g ha^{-1})
Total labour	Total family and hired labour used for all operations related to maize cultivation (man hour ha^{-1})
Soil problem	Perceived proportion of areas affected by soil problem on which the maize crop was grown
Severity of soil problem	Perceived strength of soil problem; No – 0; Light – 1; Moderate – 2; Strong – 3; Severe – 4
Total investment	Total monetary expenses incurred for all operations related to maize cultivation (US$ year $^{-1}$ ha^{-1})
Structural variables	
Institutional credit	Whether has access to formal institutional credit; Yes=1; Otherwise=0
Access to deep irrigation	Whether the farm family has physical and/or financial access to deep irrigation sources; Yes=1; Otherwise=0
Irrigation by Shallow pump	Whether the farm family has physical and/or financial access to shallow irrigation sources; Yes=1; Otherwise=0
Pond Irrigation	Whether the farm family has physical access to irrigation water from farm ponds; Yes=1; Otherwise=0
Distance to input	Physical distance (km) of farms to farm input market
Distance to market	Physical distance (km) of farms to farm output market
Productivity	Production of maize grain per unit area (t ha^{-1})

inventory, crop management practices, maize productivity, production related problems, soil resource use, and water resource use. The schedule is then pre-tested on non-sampled respondents for standardization.

2.3. Data collection and processing

Structured interviews with standardized interview schedule were conducted in 180 farms (90 farms per district) and were coupled with individual field visit. The area of each of the identified farm unit was measured using a hand-held garmin eTrex GPS receiver (Garmin Ltd., Schaffhausen, Switzerland). A database was created, manipulated and screened in SPSS, Version 17 (SPSS Inc., Chicago, USA). Farmers were requested to give their criteria on why performance of maize crop varied among fields. This information, along with relevant reviews of literature, nature of data, and initial data analysis led to a selected set of variables which were used in classification and regression tree (CART) analysis (Table 2). After screening and elimination of outliers in yield data, 167 entries were retained in the database.

2.4. Data analysis

Explanatory variables for yield variability were grouped into the following categories: socio-economic situation, crop management practices, and some structural variables embodying access of farmers to inputs, markets, and credit. Details of the variables used in the regression analysis along with their measurements are given in Table 2.

Further, to investigate the level of efficiency or inefficiency using a normal production function and to determine the factors that determine levels of technical efficiency in maize production, we used stochastic frontier production function [35,36] which has developed into a popular field of study in econometrics. The stochastic production function is defined by:

$$Y_i = f(x_i; \beta) + e_i \quad where,\ i = 1, 2, 3 \ldots N \tag{1}$$

$$e_i = v_i - u_i \tag{2}$$

Where Y_i represent the output level of the ith maize grower; $f(x_i;\ \beta)$ is a function such as Cobb-Douglas or translog production functions of vector, x_i, of inputs used by the i^{th} maize grower and a vector β of unknown parameters. e_i is an error term made up of two components: v_i is a random error having zero mean $N(0; \sigma^2 v)$ which is associated with random factors such as measurement errors in production and uncontrollable climatic factors. u_i denotes a *non-negative* random variable associated with farm-specific factors, which hinders the i^{th} firm from attaining maximum production efficiency; u_i is associated with technical inefficiency of the farm and ranges between 0 to 1. Besides, N represents the number of firms involved in the cross-sectional survey.

Technical efficiency of an individual firm is defined as the ratio of the observed output to the corresponding frontier output, which is conditioned on the level of inputs used by the firm. Technical inefficiency is therefore defined as the amount by which the level of production for the firm is less than the frontier output.

$$TE_i = \frac{Y_i}{Y_{i*}},\ where,\ Y_i* = f(x_i; \beta),$$

$$\text{highest predicted value for the ith farm} \quad (3)$$

$$TE_i = Exp(-u_i) \quad (4)$$

$$Technical\ inefficiency = 1 - TE_i \quad (5)$$

Although several studies specified Cobb-Douglas production function to represent the frontier function, this is thought to be imposing prior restrictions on the farm's technology by restricting the production elasticities to be constant and the elasticities of input substitution to unity [37]. In order to select the model that best fits the data, likelihood ratio test was conducted. The test results rejected the null hypothesis of Cobb-Douglas at 5% level of significance, suggesting the suitability of Translog Stochastic Frontier Production Function (SFPF). Thus, the model was specified as–

$$\ln Yi = \beta_0 + \sum_{j=1}^{4} \beta_j \ln X_{ij} + \sum_{k=1}^{4}\sum_{j\le k}^{4} \beta_{jk} \ln X_{ij} \ln X_{ik} \quad (6)$$

Where, i indicates the i^{th} farmer, Y and X variables are yield and explanatory variables (listed in Table 2) respectively. βs are parameters to be estimated. ln is natural logarithm and $\ln X_{ij} \ln X_{ik}$ includes the input interactions. The inefficiency model is estimated by–

$$u_i = \delta_0 + \sum_{k=1}^{9} \delta_k Z_{ik} \quad (7)$$

Where, δ_k is parameter to be estimated and the variables Zi are the variables in the inefficiency equation and given in Table 2. The inefficiency component of the error term follows a normal distribution with mean μ_i and variance σ_u^2 truncated from below at zero–

$$u_i \sim N^+(\mu_i, \sigma_u^2)$$

The mean of the distribution varies by observation and it is assumed that:

$$\mu_i = \delta_0 + \sum_{k=1}^{9} \delta_k Z_{ik} \quad (8)$$

The half-normal model simply restricts μ_i to zero for all observations [38].

We tested the null hypothesis that the distribution of inefficiency could be reduced from truncated normal to half normal distribution and technical inefficiency effects were not present in the model. Both these hypotheses were rejected at 5% level of significance implying the existence of inefficiency in the study areas. The data was analysed by the computer program FRONTIER Version 4.1 [39].

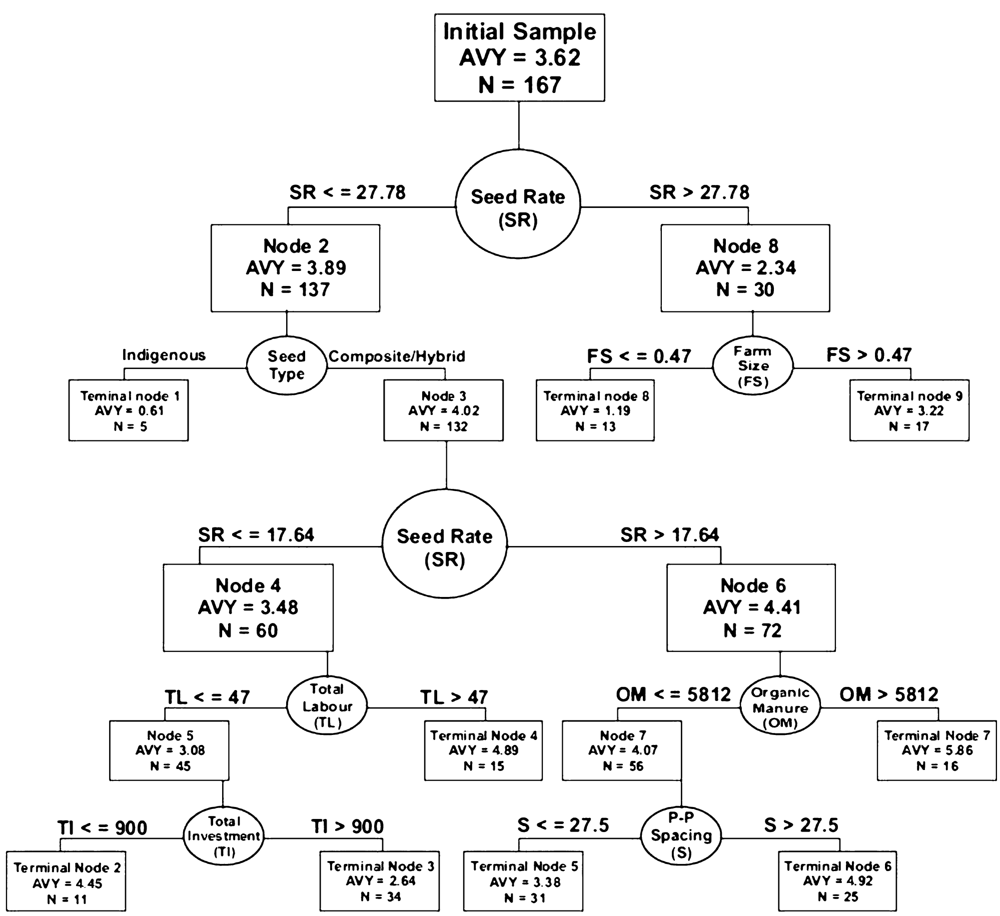

Fig. 2. Classification and regression tree models to describe maize grain yield for all seasons taken together as a function of variables describing agronomic management and socio-economic conditions.

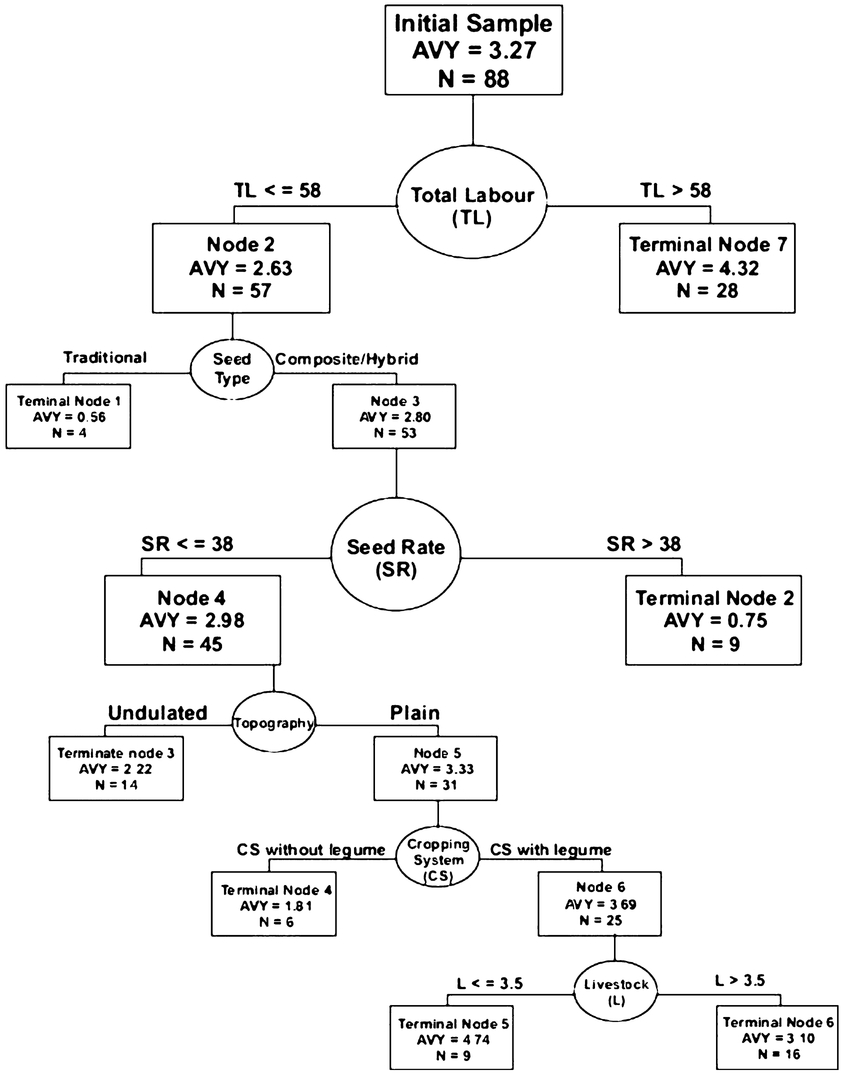

Fig. 3. Classification and regression tree models to describe maize grain yield for *kharif* season as a function of variables describing agronomic management and socio-economic conditions. Each splitting variable is associated to a threshold value in its own units that separate the larger group of data in two subgroups. In the square box the AVY value is the average yield of the group and the N value corresponds to the number of observation contained in that group.

Subsequently, CART was used to identify the main factors controlling yield variability and categorized the observations into relatively homogeneous groups (Figs. 2–4). Although linear regression is widely used to identify factors affecting yield of a crop, the outcome is often questioned when nature of data is non-linear. This was true for our dataset. The methods and its applicability in agricultural research are already described in detail by Tittonell et al. [31]. Briefly, the classification trees consist of splitting variables (criteria), nodes, and terminal nodes (clusters). Trees can be built stepwise by adding explanatory variables to split the data into increasing numbers of clusters with less internal variability. When outliers are present in the dataset, they may be grouped within an independent terminal node (TN) containing few observations. The relative error of the regression model decreases as the number of terminal nodes increases. Beyond a certain number of terminal nodes the relative error may increase again, as adding new explanatory variables does not improve the model [33]. The analysis was done by Salford Predictive Modeler Builder (Salford Systems, San Diego, CA, USA).

A presumed limitation of the study might be its omission of climatic and soil fertility related variables in the analysis. This was, however, addressed by employing proxy variables such as farmers' perception of soil fertility or soil problem and irrigation constraint that can be recorded by questionnaire survey. Notably, studies conducted in smallholder farming systems have shown a strong agreement between soil analysis results and farmer-based criteria for determining soil fertility status [16].

3. Results

3.1. Maize yield in different crop growing seasons in two study locations

While overall productivity of Malda (3.79 $t ha^{-1}$) was higher than Bankura (3.41 $t ha^{-1}$), mean yield of kharif (3.34 $t ha^{-1}$) and summer maize (5.25 $t ha^{-1}$) was higher in Bankura district (Table 3). Interestingly, the yield difference was found to be significant among growing seasons ($F < 0.05$), but not between two agro-ecological zones represented by Malda and Bankura districts. Yield variability of maize was inherently wide, perhaps due to difference in sowing dates and growing environment or the choice of cultivar. Conventionally grown irrigated maize yield was less variable despite very high yields (up to 10 $t ha^{-1}$). Nevertheless, in the *kharif* season the

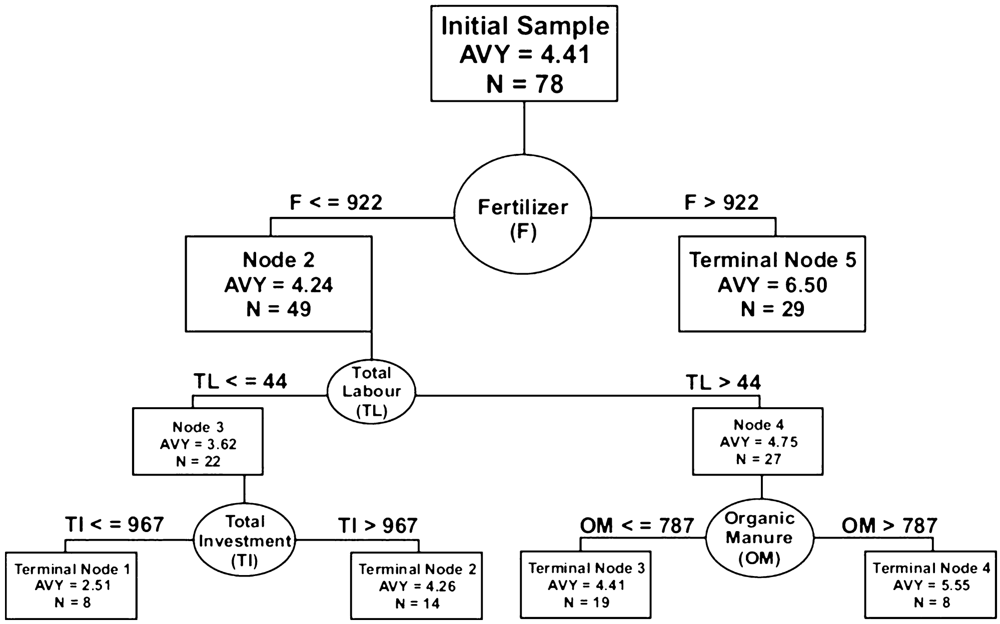

Fig. 4. Classification and regression tree models to describe maize grain yield for *rabi* season, as a function of variables describing agronomic management and socio-economic conditions.

Table 3
Season-wise maize grain yield (t ha^{-1}) in Bankura and Malda districts of West Bengal, India.

District	Yield (t/ha)				F-Significance
	Kharif	Rabi	Summer	Total	
Bankura	3.34 ± 0.25	-	3.25 ± 1.56	3.41 ± 0.25	0.325
Malda	2.42 ± 0.55^{b,x}	4.49 ± 0.22^{a}	3.08 ± 0.39b	3.79 ± 0.21	0.000
Total	3.27 ± 0.23^{b}	4.41 ± 0.21^{a}	3.28 ± 0.16^{b}	3.62 ± 0.16	0.002

[x]LSD analysis: within a row, numbers followed by different letters in smaller case indicate significant difference at 95% level

yield variability was high due to aberrant weather condition that often prevails in the entire eastern India.

3.2. Socio-economic factors and crop management practices relevant to yield gap

More than 30% of the surveyed farmers were illiterate while nearly 55% of the surveyed farmers had 10th grade of school education. Nevertheless, literacy didn't show any significant correlation with maize yield (Table 4). The farmers had 24.4 years of average farming experience, which is perhaps more crucial for adopting new crops and associated innovations. Notably, this experience was also found to be correlated with maize yield of *rabi* season which is relatively more capital intensive and requires experienced and risk-taking farmers (Table 5). The farmers had an average family size of 3.9 and more than half of the family members (2.4 on an average) were engaged in family farming activities. Both these variables were significantly correlated with overall maize yield produced in all growing seasons (Table 5).

In the present study, most of the surveyed farmers were from general caste (38.3%) or scheduled tribe (31.7%). The scheduled caste farmers (24.6%), traditional cultivators for generations, achieved higher average yield (4.3 t ha^{-1}) than the other groups (Table 4). However, most of these farmers (88.6%) did not have legal ownership of farmland and even lesser had their own pond (84.4%) that could be used for irrigation in dry periods. Land owning farmers showed higher mean yield (4.19 t ha^{-1}) than the farmers who did not have legal ownership of land (3.54 t ha^{-1}) (Table 4). Average land holding of the respondents was 0.86 ha, which was higher than the average of West Bengal (0.82 ha). This was further significantly correlated with the summer maize yield (Table 5).

Average farm and non-farm income of the respondents were 382.95 USD year $^{-1}$ and 265.12 USD year $^{-1}$, respectively and these were found to have significant correlation (p = 0.02 and 0.03) with maize yield in capital-intensive rabi season (Table 4). Total labor input in the maize cultivation was about 283 man-hours ha^{-1} season^{-1} which was significantly correlated with kharif and overall maize yield (Table 5). In general, maize farmers in Red and Lateritic zone depending largely on household labor, mostly grew kharif maize. Total investment in maize cultivation was positively correlated with total maize productivity (Table 5).

Farmers who had leguminous crop in their cropping sequence (10.8%) achieved higher average yield (3.74 t ha^{-1}) than those not growing legumes (2.57 t ha^{-1}) (Table 4). Legume, through biological nitrogen fixation, could have improved the fertility status of soil leading to better availability of nitrogen to the succeeding maize. A majority of farmers (70.7%) reported timely irrigation as a major constraint to maize cultivation and also recorded lower yield (3.07 t ha^{-1}) than those who reported no irrigation constraint (3.84 t ha^{-1}) (Table 4). In Old Alluvial zone, majority of the surveyed farmers had access to irrigation and could achieve higher yields, while farmers of Red and Lateritic zone struggled to manage irrigation in winter season that restricted maize cultivation to rainy season with lower yield potential.

While examining the status of variables on infrastructure, we found a mean distance of 1.78 km and 5.77 km from the households to metal road and agri-input market, respectively. These were in turn correlated significantly (p = 0.03) with the maize yield in summer. Most of the farmers used hybrid maize seed (92.8%) and

Table 4
Background variables (categorical) of the respondents (n=180) and yield analysis.

Variables	Frequency distribution		Yield (t/ha)	t/F Significance
	Class	Frequency (%)		
Education	Illiterate	91 (30.5)	3.44 ± 0.30	0.508
	Upto 10th	93 (55.7)	3.76 ± 0.21	
	Upto 12th	11 (6.6)	3.95 ± 0.51	
	Above 12th	13 (7.2)	2.95 ± 0.51	
Ethnic Origin	General	64 (38.3)	3.49 ± 0.26	0.009
	SC	41 (24.6)	4.29 ± 0.26	
	ST	53 (31.7)	3.27 ± 0.31	
	OBC	9 (5.4)	3.48 ± 0.56	
Wage earner	Yes	89 (53.3)	3.39 ± 2.08	0.128
	No	78 (46.7)	3.88 ± 2.01	
Ownership of cultivable land	Yes	19 (11.4)	4.19 ± 1.43	0.009
	No	148 (88.6)	3.54 ± 2.12	
Topography of land	Level	120 (71.9)	3.66 ± 2.03	0.626
	Undulated	47 (28.1)	3.49 ± 2.16	
Ownership of pond	Yes	26 (15.6)	3.71 ± 2.15	0.792
	No	141 (84.4)	3.59 ± 2.05	
Legumes in the cropping sequence	Yes	18 (10.8)	3.74 ± 1.96	0.022
	No	149 (89.2)	2.57 ± 2.04	
Irrigation by deep tube well	Yes	37 (22.2)	3.86 ± 1.89	0.425
	No	130 (77.8)	3.55 ± 2.11	
Irrigation by Shallow pump	Yes	58 (22.2)	3.44 ± 2.11	0.420
	No	109 (77.8)	3.71 ± 2.03	
Pond Irrigation	Yes	70 (41.9)	3.67 ± 2.19	0.789
	No	97 (58.1)	3.54 ± 1.97	
Constraint in Irrigation	Yes	118 (70.7)	3.07 ± 2.12	0.006
	No	49 (29.3)	3.84 ± 2.00	
Access to institutional credit	Yes	62 (37.1)	3.92 ± 2.12	0.139
	No	105 (62.9)	3.43 ± 2.01	
Seed type	Composite	5 (3.0)	3.41 ± 0.59	0.029
	Hybrid	155 (92.8)	3.71 ± 0.16	
	Traditional	7 (4.2)	1.61 ± 0.98	
Severity of soil problem	No problem	104 (62.3)	3.63 ± 0.20	0.511
	Little	24 (14.4)	3.95 ± 0.35	
	Moderate	26 (15.6)	3.04 ± 0.43	
	Strong	9 (5.4)	3.95 ± 0.80	
	Severe	4 (2.4)	3.26 ± 0.79	

achieved higher yield (3.7 t ha^{-1}) over those using composite (3.4 t ha^{-1}) or traditional (1.6 t ha^{-1}) seed types (Table 4). The effect of hybrids in increasing maize yield is more evident in the *rabi* season due to favorable climate with a longer grain-filling period [20] and better utilization of water and fertilizer during the winter season that usually results in higher maize yields in the region [40]. Average seed rate used by the respondents was 20.48 kg ha^{-1}, which was negatively correlated (p= 0.02) with maize yield of summer months. Plant to plant spacing (average 25.65 cm), on the other hand, was correlated (p = 0.04) with overall maize yield. The mean

Table 5
Descriptive statistics of background variables and their correlation with maize grain yield under different crop seasons.

	Mean	Standard Error	Correlation with yield[a]			
			Kharif	Rabi	Summer	Overall
Farming experience (year)	24.37	1.019	-0.058	0.308*	0.070	-0.150
Farm size (ha)	0.86	0.062	0.074	0.081	0.494**	-0.045
Livestock (nos.)	7.10	0.584	0.036	0.010	-0.269	0.011
Household size (ha)	3.87	0.132	0.138	-0.044	0.098	0.230**
Family members working in Farm (nos.)	2.44	0.116	0.059	-0.233	0.085	0.236**
Farm income (US$[b] year $^{-1}$)	382.95	1726.167	0.058	-0.127	0.402*	0.033
Non-farm income (US$ year $^{-1}$)	265.12	2559.668	-0.098	0.129	-0.425*	-0.087
Total income (US$ year $^{-1}$)	648.07	3107.132	-0.050	-0.008	-0.150	-0.054
Total labour (man hours year^{-1})	282.89	19.059	0.293**	-0.268	0.000	0.412**
Total investment (US$ year $^{-1}$)	96.86	9.16	-0.072	-0.018	0.206	0.298**
Distance Metal Road (km)	1.78	0.123	0.039	-0.099	0.439*	0.037
Market distance (km)	5.07	0.291	-0.033	0.097	0.119	-0.027
Input market distance (km)	5.77	0.316	0.022	0.126	0.566**	0.065
Insecticide (kg ha^{-1})	6.13	3.976	-0.160	0.082	0.575**	-0.077
Fertilizer (kg ha^{-1})	546	35.395	0.054	-0.063	-0.109	0.036
Organic manure (t ha^{-1})	4348	508.389	0.062	-0.072	0.379*	0.265**
Seed rate (kg ha^{-1})	20.48	0.688	-0.053	-0.002	-0.402*	-0.158*
Soil problem (%)	5.90	1.514	-0.175	-0.084	-0.090	-0.017
Spacing P-P (cm)	25.65	0.695	0.212	0.185	0.306	0.182*
Spacing R-R (cm)	43.31	0.656	-0.019	0.187	0.108	-0.032

[a] *,** indicate significant correlation at 95% and 99% confidence level, respectively
[b] US$ = '57.71 (Indian rupee) as on 10.06.2013

Table 6
Socio-economic backgrounds and crop management practices of the respondents under different yield classes of maize grain in West Bengal, India.

	Yield Class I[a](27)[b]	Yield Class II(41)	Yield Class III(63)	Yield Class IV(24)	Yield Class V(12)	F significance
Distance from metal road (km)	1.48	1.68	2.08	1.45	1.87	0.351
Farm income (US$ year $^{-1}$)	256.45	362.15	436.67	391.61	431.47	0.350
Farm size (ha)	0.62	0.81	0.96	0.82	1.14	0.300
Farming experience (year)	22.48	24.49	23.89	26.71	26.00	0.816
Fertilizer application (kg ha^{-1})	474	589	517	489	831	0.177
Household size (ha)	4.44	3.66	3.75	3.58	4.50	0.175
Distance from Input Market (km)	4.15	5.37	6.32	6.35	6.75	0.135
Insecticide applied (kg ha^{-1})	29.59	2.49	3.07	6.42	4.49	0.145
Livestock ownership (nos.)	8.56	5.51	7.22	6.62	9.58	0.378
Market distance (km)	4.50	4.71	5.08	6.15	5.42	0.551
Members working on farm (nos.)	3.33	2.37	2.30	2.04	3.00	0.099
Non-farm income (US$[c] year $^{-1}$)	509.44	169.88	209.67	367.35	128.52	0.086
Organic manure (kg ha^{-1})	6401	2579	4772	2813	6615	0.070
Seed rate (kg ha^{-1})	22.72	20.89	19.65	18.49	22.40	0.393
Soil problem (%)	15.37	5.24	4.13	3.96	0.08	0.083
Spacing P-P (cm)	23.70	23.76	26.35	27.42	29.33	0.170
Spacing R-R (cm)	42.96	42.20	43.41	44.92	44.17	0.786
Total income (US$ year $^{-1}$)	765.89	531.97	646.33	757.23	559.69	0.613
Total investment (US$ year $^{-1}$)	132.67	65.02	102.67	76.08	136.21	0.103
Total labour (man hours year^{-1})	249.84	277.02	289.22	297.40	315.03	0.935

[a]Yield class I, < 1 t ha^{-1}; Yield class II, 1.0-3.0 t ha^{-1}; Yield class III, 3.1-5.0 t ha^{-1}; Yield class IV, 5.1-7.0 t ha^{-1}; Yield class V, > 7 t ha^{-1}
[a] No of farm households
[c] US$ = 57.71 (Indian rupee) as on 10.06.2013

Insecticide, fertilizer, and organic manure application were recorded to be 6.13 kg ha^{-1}, 546 kg ha^{-1} and 4.35 t ha^{-1}, respectively (Table 5). Insecticide and organic manure were correlated ($p < 0.05$) with the maize yield in summer, which was less resource intensive.

It was difficult to arrive at statistically significant relationship between maize yield and several continuous variables from Table 6 indicating prevalence of a complex and multidimensional relationship in a multivariate system.

Table 7 shows the maximum likelihood estimates of the parameters in the translog stochastic frontier and inefficiency model for the studied maize farmers. In the frontier model, the coefficient of seed rate, fertilizer, and organic manure were significant and positive, implying that an increase in these inputs for maize would increase the productivity. The coefficient of interactions between seed rate and fertilizer, and fertilizer and organic manure were positive and significant. There was organic relation between plant population and availability of plant nutrient in maize field which was further improved when the nutrients were provided through organic and inorganic forms. In estimating the inefficiency model, out of the nine variables used, five variables were found significantly affecting the inefficiency of maize farmers. Farming experience (negative), Farm income, Farm size, Pond ownership, and Access to input (positive) significantly affected the maize yield. While the TE was computed for each maize grower, the minimum and maximum estimated efficiency were 17.09 and 87.32%, respectively, with a mean of 53%. On an average, 47% maize was lost because of inefficiency and the gap may be offset by intensifying inputs and removing socio-economic and structural constraints.

3.3. Categorising the variability of maize yield

During descriptive analysis, categorisation of the dataset was essential to explain the variability arising from multiple interactions among socio-economic, crop management, and infrastructural variables. For this, we employed three regression tree analyses for maize grain yield–with kharif, rabi, and total (kharif + rabi) productivity as target variables. First, the whole dataset was used for CART analysis (n = 167), with total maize grain yield as the target variable. CART identified seed rate as the main factor explaining yield variability (Fig. 2). Maize farmers who used less than 27.78 kg ha^{-1} (Node 2, n = 137) seed produced an average maize grain yield of 3.9 t ha^{-1}, whereas farms where seed rates were more than 27.78 kg ha^{-1} achieved an average yield of 2.34 t ha^{-1} (Node no. 8; n = 30). Node 8 is further split by farm size, with less than 0.47 ha farms yielding 1.2 t ha^{-1} (TN8, n = 13) on an average and farms of more than 0.47 ha yielding 3.2 t ha^{-1} (TN9, n = 17). Node 2 is further split by the type of seed used. Seed type 3 i.e. traditional seed type produced a mean yield of 0.61 t ha^{-1} (TN1, n = 5),

Table 7
Maximum likelihood estimates of the stochastic frontier production and factors influencing inefficiency of maize production in the study area.

Variables	Parameter	Coefficient[a]
Stochastic Frontier[b]		
Constant	β_0	82.16***
lnSR	β_1	4.67**
lnFERT	β_2	.96**
lnORGMAN	β_3	.64*
lnMANLAB	β_4	.28
lnSR*lnFERT	β_{12}	1.03**
lnSR*lnORGMAN	β_{13}	0.10
lnSR*lnMANLAB	β_{13}	0.78
lnFERT*lnORGMAN	β_{23}	1.97**
lnFERT*lnMANLAB	β_{24}	0.16
lnORGMAN*lnMANLAB	β_{34}	0.67
Inefficiency model		
Constant	δ_0	14.68***
Farming Experience	δ_1	-.26*
Family Size	δ_2	-.18
Farm Income	δ_3	3.03**
Livestock	δ_4	.14
Farm Size	δ_5	2.04*
Pond ownership	δ_6	5.17**
Access to credit	δ_7	-0.71
Access to input	δ_8	6.95***
Access to market	δ_9	0.78
Variance parameters		
Sigma	σ	15.97
Lambda	λ	1.70
Sigma squared (u)	σ_u^2	15.09**
Sigma squared (v)	σ_v^2	5.22*
Gamma	γ	0.69**
Mean technical efficiency		53%

[a]*,**, *** indicate significant at 10, 5 and 1% respectively
[b]SR. Seed rate; FERT, fertilizer; ORGMAN, organic manure; MANLAB, manual labor.

whereas seed type 1 and 2 i.e. composite and hybrid seeds yielded 4. t ha^{-1} (Node 3, n = 132). This node is, in turn, again split by seed rate. Plots where less than 17.64 kg ha^{-1} seed was used yielded average 3.48 t ha^{-1} (Node 4, n = 60), whereas an average yield of 4.41 t ha^{-1} was achieved when more than 17.64 kg seed ha^{-1} (Node 6, n = 72) was used. Interestingly, it was observed that seed rate had multiple threshold values that reappear as splitting criteria indicating its multi-modal distribution in the dataset. Node 4 is further split by total labor. An average yield of 3.08 t ha^{-1} was recorded (Node 5, n = 45) when less than 47 man days were used in maize production; the mean yield increased to 4.89 t ha^{-1} (TN4, n = 15) when more man days were employed for cultivation. Node 5 is split by total investment, with investment less than INR 900 ha^{-1} resulting in a yield of 2.6 t ha^{-1} (TN2, n = 34) and investment in excess of that resulted 4.5 t ha^{-1} of yield (TN3, n = 11). Node 6 was split by organic manure. When less than 5.8 t ha^{-1} organic manure was used, a yield of 4.1 t ha^{-1} (Node 7, n = 56) was observed; the average yield increased to 5.9 t ha^{-1} (TN7; n = 16) with higher application of organic manure. Node 7 was split by P-P spacing of maize. Average maize yield was 3.4 t ha^{-1} (TN5, n = 31) when spacing is less than 27.50 cm; mean yield of 4.9 t ha^{-1} (TN6; n = 25) was recorded with higher P-P spacing.

3.4. Categorisation of maize yield under kharif and rabi season

The descriptive analyses of yield indicated that classification and regression for different crop seasons should be done separately. A CART for maize grain yield in *kharif* season on 88 fields produced the tree with several variables as splitting criteria. In order of importance they were: total labor, seed type, seed rate, topography of the farm, presence of legume in cropping sequence, and livestock ownership (Fig. 3). The average yield of kharif crop was 3.2 t ha^{-1} (n = 88) which was about 1.02 t ha^{-1} higher than the regional average. The highest yield (4.74 t ha^{-1}, TN5) was obtained when < 58 man days were employed in production (Node 2, n = 57), composite or hybrid seed was used (Node 3, n = 53), < 38 kg ha^{-1} seed rate was followed (Node 4, n = 45), the land was level (Node 5, n = 31), at least one leguminous crop was there in the cropping sequence (Node 6, n = 25), and < 3.5 livestock owned by the households (TN5, n = 9). Poorer yields were observed in traditional seed type (TN1, n = 4). For hybrid seed types, poor yield was observed when seed rate in excess of 38 kg ha^{-1} was used, or when maize was cultivated in undulated lands (TN2, n = 14) with seed rate < 38 kg ha^{-1}, or in fields where no legumes were grown (TN4, n = 6) even if the seed rate was < 38 kg ha^{-1} and cultivation was done in plain lands.

Maize yield variability in *rabi* season was categorised in four groups through the following criteria. In order of decreasing importance these were–fertilizer dose, total labor employed in maize cultivation, total investment in maize cultivation, and organic manure application (Fig. 4). The average yield of rabi crop was 4.4 t ha^{-1} (n = 79) which was about 1.22 t ha^{-1} higher than the regional average. The highest yield (6.5 t ha^{-1}, TN5) was obtained with high dose of fertilizer used (922 kg ha^{-1}); for field where < 900 kg ha^{-1} fertilizer was used, highest yield (5.55 t ha^{-1}, TN4) was obtained with < 44 man days employed in production (Node 4, n = 27), and application of more than 787 kg ha^{-1} organic manure (TN4, n = 8). Lower yields were observed in farms where investment was < INR 967 (TN1, n = 8) with < 44 man days employed in maize production.

3.5. Factors discriminating highest and lowest yield

The highest and lowest yield classes represented in different nodes of the regression trees (Figs. 2–4) were used to compare the mean values of different splitting variables in these nodes (Fig. 5). Comparing the lowest and highest yields for overall maize grain yield (TN 8 and TN 7, respectively) revealed that highest yield was

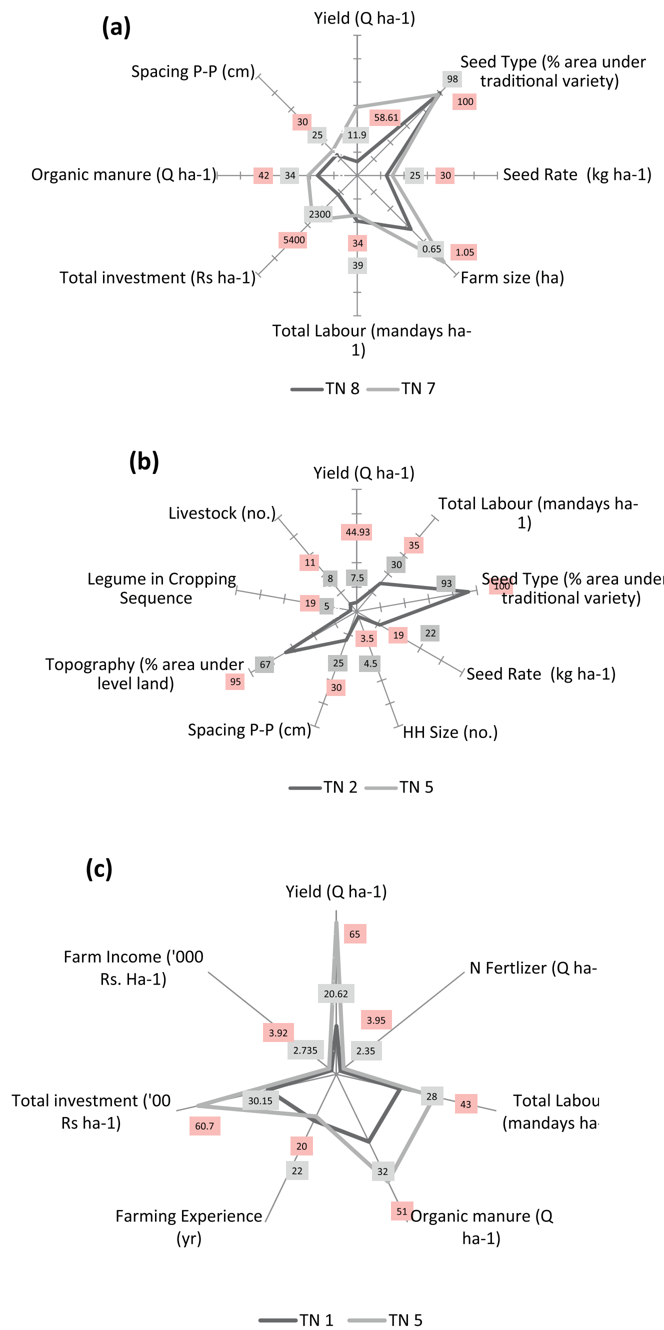

Fig. 5. Spider diagrams representing the yield and some selected factors discriminating the lowest and highest yield in (a) Overall, (b) *kharif*, and (c) *rabi* seasons. Terminal node for lowest and highest yield is represented by separate lines.

obtained because of sowing hybrid seed (and not traditional type), higher seed rate (30 kg ha^{-1} against 25 kg ha^{-1}), higher farm size (1.05 ha against 0.65 ha), lower total man days used (34 man days against 39 man days), higher investment in maize cultivation (INR. 5400 ha^{-1} against INR. 2300 ha^{-1}), higher organic manure application (42 q ha^{-1} against 34 q ha^{-1}) and higher P-P spacing (30 cm against 25 cm) (Fig. 5a). These differences led to a yield gap of 4.67 t ha^{-1}. Moreover, while comparing the lowest and highest yields for overall *kharif* maize grain yield (TN 2 and TN 5, respectively) it was revealed that a combination of more labor days (35 man days against 30 man days), more area under improved seed (100% against 93%), higher seed rate (22 kg ha^{-1} against 19 kg ha^{-1}), lower size of household who may be used as farm labors (3.5 against 4.5), higher P-P spacing (30 cm against 25 cm), more area of plain

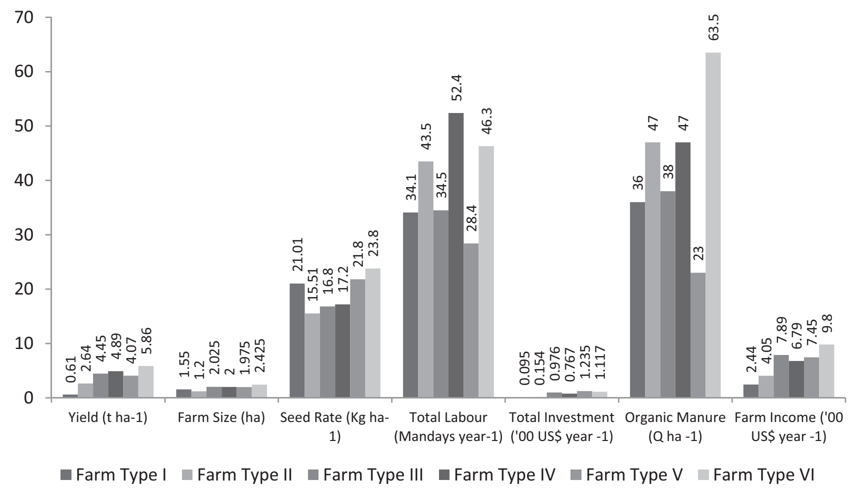

Fig. 6. Comparison of Farm Types in terms of selected splitting criteria used in regression tree analysis (Fig. 2). Units have been transformed for better visual representation.

cultivable land (not undulating), more farms growing legumes (19% vs. 5%), and higher livestock ownership (11 against 8) produced higher yield (Fig. 5b). For *rabi*, maize yield gaps (between TN 1 and TN 5) were observed for nitrogenous fertilizers (3.95 q ha^{-1} against 2.35 q ha^{-1}), total labor use (43 man days ha^{-1} vs. 28 man days ha^{-1}), organic manure use (51 q ha^{-1} against 32 q ha^{-1}), experience of farmers (20 years against 22 years), total investment (INR.6070 ha^{-1} against INR. 3015 ha^{-1}), and farm income (INR.39200 ha^{-1} against INR. 27350 ha^{-1}) (Fig. 5c).

3.6. Construction of an indicative farm typology

Apart from explaining yield variability in maize, the CART analysis also helped to identify probable farm typologies in the study locations. Farm typology delineation typically follows cluster analysis (CA) [41] or a combination of principal component analysis (PCA) followed by CA with the extracted principal components [42]. However, due to the non-linear nature of data and huge diversity in the smallholder systems we preferred CART for the present study. This is typically suitable for smallholder systems of the study area where different farm types could ideally be characterized by different variables. Moreover, preprocessing or rescaling of the data is not required since the clustering method is not influenced by data scaling. In addition, CART successfully manages missing data and exhibits easy control over the selection of optimal number of clusters. Readers are referred to Duvernoy [43] for more details.

Taking the whole dataset together and maize yield as the target variable, we identified six farm types from 9 TNs. TN 1 represented farms those use indigenous maize seed with low seed rate. These were the tribal farmers growing maize for cattle feed and subsistence purpose only (Farm type - I). Subsequently, TN 2 represented farms those use low seed rate of improved varieties and employed less labor and capital. These were typical resource-poor smallholders of the region and grow maize for subsistence (Farm type - II). Notably, there was another group of farms with higher investment in maize (TN 3) and represented resource-rich farmers operating under input-intensive and non-labor intensive systems (Farm type - III). Yet, another group of farms, typical family farms, employed more human labor than others (TN 4) (Farm type - IV). Farms (TN 5 and TN 6) those used higher seed rate of improved varieties and applied relatively less organic manure constituted another farm type (Farm type - V). We did not distinguish TN 5 and TN 6 that are based on P-P spacing, and thus differing only in management decision. This would not have led to the conceptualisation of a logical farm type. These farms were resource-rich farms depending highly on inorganic nutrient sources. Another farm type, achieving highest yield, employed high organic manure in addition to the said parameters (TN 7). These farms belonged to resource rich farmers employing both inorganic and organic nutrient sources (farm type - VI). Other groups of farm were based on farm size only (TN 8 and TN 9), and we did not consider them as distinct group assuming that farm size would have a ubiquitous effect on typology that needs separate enquiry. For characterisation of the identified farm types, we have separately compared the magnitude of splitting criterion of the regression tree (Fig. 6). We did not construct further typology for different crop seasons since seasons would only affect management decisions without directly affecting farm resource endowments.

4. Discussion

4.1. Agro-ecological constraints of maize productivity in surveyed locations

Findings of this study were presented in terms of–maize yield recorded in different crop seasons in two distinct agro-ecological situations, the relationship between different socio-economic and crop management factors and maize yield, and categorization of maize growers into relatively homogenous groups. We used some proxy variables for soil fertility (e.g. extent of soil problem) and soil moisture (e.g. irrigation constraints) along with the socio-economic and crop management factors. As farmers are believed to be keen observers of their agro-ecological situation including climatic events [44] and soil [45], their perception and use of proxy variables were used as alternatives to soil testing.

Maize production in our study area was affected by crop seasons that differed strongly across agro-ecological zones (Table 3) and was further aggravated by sub-optimal management practices (Table 4, discussed in Section 4.2). Accordingly, current yields were found to be less than the maximum yield recorded in the same region [34]. To achieve maximum yield, maize requires high solar radiation, high mean day temperature, ample supply of all limiting plant nutrients, good rainfall distribution during crop establishment, and possibly a dry period before harvesting [46]. Adequate rainfall is imperative for proper functioning and subsequent adoption of improved maize technologies developed for higher maize yield [63]. In addition to low and erratic rainfall during kharif season (either post- planting or throughout the crop cycle), excessive run-off in undulating terrains creates moisture stress in both zones. Although maize is a less water intensive than rice or wheat [20], poor yield can results under such highly water constrained situations.

Poor soil fertility was identified as a major constraint to maize productivity that affected the majority of farmers' fields (Tables 4 and 5) and overruled yield gaps between sites. The lowest yields were found on farms with soils that were perceived as poor by farmers. Based on the farmers' perception and some basic data, it can be concluded that soil fertility constraints in Red and Lateritic zone were generally more severe than that of Old Alluvial zone due to lack of plant available nutrients and low pH [47]. These constraints were further aggravated by inefficient management of land resources.

Soil heterogeneity not only determines water and nutrient limitations, but also influences farmers' management decisions [31]. Since most of our study area, especially the Red and Lateritic zone was characterized by rainfed maize production, the date of sowing is likely to be affected by the erratic onset of monsoon. Indeed, farmers in eastern India often experience yield reduction in maize due to delayed sowing leading to a shorter growing season [46]. Besides, yield reduction tends to be > 3% per day if moisture stress reduces the leaf area index (LAI) considerably after 50 days of planting. Furthermore, moisture stress around tasseling and silking stages could result in nearly 13% yield reduction and may sometimes stop pollination and subsequent crop failure. Soil moisture stress further reduces nutrient availability and thereby doubling the harmful impacts. To combat this problem, adoption of short duration and drought tolerant varieties for drier tracts, particularly in Red and Lateritic zone could be a better alternative. Unfortunately, till date the availability of short duration varieties of maize for dry land areas is scant indicating a pressing need for immediate intervention. Multi-eared hybrids appear to be less sensitive to moisture than typical single-eared hybrids [46].

The study also highlighted the importance of growing legumes to improve inherent soil fertility and enhance maize yield. However, very few farmers (18%) included legumes in the cropping sequence to achieve the yield advantage than others (Table 4). Although conservation farming advises farmers to rotate cereals with legumes [48], farmers still accord priority to cereals over other crops including legumes. Apart from improving soil organic carbon, growing of legume in a cropping system is a well-established practice for restoring soil fertility that adds residual N to the tune of 30-60 kg ha^{-1} [46].

4.2. Interaction between socio-economic constraints and management intensity

Socio-economic factors play an important role in determining crop yield by affecting crop management practices vis-à-vis input intensity [49]. Present study identified significant associations between maize yield and ethnic origin ($p = 0.00$), ownership of land ($p = 0.00$), farming experience ($p = 0.04$), farm size ($p = 0.00$), and family size ($p = 0.00$). In this study, scheduled caste community is of agrarian caste and has accumulated experience on farming for generations [50] that helped them to achieve higher yields. On the contrary, tribal people generally follow traditional farming and hesitate to adopt innovations readily [51]. Problem in legal ownership of land exacerbates the agricultural productivity of tribal farmers [52] and affects agricultural practices in two ways. Firstly, landowners generally employ a more sustainable production strategy than tenant farmers who exploit the land resources unsustainably, thus leading to lower yield. Secondly, farmers often get less fertile leased in lands from the owners who keep better quality lands (typically lands with higher soil depth) for their own cultivation [53]. The experience of the farmer recorded a significant substantive impact on the yield, particularly in *rabi* season. The experience profile of a farmer exposes him to diverse surroundings and events which helps in building up management orientation and desire to maximize the profit of his farming [54]. Experienced farmers are generally more prone to accept innovations, although after a certain age risk bearing ability is believed to go down [55,56].

In the present study, the economic factors included farm size and non-farm income generation activities that farm households were engaged in. Farm size is almost universally been believed to have relationship with adoption of innovations and higher crop productivity [56]. In our study, farm size was found to have a positive relationship in general with the probability of getting higher average yield of maize. This was due to more efficient input management in larger farms when cultivation is technology driven [57]. Moreover, farmers with larger holding are generally resource-rich and could invest more in maize cultivation. Literature also suggests that large-scale farmers are more inclined to adopting new improved technologies than small-scale farmers [56,58,59]. This presents a serious challenge to policy makers because majority of farms in the studied districts are small scale with average farm size below 1 ha. Nevertheless, this finding stand different from several findings in the context of Indian agriculture in general [60,61], and maize yield in particular [62], where inverse relationship between farm size and productivity was reported. This might be due to the fact that maize is not generally cultivated as a food crop in India but as a cash crop (for feed industry) that necessitates higher management intensity mostly affordable by resource-rich farmers. Moreover, efficiency of family farms largely rests on the intensity of family labor use, which is becoming scarce due to slow transition from joint to nuclear family system in India. The significance of the household size on overall yield of maize shows that farmers with larger household size have the required family labor for maize cultivation, but more mouths to feed and more income to sustain their needs. They seek alternative ways of diversifying their livelihoods to earn additional income [63]. Maize yield in surveyed area also depended on farmers' investment options. Higher Investment for purchasing hybrid seed (desired quantity), organic manures, fertilizers, and pesticides by wealthier farmer can result into higher productivity of the crop. Small-scale operators, particularly in the challenged Red and Lateritic agro-ecosystem, might have lower capacity and higher risk perception about a new crop like maize and is expected to be resistant to the adoption decision of improved maize technology package [64]. Investment in maize cultivation also has a close association with income of the farm family where higher income provides farmers the ability to afford needed inputs and equipment for proper crop management [63]. The annual income of the farmer determines the risk taking ability, capital investment in farming practice, and knowledge sharing for technological intervention to maximize the profit [54]; thereby yielding substantive effect on maize cultivation. Similar links between poverty and low crop yields were found by Zingore et al. [19] and Tittonell et al. [65] for maize and groundnut in Africa. It will be more difficult for less endowed households than more endowed households to increase maize yields because: (i) less endowed households face multiple production constraints and lack the social and economic capital to intensify crop management, and (ii) removing one stress in a multi-stress environment will produce lesser productivity gain than in an environment facing only one or two stresses. Annual income is found to be instrumental in exerting highest indirect effect on other variables, which, in turn, affect agricultural productivity [66]. Further, though off-farm activities were significant only in kharif maize cultivation (Table 5), they were always believed to have negative relationship with agricultural productivity. This implies that with higher rate of off-farm activities reduces the probability of getting higher yield of the crop.

The present study also showed that the seed type (for Kharif and overallyield), seed rate (for Kharif and overall production), spacing (P-P), and organic manure application (for overall production) determined the maize yield in both surveyed locations (Figs. 2, 3, 4). Survey also showed that household labor availability significantly influenced the overall maize production (Table 5). Topography of land affects the ease of crop cultivation and many of the crop management practices. In Red and lateritic zone, many maize growing fields were undulated and caused severe problem in crop cultivation irrespective of growing season. This problem was, however, not so pronounced in Old Alluvial zone and therefore presumed not affected maize yield. Distance of farms from metal road and input markets are of immense importance for crop management practices. Romney et al. [67] concluded that farmers having land near road can easily transport the produce to nearest market place and therefore are able to save a significant extent of expenditure. Similar relationship exists with physical access to input markets. This is particularly true when new technologies are widely available in the market. Both easy procurement of input and free counseling from input retailers make the farmers' assured of input and advisory services.

The CART analysis allowed us to identify overall trends for factors affecting maize yields taking into account the variable interactions and identified the limiting factors for each individual field while ignoring interactions. This approach ascribed similar importance to bio-physical, structural, and socio-economic factors but gave different weights as a yield-determining factor. The importance given to variables in the CART model depended on whether or not the variables showed significant correlations with yield. CART exhibited interactions between factors influencing maize yield for two different agro-climatic situations in eastern India and also helped us to categorize farms in six distinct types namely, i) tribal farmers growing maize for cattle feed and subsistence purpose, ii) resource-poor smallholders of growing maize for subsistence with low management intensity, iii) resource-rich farmers operating under input-intensive and non-labor intensive systems, iv) typical family farms investing high human labor, v) resource-rich farms applying high inorganic nutrient sources, and vi) resource rich farms employing both inorganic and organic nutrient sources. Summarily, this will help policy makers and public extension to target maize cultivation packages according to the need of the type of farms.

4.3. *Scope of closing the maize yield gap through improved production practices*

Present study has indicated possible ways to reduce the maize yield gaps (Fig. 5). Overall, increased coverage of area under hybrid seed, appropriate seed rate, P-P spacing, capital and labor investment, and application of organic manure are the key areas that need policy or extension intervention. Biophysical environment such as land situation and management practices such as incorporation of legume in cropping sequence also can contribute to diminish yield gap, especially in *kharif* season. In contrast, better nutrient management and higher management intensity through higher investment appeared to be important areas for intervention for the *Rabi* maize. While a comprehensive production package is expected to address most of these issues others may require access to institutional support or cross-subsidy and capacity building of farmers in part of the public extension.

The identified yield gaps for maize may be, at least partially, closed through improved production practices and yields can be doubled with the full technology package recommended. Nonetheless, there is scope for yield improvement even without introducing new genotypes, as was clear from the large variation in maize yields under current farmer practice. This may be explained from the differences in financial and human capital among farmers which were translated into variations in input use and labor availability for crop management. During the survey, many farmers indicated soil related problems in maize fields and perceived maize to be highly sensitive to soil fertility constraints. Studies have emphasized the importance of nutrient management for good maize productivity [20]. The promotion of options to improve or overcome severity of soil fertility problem thus seems crucial to improve maize yield. Average maize plant densities on farmers' fields in the region are low. Increasing plant density to the recommended number of plants ha^{-1} on fertile as well as poorer soils, with adequate and balanced nutrient application, is expected to result in better crop establishment and subsequently higher yield. This effect can be reinforced through the use of vigorous early maturing genotypes (hybrids) instead of traditional genotypes. Maize breeders will need to find a balance between yield potential and fertilizer management as early traditional genotypes generally have less yield potential than hybrids.

Earning reasonably good profit from cereal crops in smallholder farming is difficult due to high input costs and relatively less output value in the market [68]. Smallholder farmers often are less aware of or have no access to knowledge about site-specific input management requirements for individual farms [69]. Often input managements are sub-optimal or in excess than required, causing economic losses to farmers. This highlights the necessity of disseminating improved input management strategies, particularly nutrient management to improve the economic conditions of smallholder farmers in Eastern India [70]. To reduce the impact of soil fertility constraints in maize productivity, fertilizer is perhaps the easiest, but probably also the most expensive technology. Fertilizer use is a key component for maize yield [71], however, rapid introduction of maize in non-traditional areas with lack of adequate knowledge regarding nutrient requirement has not allowed farmers to achieve the expected high yields or profit [72]. The nutrient recommendations currently in vogue are blanket in nature and do not consider the spatial and temporal variability so often encountered in maize production ecologies. Often a single nutrient recommendation is provided to large group of farmers that largely differ in terms of resource endowment and socio-economic parameters. New technologies, starting from hybrid and biotic/abiotic stress tolerant germplasms, planting machinery, fertilizer decision support tools, new generation herbicidal and crop protection molecules, and post-harvest preservation techniques are now available to support maize production in the country.

Still, as was evident in this study, the socio-economic parameters of maize farmers strongly influence maize yield. Technologies have to adapt to the scale and resource availability of smallholder farmers to ensure adoption of technologies and subsequent improvement of maize productivity. Since KVKs are actively engaged in technology assessment and refinement, role of this institution will be crucial in tailoring maize cultivation packages for farmers of different resource-endowment in different agro-ecological systems. Management intensity, directly governed by capital and labor investment, may be maintained by appropriate policy and public extension support. Since, we have found differential importance of yield determining factors in different crop seasons, a seasonal intervention policy seems to be a more pragmatic approach in reducing yield gap. For e.g. extension support in the form of credit or other forms of policy support or incentive is particularly important in *Rabi* season.

5. Conslusion

Series of farm surveys in two different agro-ecological zones of eastern India demonstrated substantial yield gap and yield variations among farms across growing seasons. Lower yields of farmers were associated with ethnic origin of farmers, availability of family labors, land ownership, legumes in cropping sequence, constraint of irrigation, seed type, optimal plant population, labor and capital investment, and use of organic manure. These constraints for maize productivity varied strongly between sites as well as growing seasons. Stochastic Frontier Analysis suggested intensification of farm input use and removal of socio-economic and structural constraints for increasing efficiency in maize production.CART revealed that maize yield in farmers' fields were affected by multiple and interacting production constraints, and differentiated the surveyed farms in six distinct resource groups. These farm types lend scope for introducing typology-specific crop management practices through appropriate participatory on-farm evaluation/trials.

Improved crop establishment methods and genotypes, assured irrigation along with efficient nutrient management, may be particularly important to improve maize yield in farmer fields. The interacting production constraints should be addressed simultaneously, considering the need of different farm types, if significant productivity improvements are to be achieved. However, this will be more difficult for less endowed than for better endowed farm households, since the former lack of resources to improve management intensity. A typology-specific farm support strategy may be formulated to offset this lack of entitlement among resource-poor farmers.

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