SPATIAL VARIABILITY OF SPIKELET STERILITY IN TEMPERATE RICE IN CHILE

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ABSTRACT

Spikelet sterility ("blanking") causes large economic losses to rice farmers in Chile. Available varieties are susceptible to low air and water temperatures during pollen formation, producing spikelet sterility, which is the main responsible for the large year to year variation observed in terms of grain yield. The present work had for objective to study the spatial variability of spikelet sterility within two rice fields and relate it to water and air temperature as well as soil properties within the field. Two fields of approximately 20 and 10 ha were studied during the 2007/2008 and 2008/2009 growing seasons. A network of 24 and 19 temperature sensors, with their corresponding loggers, was deployed within the fields using a systematic non-aligned design, with the help of a GPS and GIS program. Air, at canopy level, and water temperature were measured at 1-hr intervals during the growing seasons. At the same positions, soil chemical properties were measured before planting. At harvest, grain yield and spikelet sterility were determined. Resulted showed a large spatial variability in terms of spikelet sterility within the field which related to water and air temperature as well as to their differences. Differences in the results were observed between seasons.

Key words: temperate rice, spikelet sterility, blanking, spatial variability, loggers

INTRODUCTION

Spikelet sterility, commonly called "blanking", is one of the most limiting factors of flooded rice productivity in Chile. It is mainly associated with low air and/or water temperature (< 20°C) during critical crop development stages such as pollen formation and flowering. Commercially accepted yield losses caused by spikelet sterility for temperate rice are up to twelve percent, however in cold years they can reach up to 60% (Alvarado, 1999).

Spikelet sterility in rice is caused mainly by low temperatures during the period of pollen formation that occurs during panicle initiation, approximately ten to fourteen days before flowering, with the stage of young microspore being the most susceptible (Satake and Hayase, 1970). Other management factors such as water level and nitrogen availability may also affect pollen development (Godwin et al., 1994; Williams and Angus, 1994; Gunawardena et al., 2003; Roel et al., 2005). Low temperatures affect the development of pollen grains, decreasing the number of engorged ones, preventing fertilization and causing spikelet sterility (Nishiyama, 1983), which in turns lowers grain yields (Lee, 2001). Gunawardena et al. (2003) found that low temperature during very early and peak microspore development caused a severe reduction in engorged pollen production mainly as a result of a reduction of total pollen production.

Low temperature during flowering also may cause spikelet sterility, however its effects are not as pronounced as the ones caused by cold during pollen formation. Based on data reported by Alvarado (1999), a decrease in temperature of one degree, below the threshold air temperature of 20°C, increases spikelet sterility by 6%.

Roel et al. (2005) demonstrated that spikelet sterility is highly variable within rice fields, mainly due to variations in water temperature. On the other hand Ortega (2007) concluded that water temperature also determined differences in spikelet sterility under low air temperatures during pollen formation.

The present work had for objective to study the spatial variability of spikelet sterility within a commercial rice fields and relate it to water and air temperature as well as to some selected soil properties.

MATERIALS AND METHODS

The study was performed during the 2007/2008 and 2008/2009 growing seasons over two fields of 20 and 10 ha, respectively. Fields were located near the city of Parral, in the heart of the rice area of Chile. The geographic coordinates were: field 1 (-71.88°,-36.02°) and field 2 (-71.53°, -36.06°).

Rice was seeded over the water table using pre germinated seed at rate of 140 kg ha^{-1}; varietiy Diamante was used in both seasons; planting dates were, October 30, 2007, and November 15, 2008.

After measuring the perimeter and determining the total area, 24 and 19 loggers and their corresponding temperature sensors, were deployed over each field, using a systematic, non-aligned grid with the help of GPS and the EZ Map software (Figure 1). Loggers recorded air temperature at canopy level (1 m aboveground) and water temperature at soil surface at 1-hr interval.

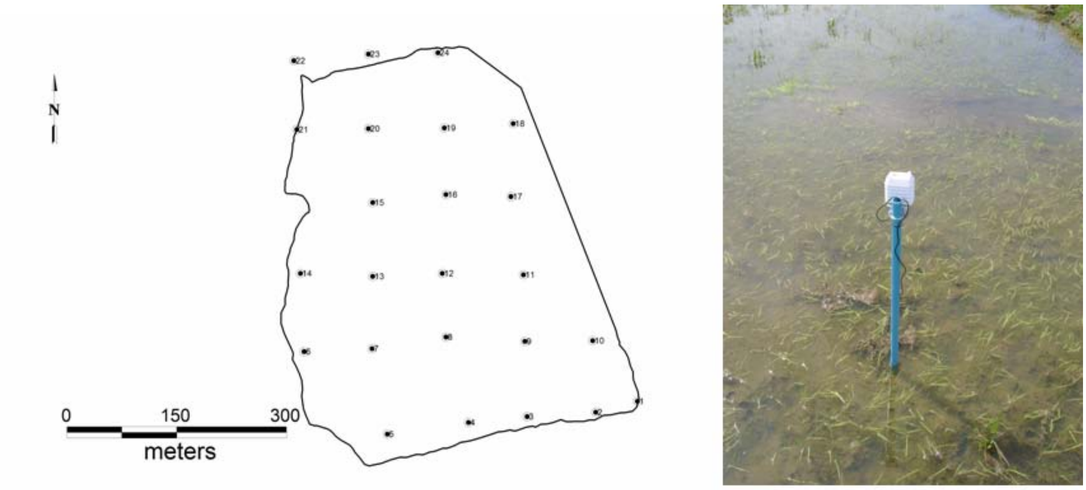

Figure 1. Sampling scheme over a 20-ha field. Parral, 2007/2008 season.

At each sampling position a composite soil sample (0-20 cm depth) was collected and analyzed for extractable N, P, and K, besides pH and electrical conductivity, using standard methods.

To determine the date interval on which pollen formation occurred, the following procedure was followed at each sampling position: 1) cumulative heat using degree days was computed from planting date using a lower threshold temperature of zero °C; 2) anthesis was set at the time when 1800 degree days were accumulated; 3) pollen formation date was set to happen ten to fourteen days prior to anthesis (Hill, 2004; Ortega, 2007). Temperatures from that time interval were extracted from each logger and the following variables were determined: Minimum Water Temperature (MINWT), Minimum Air Temperature (MINAT), Maximum Water Temperature (MAXWT), Maximum Air Temperature (MAXAT), Average Water Temperature (AVWT), and Average Air Temperature (AVAT). From these variables, the following variables were derived: Delta Minimum Temperature (DMINT), is the difference between minimum water and minimum air temperatures; Delta Maximum Temperature (DMAXT), is the difference between maximum water and maximum air temperature; Delta Average Temperature (DAVT), is the difference between average water and average air temperatures; and Delta Mix Temperature (DMIXT), is the difference between minimum water and maximum air temperatures.

At harvest, yield was determined by sampling two 0.2-m^2 quadrants around each logger position within the field, threshing the samples and weighting them. Grain moisture content was determined for each grain sample in order to correct yields at 14% moisture. Spikelet sterility was determined by counting filled and unfilled grains over a 200-g sub sample. Blanking was expressed in percent by dividing unfilled grain by the total number of grains.

All variables were interpolated using inverse distance weighting and mapped in the GIS Mapinfo (Mapinfo Professional 8.0). Descriptive statistics on each variable was performed in Excel.

Correlation analysis between spikelet sterility, yield, temperature and selected soil properties was performed in SAS (SAS Institute, 1991).

RESULTS AND DISCUSSION

Spatial variability of selected variables

Average air temperature at canopy level during pollen formation showed a very low variation with CV of 1%; larger variations were observed for minimum and maximum air temperature, although their CVs were also low. On the other hand, water temperature during pollen formation showed a larger variation within the fields as compared to air temperature; for the 2007/08 season the largest variation was observed for minimum water temperature (MINWT) which varied between 14 and 20 ºC and had a CV of 8% (Table 1, Figure 2).

Since air temperature at canopy level (1 m above soil surface) within the field does not vary as much as water temperature does, it would be possible to determine it at a lower sampling intensity as compared with the latter.

The largest variation was found for DAVT, which corresponds to the difference between the average water and air temperatures (CV=148 %).

Spikelet sterility was highly variable within the field (Figure 2), with a CV of 139 % for the 2007/2008 season (Table 1) and 45% for the 2008/2009 season (data not shown). Spatial pattern of blanking corresponded very well with that of water temperature (Figure 2); During the 2007/08 season, higher levels of sterility were located at the south east part of the field, where the cold water coming from the irrigation canal entered the field. In both seasons, almost half of the fields had blanking levels over the norm (12%).

Grain yield showed lower variability than spikelet sterility (CV=29% and 22%, for the 2007/08 and 2008/09 seasons, respectively) which means that the rice plant is able to partially compensate yield components, particularly grain weight under high blanking conditions. Nevertheless, grain yield varied from 1.5 to 11 ton ha^{-1}, and from 3.5 to 7.9 ton ha^{-1}, for the 2007/2008 and 2008/2009 seasons, respectively, with an inverse pattern compared to spikelet sterility and water temperature; higher yields were generally found at the furthest point from irrigation water entrance, where it was warmer (Table 1, Figure 2). These results are coherent with those reported by Roel et al. (2005) in California.

Table 1. Descriptive statistics for the measured and derived variables. 2007/08 season.

Variable	Unit	Mean	Std. Dev.	Minimum	Maximum	CV (%)
Available N ($N\text{-}NO_3$+$N\text{-}NH_4$)	mg kg^{-1}	23.7	5.7	15.8	35.8	24.3
Olsen P	mg kg^{-1}	8.4	2.4	5.1	14.8	28.9
Extractable K	mg kg^{-1}	44.8	12.7	23.2	66.7	28.3
pH		4.4	0.3	4.0	5.4	6.8
EC	uS cm^{-1}	57.4	26.6	23.6	121.8	46.4
MINWT	ºC	18.6	1.4	14.1	20.2	7.8
MINAT	ºC	11.0	0.4	9.8	11.3	3.8
MAXWT	ºC	21.8	1.0	19.8	24.0	4.7
MAXAT	ºC	33.7	0.6	32.8	34.9	1.9
AVWT	ºC	20.0	1.1	16.8	21.4	5.3
AVAT	ºC	20.7	0.2	20.1	20.9	1.0
DMINT	ºC	7.6	1.2	4.0	9.3	15.8
DMAXT	ºC	-11.9	1.4	-15.1	-8.8	-12.0

DAVT	ºC	-0.6	0.9	-3.2	0.8	-148.2
DMIXT	ºC	-15.1	1.8	-13.4	-20.4	-11.9
Yield	ton ha^{-1}	7.2	2.1	1.5	10.8	28.7
Spikelet sterility	%	15.6	21.6	3.0	83.1	138.5

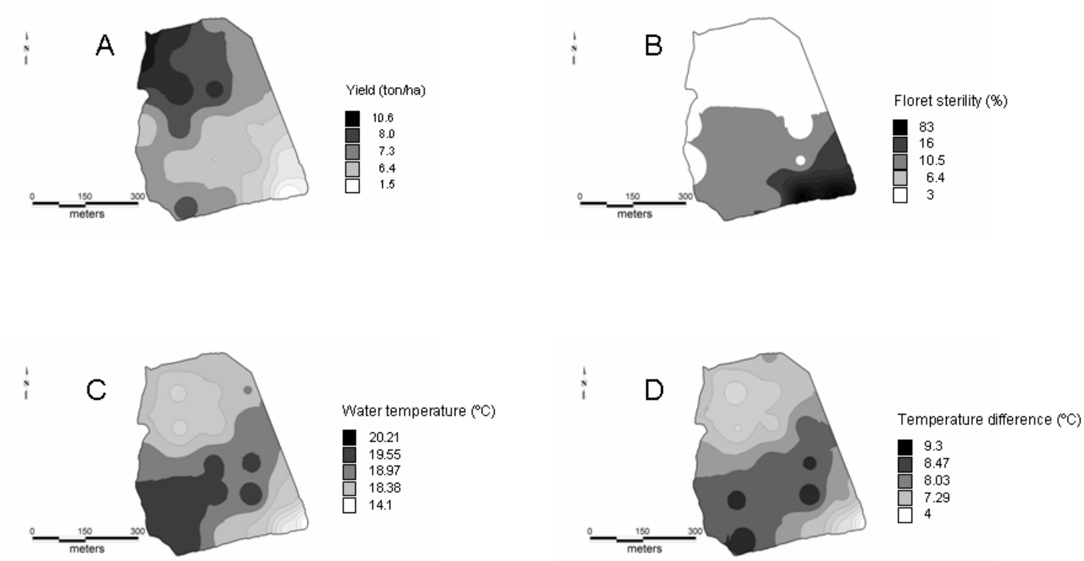

Figure 2. Spatial variation of selected variables: A) grain yield, B) spikelet sterility, C) minimum water temperature (MINWT), and D) delta minimum temperature (DMINT). 2007/2008 season.

Correlation analysis

During the 2007/2008 season, spikelet sterility significantly correlated ($P < 0.05$) with MINWT, MINAT, MAXAT, and AVWT during pollen formation. Blanking decreased with the increase in MINWT, MINAT, and AVWT; however it decreased with the increase of MAXAT. This means that spikelet sterility was maximized under cold water and high air temperature; this effect can be clearly appreciated when correlating blanking with water and air temperature difference; the larger the difference, in absolute terms, the higher the spikelet sterility. Largest correlation coefficient was found when using DMIXT, instead of DAVT (Table 2). Temperature threshold for DMIXT in order to keep blanking at values < 12 % would preliminary be 15ºC.

As expected, spikelet sterility showed a significant ($P<0.05$) negative relationship with grain yield, which confirms that blanking is the limiting factor determining yield expression of the rice crop in Chile. However, this result was not repeated during the 2008/2009 season, probably because of a shortage of water that affected yield and sterility, therefore affecting the expected results.

Table 2. Correlation coefficients among spikelet sterility, grain yield, water and air temperature. 2007/08 season.

VARIABLE	MINWT	MINAT	MAXWT	MAXAT	AVWT	AVAT	DMINT	DMAXT	DAVT	DMIXT	YIELD	STERILITY
MINWT	1											
P value	-											
MINAT	**0.68**	1										
P value	0.00	-										
MAXWT	0.30	0.37	1									
P value	0.16	0.08	-									
MAXAT	-0.39	**-0.57**	**-0.46**	1								
P value	0.07	0.00	0.03	-								
AVWT	**0.90**	**0.67**	**0.67**	**-0.50**	1							
P value	0.00	0.00	0.00	0.02	-							
AVAT	**0.69**	**0.70**	0.38	-0.15	**0.70**	1						
P value	0.00	0.00	0.07	0.49	0.00	-						
DMINT	**0.97**	**0.48**	0.24	-0.27	**0.86**	**0.59**	1					
P value	0.00	0.02	0.27	0.21	0.00	0.00	-					
DMAXT	0.39	**0.51**	**0.92**	**-0.77**	**0.70**	0.34	0.29	1				
P value	0.07	0.01	0.00	0.00	0.00	0.11	0.18	-				
DAVT	**0.88**	**0.60**	**0.68**	**-0.53**	**0.99**	**0.58**	**0.85**	**0.73**	1			
P value	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	-			
DMIXT	**0.95**	**0.75**	0.41	**-0.66**	**0.90**	**0.61**	**0.88**	**0.58**	**0.90**	1		
P value	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	-		
YIELD	0.15	**0.60**	0.30	-0.35	0.27	**0.54**	-0.06	0.38	0.17	0.28	1	
P value	0.49	0.00	0.17	0.11	0.22	0.01	0.78	0.08	0.44	0.21	-	
STERILITY	**-0.49**	**-0.60**	-0.39	**0.64**	**-0.58**	-0.23	-0.33	**-0.57**	**-0.58**	**-0.67**	**-0.64**	1
P value	0.02	0.00	0.07	0.00	0.00	0.30	0.13	0.01	0.00	0.00	0.00	-

CONCLUSIONS

Spatial variability of spikelet sterility within the rice fields was large and related to water and air temperature at the canopy level, particularly during the 2007/2008 season.

Air temperature at the canopy level could be determined at a lower sampling intensity than water temperature that varied more within the field.

Grain yield was explained in part by spikelet sterility, particularly during the 2007/08 growing season, showing a lower variation than blanking, probably by yield component compensation.

The knowledge of the spatial variability of water temperature, particularly in real time, will allow reducing spikelet sterility, by taking proper measures, allowing the rice crop reaching its yield potential under Chilean conditions.

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