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Full Length Article

Estimating Grain Yield Based on BSW and SPAD at Grain Filling Stage in Double Rice Cropping System of China

Liu Kailou[1,2], Li Yazhen[2], Yu Paolan[2], Wu Yan[2], Zhou Lijun[2], Hu Huiwen[2] and Zhang Huimin[1*]
[1]*National Engineering Laboratory for Improving Quality of Arable Land / Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, China*
[2]*National Engineering and Technology Research Center for Red Soil Improvement; Jiangxi Institute of Red Soil, Jinxian 331717, China*
[*]For correspondence: zhanghuimin@caas.cn

Abstract

It may be good to estimate rice yield based on root bleeding snap weight (BSW) and leaf soil plant analysis development (SPAD) at grain filling stages in southeast China. There were seven treatments: (N-butyl) thiophosphoric triamide (NBPT) applied at rates of 0.00, 0.50, 0.75, 1.00, 1.25, 1.50% with urea @ 135 kg N ha^{-1} and CK (no NBPT or urea). All treatments received 75 kg P_2O_5 ha^{-1} (superphosphate, P_2O_5 12%) and 150 kg K_2O ha^{-1} (potassium sulfate, K_2O 60%), and then all fertilizer and inhibitor were applied once as base fertilizer. At grain filling stage, both of early and late rice, root BSW and leaf SPAD readings were obtained and grain yield determined at harvesting. In addition, the relationship between BSW, SPAD and grain yield was established. The results showed that the grain yield of rice, root BSW and leaf SPAD were increased significantly in application of NBPT with urea. Compared with 0% NBPT, grain yield, BSW and SPAD in 1.00% NBPT were improved by11.9–33.0%, 7.1–74.3% and 4.6–31.7% in early rice; and increased by 8.4–33.0%, 7.9–75.0% and 4.4–19.5% in late rice. However, these decreased when NBPT was less or more than 1.00%. On the other hand, the relationship between BSW, SPAD at grain filling stage and grain yield could be fitted by two-variable linear equation (p<0.05); and which provided better of validation experiment. Therefore, the grain yield could be predicted better by BSW and SPAD at grain filling stage in double rice cropping system. © 2016 Friends Science Publishers

Keywords: Grain yield; Root BSW; Leaf SPAD; Double rice; Relationship
Abbreviation: BSW: bleeding snap weight; SPAD: Soil plant analysis development; NDVI: normalized difference vegetation index; LCC: leaf color chart; NBPT: N-(n-butyl) thiophosphoric triamide; RMSE: mean square; N: nitrogen; R^2: coefficients of determination; RER: range error ratio.

Introduction

Rice (*Oryza sativa* L.) is the staple food for billions of people worldwide. China is the largest rice producer in the world, with approximately 31 million ha paddy rice cultivation in the country (Lin *et al.,* 2009). Therefore, grain yield improvement is an important evaluation index for rice production.

In rice growth season, prediction of potential yields is important for successful agricultural decision-making. Recently, tools such as leaf color chart (LCC), soil plant analysis development (SPAD) and GreenSeeker optical sensor have become available for the site-specific nitrogen (N) management strategies and prediction of yield potential during rice growth season (Ramesh *et al*., 2002; Li *et al*., 2009; Thind *et al*., 2011; Gnyp *et al*., 2014). In previous studies, it was found that normalized difference vegetation index (NDVI), SPAD and LCC have been used successfully to assess grain yield through building their relationships with N content of leaf or plant population. At different growth stages, Ramesh *et al.* (2002) found that the SPAD values at 79 days after rice sowing correlated well with the grain yield. And LCC has been used successfully to guide fertilizer N application in rice, wheat and maize. The NDVI readings at panicle initiation growth stage exhibited the highest coefficient of determination and explained 63% of the variation in rice grain yield (Ali *et al.,* 2014). Liu *et al*. (2015) also suggested that NDVI at heading stage could be used to estimate yield grain. However, these studies had paid little attention on bleeding snap weight (BSW) in estimating grain yield, although BSW is important in nutrition uptake of grain. At grain filling stage, rice roots could supply more N for grain. On 10 days after heading, the correlation of BSW with flag leaf net photosynthetic rate reached significant level (Xiao *et al.,* 2012).

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The SPAD and BSW could be affected by different N rates and application patterns. As a urease inhibitor, N-(n-butyl) thiophosphoric triamide (NBPT) with urea would improve N use efficiency and grain yield (Chaiwanakupt *et al.,* 1996), meanwhile, the roots activity and SPAD value may increase and lead to higher N uptake. Therefore, it may be a promising way that estimating rice yield of based on SPAD and BSW together at key growth stages in southeast China. The objectives of this study were (1) to examine the effects of different NBPT rates on SPAD and BSW in early and late rice, (2) to identify and establish the fitted equation of SPAD, BSW and grain yield, and then (3) discuss and evaluate the effect of the model vivification.

Materials and Methods

Site Description

The field experiment was conducted in 2012 and 2013 at the Jiangxi Institute of Red Soil, Jinxian county (116°17'57″E, 28°35'30″N, 31 m above sea level), Jiangxi Province, China. This site is under a typical subtropical climate with a distinct arid (July–September) and a humid (March–June) season. The mean annual temperature and rainfall are 17.2°C and 1549 mm, respectively. The soil was developed from Quaternary red clay and contained 9.4 g of organic C kg^{-1}, 0.98 g of total N kg^{-1}, 0.62 g of total P kg^{-1}, and 11.4 g of total K kg^{-1} with pH of 6.0.

Experimental Design

There are seven treatments with (N-butyl) thiophosphoric triamide (NBPT) rates applied at 0.00%, 0.50%, 0.75%, 1.00%, 1.25%, 1.50% with urea of 135 kg N ha^{-1} and CK (no NBPT or urea). All treatments were applied with 75 kg P_2O_5 ha^{-1} (superphosphate, P_2O_5 12%), 150 kg K_2O ha^{-1} (potassium sulfate, K_2O 60%) and all fertilizer and inhibitor applied one time as base fertilizer.

Seeds of early rice variety Denong 88 were sown on 22nd March, and planted in a paddy field with a mean of 25 hills m^{-2} (20 cm × 20 cm) on 23rd April, and late rice Shanyou 456 sown on 20th June, and planted in a paddy field with a mean of 25 hills m^{-2} (20 cm × 20 cm) on 24th July. The plots were separated by the clay (the height was 40 cm over the soil surface) with size of 50 m^2 (5 m × 10 m) and arranged in a randomized complete block design with three replications.

Plant Measurements

Grain yield: Grain yield was determined from 20 m^2 area from each plot and adjusted to a moisture content of 13.5%.
SPAD measurements: The chlorophyll meter used was the hand-held Minolta SPAD-502. The SPAD values were recorded by inserting the middle portion of index leaf in slit of SPAD meter. From each plot, readings from ten randomly selected plants were averaged. SPAD value was measured at grain filling stage i.e., 10 days after heading stage both in early and late rice.
BSW measurements: Starting at 10 days after heading stage in early and late rice, the bleeding rate from the root zone was measured in three hills per plot in different treatments. Starting at 14:30 h, shoots cut at 15 cm from the soil surface, and cut stems connected to the undisturbed root system were wrapped in a 625 cm^2 cotton towel, then covered with a polyethylene bag, sealed at the base with a rubber band, and left overnight to absorb xylem sap that flowed from the cut stems. The towel, bag, and rubber band used for each hill were weighed before use in the field. Starting at 07:30 h the following day, bags and towels were removed from the stems, sealed, and immediately weighed to quantify the bleeding rate from the intact root system.

Model Validation

In 2012, the field experiment was conducted by building model for estimating rice grain yield based on BSW and SPAD at grain filling stage, while the model was validated in 2013.

The validity of the models was estimated from the R^2 (coefficients of determination), RER (range error ratio), and RMSE (mean square).

$$RER = \frac{X_0 - X_S}{X_O} \times 100\% \qquad (2)$$

$$RMSE = \sqrt{\frac{\sum (X_0 - X_S)^2}{n}} \qquad (3)$$

Here, X_0 and X_S are the measured and estimated values, respectively.

Data were analyzed according to completely randomized design following analysis of variance (SPSS 16.0) and mean comparison between treatments was performed based on the Least Significant Difference (LSD) test at the 0.05 probability level.

Results

Effects on Grain and Straw Yield atDifferent NBPT Rates with Urea

There was significant difference in grain and straw yield of different NBPT rates. Compared with CK, the grain and straw yields of rice increased significantly when urea applied with NBPT (Fig. 1, Table 1). At different rates of NBPT, application of urease inhibitors with urea improved the grain and straw yields than 0% NBPT by 11.9–33.0% and 3.5–24.3% in early rice and late rice by 8.4–29.7% and 2.5–37.6%. The changes of grain and straw yields showed as 1% > 1.25%, 1.5% > 0.75% > 0.5% > 0%. The grain and straw yields in 1.00% NBPT (wt/wt) were

Table 1: ANOVA of grain yield, straw yield, BSW and SPAD in different treatments for early and late rice in 2012

Parameter	Source	DF	Sum of Squares	Mean Square	*F* values	*p*	$LSD_{0.05}$
Grain yield	Early rice	6	18799978.36	3133329.73	35.38	<0.001	521.12
	Late rice	6	11582890.45	1930481.74	21.12	<0.001	529.51
Straw yield	Early rice	6	9043312.18	1507218.70	36.94	<0.001	353.72
	Late rice	6	9476762.58	1579460.43	53.35	<0.001	301.33
BSW	Early rice	6	12625852.95	2104308.83	9.46	<0.001	826.10
	Late rice	6	22289732.42	3714955.40	20.81	<0.001	739.86
SPAD	Early rice	6	244.19	40.70	28.38	<0.001	2.10
	Late rice	6	313.39	52.23	131.97	<0.001	1.10

higher than other treatments its grain and straw yields were 7730 and 4944 kg ha^{-1} in early rice; 8258 and 6024 kg ha^{-1} in late rice. However, these were lower when the NBPT rate was more than 1.00%. Therefore, both in early and late rice, the grain and straw yields of rice increased gradually when the ratio of urease inhibitors increased from 0.50 to 1.00%, but decreased when NBPT rate was more than 1.00%. This showed that the best ratio of urease inhibitor was 1.00%.

Effects on BSW at Grain Filling Stage in Different NBPT Rates with Urea

Both in early and late rice, the BSWs at grain filling stage were affected by different NBPT rates (Table 1). In Fig. 2, it increased significantly when urea was applied with NBPT; in early rice, compared with 0% NBPT, application of urease inhibitors with urea improved BSW by 7.1–74.3%, and the increment was 7.9–75.0% in late rice. However, the BSW of 1.0% NBPT was highest in all treatments and more than 0% NBPT by 74.0% (early rice) and 75.0% (late rice).

Effects on SPAD Values at Grain Filling Stage in Different NBPT Rates with Urea

Application of urease inhibitors with urea could increase the SPAD value of flag leaf at grain filling stage (Fig. 3; Table 1). It increased gradually when the NBPT rate changed from 0 to 1.0%, but was lower when NBPT increased than 1%. In all treatments, the SPAD value was higher in 1.0% NBPT than 0% NBPT by 4.6–31.7% in early rice, and late rice by 4.4–19.5%. This also indicated that 1% NBPT with urea was best treatment to improve the SPAD.

The Relationships and Fitted Equations of BSW, SPAD and Yield in Different NBPT Rates with Urea

Fig. 4 and Fig. 5 showed linear correlation between BSW, SPAD and grain yield, and their relationships were remarkable because their *p* values were less than 0.05 both in early and late rice. This indicated that BSW and SPAD at grain filling stage could reflect directly the changes of grain yield in different rates of urease inhibitors, it proved that rice yield of different amount of urease inhibitor could be estimated based on SPAD and BSW at grain filling stage with linear equation.

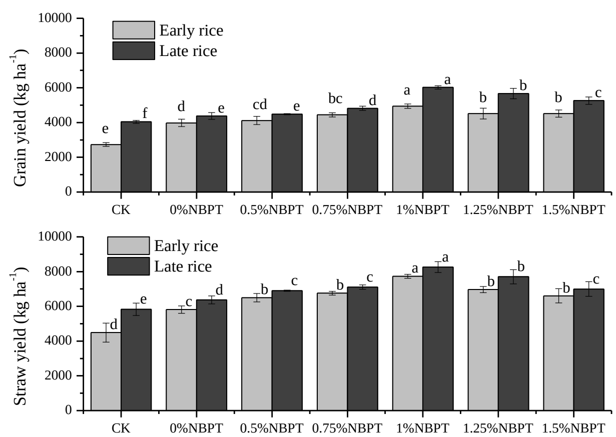

Fig. 1: The grain and straws yield of early and late rice in different NBPT rates with urea in 2012. The results represent the means ± SE (n = 3). The same letter indicates no significant difference (p<0.05)

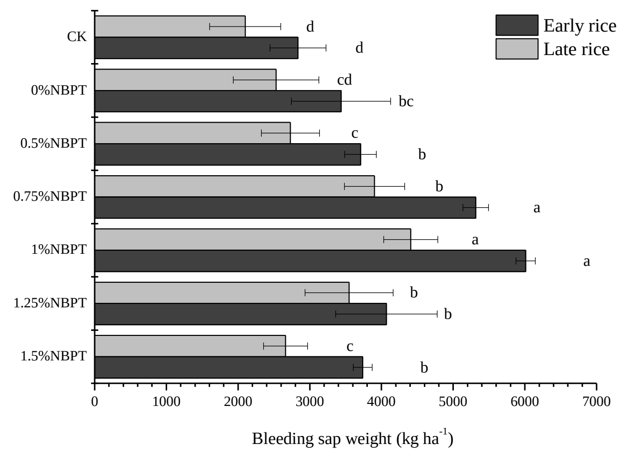

Fig. 2: The BSW changes of early and late rice in different NBPT rates with urea in 2012. The results represent the means ± SE (n = 3). The same letter indicates no significant difference (p<0.05)

In Table 2, the relationship between BSW, SPAD and yield was fitted by two-variable linear equation (p<0.05), the R^2 was 0.8584 in early rice, and 0.8787 in late rice. It was also found that the gain yield could be calculated by BSW and SPAD.

Table 2: The fitted equations between BSW(X1), SPAD(X2) and yield (Y) in 2012

Rice season	Fitted equation	R^2	*p*
Early rice	Y=10.97+0.38X1+180.16X2	0.8584	<0.05
Late rice	Y=1740.05+0.19X1+138.29X2	0.8787	<0.06

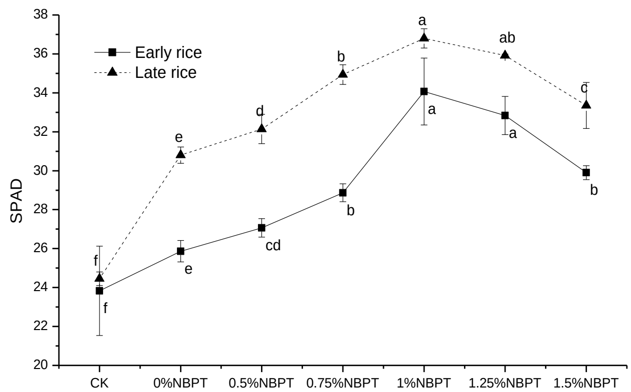

Fig. 3: The SPAD changes of early and late rice in different NBPT rates with urea in 2012. The results represent the means ± SE (n = 3). The same letter indicates no significant difference (p<0.05)

Model Validation

In validation experiment, the grain yield could be estimated by BSW and SPAD at grain filling stage (Fig. 6). The errors were little between measured and estimated values of grain yield both in early and late rice (Table 3). Their RMSE values were 791.93 and 307.55, so grain yield in early and late rice could be predicted better by BSW and SPAD at grain filling stage through the regression equation in Table 2.

Discussion

Application of NBPT with urea could improve N use efficiency, because it can reduce nitrogen loss via ammonia volatilization from urea (Rawluk *et al.,* 2001). Many reports showed that it could increase grain yield in rice, wheat, corn and so on (McKenzie *et al.,* 2010; Kawakami *et al.,* 2012; Liu *et al.,* 2014). In our study, the grain yield of rice in NBPT with urea increased than no NBPT by 11.9–33.0% and 8.4–29.7%, and the straw increased by 3.5–24.3% and 2.5–37.6%. However, yields were different when the rates of NBPT with urea changed from 0.25 to 1.25%. In double rice cropping areas of China, the best rate of NBPT with urea is 1.0% which indicates that NBPT could improve grain and straw yield, but it did not increase when the amounts of NBPT was more than 1.0%. Rawluk *et al.* (2001) suggested that it is best rate of NBPT in application with urea, and found the inhibitor helps to reduce total ammonia volatilization from soils fertilized with the beat rate of 0.5%. However, the total ammonia volatilization was not increased when the proportion of NBPT was more than 0.5%.

Table 3: Errors of the correlations of grain yield in validation experiment in 2013

Treatments	Range error ratio	R^2	RMSE
Early rice			
0% NBPT	-0.082	0.8027	791.93
0.5% NBPT	0.062		
0.75% NBPT	0.097		
1% NBPT	0.162		
1.25% NBPT	0.140		
1.5% NBPT	0.190		
Late rice			
0% NBPT	-0.005	0.7476	307.55
0.5% NBPT	-0.032		
0.75% NBPT	0.011		
1% NBPT	0.045		
1.25% NBPT	0.036		
1.5% NBPT	0.090		

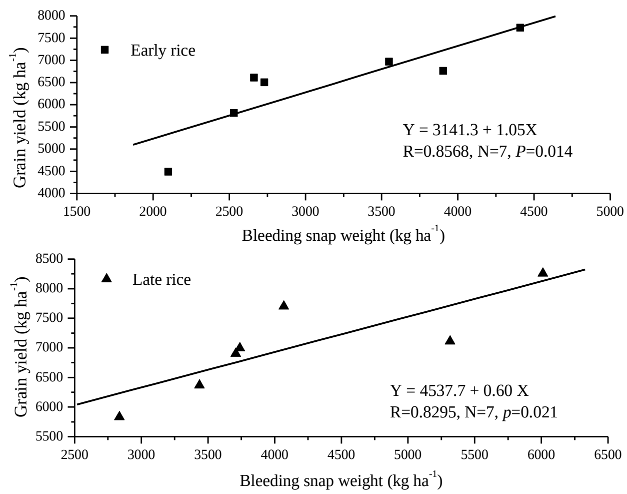

Fig. 4: The relationship between BSW at grain filling stage and grain yield of early and late rice in 2012

The roles of BSW and SPAD at grain filling stage were important in formation of grain yield (Kijoji *et al.,* 2014; Yang *et al.,* 2014). In general, the BSW could reflect the nutrient supply of root and it was shown that the grain of rice could absorb sufficient mineral nutrient when the BSW was higher (Yang *et al.,* 2004; Henry *et al.,* 2012). In present study, it increased by 7.1–74.3% and 7.9–75.0% in early and late rice when urea was applied with NBPT, and in all treatments, the BSW was highest for 1.0% NBPT. At grain filling stage, rice roots could supply more N for grain. On 10 days after heading, the correlation of BSW with flag leaf net photosynthetic rate reached significant level (Xiao *et al.,* 2012). On the other hand, SPAD values of flag leaf are one index closely related with N content of leaf. Many reports found photosynthesis and grain yield could be affected by the SPAD value of flag leaf at grain filling stage (Ramesh *et al.*, 2002; Jiang *et al.*, 2012; Huang *et*

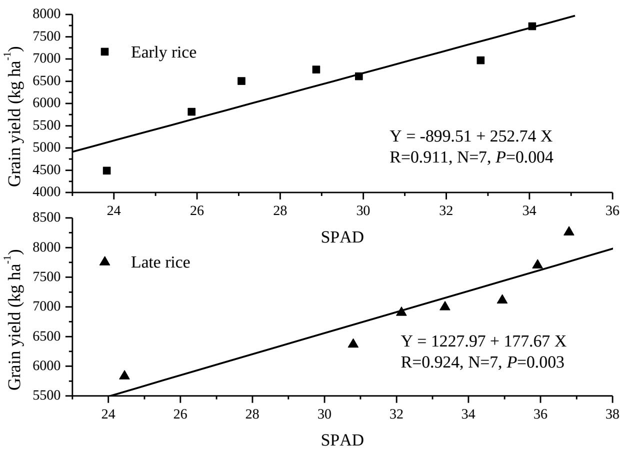

Fig. 5: The relationship between SPAD at grain filling stage and grain yield of early and late rice in 2012

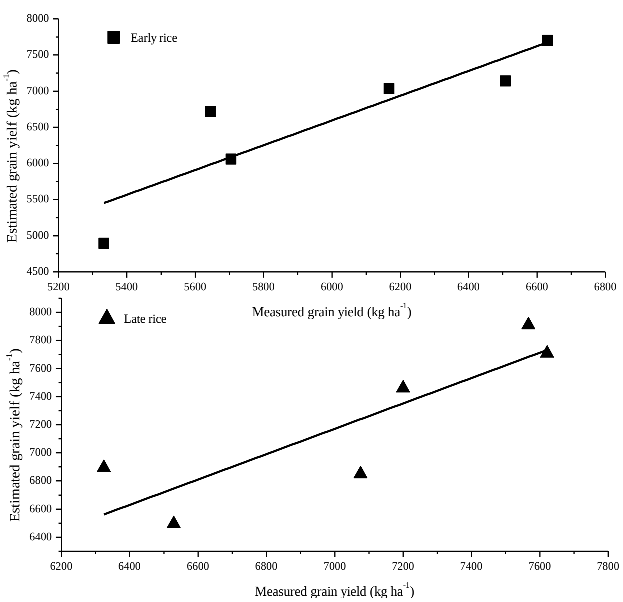

Fig. 6: The relationship between measured and estimated yield of early and late rice in 2013

al., 2014). Jiang *et al.* (2012) reported the SPAD value was different when the application of N rates changed from 60 to 180 kg ha^{-1}, and it was reported that the reasonable SPAD value could improve yield, but it varied in different rice varieties. In this study, the SPAD value of flag leaf was about 27-34 at grain filling stage in early rice, and 32-36 in late rice. The application of NBPT with urea could increase SPAD. In all treatments, it was higher with 1.0% NBPT than other treatments. This also indicated that NBPT with urea was an important pattern to improve the SPAD with 1% NBPT as best rate.

It is known that SPAD and BSW were important growth index in formation of grain yield. But little attention was paid in estimating grain yield by SPAD and BSW. In double rice cropping systems, the grain yield would be improved with increasing SPAD and BSW at grain filling stage. As found that there was linear correlation between BSW, SPAD and grain yield (Fig. 4 and 5). The results showed that BSW and SPAD at grain filling stage could indicate the change of grain yield of rice. Further, it was found that the gain yield could be calculated by BSW and SPAD with two-variable linear equation ($p<0.05$), in validation experiment, the grain yield could be estimated well by BSW and SPAD at grain filling stage, where, their RMSE values were 791.93 and 307.55.

Conclusion

The application of urease inhibitors with urea could improve the grain and straw yields by 8.4–33.0% and 2.5–37.6%. And BSW and SPAD at grain filling stage increased significantly. In double rice cropping system, the grain and straw yields in 1.00% NBPT (wt/wt) were highest in all treatments. Meanwhile, the result of BSW and SPAD was similar to yield; BSW and SPAD at 1.00% NBPT were highin both rice cultivars, and decreased when NBPT was less or more than 1.00%. This showed that the best rate of urease inhibitor was 1.00%.

The relationship between BSW, SPAD at grain filling stage and grain yield could be fitted by two-variable linear equation; therefore, the grain yield could be predicted better by BSW and SPAD at grain filling stage.

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