SITE-SPECIFIC MANAGEMENT OF RICE FERTILIZERS BASED ON GIS SOIL INFORMATION

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INTRODUCTION

Rice is the staple food in Taiwan, with a total planted area covering two cropping seasons of 339,949 ha in 2000. This was the lowest rice acreage for more than 50 years (COA 2001). Rice production in Taiwan is facing the challenge of cheap imports of up to 140,000 mt per annum under WTO. In response, the government is planning a system of fallow on a township basis.

Although rice production in Taiwan may not be as high as in the past, rice is still the most important crop, and the largest user of fertilizer. In 2000, rice growers spent an estimated US$64 million on fertilizers. This included 41,793 mt of nitrogen (N), 15,314 mt of P₂O₅ and 16,462 mt of K₂O (Lin 2001). Not only is rice the staple food in Taiwan, it also provides raw materials for food processing, and supports rural development, social stability, ecological conservation and the cultural heritage.

Fertilizer represents only 7% of the total input costs for rice (Lin 2001). However, there are many indications that the use of N fertilizer could be reduced and rice yields increased at some sites through improved timing and management of nitrogen fertilizer. Maintaining an appropriate rice acreage and adopting proper rice nutrient management is the key to the sustainable development of the rice industry in Taiwan.

Dai and Lin (1992) reported that in parts of central Taiwan, most rice farmers use split applications of nitrogen four times for each crop, and make two applications of P and K fertilizer. The average amounts of N, P₂O₅ and K₂O applied were around 220, 60 and 110 kg/ha, respectively. In another county further north, the survey found a slightly lower application rate (180:60:110 kg/ha). In general, rice farmers’ in Taiwan apply about 20% more fertilizer than the recommended rates. Reducing fertilizer applications will cut down on production costs. In addition, rice offers a unique opportunity for the development of site-specific management (SSMG) technologies, because it is cultivated over such a large area. Furthermore, rice production in Taiwan is highly mechanized.

Factors affecting crop yield and quality are site-specific (Reets and Fixen 2000). Soil and fertilizer management are two important factors in a successful site-specific management strategy. Site-specific nutrient management has several advantages. Not only...
can it increase farmers’ profitability, but it can also reduce the environmental impact of fertilizer applications. In 2000, an experimental plot of 10 ha was set up in 2000 at the Taiwan Agricultural Research Institute to investigate site-specific nutrient management for rice. This Bulletin discusses some of our preliminary results.

USE OF GIS

A number of agricultural organizations in Taiwan, including agricultural universities and government research institutes, established TALRIS (http://talris.besa.nchu.edu.tw), SIQS (http://www.tari.gov.tw/tal.html) and TALMIS (http://www.hdais.gov.tw) systems. These are web-based GIS systems which attempt to share and disseminate information on soil properties to potential users, particularly soil scientists, extension staff and leading farmers.

TALRIS is the Taiwan Agricultural Land Resources Information System. It is a map-based retrieving system which provides government decisions associated with agricultural land-use policies, such as crop suitability analysis, agricultural land releases and land rating. The overall development of the system relies on land evaluation and site assessment for the planning of agricultural land-use in Taiwan. Thematic maps relevant to rice production are displayed in Fig. 1 and Fig. 2 (Lin and Tsai 1994). This can be used to evaluate the levels of nitrogen fertilizer needed for rice fields in specific areas. The green, blue, yellow and red icons in the legend stand for 1-4 grades of suitability, respectively.

SIQS (Soil Information Query System) is a soil properties query system, developed by the Taiwan Agricultural Research Institute in 1997 (Guo et al. 1999). It enables users to ask for information about major soil properties covering 12 attributes, including the pH, type of parent rock, soil texture, drainage characteristics, and levels of calcium carbonate and organic matter, in the top four soil layers. It covers all soil series in all counties and cities of Taiwan. The system is a web-service system. Maps of soil properties are matched with political boundaries, as well as the road network, for convenient identification of the location of specific fields.

A powerful new system called “Agricultural Environment Expert System” is now under development by several universities and research institutes. It will include GIS-based diagnostic expert systems, and will be able to offer users fertilizer recommendations for different crops for different soils in Taiwan (Guo 2001, pers. comm.). The soil database in this system is based on a grid size of 6.25 ha.

TALMIS is an off-line system using the Mapbasic programming package (MapInfo 1993) as a development tool. The system was constructed according to long-term intensive surveys, with minimum units of 6.25 ha, in two counties on the east coast of Taiwan. This survey work, which began in 1992, has attempted to build up an integrated spatial soil database for identifying soil constraints and adopting ameliorative technologies needed to improve crop production. Fig. 3 and Fig. 4 show the soil P and K response information in Chian, a township in eastern Taiwan. This provides recommended management of nutrients, and fertilizer application for compound fertilizers, P and K in the area.

The east coast of Taiwan has a number of problem soils. Fig. 5 shows the distribution of extractable zinc in Hwalien County (Chen 1997). It shows that considerable areas can be identified as possibly deficient in zinc.

Table 1 gives the nitrogen recommendations for rice production in different regions of Taiwan. Generally, more nitrogen fertilizer is recommended for the first...
crop than for the second crop, as the first crop tends to have a higher yield than the second. Rice yields are normally lower in the north of Taiwan, which has a slightly cooler climate. As a result, recommended N application rates in the north are relatively low.

The soil test used to determine levels of phosphorus (P) in the soil is the Bray 1 method. If ICP is used for element analysis, a universal Mehlich extractant is used for extracting soil solution for measurement. Based on tested P levels, ranging from very low to very high, five rates of P₂O₅ are recommended (Table 2).

The soil test used to determine the levels of potassium (K) is an extraction using the Mehlich method. Current recommendations allow the rice grower to apply potash fertilizer based on the results of the tested K in the soil of his fields (Table 3). Recent surveys in Taiwan have clearly demonstrated that indigenous supplies of P and K are highly variable on different rice farms (Lin et al. 2001). Therefore, new concepts and tools are needed for site-specific nutrient management for rice. A decision support system for site-specific fertilizer management for rice as a field level is now under development.

**USING EMI TO CHARACTERIZE PADDY SOILS**

The spatial distribution of available phosphorus and extractable potassium at a field level is an important feature of site-specific nutrient management decisions. Phosphorus tends to show greater stability.
Fig. 2. The productivity of the second crop of rice in Taiwan
Source: Lin and Tsai 1994

Effect of P fertilizer
- Marked
- Intermediate
- Slight
- No obvious effect

Fig. 3. Soil available P around Chian Township, eastern Taiwan
Source: Chen 1997
Fig. 4. Soil K map of Chian township, eastern Taiwan
Source: Chen 1997

Fig. 5. Soil Zn map of Chian township, eastern Taiwan
Source: Chen 1997
than potassium. The development of an information-based system which allows growers to manage resources better, optimizing their yields and profits, is the first step in adopting site-specific nutrient management. EMI (electromagnetic induction) is a convenient and low-cost method of measuring soil variability. The EMI technique is a non-invasive and non-destructive sampling method. Soils which contain a lot of sand have more resistance to an electrical current than soils which contain a lot of clay. Calibrating an EMI meter for a specific soil series needs to be based on the EM sensor reading, and the particular soil attribute of interest. EMI technology has been widely used in precision farming for upland crops in the United States (Davis et al. 1997). Only a few measurements were available for rice fields. In 1999, the United States Department of Agriculture began to evaluate electromagnetic induction and electrical resistivity in rice fields in Missouri. In this way, detailed maps were created which illustrated the spatial distribution of soil properties. This information may help identify optimum fertilizer rates in various areas.

We have used a commercial instrument,
Fig. 6. EMI reading map (ms/dm) of Plot 39, 1st crop, 2001

Fig. 7. Relationship between EMI reading (mS/dm) and level of exchangeable K in the soil (ppm) (r=0.2328*, n=100)
the Geonics EM-38, to measure rice soil properties in our precision farming experimental sites (Fig. 6) as well as in farmers’ fields. The distribution of the EM readings was consistent with field drainage.

A mobilized soil conductivity assessment (MSCA) system, with a mobile EM-38 sensor unit pulled by an ATV, equipped with a laptop computer and DGPS antenna, is under construction. We are trying to use this equipment to map and/or categorize a wide range of physical and chemical soil properties. Our objective is to acquire quickly and accurately site-specific management information for small fields.

Current research shows that there is a poor correlation between soil available P and the EMI reading. However, there is a statistically significant relationship between the EMI value and the level of exchangeable soil K (Fig. 7). This suggests that a soil K map could be made, calculated on the basis of a regression equation between the EM sensor reading and observed exchangeable soil K.

Specialized software, the ESAP-95 (Version 2.01R) (Lesch et al. 2000) was used to generate optimal sampling designs from conductivity survey information. The spatial response surface (SRS) sampling design software in the ESAP-95 is a useful package which allows users to generate calibration sample sizes of 6, 12, or 20 sites per field. Alternatively, users may adopt a custom sampling design, using a special statistical technique. Fig. 8 is an optimized sample site map for Plot 39 in our experimental farm at the Taiwan Agricultural Research Institute. Given the location of our sample sites, only six samples had to be collected to represent the whole field. Further physical and chemical analysis can be carried out to understand the soil properties.
Fig. 9. Variation in soil available P (ppm) in 21 contiguous fields

Fig. 10. Variation in soil extractable K (ppm) in 21 contiguous fields

16-30: 2, 4, 7, 9, 10, 11, 12, 13, 14, 17, 21. 31-50: 1, 3, 5, 6, 8, 15, 16, 18, 19, 20
Fig. 11. Distribution of recommended nutrient content ratio of $P_2O_5$ and $K_2O$ (0.5 ha)

Table 4. Available compound fertilizers used by farmers in Taiwan

<table>
<thead>
<tr>
<th>Compound</th>
<th>Fert. No.</th>
<th>N</th>
<th>$P_2O_5$</th>
<th>$K_2O$</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>5</td>
<td>10</td>
<td></td>
<td>1:0.25:0.5</td>
</tr>
<tr>
<td>2</td>
<td>11</td>
<td>9</td>
<td>18</td>
<td></td>
<td>1:0.82:1.64</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>5.5</td>
<td>22</td>
<td></td>
<td>1:0.5:2</td>
</tr>
<tr>
<td>5</td>
<td>16</td>
<td>8</td>
<td>12</td>
<td></td>
<td>1:0.5:0.75</td>
</tr>
<tr>
<td>36*</td>
<td>7</td>
<td>21</td>
<td>21</td>
<td></td>
<td>1:3:3</td>
</tr>
<tr>
<td>39*</td>
<td>12</td>
<td>18</td>
<td>12</td>
<td></td>
<td>1:1.5:1</td>
</tr>
<tr>
<td>42</td>
<td>22</td>
<td>5</td>
<td>6</td>
<td></td>
<td>1:0.2:0.27</td>
</tr>
<tr>
<td>43</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td></td>
<td>1:1:1</td>
</tr>
</tbody>
</table>

*36: tobacco fertilizer; 39*: most common rice fertilizer

FERTILIZER APPLICATIONS BASED ON SOIL GIS INFORMATION

Variation in the levels of soil P and K is different for every rice field. This is particularly true when the fields belong to different farmers who have adopted different fertilizer regimes (Fig. 9 and Fig. 10). Our results showed that the distribution of soil P and K within a sampled field tends to follow the orientation of the drainage water.

Decision support systems to make field-specific fertilizer recommendations seem necessary, since most farmers do not know the fertility of their soils. It would be helpful if nitrogen applications could take yield potential into consideration. At present, chlorophyll meters are being used on our experimental farm to assess the nitrogen status of rice from maximum tillering to the panicle initiation stage of growth. Experiments have been conducted to determine critical meter
values associated with 95% maximum rice grain yield.

In Taiwan, most rice paddy fields are around 0.3 ha in size, and can be treated as a single management unit. If a field is larger than 0.5 ha, a knowledge of variability in the distribution of various nutrients might be useful when variable-rate applications are considered. Fig. 11 shows the relative distribution of different application rates of $P_2O_5$ and $K_2O$ in one field of 0.5 ha. Once the target yield is decided, the desired ratio of $P$ and $K$, and the ideal compound fertilizer or straight nutrient fertilizers can be selected. Optimization strategies can be done with or without checking N levels.

Compound fertilizers have long been the most common nutrient input in Taiwan’s rice fields, because of their convenience in application and transportation compared to straight nutrient fertilizers. Farmers are recommended to use Compound Fertilizer No. 39, which has a high P content, as a basal application for rice.

If more P is needed for each crop, it is added as straight fertilizer ($P_2O_5$). The remaining N and K is applied as a top dressing in the form of low-P compound fertilizers.

Strictly speaking, there is not a wide enough range of compound fertilizers for rice growers. This may be a constraint in implementing the technology of site-specific nutrient management.

CONCLUSION

Many rice producers in Taiwan are currently facing low crop prices. These are likely to fall even lower now that Taiwan has joined WTO. However, rice traditionally still ranks first in importance in crop production in Taiwan. Site-specific nutrient management is a new approach to production which may replace current uniform rate technology. It offers an opportunity to develop new and improved fertilizer recommendations for rice fertilizer management.

Rice surplus problems in the past have forced Taiwan’s rice growers to focus on improved rice quality through cultivation techniques. Site-specific or field-specific fertilizer management for rice is a good way of helping farmers to apply fertilizer to their fields rationally. Through the implementation of this technology, rice quality can be improved and the environment protected.

REFERENCES


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