Integrating Biophysical and Socio-economic Determinants into Field-specific Fertiliser Recommendations

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Socio-economic conditions of smallholder farmers, and their resource endowment, plays a major role in fertiliser application decisions in maize. The use of Rapid Rural Surveys in the present work helped identify distinct typologies of maize farmers from West Bengal in Eastern India. Farmer-specific fertiliser recommendations from the Nutrient Expert® tool, integrating biophysical and socio-economic determinants, helped improve maize productivity for different farm typologies.

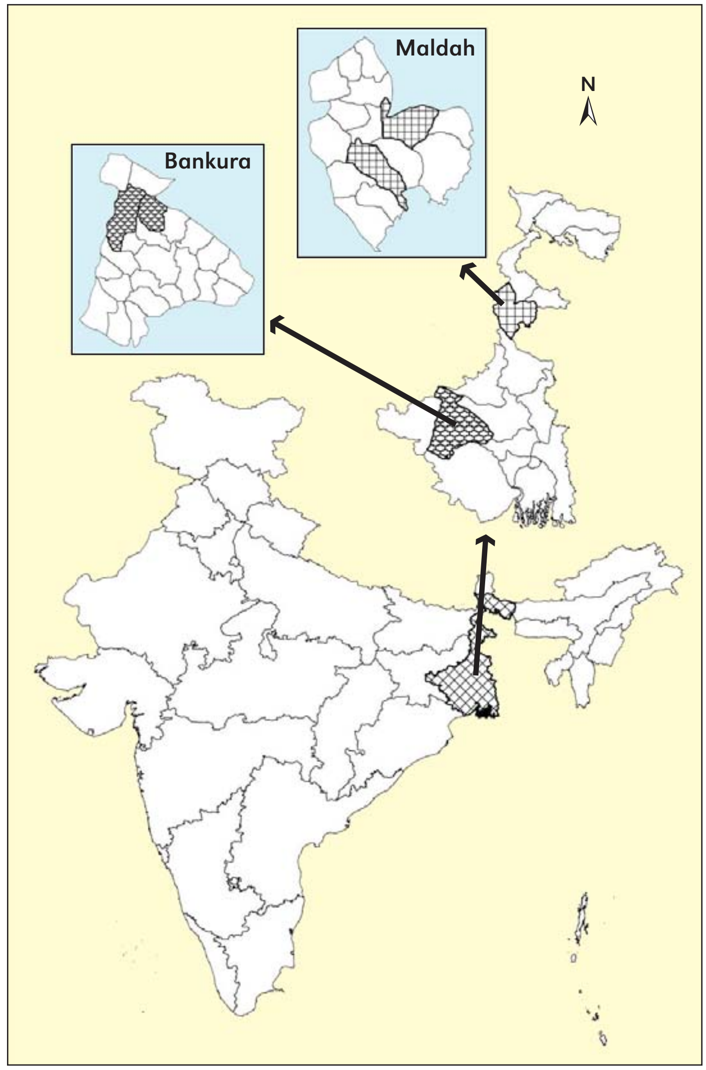
Maize farming in eastern India is dominated by smallholder farmers, operating under a wide range of soil, climate, and socio-economic conditions. Farmer resource endowment plays a potentially important role in determining profitability of maize production systems (Banerjee et al., 2014). Addressing the low productivity of maize in the region requires identification of yield-limiting factors in different socio-economic settings and characterization of farm typologies (classifications) for targeting site-specific management interventions. Farm typology recognizes that farmers are not a monolithic group and face different constraints in their farming decisions based on available resources and their lifestyle (Soule, 2011). Grouping farmers within a domain in different typologies is an essential step in realistic evaluation of the constraints and opportunities that exists within farm households for appropriate interventions. The present study was initiated to identify different typologies of smallholder maize farmers in Eastern India.

Farm typologies were determined on the basis of information derived from surveys conducted in Bankura and Malda districts of West Bengal. The two districts represented two distinct agro-ecological zones of the state and are representative of a large part of eastern India in terms of farmer socio-economic conditions and bio-physical characteristics of their farmlands. Structured interviews with a standardized questionnaire were conducted in 180 farms (90 farms per district). Survey questionnaires were designed to capture bio-physical, socio-economic, and managerial aspects of farming. A database was created and screened to eliminate outliers in the dataset—167 entries were retained in the database. 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. We hypothesized that farmer typology driven fertiliser recommendations based on the Nutrient Expert® for Maize (NE) fertiliser decision support tool (Pampolino et al., 2012) would be able to improve farmers' yield and profitability in smallholder maize systems of Eastern India.

Results and discussion

During descriptive analysis, categorization 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 total (*kharif* + *rabi*) productivity as the target variable. 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 (**Figure 1**). Maize farmers who used less than 28 kg/ha (Node 2, n = 137) seed produced an average maize grain yield of 3.9 t/ha; whereas, farms where seed rates were more than 28 kg/ha achieved an average yield of 2.3 t/ha (Node 8; n = 30). Node 8 is further split by farm size, with less than 0.5 ha farms yielding 1.2 t/ha (TN 8, n = 13) on an average and farms of more than 0.5 ha yielding 3.2 t/ha (TN 9, n = 17). Node 2 is further split into the type of seed used. Seed type 3 (traditional seed type) produced a mean yield of 0.6 t/ha (TN 1, n = 5); whereas seed type 1 and 2 (composite and hybrid seeds) yielded 4 t/ha (Node 3, n = 132). This node

Abbreviations and notes: P = phosphorus; K = potassium; TN = terminal node; ₹1 = US$61.



Study locations (Districts) within West Bengal.

is, in turn, again split by seed rate. Plots where less than 18 kg/ha seed was used yielded average 3.5 t/ha (Node 4, n = 60); whereas, an average yield of 4.4 t/ha was achieved when more than 18 kg seed/ha (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 labour. An average yield of 3.1 t/ha was recorded (Node 5, n = 45) when less than 47 man days were used in maize production; the mean yield increased to 4.9 t/ha (TN 4, n = 15) when more man days were employed for cultivation. Node 5 is split by total investment, with investment less than ₹900/ha resulting in a yield of 2.6 t/ha (TN 2, n = 34) and investment in excess of that resulted 4.5 t/ha of yield (TN 3, n = 11). Node 6 was split by organic manure. When less than 5.8 t/ha organic manure was used, a yield of 4.1 t/ha (Node 7, n = 56) was observed; the average yield increased to 5.9 t/ha (TN 7; n = 16) with higher application of organic manure. Node 7 was split by "plant-to-plant" spacing of maize; average maize yield was 3.4 t/ha (TN 5, n = 31) when spacing is less than 28 cm. Mean yield of 4.9 t/ha (TN 6; n = 25) was recorded with higher spacing.

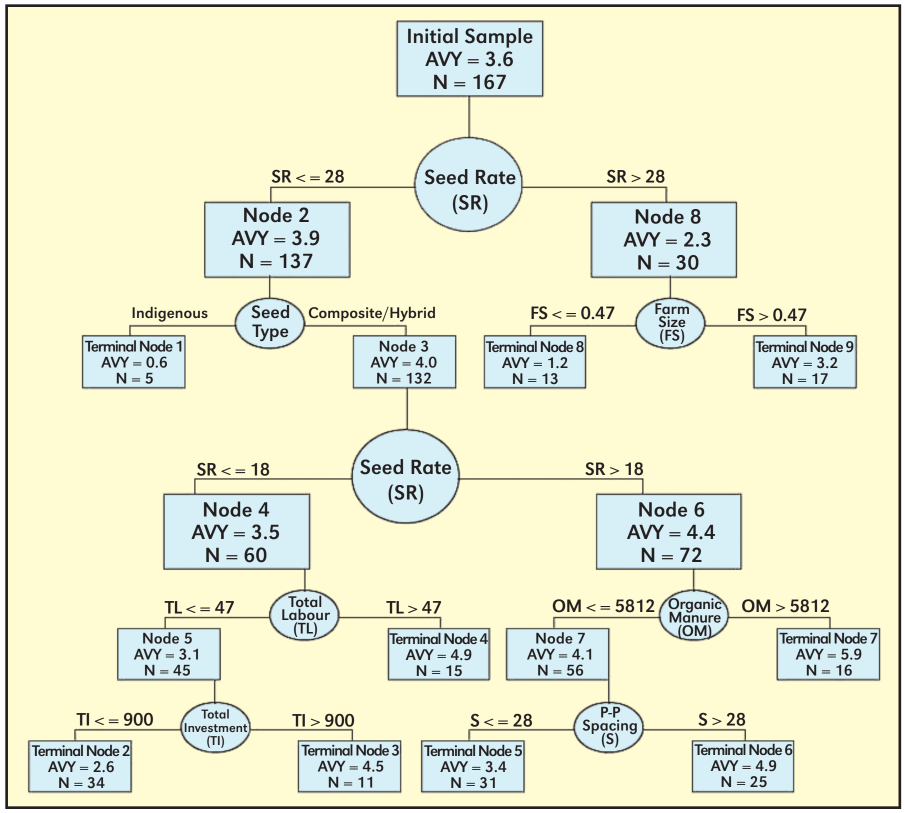


Figure 1. Classification and regression tree models to describe maize grain yield as a function of variables describing agronomic management and socio-economic conditions. Each splitting variable is associated to a threshold value in its own units that separate the larger group of data in two subgroups. In the square box the AVY value is the average yield of the group and the n value corresponds to the number of observations contained in that group.

The highest and lowest yield classes represented in different nodes of the regression trees (**Figure 1**) were used to compare the mean values of different splitting variables in these nodes (**Figure 2**). Comparing the lowest and highest yields for overall maize grain yield (TN 8 and TN 7, respectively) revealed that highest yield was obtained because of sowing hybrid seed (and not traditional type), higher seed rate (30 kg/ha against 25 kg/ha), higher farm size (1.0 ha against 0.6 ha), lower total man days used (34 man days against 39 man days), higher investment in maize cultivation (₹5,400/ha against ₹2,300/ha), higher organic manure application (4.2 t/ha against 3.4 t/ha) and higher plant-to-plant spacing (30 cm against 25 cm) (**Figure 2**). These differences led to a yield gap of 4.7 t/ha.

Apart from explaining yield variability in maize, the CART analysis also helped to identify probable farm typologies in the study locations. Taking the whole dataset together and maize yield as the target variable, we identified six farm types from 9 TNs (**Figure 2**). Farm Type – I represented farms that use indigenous maize seed with low seed rate. These were the tribal farmers growing maize for cattle feed and subsistence purpose only. Subsequently, Farm Type – II represented farms that use low seed rate of improved varieties and employed less labour and capital. These were typical resource-poor smallholders of the region and grow maize for subsistence. Farm Type – III

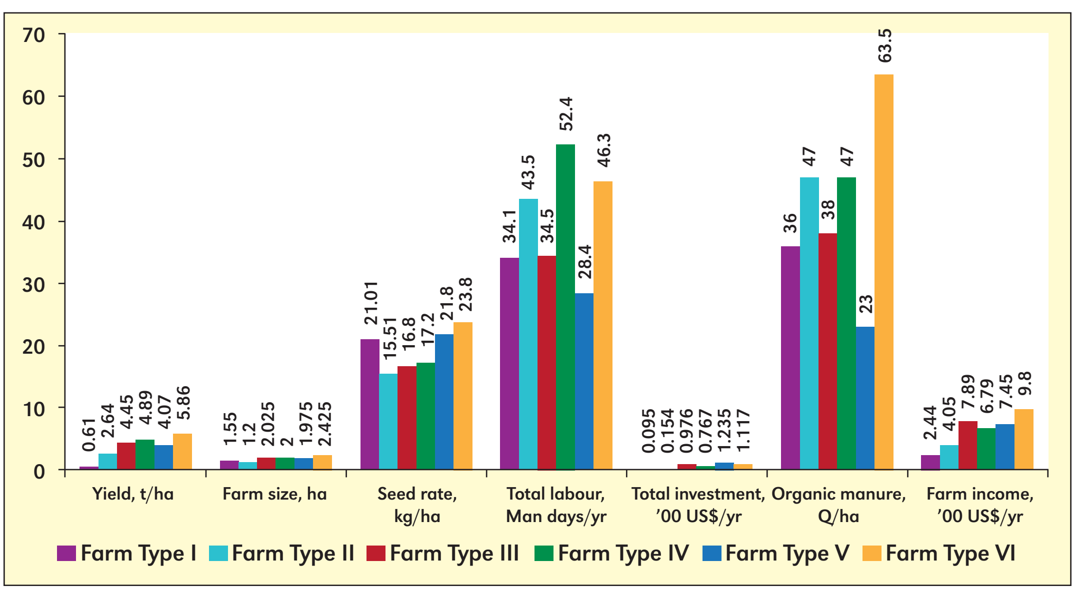


Figure 2. Comparison of Farm Types in terms of selected splitting criteria used in regression tree analysis. Units have been transformed for better visual representation.

was another group of farms with higher investment in maize and represented resource-rich farmers operating under input-intensive and non-labour intensive systems. Farm Type – IV was typical family farms that employed more human labour than others. Farms that used higher seed rate of improved varieties and applied relatively less organic manure constituted another farm type (Farm Type – V). Finally, another farm type that belonged to resource rich farmers employing both inorganic and organic nutrient sources and achieved highest yield constituted Farm Type – VI.

It is important to highlight that nutrient management had a highly significant effect on maize yield in all farm types. As a result, nutrient management was not included in the CART analysis shown in **Figure 1**, as this would have resulted in all other factors being insignificant. The impact of nutrient management is highlighted in **Table 1**, showing the "Total Investment", which is largely influenced by the cost of fertiliser.

As a test case, the effectiveness of applying NE-based fertiliser recommendation over farmers' fertiliser practices (FFP) was tested in a different set of farmers in the South 24 Pargana District of West Bengal. A total of 17 maize-growing farmers were surveyed and were grouped based on their varying existing yield status that ranged from 1.5 to 4.9 t/ha. Two groups of farmers were formed - one with last year (i.e., 2013) average yield of 2.8 t/ha (Type I) and the other group with last year average yield of 4.2 t/ha (Type II). The NE-based recommendations were given to all these farmers in the two different groups. It was observed that the maize grain yield achieved through NE-based fertiliser recommendation was significantly ($p \leq 0.05$) higher in both the types of farmers

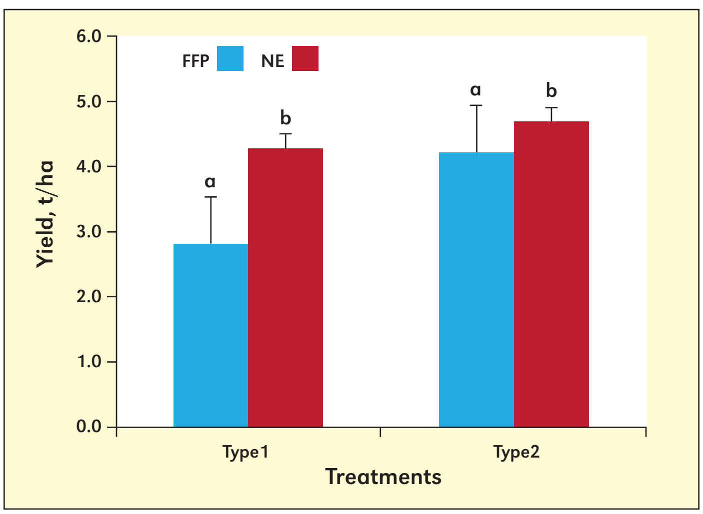


Figure 3. Maize yield at farmers field with Farmer Fertilization Practice (FFP) and Nutrient Expert® (NE) treatments at two different groups of farmers. For comparisons within farm types, columns with different letters are significantly different at $p \leq 0.05$.

(**Figure 3**). Moreover, the average total fertiliser costs were significantly ($p \leq 0.01$) less using NE in both Type I (₹3,552/ha) and Type II (₹4,722/ha) over FFP for Type I (₹4,861/ha) and Type II (₹6,681/ha) farmers (**Table 1**). This is mainly due to significant ($p \leq 0.01$) reduction in P application in the NE plots for both Type I and Type II farmers. It is interesting to see that although there was significant increase in K fertiliser consumption, still there is significant decrease in fertiliser

Table 1. Agronomic and economic performance of Nutrient Expert® (NE) over Farm Ferilization Practice (FFP) for hybrid maize.

Type of Farmer	Parameter	Unit	FP	NE	NE – FP	
Type I	Grain yield	t/ha	1.9	4.4	2.5	***
	Fertiliser N	kg/ha	71	111	40	**
	Fertiliser P_2O_5	kg/ha	72	29	- 43	***
	Fertiliser K_2O	kg/ha	29	35	6	ns
	Fertiliser cost	₹/ha	4,861	3,552	-1,309	**
	ROI[1]	₹/ha	5.83	15.28	9.45	***
Type II	Grain yield	t/ha	3.7	4.7	1.0	***
	Fertiliser N	kg/ha	150	129	- 21	ns
	Fertiliser P_2O_5	kg/ha	81	35	- 46	**
	Fertiliser K_2O	kg/ha	45	60	15	**
	Fertiliser cost	₹/ha	6,681	4,722	- 1,959	**
	ROI[1]	₹/ha	7.75	12.45	4.69	***

***, ** denote significance at <0.001, and 0.01 levels; ns = not significant; [1]ROI = Rupee received per rupee invested. Cost of N: ₹12/kg (on the basis of Urea); Cost of P_2O_5: ₹45/kg (on the basis of SSP); Cost of K_2O: ₹27/kg (on the basis of MOP); Value of maize grain: ₹11/kg.

cost for both types of farmers. Also, the Return over Fertiliser Investment (ROI), return per unit invested on fertiliser, was significantly ($p \leq 0.01$) higher in the NE plots over the FFP plots, from ₹5.83 to ₹15.28 for Type I, and from ₹7.75 to ₹12.45 for Type II farmers, respectively.

Conclusions

Results from the present study highlight that the farm survey is an effective tool in delineating farmer typology. The survey conducted in the two different agro-ecological zones of West Bengal helped identify socio-economic and bio-physical determinants for yield gap and yield variations among farms across growing seasons. NE-based fertiliser recommendation for two different farm typologies significantly ($p \leq 0.05$) improved yield and profitability over existing farmers' fertilization practices with less input cost. These results highlight that the NE tool-based fertiliser recommendations can successfully increase productivity and profitability of smallholder maize farmers, operating under a wide range of soil, climate, and socio-economic conditions. BC-SA

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