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Site Specific Nitrogen Management Simulated by CropSyst Model under Different Inputs of Nitrogen Fertilizer

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ABSTRACT

Site Specific Nitrogen Management Simulated by CropSyst Model under Different Inputs of Nitrogen Fertilizer (Y Wijayanto): Site Specific Nutrient Management (SSNM) has been suggested as the only means for increasing productivity of crops and minimizing the environmental impacts. Despite of this, it is also widely recognized that compared to uniform application, SSNM provides a significant challenges related to the level of management. This is due to the fact that SSNM relates to the management of field / site (or fields / sites) and considers also the spatial and temporal component of factors leading to crop production. A method is urgently required and the most appropriate one is crop model. This study was aimed at using CropSyst to model yields due to the difference in N applications and its implementation for SSNM. The study area was located at Jenggawah Village, Sub-District Jenggawah, Jember Regency. Thirty soil samples were taken and six farmer's fields were chosen for the purpose of modeling. Interview was conducted to obtain the information about the management of farmer's fields. Yields in each farmer's fields were used as an integrated indicator. The results suggested that the predicted yields at farmer's fields were in agreement with those in reality. Simulated yields based on different amount of N inputs showed yields were proportional with different N inputs. This study concluded that there do exist a significant amount of potential applications of CropSyst for Site Specific Nitrogen Management

Keywords: CropSyst, maize yields, nitrogen management, site-specific

INTRODUCTION

Site Specific Nutrient Management (SSNM) has been suggested as the only means for increasing productivity of crops and minimizing the environmental impacts (Pierce and Nowak 1999; Ferguson *et al*. 2002). Although the evidence is still limited, previous studies, such as Paz *et al*. (1999), Larson *et al*. (1997); Wang *et al*.(2001) and Murni *et al*. (2010) have shown the profits which can be gained by implementing SSNM. According to Dobernmann and White (1999), SSNM can be defined as the dynamic, field specific management of nutrients in particular cropping season to optimize the supply and demand of nutrient according to their differences in cycling through soil-plant systems. This definition suggests that the management of field specific of crop nutrients should be conducted dynamically by considering soil-plant systems with the aim at optimizing the supply and demand of nutrient for that particular crop. The dynamic nature of management on the basis of site specific provide the most important component which differentiate SSNM to uniform application. However, implementing the nature of being dynamic and site-specific at field level leads to a significant amount of challenges for management of nutrient.

Variability of soil properties have been underscored by previous studies as study conducted by Mueller *et al*. (2001) and this has been the obstacles for site specific nutrient recommendation with regard to how to conduct site specific recommendation, especially for Nitrogen, as shown by Dobermann *et al*. (2003) and Pierce and Nowak (1999). The dynamics of factors controlling crop production (climate, soil, and field-management) can

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increase the complexity of site specific recommendation. Tool is needed, which can fulfill criteria of being: (a) able to integrate the dynamic nature of nutrient management in one side, (b) integrate factors controlling the plant production and (c) this tool is expected to the management aids for making decision. Crop model is the only tool which can accomplish these three criteria. Confalonieri *et al*. (2006) has strongly underscored the uses of crop model for studying the dynamic nature in agricultural system, who claims that crop models have been increasingly used to study the behavior of complex agricultural system and to understand the interaction between soil and plant under different meteorological conditions.

Crop model for simulating crop yields and biomass under different condition can be found in some studies by Cavero *et al*. (2000), Confalonieri *et al*. (2006) and Yang *et al*.(2004), which used different crop models. Despite a quite number of the application of crop models for studying the dynamic nature of agricultural systems, there is a few evidence on the uses of crop model for Site Specific Nutrient Management (SSNM). The reason is most likely due to the greater consideration of spatial and temporal variability in the SSNM than other studies, and the temporal variability provides the most challenging management component for SSNM (Pierce and Nowak, 1999). Due to the capabilities of crop model to analyse dynamic nature of agriculture production, spatial and temporal aspects of SSNM can potentially be managed. This study used CropSyst model as dynamic and mechanistic model (Stockle *et al*. 2003) for simulating yield due to the difference in Nitrogen (N) fertilizer input at field level. Yields was simulated in this study because the difference in soil, moisture, nutrients and other factors controlling crop productions are ultimately realized in crop yields. Therefore, the main aim of this study is on the use of CropSyst to model yields as a result of the difference in N applications and its implementation for SSNM.

MATERIAL AND METHODS

Soil Samples

Thirty surface soil samples were taken at July to October 2008. The location were determined by using Global Positioning Systems (GPS) using the Universal Transverse Mercator (UTM) coordinate system as listed in Table 1.

Grid sampling method was employed. The analysis of soil samples was, then conducted in the laboratories (Soil Physical Laboratory and Soil Chemistry and Fertility Laboratory at the Soil Department, Faculty of Agriculture, University of Jember). The standardized methods of soil samples analysis were employed, consisting: soil texture, bulk density, cation exchange capacity and pH. All data were used for CropSyst modeling. The results of laboratory analysis for thirty samples were then input into Geographical Information Systems (GIS). The interpolation techniques (*kriging*) within GIS was then employed to determine the values of each soil property at un-sampled areas. Detailed information about interpolation techniques within GIS can be found in Mueller *et al.* (2001). The interpolated values

Table 1. The Coordinate of Soil Samples.

Samples	X coordinate	Y Coordinate
1	788700.00	9081000.00
2	788800.00	9081000.00
3	788900.00	9081000.00
4	788700.00	9081200.00
5	788800.00	9081200.00
6	789000.00	9081200.00
7	789200.00	9081200.00
8	788700.00	9081400.00
9	788800.00	9081400.00
10	789000.00	9081400.00
11	789200.00	9081400.00
12	789400.00	9081400.00
13	789000.00	9081600.00
14	789200.00	9081600.00
15	789400.00	9081600.00
16	789600.00	9081600.00
17	789200.00	9081800.00
18	789400.00	9081800.00
19	789600.00	9081800.00
20	789600.00	9081700.00
21	789400.00	9081700.00
22	789200.00	9081700.00
23	789400.00	9081500.00
24	789200.00	9081500.00
25	789000.00	9081500.00
26	789200.00	9081300.00
27	789000.00	9081300.00
28	788800.00	9081300.00
29	789000.00	9081100.00
30	788800.00	9081100.00

Table 2. Soil chemical properties and their criteria.

No.	Farmer's name	C Org (%)	Criteria	N Total(%)	Criteria	pH (H_2O)	Criteria
1	Ahmad	0.91	Very low	0.12	Low	6.91	Neutral
2.	Syairi	1.25	Low	0.08	Very low	7.04	Neutral
3.	Hanifah	1.24	Low	0.13	Low	6.96	Neutral
4.	Kanan	1.12	Low	0.16	Low	6.87	Neutral
5.	Kasiyanto	1.12	Low	0.14	Low	6.98	Neutral
6.	Syamsudin	1.41	Low	0.14	Low	7.04	Neutral
7	Toyib	1.24	Low	0.19	Low	6.87	Neutral

were then used to determine the values of each soil property within the farmer's fields.

Farmer's Fields

Seven farmer's field were determined as samples. These seven fields represents the variation of field managements in the study area. The values of soil properties within farmer's fields as a results of interpolation were then determined by averaging the values of each soil properties for every interpolated sites within each farmer field. The values of each soil properties needed for CropSyst modeling can be seen in Table 2. These values was then input into CropSyst. Another information regarding crop management within farmer's field was determined by interviewing six farmers, consisting of (a) dates of some important crop management and performances: sowing, harvest, fertilizer applications, irrigation, phenological stages; (b) the amount of application (irrigation, fertilizer N). Ten years climatic data necessary for conducting modeling was collected from averaging the interpolated records of twenty one rainfall stations in Jember.

Modeling

After inputting the necessary data for CropSyst, modeling was then conducted. Modeling was conducted by using CropSyst version 4.12. Three scenarios of the amount of fertilizer application were constructed. These scenarios were (a) the amount of fertilizer applied by farmers; (b) the amount of fertilizer applied based on general recommendation, that is 300 $kgha^{-1}$; (c) No fertilizer N applied (Table 3).

Calibration and validation of CropSyst model was then conducted. In order to calibrate model, the values of parameters obtained from previous studies (Bellocchi *et al*. 2000 and; Kiniry *et al*.(1989) were used. The values of some parameters was then adjusted. The calibrated parameters and their corresponding values were then established (Table 4).

The validation was then conducted for six farmer's fields by using Efficiency Index (EF) as stated in Loague and Green (1991). The formula used for validation was:

Table 3. Three scenarios of the amount of fertilizer applied for six farmer's fields**.**

No	Farmer's plot	N applied by farmer ($kg\ ha^{-1}$)	N applied by general recommendation ($kg\ ha^{-1}$)	Withouth N Fertilizer
1	Ahmad	260	138	0
2	H. Syairi	318	138	0
3	Hanifah	329	138	0
4	Kanan	348	138	0
5	Kasiyanto	245	138	0
6	Syamsudin	276	138	0
7	Thoyib	280	138	0

Table 4. The parameters and values used in modeling.

Parameters	Values and Sources	
	Values	Sources
Phenology		
Degree-days emergence (°C-d)	100	Bellocchi, *et al*. (2000)
Degree-days begin flowering (° C-d)	950	Bellocchi, *et al*. (2000)
Degree-days peak LAI (° C-d)	900	Bellocchi, *et al*. (2000)
Degree-days begin grain filing (° C-d)	1,200	Bellocchi, *et al*. (2000)
Degree-days physiological maturity (°C-d)	1,650	Bellocchi, *et al*. (2000)
Base temperatur (° C)	8	Stockle, *et al* (1997)
Cutoff temperatur (° C)	25	Stockle, *et al* (1997)
Phenological sensitivity to water stress	1	Bellocchi, *et al*. (2000)
Morphology		
Maximum root depth (m)	1.5	Bellocchi, *et al*. (2000)
Maximum LAI (m^2m^{-2})	7	Bellocchi, *et al*. (2000)
Specific leaf area (m^2 kg^{-1})	22	Bellocchi, *et al*. (2000)
Leaf duration (° C-d)	800	Bellocchi, *et al*. (2000)
Leaf duration sensitivity to stress	1	Bellocchi, *et al*. (2000)
Extinction coefficient for solar radiation	0.4	Bellocchi, *et al*. (2000)
ET crop coefficient at fully canopy	1.2	Bellocchi, *et al*. (2000)
Growth		
Temperatur below which growth rate is redice (° C)		
Thermal time to cease temperatur limitation (° C-d)		
Maximum water uptake rate (mm d^{-1})	12	Bellocchi, *et al*. (2000)
Critical leaf water potential (J kg^{-1})	-1,000	Bellocchi, *et al*. (2000)
Wilting leaf water potential (J kg^{-1})	-1,400	Bellocchi, *et al*. (2000)
Above ground biomass-transpiration coefficient (kpa kg m^{-3})	8.25	Bellocchi, *et al*. (2000)
Ligth to above ground biomass conversion (g MJ^{-1})	4.5	Kiniry *et al*. (1989)

$$EF = \frac{\sum_{i=1}^{n} (Oi - \bar{O})^2 - \sum_{i=1}^{n} (Pi - Oi)^2}{\sum_{i=1}^{n} (Oi - \bar{O})^2}$$

in which, O was the Observed, while P was the predicted yields, Ô was the average of Observed values, n is the number of farmer's fields, and EF was Efficiency Ind.... The interpretation of the value of EF is that if the value approaches one means the values of predicted in agreement with those in observed ones.

RESULTS AND DISCUSION

The results of modeling clearly shows that the values of predicted yields were in agreement with those in observed ones (EF equal to 0.97). Figure 1 shows the comparison between the predicted and the simulated yields, providing the evidence that CropSyst can be used for predicting the yields. Only slightly differences were observed between the observed and the predicted values.

The yield differences amongst the farmer's fields are an interesting phenomenon in this study. As shown, although the study area is a small area (± 40 Ha), there do exist the yield differences which strongly related to the differences in the management

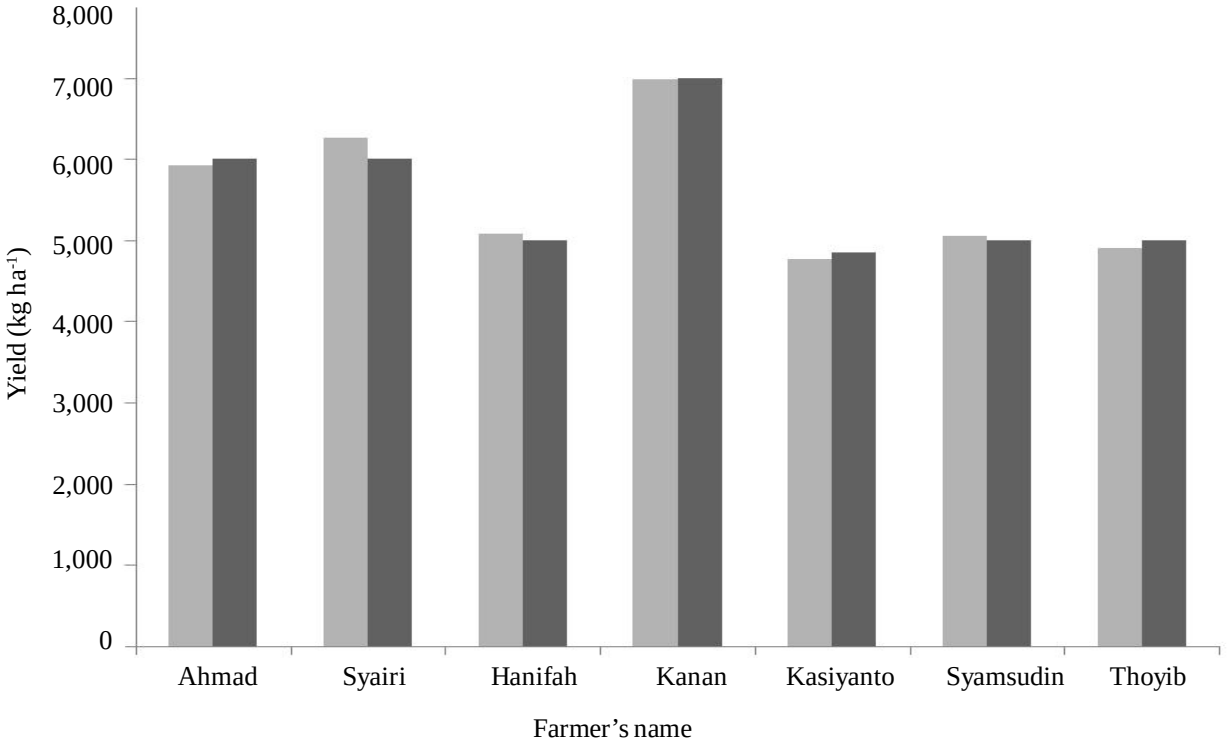

Figure 1. The comparison of observed (▒) and predicted (■)yields.

of fields. Date of sowing, fertilizer applications, irrigation were different amongst them. The amount of fertilizer applied (especially Urea) varies significantly among farmers (Table 2), although a small differences in soil characteristics was observed (Table 2). Therefore, site specific Nitrogen management is required for the study area. This results seems to agree with the Attanandana and Yost (2003) in Thailand which suggested that for the purpose of increasing the nutrient use efficiency in maize, it is necessary to implement site specific nutrient management.

Figure 2 shows the simulated yields in each farmer's fields based on the suggested N recommendation (300 kgha^{-1} Urea for uniform applications) and its correspondence values for unfertilized fields. As can be seen, for every field, the low values of simulated yields were observed in the fields without N fertilizer. Considering the yields differences between the fertilized and unfertilized yields suggested that there do exist the yield gap. Interestingly, the yield gap was different for the different field, which is most likely due to the differences in soil responds and management conditions by assuming that the management used for simulating yields as shown in Figure 2 was similar to those shown in Figure 1.

Comparing Figure 1 and Figure 2, it is apparent that by using the recommended dosage of Fertilizer N, yields were lower than current farmer practices. The only reason for this was most likely that farmers used more N fertilizer than those recommended (that is about 138 kg ha^{-1} Urea), whereas, farmers applied more that this recommended N, as shown in Table 2.

The results of the analysis of yields have clearly indicated that there do exist factors contributing to yield differences for each farmer's field. CropSyst was evidently able to model yields quite accurately for every field. Evidently, yields simulated by CropSyst were in agreement with the observed ones. Therefore, CropSyst is one of potential tool for Site Specific Nutrient Management (SSNM).

SSNM consider two main important components: space and time in the management of field, as stated by Pierce and Nowak (1999). From the above discussion, it was clear that each field has a different yield. In other words, yields was different spatially, due to the differences in farmer's management and this is likely to relate to the differences in soil characteristics, as shown in Table 1. The capabilities of CropSyst to model within daily

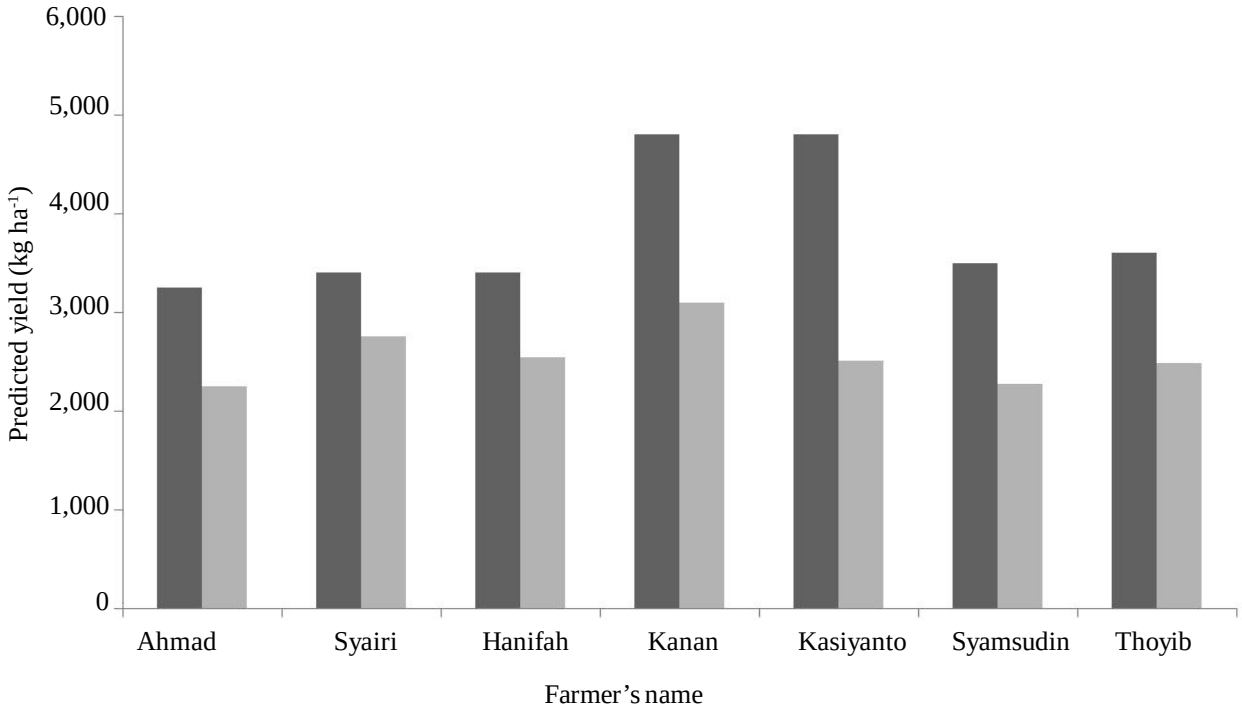

Figure 2. The comparison of yields simulated using fertilizer recommendation (▒) and without nitrogen fertilizer (■).

time step was the evidence that temporal (time) component has been considered. Therefore, the intent of SSNM to manage a field rather than whole fields and within a particular time can take a significant benefits of CropSyst model. The peak nutrient uptake demand of N as claimed by Jones and Jacobsen (2003), as for instance, can be determined by using CropSyst based on modeled daily N uptake. Consequently, splitting time of N application can be tracked by using CropSyst. Binder *et al.* (2000) claimed that the application of N fertilizer must consider the highest demand of N by maize and by using CropSyst the highest demand of N fertilizer can be determined. This shows that CropSyst can determine when the N deficiency occurs. By simulating the dosage of N fertilizer, the most appropriate amount of N can be determined to obtain the optimum yields . Because of the fact that fertilizer recommendation must take into account "how much'', "what form of" and "when" to apply nutrient inputs, as claimed by Yost *et al.* (2000), CropSyst is a valuable tool for establishing N recommendation for Site Specific Nitrogen Management.

This study has shown the merits afforded by CropSyst model for studying Site Specific Nitrogen Management. However, more studies using CropSyst are required for the fact that this study demonstrated only the use of this model for a single crop in high yielding season of maize. The applications of this model to low yielding season, crop rotation and long term simulation need to be undertaken.

CONCLUSIONS

This study has shown the benefits of crop model (CropSyst) for studying Site Specific Nitrogen Management. The results of this study suggested that each famer's field has a different characteristic. The inherent soil and management characteristics within each farmer's field has led to the yield differences amongst them. This study has ascertained the benefit of CropSyst to model maize yields under different condition of fields. The capabilities of CropSyst for simulating yields under different farmer's fields have proved that the yields were strongly affected by the integrated factors, and CropSyst allowed the integrated analysis of these factors. The results of this study clearly revealed the substantial supports of CropSyst model for Site Specific Nitrogen Management.

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