MAPPING RICE YIELD AND ITS FERTILIZER RESPONSE AT PROVINCIAL-SCALE IN TAKEO, CAMBODIA

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Abstract

Our objective was to identify responsive areas for nitrogen (N), phosphorus (P) and potassium (K) fertiliser use on rice (Oryza sativa L.) within Takeo province from trial results obtained at 2336 sites. Regression tree analysis identified in order of decreasing importance the following factors which explained the variation in yield from on-farm experiments: season, location, fertiliser, soil type. Semi variograms of the same data set indicated that a maximum spread of 12 km in datum points was required to map yield across the province. Separating the results into N response classes decreased the maximum spread of datum for mapping to only 8 km. The maps generated indicated areas in which response to fertiliser is more or less likely. Whereas P responses were predicted to be relatively uniform across the province, N and K responses were more varied. Results suggest a very strong positive response to N, particularly on the central-west of the province. They also suggest negative effects of high N rates on the most fertile soils (Kbal Po, Krakor) in the east of Takeo, and in the Prateah Lang and Koktrap soils in the flooded areas of the south east of Takeo. At the provincial scale, the maps identified areas that can be used to target extension effort to where it is likely to be most effective, and areas where further research is needed to clarify reasons for poor responses. This should enhance the strategic planning capability for delivery of extension services and fertiliser inputs.

Keywords: fertilizer, location, mapping, rice, season, soil type, yield.

Introduction

In Cambodia, as in most parts of the world, national research programmes have developed nutrient management advice based on fertiliser recommendations that are generalised to soil types (e.g. White et al. 1997a,b). Traditionally fertiliser recommendations have been based on mean responses for particular soils and ecosystems (Dobermann and White 1999), derived from responses for a number of experiments, replicated across locations and seasons. The variability of the responses is often not reported or not emphasised. However, farmers’ make decisions about fertiliser based among other things on specific responses expected on their land, and for their decision making the variability is as important as the mean response.

Avoidance of risk occupies a more important position in the decision making of rainfed farmers than for irrigated farmers (Ziegler and Puckridge 1995). Farmers in the rainfed lowlands have traditionally used little fertiliser, and it is suggested that their risk aversion behaviour is a major factor governing their decision not to adopt fertiliser. Support for this notion is provided by Pandey (1998) who reported that rates of NPK fertiliser use across Asian countries are correlated positively with the % of the rice crop that is
irrigated. Jahn et al. (1997) conducted surveys in Cambodia which showed that only 27% of rainfed farmers used inorganic fertilisers compared to 70% of dry season farmers who have access to irrigation. However, in Takeo in 2000, close to 100% of rice farmers in 3 villages were using inorganic fertilisers (Ieng et al. 2002). These villages were selected to represent rainfed, rainfed-irrigated and receding floodwater rice ecosystems and each involved surveys of 50 farmers. Hence in Takeo province at least, there is evidence of a rapid shift in adoption of fertilisers over a 5 year period. Ieng et al. (2002) suggested that a key priority with nutrient management advice in Takeo in future was not the promotion of the use of fertiliser to farmers, since use is already widespread, but rather to increase a recognition of how fertiliser requirements vary with soil type and with seasonal variations in soil water regimes.

There are a number of agencies that provide nutrient management advice to farmers in Cambodia, including CARDI, Department of Agronomy and Agricultural Land Improvement, Provincial and District Agriculture Offices and NGO’s. These agencies may also carry out their own research to develop fertiliser recommendations. Some duplication of information is inevitable, but perhaps more importantly an opportunity exists to improve the quality of information provided to farmers about nutrient management by integrating the various data sets.

The central premise of this project is that fertiliser is under-used by farmers or the balance of nutrients applied is inappropriate because of gaps in communication between researchers who indicate a significant benefit of fertiliser use and growers who are expected to risk buying it. We examined the problem at provincial scale in Takeo, south east Cambodia, where several sources of research information existed across several agencies. By bringing these data sources together, maps which represented yield and yield response could be more reliably produced. The objective of producing maps was to help provincial and district advisers and fertilizer distributors answer the following sorts of questions:

1) where is rice yield inherently high or low?
2) where is rice likely to respond to fertiliser and by how much?

**Materials and methods**

An initial data set of 748 samples, comprising 82% wet season sites, was obtained from simple field trials on farmer fields conducted by FAO and the Cambodia-IRRI-Australia Project (CIAP). Most of the initial data set (referred to as the partial data set) was located in central and northern districts of Takeo province (Figure 1). A more complete data set was obtained by adding sites from the Cambodia-Australia Agricultural Extension Project (CAAEP) and PRASAC (Table 1). All results presented, use the complete data set. The complete data set had better presentation over the whole province (Fig. 1) but comprised only 65% wet season sites. A range of attributes for each site were reported including: village and commune location, soil type, season, field type. Each site had fertilizer treatments applied and rice yields recorded. In addition observations recorded about each crop included: variety, insect damage, disease, drought, flood.

When samples were located onto a map of Takeo Province using the recorded GPS coordinates, many fell outside the province. This was attributed to the use of an incorrect datum when the GPS coordinates were recorded. To correctly locate sites, it was necessary to relate location of a site to the known coordinates of the nearest village using the Department of Geography database.

**Regression tree analysis**

Regression tree analysis was used to predict factors affecting yield from the Takeo on-farm trial data and more importantly to understand the structural relationships between yield and trial site parameters. The regression tree

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**Table 1. Source of data in the partial and complete data set for Takeo province**

<table>
<thead>
<tr>
<th>Data Provider</th>
<th>Number</th>
<th>% of wet season samples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Partial data set</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAAEP</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CIAP</td>
<td>246</td>
<td>33</td>
</tr>
<tr>
<td>FAO</td>
<td>502</td>
<td>67</td>
</tr>
<tr>
<td>PRASAC</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>748</td>
<td>56</td>
</tr>
<tr>
<td><strong>Complete data set</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAAEP</td>
<td>205</td>
<td>9</td>
</tr>
<tr>
<td>CIAP</td>
<td>246</td>
<td>11</td>
</tr>
<tr>
<td>FAO</td>
<td>502</td>
<td>21</td>
</tr>
<tr>
<td>PRASAC</td>
<td>1383</td>
<td>59</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2336</td>
<td>41</td>
</tr>
</tbody>
</table>

1CAAEP - Cambodia-Australia Agriculture Extension Project; CIAP - Cambodia-IRRI Australia Project; FAO- Food and Agriculture Organisation; PRASAC-
analysis has the advantage of scale independence, easy-to-interpret rules and use of both continuous and categorical data (Breiman et al. 1984, Venables and Ripley 1997, Math-Soft 1997).

S-PLUS was used to create regression tree models. The end point of a tree (leaf and terminal node) is a partition of space, where the dependent variable (rice yield) is predicted (Breiman et al. 1984). An iterative process of splitting nodes constructs the tree model by a series of binary splits. The split chosen is based on a goodness of fit criterion. See Breiman et al. (1984); MaltSoft (1997) and Venables and Ripley (1997), for more details.

Minimum deviance was set to 0.01 to control the threshold for splitting nodes. Minimum size and minimum cut, which control size thresholds, were set to 10 and 5, respectively. Each regression tree figure was plotted using the non-uniform spacing option to represent node importance. In addition, yield (t/ha) was predicted at each terminal node. For each chosen variable, increasing length represents greater importance. Hierarchy within the tree and the length of the tree branch determined the variables most important to yield.

**Spatial analysis of rice yield and fertiliser response**

The aim of this analysis was to use spatial visualisation to highlight broad effects of fertiliser: nitrogen (N), phosphorus (P) and potassium (K). Yield data from the complete data set was also interpolated using kriging in VESPER (Variogram Estimation and Spatial Prediction with ERtor) which is available as a shareware program (Minasy et al. 2002).

Analysing the fertiliser response data in original format was too complex because of unbalanced or uneven treatments. A pragmatic approach was therefore to create maps of each level of fertiliser and simply compare these. This gives no information about the shape of the response curve, or the interaction between fertilisers. However, as a visualisation tool this is a useful start. ArcView 3.2 with the Spatial Analyst extension, was used to visualise and process the data. An example of the procedure is as follows:

- Sort the database (containing at least fertiliser, yield, Eastings, Northings and other explanatory variables such as season) according to N rate;
- Plot the frequency distribution of N rates to determine reasonable classes for calculating N response effects. For N, these were selected as: <10 kg/ha (zero); 10-50 kg/ha (medium); > 50 kg/ha (high);
- Map (interpolate using VESPER) yield for each N rate class;
- Using simple map algebra, identify the apparent effect of N as:
  \[ \text{N effect} = (\text{Yield with high } N) - (\text{Yield with zero } N); \]
- N effects calculated were medium - zero; high- zero and high-medium.

Only two classes of K fertiliser were created; zero (including all cases with <8 kg K/ha) and plus K (including all cases with >12 kg K/ha).

**Sensitivity analysis of yield and fertiliser response data**

The aim of this activity was to identify the number of data points sufficient for provincial scale yield and fertiliser response mapping. The analysis concentrated on yield and medium nitrogen (N) response. Random samples of 2336 yield observations were taken using ArcView. Data was sampled at 10 % of the complete data set and then at 10 % increments to 90 %. The minimum sample size was determined by plotting descriptive statistics with increasing sample size.

**Results and discussion**

**Regression tree analysis**

A number of regression tree models were examined starting with simple models using only N, P and K as explanatory parameters, through to as many as nine parameters in a model (Table 2).

**Table 2.** Regression tree analysis models showing parameters tested in order of decreasing importance.

<table>
<thead>
<tr>
<th>No.</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X*, soil, variety, y*, K, P, N, year</td>
</tr>
<tr>
<td>2</td>
<td>N, P, K</td>
</tr>
<tr>
<td>3</td>
<td>Soil, N, year</td>
</tr>
<tr>
<td>4</td>
<td>Season, N, soil</td>
</tr>
<tr>
<td>5</td>
<td>Season, soil</td>
</tr>
<tr>
<td>6</td>
<td>Season, y, x, N, soil</td>
</tr>
<tr>
<td>7</td>
<td>Season, y, x, N, K, P, soil, variety, year</td>
</tr>
</tbody>
</table>

* X east- west coordinate for location; y north-south coordinate for location

The most dominant factor identified was season or rice ecosystem (Figure 2). It was the primary parameter of all regression trees in which it was included and had precedence over location, the next most dominant parameter (Table 2). Season was expected to be a primary factor since dry season crops are generally higher yielding due to improved water control, higher solar radiation and the use of modern varieties (Nesbitt 1997). For future mapping and in order to account for yield variance associated with different ecosystem conditions, the database and analysis could be separated into season accordingly. However, using this approach it may not be possible to produce a map for the whole province since there is limited dry season cropping in the western half of Takeo province and limited wet season cropping in the flooded eastern half (Figure 1).

![Figure 2. Trimmed regression tree for yield (t/ha) as a function of all variables assessed (model 7, Table 2). Variables were season, soil, N, P, K, variety, year, x, y location. Season is the most dominant factor, followed by location, N then K.](image-url)
The location parameter in the regression tree model represented a regional yield trend, east to west, of high and low yields, respectively (Figure 3). It was an unexpected parameter for yield prediction, since only indirect relationships exist between yield and location. Location apparently summarised, at the scale of mapping used, the chemical, physical, social and crop factors directly related to yield in the areas studied. For example, the soils in the west are poorer with sandy surface texture more common and a higher proportion of sites are on high fields that are more drought-prone (Figures 3, 4). Socio-economic differences along E-W and N-S gradients within Takeo may also explain why location is a significant variable. For example, areas in the west of Takeo were until the late 1990’s insecure which may account for a more recent introduction to modern rice growing technologies. Rainfall decreases along W-E and S-N gradients within Takeo (see Javier 1997) but as this would imply a decrease in rice yield with increasing rainfall it does not explain the importance of the location variable. Completeness of the picture in regression tree analysis is dependent on the data input (Breiman et al. 1984). For subsequent analyses additional parameters affecting yield such as site rainfall, drought, flood, geology, geomorphology, disease and pests are recommended.

The dominance of location in the regression tree results represents regional trends in yield that were also evident in the yield map (Figure 3). Soil was a reasonable predictor for yield (Table 3), secondary to location (Table 2). This suggests that within these locations, the soil classification explain some of the structural relationships related to yield. The Cambodia Agronomic Soil Classification is based on soil properties that affect rice yields (White et al. 1997), and generally the yields in field experiments are closely correlated with soil groups so defined (White et al. 2000; Oberthur et al. 2000). The analysis differentiated soil into two productivity groups based on season (Table 3). Although the soils within these groups were consistent with previous field trial data (White et al. 1997; White et al. 2000), the notable exceptions were yields on Bakan and Krakor soils (albeit with small sample sizes in the wet season). In addition, by managing fertiliser input, yields within poor soils increased to levels comparable with productive soils (Table 2, model 4, 6 & 7). Recent field work in Takeo province suggests that some soil types are incorrectly located on the soil map of Oberthur et al. (2000). For example, the Oroung soil has not been located in the region shown in western Takeo province (N Schoknecht, personal communication). This error in the soil map would also weaken the apparent relationship between soil type and rice yield in the regression tree models.
Table 4. Rice yields (t/ha) reported for the whole of Cambodia

<table>
<thead>
<tr>
<th>Source</th>
<th>Wet season</th>
<th>Dry season</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cambodia</td>
<td>1.81</td>
<td>3.04</td>
<td>1</td>
</tr>
<tr>
<td>Takeo: this study</td>
<td>3.28</td>
<td>4.39</td>
<td>2</td>
</tr>
<tr>
<td>Takeo: province</td>
<td>2.20</td>
<td>3.00</td>
<td>3</td>
</tr>
<tr>
<td>Takeo: Farmers’ survey</td>
<td>1.81</td>
<td>4.33</td>
<td>4</td>
</tr>
</tbody>
</table>

1. MAFF (1999-2000)
2. This study
4. Ieng et al. (2001)

There are several obvious explanations for higher field trial yields than the province average. Firstly, moisture content of paddy rice was probably >14% (the standard for reporting) in on-farm trials since it was not dried to standard moisture content before weighing and secondly, straw and other non-grain components were not thoroughly cleaned from the sample. Collectively these could account for 10-20% over-estimation of yield. The tendency for farmers to control weeds and insects better in trial plots than the average rice field may contribute to higher yields, as will the tendency for researchers to locate experiments where supplementary irrigation can be applied as necessary. Researchers...
Richard W. Bell et al. Mapping rice yield and its fertilizer response at provincial-scale in Takeo, Cambodia

tend not to report failed experiments which results in the reported statistics overestimating the potential yield. By contrast, national statistics on yield do not report actual crop area in that year but rather the potential area, depressing the average. Finally, the fact that 59% of the database in this study was for the dry season, which has higher average yield, in contrast to actual production which is mostly from the wet season, would increase the calculated average.

Mapped N-effect results suggest a very strong positive response to N, particularly on the central-western region of the province (Figure 6). They also suggest possible negative effects of high N rates on the most fertile soils (Kbal Po, Krakor) in the eastern part of Takeo, and in the Prateah Lang and Koktrap soils in the flooded areas of the south east of Takeo. The decline in yield of N fertilized sites appears to be explained by increased damage from stem borers which was reported on the trial site records to be very damaging at 2 out of 4 sites. This suggests that further attention needs to be given to studying the conditions under which N fertiliser increases stem borer damage, because this effect was not evident in the N responses on other soils. The effect of N fertiliser on incidence of other insects and on disease also perhaps needs attention. However, there were relatively few on-farm trials in the eastern Takeo province with N fertiliser treatments, and hence the negative effect of N fertiliser may be biased by the results from only a few atypical sites. Thus the decline may also be because the maximum spread of data points exceeded the maximum range for mapping based on the semi-variogram (see below). Further on-farm experiments to confirm that N fertiliser increases stem borer damage seem warranted.

Positive yield responses to K were mostly in the range 0-1 t/ha and occupied about half of the province. Visual interpretation suggests no K response on flooded-prone zones in eastern and southern Takeo (Figure 7). These are the areas with a prevalence of Kbal Po and Krakor soils which generally do not require K fertiliser (Seng et al. 2001). Another zone with no K response appears to loosely correlated with Prey Khmer soils in the north west of Takeo. Responses to K fertiliser are expected on Prey Khmer soils (Seng et al. 2001), but the sandy texture of these soils, and the prevalence of multiple nutrient deficiencies means that balanced nutrient supply is essential to achieve positive fertiliser responses (White et al. 1997a,b). Hence in the on-farms trials that included K treatments, inadequate N or P supply at a particular site could prevent a positive response to K. Alternatively excessive leaching of N or K after basal fertiliser application may prevent fertiliser response. And finally loss of soil water saturation during the growing season may decrease the availability of N or P and hence prevent responses to fertilisers (Bell et al. 2001).

Positive response to P is almost certain over the entire province (Figure 5) except for eastern and south eastern regions and two other isolated areas in the north west and north east. Very little of the province is expected to respond negatively to P. Phosphorus response peaked in central Takeo province. High flood risk seems to reduce the P response probably because of frequent replenishment of soil P in alluvial soils from fresh sediment. White and Seng (1997) note that P responses are less prevalent on the clayey alluvial soils.
Sensitivity analysis of yield and fertiliser response data, Takeo province

For yield, the mean, confidence interval (CI) and the MSE results stabilise at 40% of the data set, or 934 samples (Figure 8). This minimum data set exceeds the number of points in the partial data set. Takeo covers 3490 km² and 934 samples equates to 2.7 every 10 km². Dent and Young (1981) recommended one sample every 25 ha to map land-uses for regional land use planning at 1:50,000 scale. This is fourteen times more intense than the rice yield sample density. The recommended sampling density for rice yield estimation is more comparable to the intensity of sampling for 1:250,000 scale for national land system applications.

Figure 8. Confidence interval of yield data with increasing sample size for full data set.

When data was separated into N treatments, only yields with 50 to 80 kg N/ha reached a CI of 0.10 t/ha (Figure 9). This was due to the larger total sample size at 730 for this range of fertiliser N levels. The minimum number of samples to achieve the same CI (0.1 t/ha) was 20% lower than when all yields were analysed. Presumably separating the data into fertiliser application rates takes into account some of the yield variation and thus the CI was reached at a smaller sample size. The results indicated that for 0-10 kg N/ha 5.7 samples per 100 km² and for 10-50 kg N/ha 9.4 samples per 100 km², was sufficient for a CI of 0.2 t/ha or less. From these results, 6 to 9 samples per 100 km² are recommended to estimate fertiliser response with a CI of 0.2 t/ha.

Figure 9. Confidence interval of yield data with increasing sample size for 10-50kg N/ha data set.

The sample number required for sufficient histogram and variogram modelling both occur at around 100 data points, for the 0-10 and 10-50 kg/ha N fertiliser ranges. This represents a minimum number of sample points per fertiliser input interval for semi-variogram modelling and histogram analysis. Data spacing also needs to be considered in sampling programs. This should not be greater than the range of influence obtained from the semi-variogram analysis. Investigation of the results indicates a maximum range of influence of 8 km for N-response data. This is a conservative estimate as results stabilise around 12 km with larger sample sizes when yield was estimated spatially. If sample points are located greater than 8 km apart, the data is likely to be unreliable for mapping at the provincial scale. The results from this section can act as guides to determine sampling requirements for spatial mapping in other areas of similar environment and rice production practices.

General Discussion

The data used in the present study was generally filed as hard copy and put to little on-going use. In the past, data from the CIAP and FAO databases has been subject to critical analysis to derive fertiliser recommendations (White et al. 1997; Seng et al. 2001). Informally some joint consideration of these two databases has informed the development of CARDI fertiliser advice (P. White, personal communication). The present project adds value to previous and collected experimental data by combining the databases from four agencies to generate results from 2336 sites with good spatial coverage in the province of Takeo. Consideration of the combined data set appears to generate new information not previously recognised in individual databases. Most significant amongst these is the effect of N fertiliser on insect damage levels in Kbal Po and Krakor soils, and the poor responses to fertilisers in general on the flood-prone acid sandy soils of south east Takeo belonging predominantly to the soil groups Koktrap and Prateah Lang. As new field trial data becomes available, maps can be up-dated to explore changes in patterns of response. Similarly as farmers’ fertiliser practice changes this may be reflected in the trial data.

Maps of the sort produced in this project help to target decisions and actions for planners, investors, extension agencies and researchers. Using maps, planners can estimate how rice yield would respond across the province to the adoption of the recommended fertiliser rates. By knowing what extra yield could be produced in each district, plans can be made for the appropriate development of infrastructure to support the transport and storage of grain. Investors in rice milling and in fertiliser and pesticide products can use the predictions to identify the magnitude of markets, estimate likely sales, and decide on where to locate depots for fertiliser stocks and fertiliser sales points. Extension agencies can use maps to develop targeted advice for particular districts and communes as part of the agro-ecosystem analysis framework. There are indications that fertiliser use is a better and more reliable investment at present in some areas than in others. In areas where strong reliable response to fertilisers can be obtained using current technologies, extension programmes can be confidently mounted. In other areas, more cautious advice on fertilizers is appropriate until further research identifies the constraints to fertilizer responses.

A number of significant messages emerge for the present research. A map is a medium for dialogue on results and knowledge gaps. In the eastern, flood-prone areas there appears to be a risk of decreased rice yield when N fertiliser is added. Here the effect of N on insects warrants further examination. The severity of insect damage on yield may...
vary with the timing of the infestation as well as the level of N. Weather conditions may also affect the likelihood of insect populations building to levels that can cause crop damage. From this research, recommendations may emerge that N fertiliser should be applied only when effective insect control is planned by farmers. Alternatively lower than recommended rates of N fertilizer may be a prudent strategy for farmers who are unable to or choose not to use insecticides. The latter approach is consistent with the findings of Ieng et al. (2001) for farmers in Treang village, eastern Takeo where farmers in the receding floodwater rice ecosystems used lower N fertiliser than recommended.

In another study of farmers’ perceptions of rice yield response to fertiliser in Takeo, it was found that the expected yield response to fertilizer in a rainfed rice ecosystem was only about 0.1 t/ha (Ieng et al. 2001). In this village in Tramkak district, 50 % of farmers’ expected no response or a decrease in yield when fertiliser was added. This is at variance with the predictions from the trials reported by White et al. (1997), and from the on-farm yield responses reported here. Phosphorus and K deficiency appears to be widespread in Takeo (Figures 5,7; White et al. 1997). Further investigation is needed to verify why farmers have such modest expectations for yield increase with fertiliser use. Clearly adoption of fertiliser recommendations is likely to be impeded whilst farmers hold their present perceptions. The maps presented in the present paper may be a useful way to represent to farmers the prospects for fertilizer responses in their particular district or commune.

Finally and importantly, there is a need for a formal and organised system whereby knowledge and experience about soil fertility and fertiliser response can be stored and shared at all levels within the agriculture sector. The present study illustrates the advantages of pooling data from on-farms trials conducted by several agencies. Mining information from existing data maximises the investment in the original research and avoids the unnecessary expense of new experiments. The maps produced in this study can be updated as new research data becomes available. However, not all provinces in Cambodia will have the density of on-farm experimental data that exists in Takeo. The present authors have developed a system of predicting rice yield response in Takeo that integrates information from a range of sources, including farmer’s experience (Bell et al. 2004). The spatial model developed will predict the likely yield given soil type, flooding risk and expected N fertiliser response. Hence, the aim is to be able to generate maps such as those produced here in provinces of Cambodia where the data is more limited and patchy in distribution. Through better targeting of advice, the use of the maps aims to facilitate the improved adoption of fertiliser technology by farmers. This will also contribute to improved strategic planning on a provincial and district basis.

**Conclusions**

Provincial scale maps of yield response to fertiliser can target extension effort to areas where yield is likely to be most responsive to fertiliser application. The work also highlighted the need for further research to clarify reasons for effect of N fertiliser on insect damage levels on fertile soils (Kbal Po, Krakor) and poor responses on flood-prone acid sandy soils (Koktrap and Prateah Lang). These outcomes could enhance the strategic planning capability for delivery of extension services and fertiliser inputs. In addition, the compilation of data and subsequent mapping demonstrated the value added to existing data, emphasising the importance of efficient data and information management systems in agricultural research and the sharing of information amongst agencies.

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