Phosphorus and Potassium Decision Support System: Bridging Soil Database and Fertilizer Application

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Phosphorus and Potassium Decision Support System: Bridging Soil Database and Fertilizer Application

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Abstract

This paper discusses the Phosphorus and Potassium Decision Support System (PKDSS) developed by ICALRD and its role in bridging soil database and fertilizer application. This system is a fertilizer recommendation model, as well as a computer program, used as a tool in determining fertilizer requirement for a given crop based on soil testing. In Indonesia, balanced fertilizer application approach is adopted to increase crop production while reducing negative impact on environment. This approach requires a better insight on soil characteristics and behavior. The soil nutrient status determines fertilizer recommendation for a given crop. The PKDSS recommends fertilizer rate after correcting the standard rate by its correction factor. The correction factor indicates the effect of selected soil properties on soil nutrient dynamics. N-fertilizer is corrected by soil texture class and soil organic carbon content. P-fertilizer is corrected by soil texture class, soil pH, soil organic carbon content, and P-retention. K-fertilizer is corrected by soil texture class, soil organic carbon content, and cation exchange capacity of clay. PKDSS needs 14 soil properties as input, divided into two layers: first layer to select the standard recommendation and second layer to determine the correction factor. These soil properties can be provided by soil data stored in the soil database. These legacy data can be used to create quantitative soil property maps by using digital soil mapping techniques. These maps are inputted to PKDSS to come up with fertilizer recommendation area (FRA) for a given crop. The FRA assists the local government in planning fertilizer stock and distribution in each agricultural service. PKDSS plays an important role in bridging soil database and fertilizer application.

Keywords: PKDSS, digital soil mapping, legacy soil data, fertilizer recommendation area.

1. Introduction

Balanced fertilizer application approach is a critical issue in increasing food production while reducing negative impact on environment. This approach requires deep insight on soil characteristics and behavior since they are used as a base for formulating kind and rate of fertilizer. Based on soil map of 1:1000.000 scale, the acid soils (soil having pH< 5 and base saturation< 50%) covers 102.8 Mha (Mulyani et al., 2003) or about 55 % of Indonesian land. This is mainly from Entisols, Inceptisols, Ultisols, Oxisols, and Spodosols that lie in wet climate with high rainfall. This soil has low soil fertility that relate to low pH, high Al content and P fixation, low in exchangeable base and CEC, and Fe and Mn content toxic for plant. Fertilizer application is obligatory in Indonesia to achieve economical yield due to the fact that majority of agricultural soil have low nutrient content.

Research on fertilizer application in Indonesia began in the1970s (Adiningsih, 1992). The fertilizer rate recommendation is based on soil testing approach. The research started with correlation following calibration, mainly focused on food crops and other selected crops. Finally, there is available recommended rate for many crops. Some of them may be systematic results but others may come from trial and error. This knowledge base is a starting point to develop economical and environment-friendly fertilizer application.

Fertilizer application in fact requires support from other non-technical issues. Soil nutrient map is required to ensure that a given region is provided with the right stock of fertilizer. While preparing such map that is important in logistics, a new technique such as digital soil mapping is promising. This technique utilizes legacy soil data to come up with quantitative soil data.

This paper discusses phosphorus and potassium decision support system (PKDSS) as a bridge relating soil database and fertilizer application. The paper provides other examples on how new tools can be generated to utilize available data to answer the challenging issues. Soil fertility evaluation becomes a hot topic, considering the fact that land productivity is decreasing while food requirement is increasing. The paper starts with a brief review of existing fertilizer recommendation, followed by a discussion of the PKDSS model, how evaluation is conducted using the model, and a demonstration of the role of PKDSS software in bridging soil database and fertilizer application.

2. Concept of Fertilizer Application in Indonesia

Fertilizer application is required in Indonesia because the majority of Indonesian soil is relatively low in organic matter and nutrient availability. In addressing this issue, Indonesia adopts balanced fertilization, a framework that is founded on the site-specific nutrient management. The fertilizer is added to the soil to achieve balanced and optimum nutrient availability. The fertilizer application aims to (a) increase soil productivity and yield quality, (b) increase the efficiency of fertilizer application, (c) improve soil fertility, and (d) reduce environmental pollution.

Research on nutrient balance has been started since 1970 in Indonesian Soil Research Institute, an institute under supervision of ICALRD (Rochayati and Husnain, 2010). Comprehensive research on balanced fertilization had been conducted in 1990-2000, working on large scale. Among the research results were soil maps of P and K status at a scale of 1:250.000. These maps are used to establish P and K fertilizer recommendations. Several studies showed that site specific balanced fertilization significantly increased fertilizer use efficiency and rice yield (Adiningsih, 1984; Rochayati et al., 2001; Setyorini et al., 2004).

The rate of fertilizer is determined by soil testing results. In Indonesia, the soil testing program was introduced in 1968 by Prof. Oetit Koswara from Bogor Agricultural University (Leiwakabessy, 1995). Basically, soil testing refers to chemical analysis in the soil laboratory to estimate nutrient availability in the soil. Soil testing activity involves interpretation, evaluation, and fertilizer rate recommendation from soil chemical analysis and soil sampling (Melsted and Peck, 1972). In Indonesia, the N, P, K-fertilizer rate recommendations for wetland rice, corn, soybean and upland rice are based on soil testing. It is done by assessing the preliminary nutrient status and crop nutrient requirement.

Innovations in fertilizer technology to support balanced fertilizer application system have further developed in Indonesia. Now, the fertilizer recommendation is more on site-specific, rather than blanket, recommendation. The coverage also changed, first from national to provincial extent, and now to regencial extent. The fertilizer innovations, among others, are soil test kit for rice in 2005, soil test kit for upland crops in 2007, and soil test kit for rice planted in potential acid sulphate soil in 2011. Institutionally, the Indonesian Ministry of Agriculture released a site-specific fertilizer recommendation, as stated in Ministry Regulation No. 40/Permentan/OT.140/04/2007.

While research is responsible for the rate and technique of fertilizer application, the fertilizer stocking and distribution remains the responsibility of the Agricultural Service of the respective regencial government as well as fertilizer producer. Agricultural Service will issue the regulation regarding fertilizer stock and price, based on ministry regulation and recommendation from research and. Hence, the above objectives of fertilizer application can only be achieved if there is good collaboration and communication among stakeholders.

3. PKDSS Model

3.1 General formula

Research activities provide the fertilizer recommendation for given crops planted on a given soil. PKDSS is a model to determine the fertilizer requirement for a given crop and a given soil based on soil testing. It supports precise farming with site-specific nutrient management in the framework of balanced fertilization.

When a farmer adds fertilizer to the soil, this fertilizer will dissolve into the soil solution. Then, it can be absorbed directly by plant roots, adsorbed and fixed by soil, or lost by leaching. So, only a small part of the added fertilizer will be used by the crop. The fate of the added fertilizer is governed by soil properties controlling leaching, cation exchange, and fixing. For example, soil texture determines leaching while cation exchange capacity of the soil controls cation exchange. Thus, sandy soil tends to accelerate the loss of fertilizer due to leaching. As a result, more fertilizer should be added to this soil to replace the lost one. On the other hand, some soil properties tend to provide additional nutrient, depending on its level in the soil (e.g. high organic matter, neutral pH, etc). For this type of soil, less fertilizer is needed and the standard recommendation can be reduced.

These facts suggest that we need a correction factor for a given fertilizer. The concept of correction factor was first introduced in 2002 by Dr. Dedi Nursyamsi. As this concept needs complex calculation, a software called PKDSS was created (Sulaeman and Nursyamsi, 2005). The concept and software were introduced to many researchers and extension workers in the workshop of soil testing in Bogor. Since that time, the concept and software have been improved and the model has been tested in several locations.

PKDSS determines the final rate of fertilizer application after applying a correction factor using the following general formula:

$$N_i = R_i \times CF_i$$

Where:

N_i= The number of fertilizer for nutrient *i* must be added ($kg.ha^{-1}$).
This is the number of fertilizer as output of PKDSS. This may be higher or lower than standard recommendation.

R_i= Recommended rate of fertilizer for nutrient *i* ($kg.ha^{-1}$).
This is standard recommendation given nutrient status in the soil. The number is determined from a series of experiments on fertilizer application rates conducted by ICALRD. Further, each local agricultural service establishes the standard recommendation for a given crop.

CF_i= The correction factor. This number is a unitless factor for correcting the fertilizer rate. Each fertilizer has its own correction factor (see 3.2 for details).

3.2 Correction factor for fertilizer addition

PKDSS differs from other recommendation models in that it uses selected soil properties to correct fertilizer addition. It means that there are soil properties controlling the dynamics of N, P, and K in the soil. A soil property is selected based on expert judgment, guided by experience, knowledge, and crop performance in the field. A focus group discussion of senior soil fertility experts was conducted at ICALRD in 2002. Each expert was asked three basic questions based on his or her experience. First, what soil properties control the three nutrient dynamics in the soil? Second, how should this soil property be classified? Third, what number should be assigned to each class as its correction factor? Each expert gave a different answer and consensus was formed from their opinions.

Considering the process in establishing the correction factor, the PKDSS model was mainly developed by expert judgment. The results (i.e. soil property, its class, and its correction factor) can be true for Indonesian soil condition. However, it should be validated first before it is used in other regions. Or, similar steps can be performed to answer three basic questions in other climatic and soil condition.

Table 1 shows the correction factor for N-fertilizer covering soil texture and soil organic carbon content. Soil texture is grouped into sandy and non-sandy, indicating potential nutrient leaching. Sandy soil has higher potential for N-fertilizer loss than non-sandy soil due to leaching. Hence, the sandy soil needs more N-fertilizer than non-sandy soil.

Soil organic carbon is estimated from soil organic matter. Soil organic matter is a source of nitrogen in the soil. Soil organic carbon is grouped into <2%, 2-4% and>4%. High soil organic matter results in high soil nitrogen. Hence, soil with low organic carbon needs more N-fertilizer than the soil with high organic carbon.

Table 1. Soil properties for the correction of N-fertilizer.

Soil Texture*	Soil organic carbon	Correction factor
Sandy	<2%	1.1000
	2-4%	0.9900
	>4%	0.8800
Loamy or Clayey	<2%	1.0000
	2-4%	0.9000
	>4%	0.8000

*) Sandy: loamy sand, or sand.
Clayey: sandy clay, silty clay, or clay.
Loamy: sandy loam, sandy clay loam, silty loam, silty clay loam, loam, clay loam.

The correction factor suggests multiplying the effect of both soil properties to N dynamics in the soil. If the soil is sandy and soil organic carbon content is less than 2%, then the N-fertilizer should be added as the standard recommendation for given soil and crops multiplied by 1.1. It means that there is additional fertilizer to the standard recommendation. But if the soil is sandy and soil organic carbon content is more than 2%, then the N-fertilizer to be added is the standard recommendation multiplied by 0.88. It means that there is reduction from the standard recommendation.

Table 2 shows the soil properties that determine the correction factor of K-fertilizer covering soil texture, soil organic carbon content, and clay CEC. Soil texture is grouped into sandy and non-sandy (loamy or clayey). Soil texture indicates potential leaching, the process that is responsible for K nutrient loss. Loss of ion K due to leaching tends to be higher in sandy soil than in clay soil. Hence, sandy soil needs more K-fertilizer than loamy soil.

The soil organic carbon is grouped into <2%, 2-4%, and >4%. Soil with high organic carbon has high exchange capacity than the soil with low organic carbon. As a result, K retention is higher in soils with high organic carbon than in soil with low organic carbon. Hence, more K-fertilizer is needed for soil with low organic carbon soil than in soil with high organic carbon.

In Table 2, clay CEC is preferred than soil CEC. Clay CEC reflects cation exchange capacity of soil colloid. Clay CEC is differentiated into < 8 $cmol.kg^{-1}$, 8-16 $cmol.kg^{-1}$, 16-24 cmol.kg^{-1} and > 24 cmol.kg^{-1}. High activity clay soils retain K higher than low activity clay. Soil having clay CEC has high K retention than soil having low clay CEC.

Table 2. Soil properties for the correction of K-fertilizer.

Soil Texture	Soil Organic Carbon (%)	Clay CEC (cmol.kg^{-1})	Correction factor
Sandy	<2	<8	1.3750
		8-16	1.1000
		16-24	1.3200
		>24	1.6500
	2-4	<8	1.2375
		8-16	0.9900
		16-24	1.1880
		>24	1.4850
	>4	<8	1.1000
		8-16	0.8800
		16-24	1.0560
		>24	1.3200
Loamy or Clayey	<2	<8	1.2500
		8-16	1.0000
		16-24	1.2000
		>24	1.5000
	2-4	<8	1.2500
		8-16	0.9000
		16-24	1.0800
		>24	1.3500
	>4	<8	1.0000
		8-16	0.8000
		16-24	0.9600
		>24	1.2000

* Sandy: loamy sand, or sand
Clayey: sandy clay, silty clay, or clay
Loamy: sandy loam, sandy clay loam, silty loam, silty clay loam, loam, clay loam.

Table 3 presents the soil properties used to establish the correction factor of P-fertilizer. Soil texture, pH, soil organic carbon, and phosphorus retention mainly control phosphorus dynamics in Indonesian soil. These soil properties were then grouped into classes considering data pattern and experience in fertilizer research.

Soil texture is differentiated in two groups: clay and non-clay (i.e. loamy or sandy), where more fertilizer should be added to clayey soil than non-clayey. pH is differentiated into 4 classes, i.e. < 4.5, 4.5-5.5, 5.5-7.5 and > 7.5. pH controls the solubility of Al and Fe in acidic soil and Ca in more basic soil. These cations will make P ion unavailable for crops. Hence, the acidic soil (pH <4.5) needs more P-fertilizer than soil having pH of 5.5-7.5, as Al and Fe are relatively high in acidic soil.

Soil organic carbon is differentiated into three groups: < 2%, 2-4%, and >4%. Soil organic matter content, as estimated by soil organic content, is another source of organic phosphorus. More P-fertilizer needs to be added to low SOC than to high SOC. The phosphorus retention is differentiated into three classes: <30%, 30-60 %, and > 60%. Phosphorus retention indicates the percentage of phosphorus that is fixed by soil and becomes unavailable to the crops. More P-fertilizer is needed for soil with high P-retention.

The correction factor indicates the multiplying effect of these soil properties. Thus, clayey soil showing pH < 4.5, low organic carbon (<2%) and low retention capacity has a correction factor of 1.31. The fertilizer that should be added to this soil is 1.31 times the standard recommendation.

Table 3. Correction for P-fertilizer recommendation.

Soil Texture	pH	SOC (%)	P-retention (%)	Correction factor	Soil Texture	pH	SOC (%)	P-retention (%)	Correction factor
Clayey	<4.5	<2	<30	1.3200	Loamy or sandy	<4.5	<2	<30	1.2000
			30-60	1.5840				30-60	1.4400
			>60	1.8480				>60	1.6800
		2-4	<30	1.1880			2-4	<30	1.0800
			30-60	1.4256				30-60	1.2960
			>60	1.6632				>60	1.5120
		>4	<30	1.0560			>4	<30	0.9600
			30-60	1.2670				30-60	1.1520
			>60	1.4784				>60	1.3440
	4.5-5.5	<2	<30	1.2100		4.5-5.5	<2	<30	1.1000
			30-60	1.4520				30-60	1.3200
			>60	1.6940				>60	1.5400
		2-4	<30	1.0890			2-4	<30	0.9900
			30-60	1.3068				30-60	1.1880
			>60	1.5246				>60	1.3860
		>4	<30	0.9680			>4	<30	0.8800
			30-60	1.1616				30-60	1.0560
			>60	1.3552				>60	1.2320
	5.5-7.5	<2	<30	1.1000		5.5-7.5	<2	<30	1.0000
			30-60	1.3200				30-60	1.2000
			>60	1.5400				>60	1.4000
		2-4	<30	0.9900			2-4	<30	0.9000
			30-60	1.1880				30-60	1.0800
			>60	1.3860				>60	1.2600
		>4	<30	0.8800			>4	<30	0.8000
			30-60	1.0560				30-60	0.9600
			>60	1.2320				>60	1.1200
	>7.5	<2	<30	1.2100		>7.5	<2	<30	1.1000
			30-60	1.4520				30-60	1.3200
			>60	1.6940				>60	1.5400
		2-4	<30	1.0890			2-4	<30	0.9900
			30-60	1.3068				30-60	1.1880
			>60	1.5246				>60	1.3860
		>4	<30	0.9680			>4	<30	0.8800
			30-60	1.1616				30-60	1.0560
			>60	1.3552				>60	1.2320

Note: SOC=soil organic carbon. Soil texture: Sandy: loamy sand, or sand
Clayey: sandy clay, silty clay, or clay
Loamy: sandy loam, sandy clay loam, silty loam, silty clay loam, loam, clay loam.

3.2 Minimum dataset for running PKDSS

The previous section stressed that PKDSS considers soil properties, as represented in the correction factor, in establishing fertilizer that should be added to the soil. Also, PKDSS considers nutrient status in selecting the standard recommendation. Thus, PKDSS uses two data layers. The first layer is for determining standard fertilizer recommendation. Table 4 provides an example of P and K fertilizer recommendation for wetland rice. It suggests that if P status is low, then 100 $kg.ha^{-1}$ SP36 should be added. The second layer is soil properties required to determine the correction factor. These soil properties are soil texture class, soil organic carbon, pH, clay CEC, and P retention.

Table 4. P and K fertilizer recommendation for wetland rice in Indonesia.

Nutrient status	Nutrient content extracted by HCl 25%		Fertilizer recommendation		
	P	K	SP-36	KCl	
				Without straw	Straw added
	mg $P_2O_5.100g^{-1}$	mg $K_2O.100g^{-1}$	(…………………..$kg.ha^{-1}$	…………………)	
Low	<20	<10	100	100	50
Medium	20-40	10-20	75	50	0
High	>40	>20	50	50	0

After Setyorini et al.,2004.

Combining both data layers, the minimum soil data requirement for PKDSS can be outlined. Table 5 shows 14 soil properties that should be provided in order to run the PKDSS model. The method to determine each soil property must be considered, because different methods give different results and interpretation. The PKDSS calculation is based on the listed method. Moreover, aside from fertilizer recommendation, the PKDSS can also be used to formulate ameliorant recommendations, especially lime and organic matter. The soil properties listed in Table 4 support these two uses of PKDSS.

4. Support System

Using the PKDSS model to calculate fertilizer manually is time-consuming. Hence, a software was created in 2005 (Sulaeman and Nursyamsi, 2005). The software is continually being improved and maintained, and this year the third version will be released. It is designed to be user-friendly. Currently, some researchers and other stakeholders have used this software. Although it uses Bahasa Indonesia, it can easily be understood. In the first and second versions, there were only 4 food crops i.e. wetland rice, upland rice, corn, and soybean. The third version was improved by adding some tropical commodities, including 9 spicy crops, 11 fruit crops, 12 estate crops, 17 vegetables, and 9 food crops. To accommodate the organic farming systems issue, the third version added organic farming recommendation.

Creating software for agricultural application is challenging. The project should involve at least three experts, i.e. fertilizer expert, modeler, and programmer. Good collaboration and communication among the experts ensure better software. Versioning is a better way to develop such user-friendly software. Figure 1 provides a screenshot of the two versions of PKDSS, as well as input and calculation display.

Table 5. Minimum data set for PKDSS and its analysis method.

No	Soil data	Method/ Extraction	Unit	Significance
1	Soil texture	Pipet		Divided into 3 classes, for correction factor
2	pH	Water		Divided into 3 classes, for correction factor
3	Soil organic carbon	Kurmies	%	Divided into 3 classes, for correction factor. Organic matter addition
4	Total Nitrogen	Kjehdal	%	For fertilizer determination
5	Soil CEC	NH_4OAc 1N	$cmol.kg^{-1}$	Needed for calculating clay CEC, for correction factor
6	Available P_2O_5	Olsen	ppm	For P-fertilizer determination, soil pH >5.5, upland crops
7	Available P_2O_5	Bray 1	ppm	For P-fertilizer determination, soil pH <5.5, upland crops
8	Potential P_2O_5	HCl 25%	$mg.100g^{-1}$	For P-fertilizer determination, wetland rice
9	P retention	KH_2PO_4	%	Divided into 3 classes, for correction factor
10	Potential K_2O	HCl 25 %	$mg.100g^{-1}$	For K-fertilizer determination, soil pH >5.5, wetland rice
11	Exchangeable K	NH_4OAc 1N	$cmol.kg^{-1}$	For lime calculation
12	Exchangeable Ca	NH_4OAc 1N	$cmol.kg^{-1}$	For lime calculation
13	Exchangeable Mg	NH_4OAc 1N	$cmol.kg^{-1}$	For lime calculation
14	Exchangeable Al	KCl 1N	$cmol.kg^{-1}$	For lime calculation

Fig. 1. Sample display of the software module.

5. Model Comparison

The performance of PKDSS recommendations had been compared to others based on biomass, rice yield, benefit and cost ratio parameters. Models of the fertilizer recommendation were validated in four locations in Java representing different soil properties and climatic condition. Table 6 shows the performance of the fertilizer recommendation model (FRM) based on biomass and economic yield.

Table 6. Performance of the recommendation model to biomass and yield at four sites in Java, dry season 2004.

Model	Urea	SP36	KCl	Straw	Dry Yield	B/C
	(………kg.ha^{-1}	…….	)	t.ha^{-1}	ku.ha^{-1}	
Inceptisol Tempuran-Karawang_West Java Province						
Control	200	50	0	0	64.6	2.7
Farmer practice	250	100	50	0	63.0	2.4
General curve	200	45	0	5	65.5	2.5
Mitscherlich	200	50	170	0	68.3	2.4
P and K map	200	50	50	0	66.7	2.6
PKDSS	***180***	***71***	***0***	***5***	***63.3***	***2.4***
IRRI	152	80	62.5	0	64.6	2.5
Inceptisol Karanganyar_Central Java Province						
Control	200	75	0	0	72.5	2.7
Farmer Practice	300	150	100	0	73.1	2.3
General Curve	200	70	0	5	86.1	3.1
Mitscherlich	200	50	0	0	75.6	2.8
P and K map	200	75	0	5	78.1	3.0
PKDSS	***200***	***145***	***0***	***5***	***73.7***	***2.4***
IRRI	150	80	63	0	64.8	2.2
Vertisol Kromengan-Malang_East Java Province						
Control	250	75	0	0	81.2	3.0
Farmer Practice	300	100	75	0	81.7	2.9
General Curve	250	50	0	5	76.3	2.6
Mitscherlich	250	50	50	0	80.0	2.9
P and K map	250	75	0	5	81.0	2.8
PKDSS	***230***	***98***	***0***	***5***	***74.8***	***2.5***
IRRI	202	80	63	0	75.0	2.6
Vertisol Kracak_Kediri_East Java Province						
Control	300	75	0	0	72.6	2.8
Farmer Practice	300	100	100	0	79.1	3.1
General Curve	300	70	0	5	72.9	2.6
Mitscherlich	300	50	50	0	72.5	2.8
P and K map	300	75	0	5	76.4	2.8
PKDSS	***250***	***75***	***35***	***5***	***70.7***	***2.5***
IRRI	202	95	95	0	69.4	2.5

Source: Kasno and Widowati (2004)

Compared to farmer's practice, PKDSS recommended lower fertilizer rates in four locations. Nevertheless, the recommendation resulted in higher yield and BC ratio in Inceptisols. This suggests that for Inceptisols, the PKDSS-recommended fertilizers were more efficient than those of the farmer's practice. On the other hand, the recommendation resulted in lower yield and BC ratio in Vertisols. This suggests that for Vertisols, K recommendation by PKDSS is less effective in improving yield. However, similar pattern was also demonstrated by other recommendations.

6. Soil Database and Information System versus Fertilizer Application

6.1 Quantitative soil properties mapping using legacy soil data

The availability and quality of soil data become main issues in any soil-related project. Also, fertilizer application need support from good soil data. Section 3 outlined that 14 soil properties are needed for running the PKDSS. Thus, the fertilizer recommendation should consider soil variation in the landscape, crop variation, fertilizer stocking, and fertilizer distribution.

Digital soil mapping (DSM) literally means creating soil map digitally. It differs from map digitalization that converts an existing soil map into digital form. However, this digitalized soil map can be an important step in digital soil mapping. Legacheri and McBratney (2007) defined DSM as "the creation and population of spatial soil information systems by the use of field and laboratory observational methods coupled with spatial and non-spatial soil inference systems." It is also called predictive soil mapping (Hewitt, 1993; Scull et al., 2003) or quantitative soil survey (McKenzie and Ryan, 1999).

In digital soil mapping, the soil and auxiliary legacy data are used to derive soil properties dataset and environmental variable. From both datasets, soil-landscape model is built. The resulting model is then used to create soil properties map. These are baseline soil maps, meaning that field visits must be conducted to verify the generated soil map.

Figure 2 show an example of a quantitative soil property map, in this case soil pH map. This map used cell size as analysis unit. The resolution is 90 x 90 m, at regional scale. Each cell represents one value of pH. Here, soil properties information in a given site are more important than unit boundary. Yet, spatial variation of pH is clear in this map. The southern part of this region is upland with pH 5.

Digital soil mapping technique also provides accurate information of predicted soil property map. Figure 2 also shows the upper and lower values of pH. If someone visits a site and measures the pH, then compares it with the predicted pH map, he/she can conclude that the map is accurate if the pH value is between the upper and lower limits. The accuracy expression is important particularly in risk analysis as it provides uncertainty of the data. Digital soil mapping technique can create other 13 soil properties needed for fertilizer application.

6.2 The significance of fertilizer recommendation area

Soil properties vary across landscapes. Soil mapping tries to segregate a landscape into units having similar soil properties. As soil properties determine fertilizer requirement, the fertilizer recommendation area (FRA) can be delineated. FRA refers to the areas having similar soil properties, crops, and type of fertilizer. The FRA map has not been developed yet, although in fact this map is required for fertilizer management. For a given region, there is N-FRA for corn, P-FRA for corn, and K-FRA for corn. Furthermore, these FRA layers can be displayed in single maps using geographical information system.

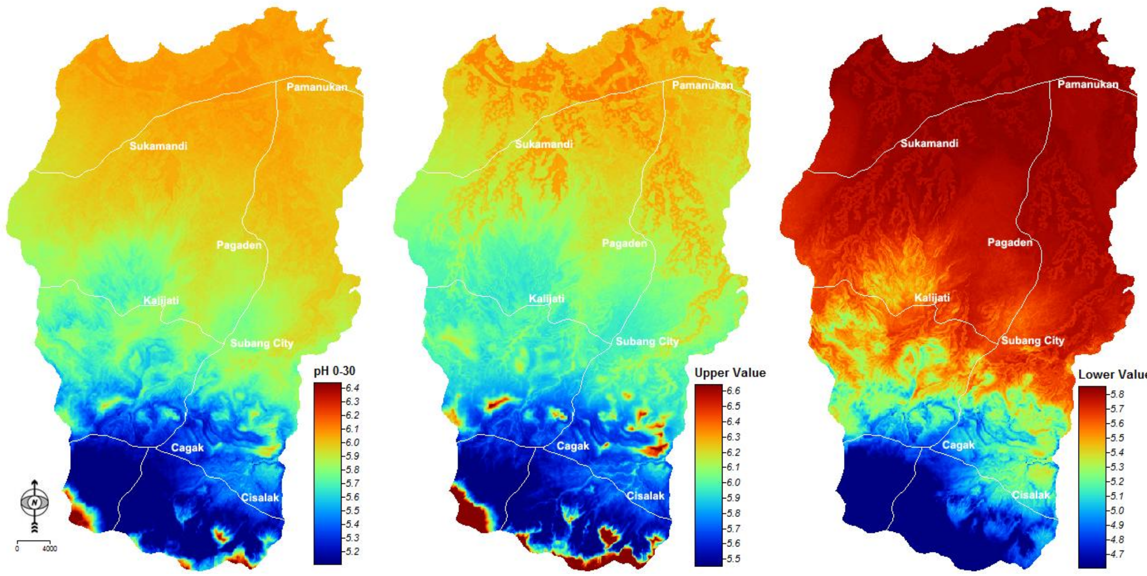

Fig 2. Soil pH map for 0-30 cm depth and its 95% prediction interval (upper-lower) in Subang Region (after Sulaeman et al., 2012).

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The FRA map offers basic information for the Agricultural Service of the local government to determine the type and number of fertilizers for every planting season. Indonesia is a large country with 33 provinces, where each province has several regencies or municipalities. Currently, Indonesia has 497 regencies, and each has its own agricultural service. Fertilizer stocking and distribution became major issues in crop production for almost all local government. In some cases, fertilizer is not available when farmers need it.

Hence, fertilizer production planning is crucial to get high crop production. The Agricultural Service Office should calculate how many tons of fertilizer should be available each year in their region. This office must also determine how much money should be allocated to subsidize the fertilizer cost. The FRA may be used as basis for this calculation.

For fertilizer producers, the FRA is beneficial to estimate the fertilizer need of every regency. Several regencies may need more fertilizers than others. The climate of Indonesia varies among regions, thus planting date also varies. On the same date, farmers of one regency are planting rice, while farmers in another regency are harvesting rice. This condition must be considered by fertilizer producers to make sure that fertilizers are available at the right time in the right region.

6.3 Bridging soil database and fertilizer application

Figure 3 shows the schematic relationship between spatial soil database and fertilizer application, where PKDSS bridges both systems. Digital soil mapping technique can be used to create 14 quantitative soil property maps using legacy soil data stored in the soil database. On the other side, three FRA maps are required in a given administrative region for fertilizer management. The management covers planning and monitoring fertilizer availability and accessibility so that fertilizers are available at the right time and in the right volume.

Between FRA map and soil database, there is PKDSS that interprets legacy data in connection to crop requirement. Thus, PKDSS is a bridge between soil database and fertilizer application. It is possible since PKDSS is a model that uses soil information to formulate its fertilizer recommendation.

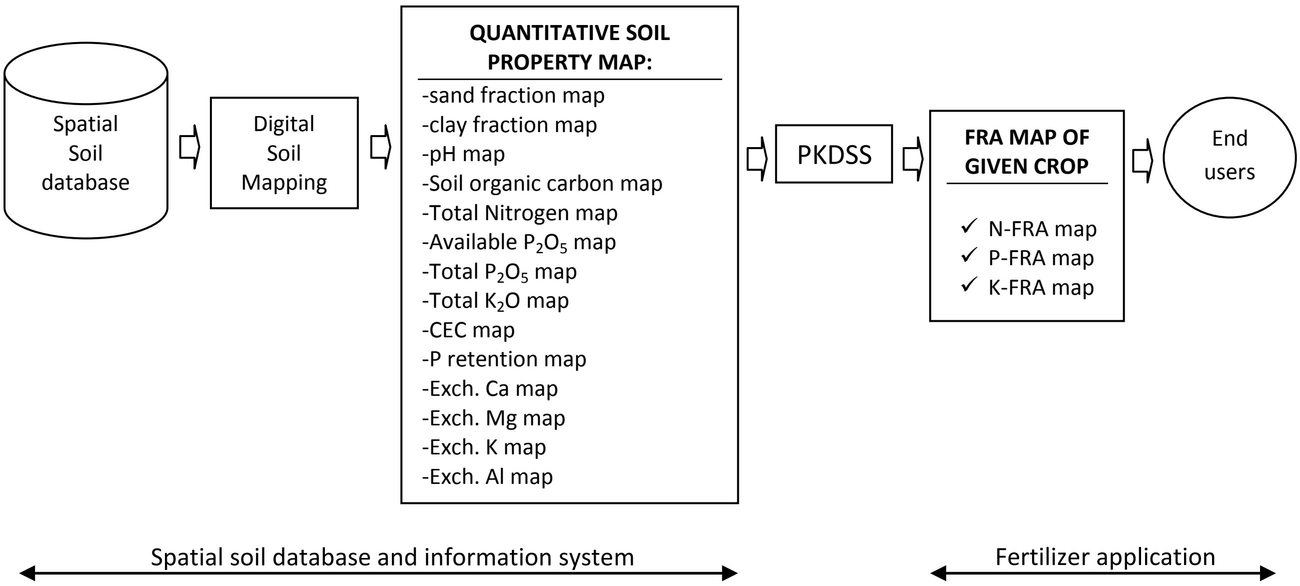

Fig. 3. Schematic outline of PKDSS bridging soil database and fertilizer application.

7. Future Work

Considering the issues discussed in the previous sections, the future work in Indonesia can be directed to the following:

1. Soil-landscape modeling to search and establish the best spatial predictor for each soil property required by PKDSS. This research also includes model development and evaluation. Sulaeman (2012) has developed several soil-landscape models to predict some soil properties in Java. But, the transportability of these models to other landscapes must be evaluated.
2. Establish soil fertility information system that is rooted in spatial soil database. This system will store, among others, the soil-landscape model and 14 soil properties map. A pilot project can be done in one regencial level.
3. Create FRA for main crops using established soil fertility information system. This work can also be integrated with the current project to map the soil nutrient status. This integration may accelerate the current project.
4. Improve PKDSS software by adding more crops. The software development may also be directed to open-source software so that more people can use the software.

This work could strengthen the use of soil information system in nutrient management in Indonesia. Good soil information system, supported by well-designed database, is a capital to create advanced, web-base nutrient monitoring as well as crop production monitoring.

8. Conclusion

Indonesia follows the balanced fertilization approach. Soil testing approach is used to formulate fertilizer recommendation. Several tools were developed to support soil-based recommendation, including soil test kit, nutrient status map, and PKDSS software. The PKDSS software was developed following the PKDSS recommendation model in which two data layers were used in formulating the recommendation. The first layer is the standard recommendation for a given crop, while the second layer is soil properties affecting the availability of the nutrients. Overall, 14 soil properties are required to run PKDSS.

Indonesia stores voluminous legacy soil data in the soil database. Digital soil mapping framework was found helpful in providing quantitative soil property map. Maps, as input for PKDSS, can be developed using this technique and available legacy data.

In practice, fertilizer application also includes fertilizer stocking and distribution besides the fertilizer dose for a given crop. The agricultural service of the local government and fertilizer producer is responsible for this fertilizer logistic issue. The FRA map can be created and used to assist the agricultural service in allocating fertilizer to farmers so that they can get fertilizer at the right time and right dose.

The PKDSS has a central role in bridging soil database and fertilizer application. Digital soil mapping products derived from legacy data in soil database are inputs for PKDSS to come up with fertilizer recommendations and FRA for specific crops in a given region.

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