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Calibration of the Jensen' Yield Prediction Model for Rice Crop Cultivated in the Northern Region of Vietnam

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ABSTRACT

Water stress and sensitive coefficient of crops are important parameters, indicating the effect of water regime on productivity. They provide a scientific basis for management agencies and farmers to manage and operate their irrigation systems. A field experiment was carried out on an area of 450m^2, divided into 42 experimental plots with different cultivation methods (conventional and SRI) and under different water regimes. Measurement parameters of each plot included irrigation water, rainfall, in-flow, evapotranspiration, capillary water going up while the surface soil layer was revealing and drying, in/out underground water flows in cultivating soil layer, infiltration water, difference of water levels on the experimental plots at the beginning and end of the study. Evapotranspiration in each growth stages of rice crops and in each experimental plot was determined. Then Jensen's yield prediction model was calibrated to predict rice yield as affected by the water stress. The result revealed that if water shortage had occurred, the yield of spring rice which was cultivated following SRI methods would be less than that cultivated by conventional method. Moreover, the effects of water shortage in 1st and 2nd growth stages of conventional cultivated summer rice were less than that cultivated following SRI method in the same stages. The yield of rice crops cultivated following the SRI method was less affected by the lack of water in 3rd and 4th growth stages, as compared to that cultivated by conventional method.

Keywords: Crop growth stages, rice, sensitive coefficient, water regimes, yield prediction model

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INTRODUCTION

The Northern Delta of Vietnam has about 1,141,400 ha of rice crops in a year, accounting for 15% of the total rice cropped area of the country (Vietnam General Statistics Office, 2017). Since last decade, about 142,000 to 242,000 ha of rice crops have been facing inadequate water resources in the spring season annually. Even within the area covered by large irrigation works, about 123,000 ha/year of cropped area was experiencing insufficient irrigation water problem (Hoa, 2011). Due to inadequate water for irrigation, farmers in the region have to change their farming practices. In addition, most of the rice cropped areas are affected such as late seeding, and changes of the cropping pattern due to insufficient watering. This situation greatly affects the food production of the country in general and the socio-economic stability of the region in particular (Directorate of Water Resources, 2010).

For any rice variety, the magnitude of yield reduction depends mostly on the severity of the drought and on the frequency drought has occured within the growing season. It is generally agreed that the period during anthesis is especially sensitive to drought (Bouman & Tuong, 2000; Garrity & O'Toole, 1995). The variation in drought sensitivity among cultivars suggests that there is scope for breeding and selecting cultivars that are suitable for water-saving irrigation. In addition, most of the rice cropped areas are affected by several other factors, such as late seeding, and changes of the cropping pattern due to insufficient watering. This situation greatly affects the food production of the country in general and the socio-economic stability of the region in particular (Directorate of Water Resources, 2010).

In order to provide more scientific information for management agencies and famers to improve performance of rice based on irrigation systems, this paper presents the results of assessing water stress and calibration of Jensen's yield prediction model for rice crops (Khang Dan variety) which were cultivated by conventional and SRI modes in the Northern Delta. This region is characterized by tropical climate, which has four distinct seasons of spring, summer, fall, and winter. The average temperature of about 25 ^{0}C, and then gradually increases from north to south; the average rainfall is ranging from 1700 to 2400 mm, in the period from 1997 to 2016. The weather in summer (from May to October) is hot, humid, and rainy until the presence of monsoons. The temperature may rise to 37 ^{0}C in the peaks of June and July. In the winter, the temperature falls, especially in December and January.

Research on water stress and sensitivity of crop due to shortage of water is very important, especially in the context of global climate change and trend of serious environmental degradation. Understanding the sensitivity of plants to water regimes will help organizations and individuals to manage their irrigation systems efficiently and effectively (Anbumozhi et al., 1998; Bouman & Tuong, 2000). Hence, the information revealed from this study will assist in selecting appropriate crop species and cropping pattern under specific water conditions.

MATERIALS AND METHODS

Jensen's Yield Prediction Model

Physiological nature of the plant itself is that it has some responses to resistance and adapts to adverse changes in environmental conditions. Overcoming certain resistance of an entity, the survival and growth of plants will be affected and their yield will be decreased. For each variety or species, the tolerance and extent of damage caused by this factor varied. These differences are called the sensitivity of the plant to the environment. Jensen (1968) derived a multiplicative crop yield model to determine crop yield as defined by the Eq.1, bringing the time into the expression by a sensitivity coefficient (λ) and defining the relative sensitivity of a crop to water stress at a given growth stage using the ratio of actual and maximum evapotranspiration. Water deficiency at each growth stage not only affects the biomass of the crop, but also resulting in the combined effect in the subsequent periods (Jensen, 1968; Thinh, 2006).

$$\frac{Y_a}{Y_{max}} = \prod_{i=1}^{ns} \left(\frac{ET_a}{ET_{max}} \right)_i^{\lambda_i} \qquad [1]$$

Where, λ_i: is sensitivity coefficient by water in i^{th} growth stages; Y_a: actual yield of the crop (kg/ha); Y_{max}: maximum crop yield in sufficient watering conditions (kg/ha); ET_a: actual evapotranspiration, corresponding to Y_a in i^{th} growth stage (mm); ET_{max}: evaporation corresponding to Y_{max} in i^{th} growth stage (mm); ns: number of growth stages of the crop.

Logarithms of both sides Eq.1, it is equivalent to

$$\mathrm{Ln}\frac{Y_a}{Y_{max}} = \sum_{i=1}^{ns} \lambda_i . \mathrm{Ln}\left(\frac{ET_a}{ET_{max}}\right)_i \qquad [2]$$

Set z = $\mathrm{Ln}\frac{Y_a}{Y_{max}}$; $x_i = \mathrm{Ln}\left(\frac{ET_a}{ET_{max}}\right)_i$ then Eq.2 is rewritten as

$$z = \sum_{i=1}^{ns} \lambda_i . x_i \qquad [3]$$

If set of observed data is presented as $(x_{j,i}, z_j)$, j = 1, 2, 3 ... N, Eq.3 may be expressed as a matrix equation: $Z = \Lambda.X$. This is solved by Ordinary Least Square method. However, to calibrate the Jensen (1968) model and apply the results, the ET_a, ET_{max}, Y_{max}, and N should be determined by field experiments.

Characteristics of Experimental Sites

The experiment was conducted in South Yen Dung irrigation system, Bac Giang Province, Northern region of Vietnam. This area is surrounded by Cau River, Thuong River and Nham Bien mountain, thus the ground water level appears relatively low. With those features, it is convenient to drain water to avoid flooding during the experimental period. The soil of the experiment area is formed by erosion and has been used for farming for a long time. The medium elevation of the field surface ranges from +2.0 to +4.0 and are distributed widely on the irrigation system. The surface soil layer is consisted of mainly clay and humus with high level of protein, potassium, and phosphorus contents. Generally, soil in this area is considered very appropriate with cultivation of rice crops. The subsoil below surface is very poor in nutrition and other fertilizers. So, the effective root of the rice crop is mainly concentrated in the surface soil.

There are two rice crop seasons in the experimental sites. The rice crops are cultivated by two methods namely i) conventional mode (C) and ii) System of Rice Intensification (SRI) methods. The main differences of these two farming practices are presented in Table 1. According to Division of Agriculture and Rural Development of South Yen Dung District, Bac Giang province, Vietnam and current local practices, the conventional farming methods are often associated with regular irrigating (flooding). On the other hand, wet-dry alternative irrigation is one of the mandatory requirements for SRI cultivation method.

Table 1
Characteristics of rice cultivation methods in the study area

Conventional				SRI			
roots/ m^2	plants/ m^2	density (cm)	seedling age (days)	roots/ m^2	plants/ m^2	density (cm)	seedling age (days)
33.3	133.2	15 x 20	>20	20	40	20 x 25	8 to 10

Experimental Processes

Numbers of Observed Parameters. The number of parameters to be identified would determine the cases, sizes and forms of the experiment. In this study, the main variables to be identified are (ET_{max}, ET_a, Y_{max}, and Y_a) for different farming practices. The evapotranspiration of rice crops was determined from the water balance equation on the field plots -

$$M + Rf + Q_{in} + N_c = ET_a + W_{in} \pm \Delta Q_g \pm \Delta a \qquad [4]$$

Where, M is amount of irrigation water (mm); Rf is rainfall (mm); Q_{in} is in-flow (water come from outside, mm); ET_a is actual evapotranspiration at the rice field surface (mm); N_c is capillary water going up on the surface soil; ΔQ_g is in/out ground water (mm); W_{in} is infiltration water (mm/day); Δa is difference of water level (mm) on the rice field surface of experimental plots at the beginning and end of the study period. To determine ET_a, all the parameters in Eq.4 need to be monitored, includes: M, Rf, N_c, Q_{in}, W_{in}, ΔQ_g, and Δa. However, with the features of experimental site and including experiment design, it was not necessary to pay attention to observe Q_{in} and ΔQ_g because the experimental site was not much affected by surface and ground water. In addition, other parameters such as growth and yield of rice (including growth stages, number of plants, crop height, number of effective tillers, number of grain) were also measured.

Water Regimes. The experimental cases reflect different water regimes. The volume of irrigation water in experimental plot for each irrigation period was determined using the CROPWAT model (FAO, 1998). Meteorological data recorded from local weather station was used to forecast evaporation. Soil properties were determined by field testing. With flood irrigation, the applied water for the experimental plot was at least equal to 100% of the calculated value. In contrast, during the limited irrigation period (wet-dry alternative), the applied water was within the range of 50% to 100% of the calculated value. For each experimental plot, flooding or wet-dry irrigation were applied alternately during the four growth stages of rice crop. In order to avoid the bias of the water regimes to the sensitive coefficient of the rice crop in each growth stage, the experimental plots were designed to be symmetrical, corresponding to flooding or wet-dry irrigation (Table 2).

Layout and Experimental Design. With the above defined variables, each cultivation method would have 16 ($=2^4$) experimental plots, where flooding and wet-dry irrigation were applied depending on particular growth stages of rice crop. In addition, 5 controlled plots were arranged for each cultivation method (based on experience of the local people). The total number of plots was 42 (Figure 1). The experiment was conducted in 4 crop seasons (2 spring rice crops, and other 2 summer rice crops).

Methods and Equipment

Corresponding to the parameters needed to be observed as discussed above, the methods and equipment which were used for this experiment includes -

(i) Irrigated water (M): measured by water counter and combining with water column

(ii) Precipitation and effective rainfall (Rf): measured by rain counter and water column

(iii) Capillary water (N_c) and (W_g) were calculated by using the experimental equations.

In which, these parameters were determined by the instantaneous surface water and moisture in the soil layer (Dat, 2011, 2012).

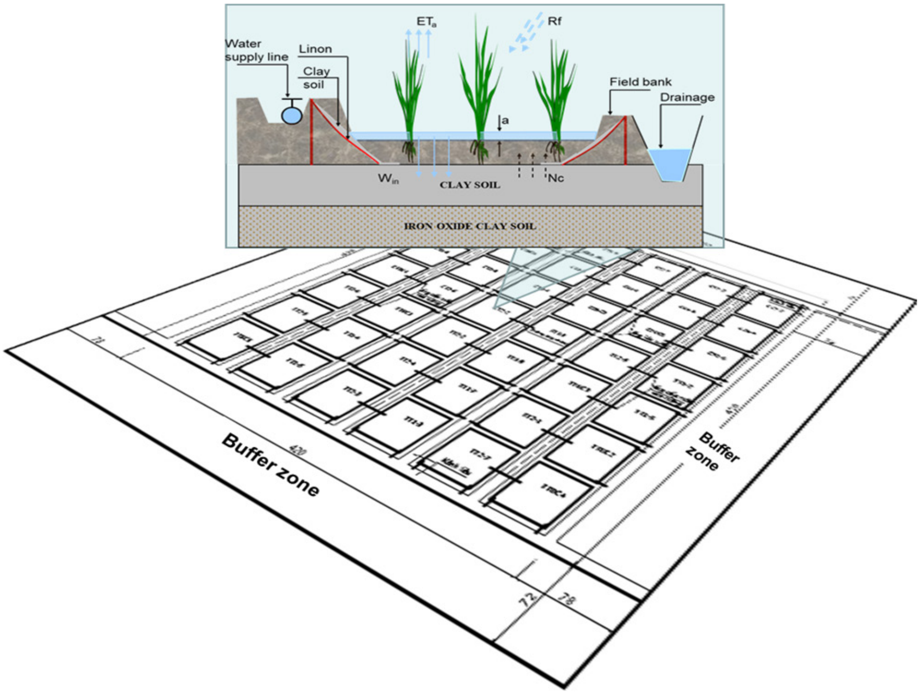


Figure 1. Layout of experimental area representing irrigation management for rice crops.

Table 2

Water regimes on different rice field plots

TT	Plots (experimental cases)[1(*)]	Water regimes at particular growth stage[(†)]			
		1	2	3	4
1	SRI1-1 (and C1-1)[(**)]	flooding	flooding	flooding	flooding
2	SRI 1-2 (and C1-2)	flooding	flooding	flooding	wet-dry
3	SRI 1-3 (and C1-3)	flooding	flooding	wet-dry	flooding
4	SRI 1-4 (and C1-4)	flooding	flooding	wet-dry	wet-dry
5	SRI 1-5 (and C1-5)	flooding	wet-dry	flooding	flooding
6	SRI 1-6 (and C1-6)	flooding	wet-dry	flooding	wet-dry
7	SRI 1-7 (and C1-7)	flooding	wet-dry	wet-dry	flooding
8	SRI 1-8 (and C1-8)	flooding	wet-dry	wet-dry	wet-dry
9	SRI 2-1 (and C2-1)	wet-dry	wet-dry	wet-dry	wet-dry

Table 2 *(Continued)*

TT	Plots (experimental cases)1(*)	Water regimes at particular growth stage(†)			
		1	2	3	4
10	SRI 2-2 (and C2-2)	wet-dry	wet-dry	wet-dry	flooding
11	SRI 2-3 (and C2-3)	wet-dry	wet-dry	flooding	wet-dry
12	SRI 2-4 (and C2-4)	wet-dry	wet-dry	flooding	flooding
13	SRI 2-5 (and C2-5)	wet-dry	flooding	wet-dry	wet-dry
14	SRI 2-6 (and C2-6)	wet-dry	flooding	wet-dry	flooding
15	SRI 2-7 (and C2-7)	wet-dry	flooding	flooding	wet-dry
16	SRI 2-8 (and C2-8)	wet-dry	flooding	flooding	flooding
17	SRI-Controlled (1 - 5)	Local irrigation practices applied			
18	C-Controlled (1- 5)	Local irrigation practices applied			

(Footnotes)
(*) SRI: farming practiced following System of Rice Intensification, water regimes controlled as design; C: farming practiced following conventional method, water regimes controlled as design; SRI-Control: farming practiced following System of Rice Intensification, water regimes controlled as local experiences; C-Controlled: farming practiced following conventional method, water regimes controlled as local experiences.

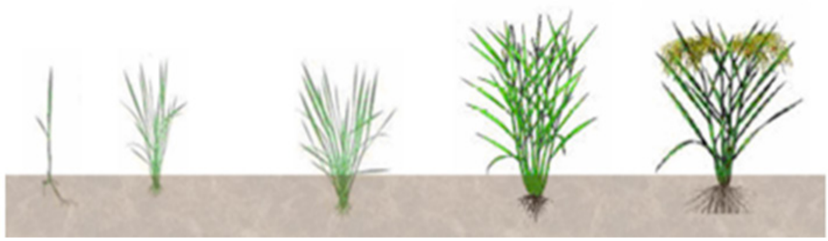
(**) 1-x, 2-x: corresponding with major flooding or wet-dry irrigation applied; y-1, y-2: order of alternative irrigation mode applied. (†) Growth stage: 1 = Transplanting → tillering, 2 = tillering → panicle formation, 3 = panicle formation → flowering, 4 = flowering → maturity.

RESULT AND DISCUSSIONS

Growth Stages of Rice Crops

The transplanting calendar was applied parallelly for both conventional and SRI. However, due to weather conditions and biological processes of different rice crops, their growing time was relatively different between seasons and cultivating methods. Observation of different growth stages of rice crops in four experimental seasons is summarized in Table 3. The result showed that, for spring rice crops cultivated conventionally, the growth stage was about 100 days. In the same season, rice crop cultivated by SRI method had a longer growth stages (106 days). In summer season, growth time of rice crops was more stable. The rice crop cultivated by conventional method had a growing time of 88 days, while the rice crop cultivated by SRI method needed more time for growing (93 days).

Table 3
Variations in different growth stages of rice

	Growing time (days)			
Crop season	 transplanting → tillering → panicle formation → flowering → maturity			
	1^{st} stage	2^{nd} stage	3^{rd} stage	4^{th} stage
Spring rice	13 (13)	39 (33)	23 (23)	31 (31)[(*)]
Std. Dev.	4.43 (4.54)	1.44 (2.72)	5.87 (5.98)	2.84 (3.06)
Summer rice	5 (6)	40 (38)	15 (15)	30 (32)
Std. Dev.	0.67 (0.67)	1.16 (3.00)	1.28 (1.84)	1.17 (1.91)

The data in "()" indicates days of rice crops cultivated by conventional method.

Note. The size of the plot was 25m^2; Total plots were 42; Irrigation water was controlled by pipeline system with meter; plots were randomly placed in each crop season.

Water Stress and Sensitive Coefficient of Rice Crops

Relationship between actual evapotranspiration (ET_a) and rice yield (Y_a): Based on the observed data, the actual evapotranspiration (ET_a) and actual rice crop yield (Y_a) were calculated. The relationship between these parameters was established and presented in Figures 2 and 3. Accordingly, all the correlation has the form of polynomial of degree 2 with high reliability with R^2 ranging from 0.7064 to 0.8269. Evapotranspiration corresponds to different growth stages maximum yield of rice cultivated by conventional and SRI method both in spring and summer seasons are presented in Table 4.

Determination of rice crop's sensitivity coefficient due to water stress: From Eq.1, the sensitivity coefficient λ may be positive, negative or equal to zero. When λ is less than 0, it means that crop yield (Y_a) decreased if ET_a is increases. This generally contradicts the objective of irrigation system management. Therefore, all the pair of data (Y_a and ET_a) corresponding to $ET_a > ET_{amax}$ should be eliminated in the analyzing process. The remaining pairs of data used for determination of λ is called the useful data and counted as N. While N is determined from the recorded data set (as described in Figures 2 and 3).

Later, the equation of Z = Λ.X was solved for spring rice crop cultivated by conventional methods (N = 26); spring rice crop cultivated by SRI method (N = 27); summer rice crop cultivated by conventional method (N = 23), and summer rice crop cultivated by SRI method (N = 28). The result of determining λ is presented in Table 5. In all cases, R^2 was relatively high, ranging from 0.843 (spring rice crop cultivated with SRI method) to 0.959 (summer rice crop cultivated with conventional method). This indicates that there is a close relationship between evapotranspiration of the rice crop growth stages and rice crop yields in the study area.

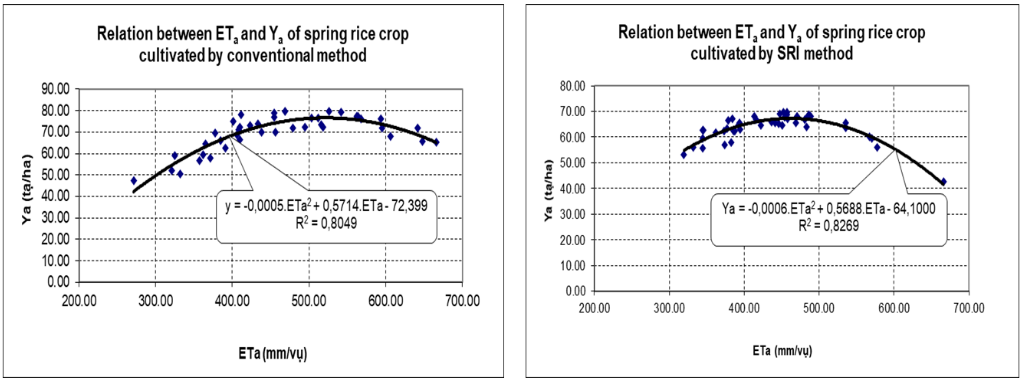
For spring rice, the lowest sensitive coefficient was obtained in the first growth stage (transplanting → tillering). The highest sensitivity coefficient was achieved during the third growth stage. This result corresponded well to the weather conditions during the first stage of cultivation when light rainfall occurred, which reduced the water demand for rice crop. Therefore, if the air temperature is reasonable, rice crop might grow well even there is insufficient water for irrigation. However, during summer when dry and hot wind blows in the study area at the 3rd growth stage of rice crop, the lack of available water for rice crops during this time may lead to reduce the yield.

Moreover, after the transplanting, spring rice crops shown good tolerant to drought (especially for rice crop cultivated by SRI method) with less yield loss. This result indicates a great opportunity to improve performance of the irrigation system in poor water resource conditions if management agencies and local people applying less irrigation during soaking, land preparation and transplanting period. The result also showed that water was more important in the 3rd growth stage (panicle formation → flowering) of summer rice crop (Table 5). For the study area, during the period of panicle formation and flowering of summer rice crop, the weather was always sunny and the temperature appeared so high, then water demand of the rice crops was greater (although it is a rainy season). Therefore, water shortages for rice crops during this time may affect the panicle formation, flowering and cause reduction of the rice crop yields.

Table 4

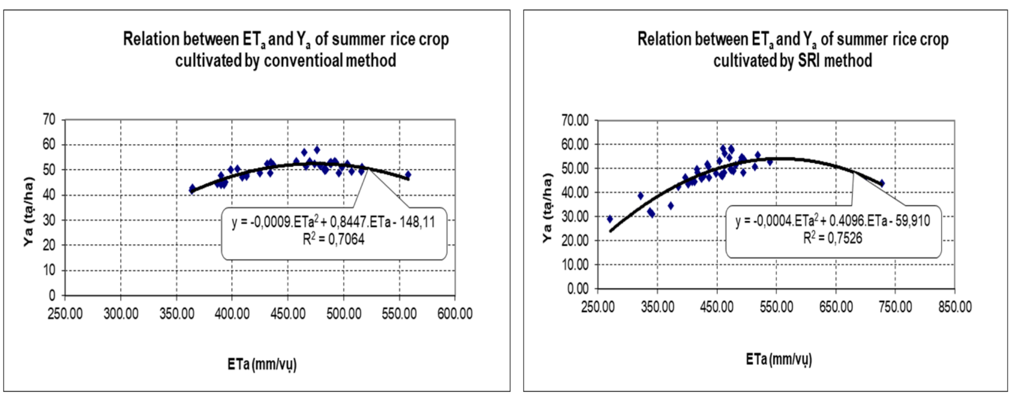
Rice crop yield and potential evapotranspiration

Parameters	Conventional cultivation		SRI cultivation	
	Spring	Summer	Spring	Summer
Y_{max} (ton/ha)	78.60	58.37	69.75	58.00
ET_{max} (mm/season)	469.11	476.22	452.23	474.26
ET_{a1}(mm/stage 1)	30.90	29.72	24.33	22.54
ET_{a2}(mm/stage 2)	158.43	238.14	147.97	199.86
ET_{a3}(mm/stage 3)	163.97	83.28	155.65	89.20
ET_{a4}(mm/stage 4)	115.81	125.09	124.28	162.64



a. Conventional cultivation b. SRI cultivation

Figure 2. Correlation between ET_a and Y_a of spring rice crops



a. Conventional cultivation b. SRI cultivation

Figure 3. Correlation between ET_a and Y_a of summer rice crop

Table 5

Rice crops sensitivity coefficient due to water stress

Sensitivity coefficient	Conventional cultivation		SRI cultivation	
	Spring rice	Summer rice	Spring rice	Summer rice
λ stage 1	0.111	0.188	0.055	0.266
λ stage 2	0.303	0.255	0.172	0.337
λ stage 3	0.425	0.524	0.212	0.516
λ stage 4	0.079	0.084	0.111	0.078
R^2	0.888	0.959	0.843	0.907

CONCLUSION AND RECOMMENDATION

The experimental result indicates that spring rice crop cultivated by SRI method is better than conventional method (less reduction of yield) if water shortage occurs in 1st, 2nd and 3rd growth stages. However, the effects of water shortage in 1st and 2nd growth stages of conventional summer rice crop are less than that of summer rice cultivated with SRI method. If water stress occurs in 3rd and 4th growth stages of summer rice cultivated with SRI method, the yield loss would be less than that of conventional rice.

Depending on the actual condition of the water resources, organizing rice production or arranging crop pattern needs to be considered carefully. Optimizing operation of rice based irrigation system needs to be taken in account on the basis of analyzing potential for increasing or decreasing the gross productivity and profits of the production system as a whole. For irrigation system operational practices in Northern Region of Vietnam, the management agencies and farmers could apply less water regime at the beginning of rice crop season because the rice crops are less sensitive to water stress in first growth stage (if temperature is reasonable for rice crops). Irrigation practice is particularly significant for the spring rice crops, when the water demand is very high for land preparation but the water source is much constrained because of dry season.

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