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# Soil and Water Management for Sprinkler Irrigated Rice in Southern Brazil

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José Maria Barbat Parfitt, Germani Concenço,  
Walkyria Bueno Scivittaro, André Andres,  
Jaqueline Trombetta da Silva and  
Marília Alves Brito Pinto

Additional information is available at the end of the chapter

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## Abstract

Rice is grown in lowland paddies, which is flood irrigated. In the most undulating areas, continuous flooding is difficult and some farmers seek alternative irrigation methods. Grain yield in sprinkler irrigated rice ranges between 80 and 100% of that obtained under flooding, but for this, fertilizer and water should be properly managed. For sprinkler irrigated rice, fertilizer should be corrected by adding 10 kg/ha of  $P_2O_5$  and 15 kg/ha of  $K_2O$  for every expected additional ton of grains, over the standard recommendation. Regarding nitrogen fertilizer, it is recommended to be applied about 20 kg/ha of N at planting and the rest as topdressing. This can be done via soil, split into two applications: 50–60% of the topdressing dose at tillering start and the rest at panicle initiation. When N is applied by fertigation, 25% of the recommended topdressing N should be applied at tillering start; the remainder of the dose may be partitioned into four to six weekly applications through irrigation water. For water management, soil water tension should be kept below 10 kPa. At the vegetative stage, irrigation can be applied aiming to avoid water tensions in soil above 30 kPa at any moment.

**Keywords:** *Oryza sativa*, soil moisture, water application, fertilizer, center pivots

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## 1. Introduction

Rice is among the most consumed cereals in the world, constituting a staple food. The Brazilian *per capita* consumption of rice is 25 kg/year, and it is the ninth largest producer, with production concentrated in the Southern region, particularly in the state of Rio Grande do Sul,

which accounts for about 60% of national production. The projections for rice production and consumption show that Brazil will harvest 14.12 million tons of rice in the 2019/2020 cropping season, which is equivalent to an annual increase in production of 1.15% [1].

In the state of Rio Grande do Sul, rice is grown in flood irrigated lowland paddies. Cropping systems include conventional system, where soil tillage is accomplished in the spring; minimum tillage, with advanced soil preparation in the fall / winter and later direct planting in the spring; and water-seeded rice, restricted to leveled flat areas.

The lowland areas of Rio Grande do Sul present diversified relief, ranging from very flat areas (slope  $<0.2\%$ ) to gently undulating areas (slope  $>2\%$ ). The latter occur more frequently in the region called *Fronteira Oeste* (West Border), although they can occur in all rice-growing regions of the state. In the most undulating areas, the method of continuous flood irrigation hinders crop management, particularly planting, harvesting, and irrigation, due to the large amount of levees necessary for keeping the water layer into the field. This has led some producers of that region to seek alternative irrigation methods for rice, among which the sprinkler irrigation under center pivots stands out.

The rice grain yield obtained in sprinkler irrigated system, in some cases, has proved comparable to those under flood irrigation, and in other cases, varied between 80 and 90% of that obtained under continuous flooding. Research data show that, even when water management and other practices are appropriate, some soil types can promote yield drops when rice is sprinkler irrigated, which is directly related to the fraction of the micropores in soil [2].

It is estimated that for every kilogram of rice produced under flood irrigation, 1300 L of water is required, which is not much compared to crops such as soybeans, which demands about 2300 L per kg of grain produced. However, the difference in water demand between these crops lies in the fact that for rice, nearly 100% of the water comes from irrigation, while for soybean the water demand is supplied primarily by rain.

According to Mota et al. [3], rice evapotranspiration averages 650 mm per cropping season. However, when flood irrigated, the total amount of water required to meet rice demand include other components such as soil saturation, keeping the layer of standing water, as well as losses by percolation or lateral runoff [4]. In this system, there is also greater loss by evaporation from the free standing water surface mainly in the early crop stages. Thus, sprinkler irrigation in rice is of great importance, especially for regions with scarce water resources, which is the current condition in many regions of Brazil and other countries.

Another important aspect in rice production is that the no-till planting system is not easily possible, due mainly to the physical damage inflicted to the flooded soil by machinery tires during crop management and harvest. Such damage practically require soil disturbance at least for soil leveling, preceding the next planting [5]. With sprinkler irrigation, soil physics is not strongly impacted, being dispensable a new tillage operation before the next planting.

The perspectives for sprinkler irrigated rice can be classified into two groups: (a) *needs*: imposed by climatic conditions, increased demand for food, and the requirement of environmental agencies

and (b) *expectations*: increasingly search for positive results following adoption of the technology. The perspectives of the first group (needs) consider the increasing limitations on water availability on the planet [6], requiring the adoption of technologies that provide a more rational use of this natural resource. Moreover, the required increase in food production due to the exponential growth of the world population will be a result of both increased productivity and production area expansion [7]. The sprinkler irrigated rice (mainly by center pivots and lateral-movement irrigation equipment [linears]) will help in these two aspects, since the technology is adopted with proper technical and scientific basis. The multiple use of water requires that all water consuming sectors contribute to the more efficient use of water in their activities [8], which is the only alternative capable of accommodating the various needs of use of this renewable but finite resource.

The expectations comprise the equalization of rice productivity levels under sprinkler irrigation to those obtained in paddy rice, with the development of research aimed at overcoming the current grain yields obtained under sprinkler irrigation. Such superiority will be achieved by adapting cultivars to new water regime plus improvement in management techniques, resulting in lower environmental impact of rice production, with social benefits that include better quality of the final product, rational use of pesticides, and cost reduction. In addition, improvement in working conditions of rural staff, who no longer would work in flooded paddy, unstable, and irregular environment, would work on a stable and less laborious soil.

In rice fields established in areas with slopes higher than 2%, water is saved by sprinkler irrigating the rice. Research reports that the cost for growing rice under center pivot is smaller than flooded paddy rice cultivation, with higher net profit. The management of the flooded rice paddies demand greater number of machines per area due to the lower speed in agricultural operations, the presence of levees, and the wheel drive slipping on the muddy soil; at the same time, there is need for more powerful machines and often adjustments are required in the equipment to specific operation conditions for areas with great number of levees. This results in increased costs with fuel and maintenance. The cost for rice production under center pivot in the West Border region of Rio Grande do Sul was about 20–25% lower than the average cost of nearby flooded rice paddies. The main economy factors under center pivot were fuel for machinery and irrigation costs, which included electricity, machinery repair and maintenance, and human labor.

The evolution of crop production systems requires that at a given time, new technologies should be adopted to ensure the achievement of further increases in the efficiency of use of natural resources and production levels. The sprinkler irrigation stands out among the alternatives studied to save water in rice production due to its flexibility, high productivity potential, and ease of adoption. Evidently, only research and continuous improvement will keep the technology ahead of other alternatives. Currently, the opportunities associated to sprinkler irrigation in rice are promising, including the possibility of full adoption of no-till and crop rotation practices in rice production; but for its success, there are many aspects that need to be improved.

This chapter is aimed at presenting the basic aspects for soil and water management in sprinkler irrigated rice, based on research results carried out for over 5 years, as well as through experiences of the productive sector in the Brazilian state of Rio Grande do Sul.

## 2. Cropping system

In Rio Grande do Sul, although rice cultivars recommended for sprinkler irrigation are those developed for flooding, crop management practices differ. The main reason is the lack of standing water in the sprinkler irrigation, eliminating the levees. This feature, on the one hand, gives some advantages to the system, such as the possibility of no-till adoption and application of all practices by ground, with no need for fertilizer and pesticide applications with aircrafts; on the other hand, there is need for more attention to soil fertility and integrated pest management.

The Brazilian rice cultivars developed to be grown in flooded paddies present high grain yield potential, but they are very susceptible to water stress, especially during the reproductive stages. Research results by Embrapa Clima Temperado conducted under conventional soil tillage, reported severe damage to rice plants in several spots into the experimental fields, even when adopting the recommended water management, e.g., by irrigating back to saturation when water tension in soil reached a maximum of 10 kPa. This was mainly due to the absence of mulching on soil at the experimental areas; in this situation, the water droplets caused disruption of topsoil, resulting in the formation of a crust and making water infiltration into soil difficult. This behavior is hardly observed when rice is grown on mulch and especially under consolidated no-till systems, which were established for some years. Therefore, it is clear that sprinkler irrigated rice should be grown in a production system involving both no-till and crop rotation.

Suggestions for a possible production system include rice, corn, and soybeans in rotation in summer, succeeding winter cover crops (pasture species), with or without cattle grazing in winter. Regardless of the established cropping system, an essential practice to be applied is the need for burndown several weeks preceding rice planting. This is because soil needs to be warm as rice seeds require a minimum temperature of 11°C to start germination [9], but the emergence is not quick and effective at temperatures below 18–20°C [10]. Thus, due to the cool climatic conditions of Rio Grande do Sul during spring, when too much mulching rests on soil, there is the risk of not reaching proper crop stand.

Research data held in Typic Albaqualf [11] cultivated with rice cv. BRS-Pampa for five consecutive seasons, with and without rotation with soybeans, showed that the rice-soybean rotation increases rice productivity (8671 kg/ha) compared to the monocrop (7464 kg/ha). This effect was independent of the presence of ryegrass as ground cover in winter.

## 3. Soils of Rio Grande do Sul, Brazil

The cultivation of paddy rice in Rio Grande do Sul is done in lowlands, comprising the floodplain soils and soils located at higher levels. Lowland soils are found in river, lakes, and lagoons, presenting as common characteristic its formation in various conditions of drainage deficiency (hydromorphism). In the state of Rio Grande do Sul, they cover large areas with relief ranging from flat to gently undulated, being found in the South Coast, Inner Coastal



Plain, Outer Coastal Plain, Central Depression, Campaign, and West Border regions. They occur usually at low altitudes (0–200 m) and cover an area of about 4,395,000 ha.

Floodplain soils have developed from fluvial, lagoons, and marine sediments from coastal plains and alluvial sediments derived from sedimentary, igneous, and metamorphic rocks of the depressions, plateaus, and mountains of Rio Grande do Sul; thus, source materials are very distinct.

Poor drainage or natural hydromorphism is usually motivated by the predominantly flat terrain, often associated with a profile with shallow surface layer and more impermeable subsurface layer. This characteristic is identified in maximum intensity by the gley soil feature—greyish or blue-grey colors, and less accentuated intensity of red/orange mottling dispersed in a gray background. In the landscape, this trait is less present in higher level soils, and may even be absent in the case of sandy soils.

Paddy rice cultivation in Rio Grande do Sul is also developed in higher levels floodplains or lowlands, which are adjacent to the floodplains, with undulated to plain relief. Such areas are preferred for sprinkler irrigation, facilitating management operations, particularly planting, harvesting, and irrigation, and eliminating the use of levees. These soils are found in the West Border and Campaign regions, developing from basalts and its sediments, or from silt or clay sedimentary rocks (siltstones, shales, and mudstones), respectively.

#### 4. Fertilizer and liming management

In flood conditions, soils undergo profound chemical transformations resulting from the reduction process caused by anaerobic microorganisms, which use the oxygen of oxidized substances for their metabolism [12]. The changes resulting from flooding increase the availability of soil nutrients, both native and supplied through fertilizers, especially phosphorus (P) and potassium (K). Raising of the pH of acidic soils to between 6.0 and 6.5 is also reported, with subsequent neutralization of toxic aluminum [13].

The changes resulting from soil submersion have direct influence on the response of rice to soil liming, P and K fertilizers, which is smaller than that is observed in cultivations on aerated conditions [14], including sprinkler irrigated rice. This fact, along with low to moderate fertility of Rio Grande do Sul soils [15–17], make the adequacy of fertilization and liming essential to meet nutritional demand of sprinkler irrigated rice, enabling it to achieve yields consistent with the potential of the rice cultivars, which were developed for the flooded system, making the sprinkler irrigated rice economically viable.

The main aspects related to the management of soil fertility, fertilizer recommendations, and liming for sprinkler irrigated rice in lowlands in Rio Grande do Sul are discussed below. We consider information contained in the *Fertilization and Liming Manual for the States of Rio Grande do Sul and Santa Catarina* [18] and also the *Technical Recommendations of the Research for Southern Brazil* [10], as well as the results of research on nutrition and fertilization of rice produced in sprinkler irrigated rice system [19–21].

#### 4.1. Fertilizer and liming management in sprinkler irrigated rice

The management of fertilization and liming for sprinkler irrigated rice should be based on the diagnosis of soil fertility and the nutritional requirements of rice into production systems involving rotations and crop sequences. The adequacy of these practices is critical to the performance of rice crop, as well as other species, which take part into the production system.

Recommendations for rice Based on soil analysis are basic instrument to determine the need of using liming and fertilizers. In the case of cultivation on drained soils, or on saturated soils with no water layer, rice should be treated as a component of a “dry system.” Thus, soil samples for fertility evaluation should be performed at least every two crops.

The success of the recommendations depends on the adequacy of the collection and analysis of soil samples and the interpretation of analytical results and other production factors involved, in particular climatic conditions, rice cultivar, planting time and density, water, and integrated pest management.

Nutritional requirement varies among rice cultivars, particularly with its productivity potential and genetic background, which depends on the adequacy of production factors. Thus, crops with higher yield potential and expected response to fertilization require greater supply of nutrients compared to those less productive, regardless of the irrigation method, be it by flooding or sprinkling.

##### 4.1.1. Liming

In general, lowland soils of Rio Grande do Sul are acidic, prevailing pH in water between 4.5 and 5.4, which correspond to the interpretation as “very low” ( $4.5 < \text{pH} < 4.9$ ) and “low” ( $5.0 < \text{pH} < 5.4$ ). In this pH range, the availability of many essential nutrients to crops is low, except for some micronutrient (copper, iron, manganese, and zinc). The acidity, in many cases, leads to high saturation by aluminum ( $m > 20\%$ ), affecting root development and, consequently, absorption of water and nutrients by plants.

As rice and other components of lowland crop production systems grow best in soils with pH near neutral ( $\text{pH} > 6.0$ ), special attention should be given to liming, making it a major issue in sprinkler irrigation. The water layer in the flooded paddies automatically increase the soil pH to between 6.0 and 6.5 with subsequent neutralization of toxic aluminum due to reduction processes, which does not occur under sprinkler irrigation. Liming reduces or eliminates also the toxic effects of manganese. Other benefits associated with this practice are improved root environment for absorption of nutrients favoring microbial activity and increasing the availability of nutrients and the supply of calcium (Ca) and magnesium (Mg).

The amount of limestone to be used varies with the pH to be reached and soil characteristics, in particular aluminum, clay, and organic matter content, which are the main sources of acidity and pH buffering. Larger liming will be required in soils where these attributes have higher values. In practice, in Brazil, the need for liming is estimated by the SMP index, supplied by soil analysis. The indication of general liming for rice as well as for the major component species of sprinkler irrigated production systems, particularly soybeans, corn, and cover crops, aims at increasing soil water pH to 6.0.

Liming has an average persistence of 3–5 years, depending on the amount and type of corrective used, the intensity of cultivation, soil and crop management, etc. In the field, the efficiency of liming depends on the amount and type of corrective, on the homogeneity of the mixture, soil moisture, and period allowed for the reactions after application. Soil pH reaches its maximum value between 3 and 12 months after liming. Thus, this operation should be accomplished at least 3 months prior to planting rice or other crops, which will comprise the production system.

#### 4.1.2. Fertilization

Fertilization indications for rice aim a rational use of inputs in order to increase and maintain soil nutrient content and to optimize the economic return for each crop. They assume, also, that the use of the fertilizer will be accomplished under adequate correct soil acidity levels and the application of proper soil and crop management practices. Furthermore, indications are related to different crop response expectations to fertilizer. This is because the production factors (genetic potential of cultivars, soil and climate conditions, as well as management practices) determine different crop yield potential and therefore response to fertilizers.

Current fertilizer indications for rice consider two levels of expected yield levels: “average” and “high,” and can be extrapolated to the respective response expectations to fertilization: “low” and “very high,” adjusting the doses recommended for less or more, respectively. Thus, fertilization indications for rice are flexible and adaptable to the diversity of cultivars, environmental conditions, and crop management, as well as the availability of farmer's financial resources.

#### 4.2. Soil analysis interpretation for fertilizers

Fertilizer recommendations for rice are based on soil analysis, using the contents of organic matter, phosphorus and potassium extracted by the Mehlich-I method, to estimate the availability of nitrogen, phosphorus, and potassium, respectively. For phosphorus and potassium, interpretation classes are set (**Tables 1** and **2**). Although the interpretation of phosphorus content in soil has been established for the flood irrigation, this can also be used for sprinkler system, with no changes being demanded.

Interpretation of potassium fertilizer for rice considers the cation exchange capacity (CTC) of the soil.

P content in soil	P extracted (mg/dm <sup>3</sup> ) <sup>1</sup>
Low	≤3
Mean	3.1–6.0
High	6.1–12.0
Very high	>12

<sup>1</sup> Extractor Mehlich-I.

Source: Adapted from Ref. [10].

**Table 1.** Interpretation of phosphorus (P) content in soil for phosphorus recommendation in rice (flood and sprinkler irrigation).



K content in soil		CTC <sub>pH 7.0</sub> (cmol <sub>c</sub> /dm <sup>3</sup> )	
	<5	5–15	>15
		K extracted <sup>1</sup> (mg/dm <sup>3</sup> )	
Low	≤30	≤40	≤60
Mean	31–45	41–60	61–90
High	46–90	61–120	91–180
Very high	>90	>120	>180
<sup>1</sup> Extractor Mehlich-I. Source: Adapted from Ref. [10].			

**Table 2.** Interpretation of potassium (K) content in soil for potassium recommendation in rice (flood and sprinkler irrigation).

4.2.1. Indications for phosphorus and potassium fertilization

As mentioned, it is necessary to increase phosphorus and potassium fertilization indications for sprinkler irrigated rice, compared to the doses recommended for the flooded system.

Accordingly, an approach that has provided good results, especially when the system is first installed, consists of adding 10 kg/ha of P<sub>2</sub>O<sub>5</sub> and 15 kg/ha of K<sub>2</sub>O for every expected additional ton of grains compared to that obtained with the recommendation established for the flooded system, considering a high expectation to fertilization response (**Tables 3 and 4**). As an example, considering a sprinkler irrigated area that used fertilizer recommendation established for the flooded rice and obtained an average yield of 7000 kg/ha, it is indicated to be added to the recommendation of the flooded system, 10 kg/ha of P<sub>2</sub>O<sub>5</sub> and 15 kg/ha of K<sub>2</sub>O for every expected additional ton of grain. It is limited, however, to a maximum of 90 kg/ha of P<sub>2</sub>O<sub>5</sub> and 120 kg/ha of K<sub>2</sub>O per cropping cycle.

It is recommended to supply phosphorus and potassium during rice planting. However, when the recommended dose of potassium is higher than 80 kg/ha of K<sub>2</sub>O, its partitioning is

P content in soil <sup>1</sup>	Response expectation to fertilization	
	Mean	High <sup>2</sup>
	kg/ha of P <sub>2</sub> O <sub>5</sub>	
Low	50	60
Mean	40	50
High	30	40
Very high	≤30	≤40

<sup>1</sup>Mehlich-I method.  
<sup>2</sup>The doses of P<sub>2</sub>O<sub>5</sub> recommended for the high response expectation should be added with 10 kg/ha of P<sub>2</sub>O<sub>5</sub> per each ton of additional expected grain yield, compared to the obtained with the recommendation for the flooded rice.  
Source: Adapted from Ref. [10].

**Table 3.** Recommendation for phosphorus (P) fertilization for irrigated rice, considering the expected response to fertilization.

K content in soil <sup>1</sup>	Response expectation to fertilization	
	Mean	High <sup>2</sup>
	kg/ha of K <sub>2</sub> O	
Low	75	90
Mean	55	70
High	35	50
Very high	≤35	≤50

<sup>1</sup>Mehlich-I method.

<sup>2</sup>The doses of K<sub>2</sub>O recommended for the high response expectation should be added with 15 kg/ha of K<sub>2</sub>O, per each ton of additional expected grain yield, compared to the obtained with the recommendation for the flooded rice.

Source: Adapted from Ref. [10].

**Table 4.** Recommendation for potassium (K) fertilization for irrigated rice, considering the expected response to fertilization.

especially necessary for sandy soils where the risk of nutrient losses is greater. In this case, it is indicated that half the recommended dose of potassium be applied at planting and the rest in topdressing associated to the nitrogen at the beginning of the reproductive stage.

#### 4.2.2. Indications for nitrogen fertilization

The level of nitrogen fertilization, which leads to maximum economic yield of rice grains, depends on the interaction of several factors, especially the availability of N in the soil, plant type, and climatic conditions, particularly the temperature and solar radiation.

Also, nitrogen management for sprinkler irrigated rice requires changes compared to flooding. The sprinkler irrigation method is most prone to redox conditions, favoring nitrogen losses from soil-plant system. On the other hand, it allows flexibility in the topdressing fertilization, which can be accomplished directly to soil or through the irrigation water. When opting for fertilizing the soil, those in which the organic matter content is low (<2.5%), demand of N doses range from 120 to 150 kg/ha for crops with response expected equal to mean and high fertilization levels, respectively. This depends on the previous crop, climate, and crop management level [10]. N rates should be reduced by 10 and 20 kg/ha of N, for soils with mean (2.6–5.0%) and high (>5.0%) levels of organic matter.

Regarding timing and partitioning of nitrogen fertilizer, it is indicated to apply about 20 kg/ha of N at planting and the rest as topdressing. This can be done via soil, split into two applications: 50–60% of the topdressing dose at the start of tillering (V4 stage) and the rest at the beginning of the reproductive stage, corresponding to panicle initiation (R0). In rainy years, the topdressing can be split into three applications, being the first at V4 (about 30% of the dose); the second, *after 10 to 15 days*, when the plants reached the stage of six to eight leaves (about 20–30%), and the rest at panicle initiation (R0).

For sprinkler irrigated rice, nitrogen topdressing by fertigation is being studied. Recent data identified the following indication as with potential to maximize the grain yield of sprinkler irrigated rice: application of 25% of the recommended topdressing N dose to soil at the

beginning of tillering, corresponding to the four-leaf stage (V4); the remainder of the dose may be partitioned into four to six weekly applications through irrigation water, according to the cycle of the cultivar, being the largest number of applications suitable for longer cycle cultivars.

## 5. Irrigation management

In the Brazilian state of Rio Grande do Sul, rice is grown in paddies under continuous flooding. However, this irrigation method provides, in many situations, water consumption exceeding 1500 mm per crop cycle, in areas with undulated relief. At the same locations, farmers who adopted the sprinkler irrigation (through central pivot) are using between 400 and 700 mm, depending on climatic conditions throughout the cropping season.

Research data about rice under sprinkler irrigation, by using rice cultivars developed for continuous flooding, report good crop performance when water is properly managed. The results indicated also that the susceptibility of the crop to drought varies with the phenological stage.

### 5.1. Susceptibility of rice crop to water deficit and water demand

In order to know the effect of soil water deficit on rice, experiments were conducted by Embrapa Clima Temperado with the cultivar BRS Pampa (early cycle) in the 2011/2012 and 2012/2013 cropping seasons [2].

To analyze the results of the effect of soil water deficit on rice productivity, the water-yield model proposed by Jensen [22] was adopted. For application of the model, the crop cycle was divided into two periods: L1—vegetative stage (from emergence to panicle initiation) and L2—reproductive stage (panicle initiation to maturation). When using the model, the variable “evapotranspiration” was replaced by the “water tension” in soil. The adaptation of the Jensen's model is shown as follows:

$$\frac{Y}{Y_m} = \prod_{i=1}^n \left( \frac{ET}{ET_m} \right)^\lambda \rightarrow \frac{Y}{Y_m} = \prod_{i=1}^n \left( \frac{T_{\min}}{T_{\text{obs}}} \right)^\lambda$$

where:

$Y$  = reported grain yield (kg/ha);

$Y_m$  = maximum grain yield reported in absence of water deficit (kg/ha);

$n$  = number of stages in the phenological cycle;

$\lambda$  = susceptibility of rice to drought per phenological stage in the relative productivity;

$ET$  = true evapotranspiration (mm);

$ET_m$  = maximal evapotranspiration (mm);

$T_{\min}$  = minimal water tension in soil (kPa); and

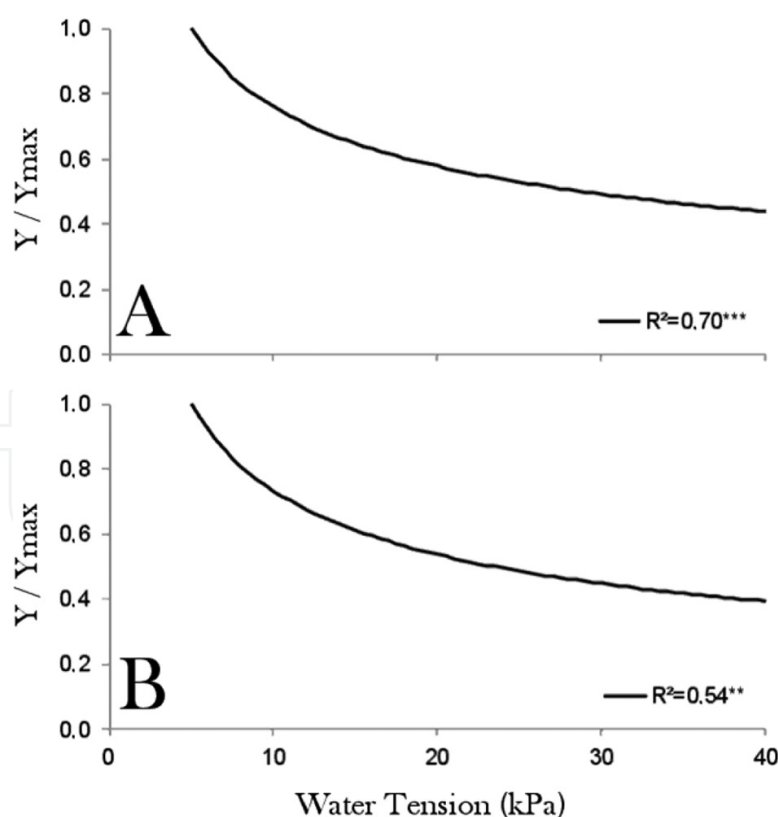
$T_{\text{obs}}$  = reported water tension in soil (kPa).

Crop stage	Parameter	Estimation	Pr >  t
2011/2012 Cropping season			
Vegetative	$\lambda_1$	0.15	0.0001
Reproductive	$\lambda_2$	0.25	<0.0001
2012/2013 Cropping season			
Vegetative	$\lambda_1$	0.16	0.0095
Reproductive	$\lambda_2$	0.29	<0.0001

**Table 5.** Estimation of the parameters for the proposed model of Jensen [22], for each phenological stage of rice under sprinkler irrigation.

**Table 5** shows the values of the parameter  $\lambda$  in the model for both vegetative and reproductive stages of rice. For both cropping seasons, the parameters were significant at 0.1% in both stages. As higher values of  $\lambda$  indicate greater susceptibility to drought, it can be inferred that the vegetative and reproductive stages have different susceptibility levels, being the reproductive stage the most sensitive period.

**Figure 1** is a graphical representation of the model fitting proposed by Jensen to the two monitored agricultural crops. The coefficients of determination ( $R^2$ ) of 0.70 and 0.54 indicate



**Figure 1.** Relation between rice grain yield when grown under sprinkler irrigation and the mean water tension in soil, adjusted by the model of Jensen [22] for the 2011/2012 (A) and 2012/2013 (B) cropping seasons. \*\*\*Significant model at 0.1%; \*\*significant model at 1%.

that, among the various agronomic factors affecting rice grain yield, such as soil fertility, pests incidence, seed and planting operation quality, among others, water availability influenced by 70 and 54% rice grain yield in the first and second cropping seasons, respectively. These data illustrate that rice is highly susceptible to water stress, thus proper water management is essential for grain yield.

**Figure 1** also shows that the closer to saturation the soil (soil water tension equal to zero), the higher the rice yield, with remarkable decrease in grain yield in water tensions beyond 15 kPa. However, from this tension, the decrease in rice productivity due to increases in soil water tension is smaller, stabilizing in about 50% of the maximum productivity. Thus, when using sprinkler irrigation in rice, the soil water tension should be kept as close as possible to saturation, since there are no significant water losses by runoff during water application.

**Table 6** shows the total irrigation applied to rice both in the vegetative and reproductive stages, under different water managements. It can be seen that the higher the water tension in soil, that is, the drier the soil, the lower the applied water and the lower the rice grain yield.

In the 2011/2012 and 2012/2013 cropping seasons, the total irrigation and rainfall in the managements of 20 kPa were 676 and 716 mm, respectively. Although the values of the applied amounts are similar, there is variation in the total irrigation between the distinct stages of the cycle (**Table 6**). In 2012/2013, water demand was lower in the vegetative and higher in the reproductive stages, compared to the previous season. This is due to the distribution of rainfall in both periods; in 2012/2013, there was higher rainfall during vegetative stage (170 mm) and less precipitation in the reproductive stage (231 mm), compared to 2011/2012, when rainfall was 102 and 283 mm in the vegetative and reproductive stages, respectively.

For the management of 20 kPa, the total amount of water (irrigation + rainfall) in 2011/2012 was 210 and 466 mm in vegetative and reproductive stages, respectively, while in the 2012/2013, the

Cropping season	Management	Applied water (mm)		
		Vegetative stage	Reproductive stage	Total
2011/2012	20 kPa	108	183	291
	40/20* kPa	81	192	273
	40 kPa	72	159	231
2012/2013	10 kPa	138	396	534
	20 kPa	63	252	315
	40 kPa	30	156	186
	40/10* kPa	30	369	399

\*The first and the second numbers regard to the soil water tension at the vegetative and the reproductive stages, respectively.

**Table 6.** Total amounts of water applied in each phenological stage of sprinkler irrigated rice, for distinct water managements, which were established based on the water tension in soil, for the 2011/2012 and 2012/2013 cropping seasons.



total amounts were 233 and 483 mm at the same stages. The total rainfall accounted for almost 50% of water supply to crop. In the management of 10 kPa, in 2012/2013, the applied water depth was greater. The results indicate that systems and/or irrigation managements that allow the maximum use of rainfall constitute an important alternative to reduce water demand by rice crop.

## 5.2. Irrigation timing

Programming the time to irrigate is a matter of fundamental importance in the management of irrigation of any crop. This aspect assumes, however, more relevance to sprinkler irrigated rice due to its susceptibility to drought. Irrigation control can be performed by monitoring climatic or soil-related variables.

For control via climate, there is need to estimate the potential evapotranspiration (ET<sub>o</sub>) and know its relationship to the actual crop evapotranspiration (ET<sub>r</sub>), which is called crop coefficient (K<sub>c</sub>). The K<sub>c</sub> varies depending on soil water content, being known for flood irrigated rice, or to saturated soil conditions. This parameter has not been established for sprinkler irrigated rice, in which cultivation soil is not saturated. In this production system, K<sub>c</sub> will vary also with the water management adopted. For this reason, it is still not possible to control irrigation via climate properly, leading one to plan sprinkler irrigation for rice based on soil-related parameters.

For water management based on soil variables, sensors are used to monitor the water tension, which is directly related to soil moisture, so that the drier the soil, the higher the measure. Knowing the water tension in soil which is ideal for proper rice development, irrigation is done in order to keep it below that value. Based on the research results discussed above, it is recommended to keep soil water tension up to 10 kPa for security reasons (time needed from measure to the irrigation to start). At the vegetative stage, if there is need to save water, irrigation can be applied aiming to avoid water tensions in soil above 30 kPa in any moment.

Currently, there are several sensor types for monitoring soil moisture, being the TDR and FDR sensor types most used for research, but tensiometers and indirect reading devices by means of electrical resistance are also vastly used. Soil sensors based on electric resistance are most accurate in higher water tensions and may present some limitations for lower water tensions.

The sensors must be installed in a representative depth of the effective plant root zone, where about 80% of the root system is located. For rice grown in lowlands of Rio Grande do Sul, the first research results indicate that the sensors can be installed up to 10 cm depth. If soil moisture is read at greater depths, there is a risk of irrigating when high humidity is still on soil surface, reflecting in increased water losses by runoff. An example would be after a rain, when infiltration rates are smaller because the rate of infiltration depends on soil moisture content.

To choose the proper installation locations of the sensors into the field, it is important to identify homogeneous areas, considering at least topography and soil type, but also fertility and other traits. In the case of undulated areas, it is important that some sensors are installed in the upper, middle, and bottom parts. In the case of rice, which is very susceptible to drought, it is better that irrigation is done according to soil moisture read in the upper areas, as these tend to be drier. Sensor should be read on a daily basis.

In the same way, as the time to start irrigation, the time to stop the process is also essential. An indication to prevent losses in milling yield in sprinkler irrigated rice is to maintain irrigation throughout the growing season, suspending it only one day before harvest.

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## Author details

José Maria Barbat Parfitt<sup>1</sup>, Germani Concenço<sup>1\*</sup>, Walkyria Bueno Scivittaro<sup>1</sup>, André Andres<sup>1</sup>, Jaqueline Trombetta da Silva<sup>2</sup> and Marília Alves Brito Pinto<sup>2</sup>

\*Address all correspondence to: gconcenco@yahoo.com.br

1 Embrapa—Temperate Agriculture Research Center, Pelotas, Brazil

2 Federal University of Pelotas, Pelotas, Brazil

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