RESEARCH

EFFECT OF NITROGEN RATES AND SPLIT NITROGEN FERTILIZATION ON GRAIN YIELD AND ITS COMPONENTS IN FLOODED RICE

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Nutritional management in rice (*Oryza sativa* L.) crops is mainly associated with N fertilization, which is difficult to adjust in field conditions due to variations in soil type and climatic conditions. Between 28 000 and 46 000 ha per year is dedicated to rice production in Chile and profits depend on fertilization. A field experiment determine the effect of N rates and split N fertilization on grain yield and its components was carried out in two locations during two consecutive seasons (2007 to 2009), where five N rates and five split N fertilizations were evaluated. The locations were in Parral (36º2' S; 72º08' W, Vertisol) and San Carlos (36º19' S; 71º59' W, Inceptisol), with N rates of 80, 100, 120, 140, and 160 kg ha^{-1} applied in different development stages, such as sowing, tillering, panicle initiation, and boot. Results indicate an important seasonal effect on grain yield. Yield increased with N rates higher than 120 and 140 kg ha^{-1} in San Carlos and Parral, respectively. Moreover, higher productivity with split N fertilization was (1) 33% of N at sowing, 33% at tillering, and 34% at panicle initiation or (2) 50% of N at sowing and 50% at panicle initiation. Yield components with the highest effect on productivity were affected by the evaluated split N. On the other hand, higher N rates increased the percentage of both stained and sterile grains per panicle.

Key words: Irrigated rice, nitrogen management, rice productivity, *Oryza sativa*.

Rice (*Oryza sativa* L.) is an important food in the diet of the world population (FAO, 2004) because of its nutritional features (Juliano, 1993) and low price. In the last decade, the cultivated area worldwide for rice was around 147.5 million ha (FAO, 2004). In Chile, rice is cropped under flooded conditions in about 28 000 ha and produces 160 315 t (ODEPA, 2007). This represents 60% of the potential crop area in the last two decades (Rojas and Alvarado, 1982).

Rice production depends on several factors: climate, physical conditions of the soil, soil fertility, water management, sowing date, cultivar, seed rate, weed control, and fertilization (Angus *et al*., 1994; Jing *et al*., 2008). For fertilization, N is the main nutrient associated with yield (Angus *et al*., 1994; Wilson *et al*., 1994a; Sahrawat, 2006; Bouman *et al*., 2007; De-Xi *et al*., 2007; Jing *et al*., 2008). Its availability promotes crop growth and tillering, finally determining the number of panicles and spikelets during the early panicle formation stage. This nutrient also provides sink during the late panicle formation stage (Mae, 1997; Artacho *et al*., 2009). New studies in Chile, carried out in two locations, indicate that the rice crop and its yield components respond to N rates of between 100 and 200 kg ha^{-1} applied before flooding (Artacho *et al*., 2009). Moreover, crop response to N fertilization is also affected by the cultivar, soil type, and climatic fluctuations between years, mainly environmental temperature (Bushong *et al*., 2007; Jing, 2007; Ortega, 2007).

The main rice cultivar cropped in Chile is 'Diamante-INIA' (Castillo and Alvarado, 2002), characterized by its tolerance to cold and high productivity, but there has been very little technological development related to its nutritional management. There are mainly three taxonomic orders of soils cropped with rice in Chile: Inceptisols, Alfisols, and Vertisols (CIREN, 1983), located between 34º and 36º S latitude (Alvarado and Hernaiz, 2007), and which represent soil types cropped with rice around the world (López, 1991; USDA, 1994). There are differences in the N supply capacity of these soils (Hirzel *et al*., 2011) since crop N uptake is mainly from soil reserves (organic matter mineralization, microbial biomass turnover, and N-NH_4^+ fixed in clay) (Schnier *et al*., 1987; Jokela and Randall, 1997; Jensen *et al*., 2000; Sainz *et al*., 2004; Sahrawat, 2006), and N fertilization (Wienhold, 2007). In addition, Sahrawat (1983) suggests that soil N supply plays an important role in N nutrition of wetland rice because one-half to two-thirds of total N taken up by rice crops, even in N-fertilized paddies, comes from the soil N pool. Schnier *et al*. (1987) indicated that in ^{15}N-labeled applications to the rice crop, only 20 to 30% of total N uptake at maturity was derived from N fertilizer. On the other hand, considering that there are actually few cultivar alternatives in Chile, climatic fluctuations between years

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affect longevity of each crop cycle by impacting on the vegetative and reproductive period of the rice crop and its yield, as has been pointed out by some authors (Atanasiu and Samy, 1985; Jing, 2007). Yield components are also affected by N availability, as was indicated by Kumura (1956) and Singh and Murayama (1963).

The N application strategy, equivalent to the number and applications or fertilization splits of this nutrient, also affect crop response to applied N rates, thus allowing the increase of N use efficiency (Beşer, 2001; Jing, 2007).

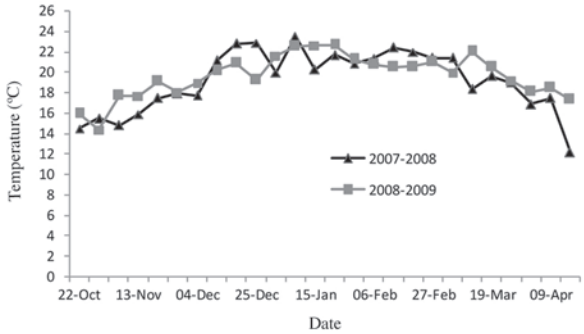
To improve N fertilization management in rice production, a 2-yr study was performed in two localities with Mediterranean conditions in south central Chile. The goal was to evaluate five N rates, within the range indicated for previous studies, and five split N fertilizations on rice production.

MATERIALS AND METHODS

The study was carried out during the 2007-2008 and 2008-2009 growing seasons in two soils with a rice monocrop located in south central Chile. Both soils had a clay loam texture, slow permeability, and imperfect drainage. The localities were Parral (36º2’ S; 72º08’ W) and San Carlos (36º19’ S; 71º59’ W), where soils are classified as Vertisol and Inceptisol, respectively, according to Soil Taxonomy-USDA. Samples were collected in cores from 0 to 20 cm before crop establishment and were physically and chemically characterized (Table 1). The climate is Mediterranean, characterized by high temperatures and low rainfall during summer and low temperatures and high rainfall during winter. Temperature conditions in each location and for each season during the crop period are shown in Figures 1 and 2.

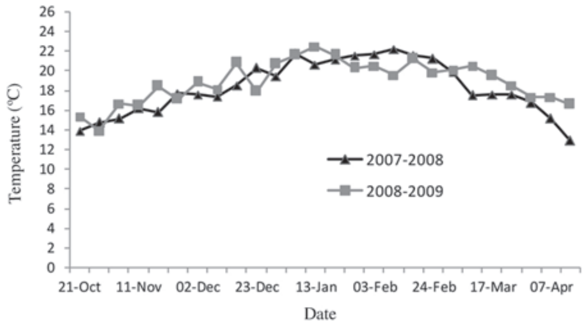
Table 1. Soil chemical characteristics at the beginning of the experiments (top 20 cm).

	Rice paddy soil	
Parameters	Vertisol (Parral)	Inceptisol (San Carlos)
Clay, %	28.50	31.40
Silt, %	39.00	31.60
Sand, %	32.60	37.00
Bulk density, g cm^{-3}	1.64	1.77
Total porosity, %	38.11	33.21
Water retention to 0.33 bars, %	33.88	26.48
Water retention to 15 bars, %	18.58	14.69
$pH_{(soil:water\ 1:5)}$	6.54	6.02
Organic matter, g kg^{-1}	1.08	1.18
Inorganic N, mg kg^{-1}	10.13	5.72
Mineralizable N, mg kg^{-1}	4.75	69.12
P-Olsen, mg kg^{-1}	6.92	7.96
Exchangeable K, $cmol_c$ kg^{-1}	0.38	0.25
Exchangeable Ca, $cmol_c$ kg^{-1}	8.24	6.86
Exchangeable Mg, $cmol_c$ kg^{-1}	4.37	3.31
Exchangeable Na, $cmol_c$ kg^{-1}	0.38	0.25
Exchangeable Al, $cmol_c$ kg^{-1}	0.01	0.02
Available Fe, mg kg^{-1}	59.62	143.80
Available Mn, mg kg^{-1}	44.39	107.38
Available Zn, mg kg^{-1}	0.07	0.25
Available Cu, mg kg^{-1}	2.20	4.28
Available B, mg kg^{-1}	0.10	0.09
Available S, mg kg^{-1}	8.37	7.16



*Flowering occurred during January and beginning of February.

Figure 1. Weekly mean temperature in Parral, 2007-2008 and 2008-2009 seasons.



*Flowering occurred during January and beginning of February.

Figure 2. Weekly mean temperature in San Carlos, 2007-2008 and 2008-2009 seasons.

Experimental sites were divided according to a split plot design with five N rates as the principal plot where 80, 100, 120, 140, and 160 kg ha^{-1} of N was applied as urea. The N rates were determined according to previous studies carried out in Chile’s rice crop area (Artacho *et al*., 2009). Subplots were five split N fertilization: (1) 100% N at sowing, (2) 50% N at sowing and 50% at tillering, (3) 33% N at sowing, 33% at tillering and 34% at the panicle initiation stage, (4) 50% N at sowing and 50% at the panicle initiation stage, and (5) 50% N at sowing and 50% at the boot stage. All treatments in both locations were fertilized with 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1} (hand-applied) as triple super phosphate and potassium chloride, respectively, 1 d before sowing, as standard management of rice crop. Treatments had three replicates and each main plot measured 5 × 3 m. Furthermore, one treatment without N was carried out as an index of the soil N supply capacity.

All plots were managed to optimize crop growth according to standard agronomic practices for rice in central Chile. The trial site was ploughed in winter with conventional tillage equipment; the seed rate of ‘Diamante-INIA’ was 140 kg ha^{-1} pre-germinated 2 d before sowing. After emergence, weed control was performed with herbicides: Quinclorac 0.45 kg ha^{-1} (Facet 25 SC), MCPA 0.18 kg ha^{-1} (MCPA 750 SL), and Bentazon 0.72 kg ha^{-1}

(Basagran). Sowing dates at San Carlos were 30 October 2007 and 23 October 2008, whereas in Parral, they were 31 October 2007, and 24 October 2008. Panicle initiation stages were 10 January 2008 and 5 January 2009 in San Carlos, and 11 January 2008 and 6 January 2009 in Parral. Heading dates were 4 February 2008 and 29 January 2009, 5 February 2008 and 30 January 2009 for San Carlos and Parral, respectively. These phenological developments were normal for the rice crop in the area of study.

The crop was harvested with 20% grain moisture on 24 March 2008 and 20 March 2009 in Parral, and 2 April 2008 and 24 March 2009 in San Carlos, and grain yield was corrected to 14% moisture. Grain moisture content was measured with a Satake model SS-5 moisture meter.

Yield was evaluated from a 2 × 3 m sample from each plot, whereas yield components of stained, sterile, and filled grains per panicle, as well as 1000-seed weight were measured from a 0.5 × 0.5 m quadrant from each plot.

Since there was no interaction among rate treatments, split N, and years evaluated, years, yield data for both seasons were combined because the effects of treatment year were not significant. Data were analyzed by ANOVA and the Least Significant Difference test (LSD, P = 0.05) was applied to determine differences between means by the SAS software general model procedure (SAS Institute, 1989). In addition, grain yield for each N rate was compared to the control without N fertilization for both locations and seasons.

Table 2. Significance of F values of contrast analysis between control without N and fertilized treatments for grain yield and yield components in both locations and seasons.

Contrast N rates	Yield component	Parral 2007-2008	Parral 2008-2009	San Carlos 2007-2008	San Carlos 2008-2009
0 - 80	G-Y	**	**	**	**
	Ste-G	ns	ns	ns	ns
	Stle-G	ns	ns	ns	ns
	Fill-G	ns	ns	ns	ns
	T-G	ns	*	ns	ns
	W-G	ns	*	ns	ns
0 - 100	G-Y	**	**	**	**
	Ste-G	ns	ns	ns	**
	Stle-G	ns	**	ns	**
	Fill-G	ns	ns	ns	ns
	T-G	ns	*	ns	**
	W-G	ns	**	ns	ns
0 - 120	G-Y	**	**	**	**
	Ste-G	ns	ns	ns	**
	Stle-G	ns	**	ns	ns
	Fill-G	ns	ns	ns	ns
	T-G	ns	ns	ns	*
	W-G	ns	*	ns	ns
0 - 140	G-Y	**	**	**	**
	Ste-G	ns	*	**	**
	Stle-G	ns	**	*	**
	Fill-G	ns	ns	**	ns
	T-G	ns	*	**	**
	W-G	ns	**	ns	ns
0 - 160	G-Y	**	**	**	**
	Ste-G	ns	ns	**	**
	Stle-G	ns	**	ns	**
	Fill-G	ns	ns	**	ns
	T-G	ns	ns	**	**
	W-G	ns	**	ns	ns

*,**Significant at the 0.05 and 0.01 probability levels, respectively; ns: non significant.
G-Y: grain yield; Ste-G: Stained grains per panicle; Stle-G: Sterile grains per panicle; Fill-G: Filled grains per panicle; T-G: Total grains per panicle; W-G: 1000-seed weight.

RESULTS AND DISCUSSION

Effect of climate and soil on grain yield

Climatic conditions registered during the rice flowering period (Figures 1 and 2) could be the reason for decreasing grain yield during the second season in both locations (data not shown); this agrees with several authors (Satake, 1991; Ortega, 2007; Changrong *et al*., 2008) who reported yield loss because of low temperatures in some rice development stages.

As an indicator of soil N supply capacity, grain yields obtained for the control without N in the first and second seasons, respectively, were 4.58 and 2.80 Mg ha^{-1} in Parral, and 5.21 and 4.70 Mg ha^{-1} in San Carlos (data not showed). These yields respond to mineralizable soil N (Table 1), as pointed out by Wilson *et al*. (1994b), and were significantly lower than the treatment with N applications (Table 2). In addition, yield components in the control (Tables 7a and 7b) for the evaluated treatments showed some statistical differences that were erratic between locations and seasons (Table 2). The percentage of stained grain in the control without N respect of treatments with N applications was different only in San Carlos in the second season and was lower than the treatment with N rates between 120 and 160 kg ha^{-1}, indicating that this characteristic is negatively affected by N rates higher than 100 kg ha^{-1} (Table 2). At the same time, the percentage of sterile grains did not, in general, show any differences in the first season in either location, while it was negatively affected by N rates higher than 100 kg ha^{-1} in the second season. Filled grains per panicle in the control for treatments with N applications only showed differences in San Carlos in the first season and this parameter was definitely affected by N rates higher than 140 kg ha^{-1} (Table 2). Total grains per panicle in the control for treatments with N applications showed differences in Parral during the second season, while there were differences in both seasons in San Carlos. An erratic effect was observed for the increase in N rate in Parral, but N use at rates higher than 100 and 140 kg ha^{-1} in San Carlos in the second and first season, respectively, improved total grains per panicle for the control without N (Table 2). Finally, 1000-seed weight in the control for treatments with N applications was only affected in Parral in the second season and all evaluated treatments generated a lower value than the control without N, indicating that using N at rates higher than 80 kg ha^{-1} negatively affected this parameter (Table 2).

Effect of evaluated treatments on grain yield and yield components

Significance of F values for evaluated parameters in Parral are shown in Tables 3 and 4, corresponding to the 2007-2008 and 2008-2009 seasons. Similarly, data from San Carlos are shown in Tables 5 and 6, corresponding to the 2007-2008 and 2008-2009 seasons. Effects of N rates on grain yields for both locations are shown in Figures 3 and 4. On the other hand, the effect of split N fertilization in both locations is shown in Figures 5 and 6. The effect of N rates and split N fertilization on yield components in both locations is shown in Tables 7 and 8, respectively. In addition grain yield for each N rate was compared to the control without N fertilization.

Table 3. Significance of F values from ANOVA for rice in Parral for the 2007-2008 season.

Parameters	N rates	Split N fertilization	N rates × split
Percent stained grains	ns	ns	ns
Percent sterile grains	ns	ns	ns
Filled grains per panicle	*	ns	ns
Total grains per panicle	**	ns	ns
1000-seed weight	ns	ns	ns

*, **Significant at 0.05 and 0.01 probability levels, respectively; ns: non significant.

Table 4. Significance of F values from ANOVA for rice in Parral for the 2008-2009 season.

Parameters	N rates	Split N fertilization	N rates × split
Percent stained grains	ns	**	ns
Percent sterile grains	*	**	ns
Filled grains per panicle	ns	**	ns
Total grains per panicle	ns	**	ns
1000-seed weight	**	**	ns

*, **Significant at 0.05 and 0.01 probability levels, respectively; ns: non significant.

Table 5. Significance of F values from ANOVA for rice in San Carlos for the 2007-2008 season.

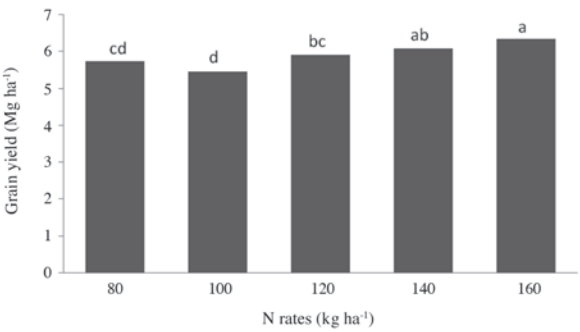
Parameters	N rates	Split N fertilization	N rates × split
Percent stained grains	ns	ns	ns
Percent sterile grains	**	**	ns
Filled grains per panicle	ns	ns	ns
Total grains per panicle	ns	ns	ns
1000-seed weight	ns	**	ns

*, **Significant at 0.05 and 0.01 probability levels, respectively; ns: non significant.

Table 6. Significance of F values from ANOVA for rice in San Carlos for the 2008-2009 season.

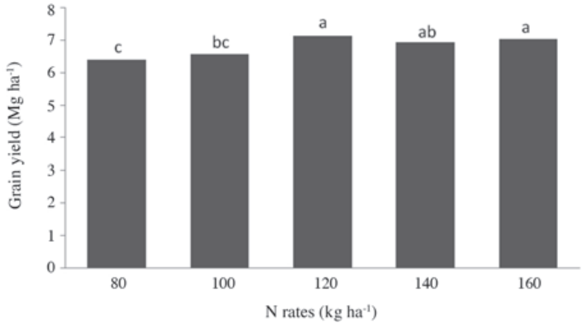
Parameters	N rates	Split N fertilization	N rates × split
Percent stained grains	**	**	ns
Percent sterile grains	**	ns	ns
Filled grains per panicle	ns	ns	ns
Total grains per panicle	**	*	ns
1000-seed weight	**	**	ns

*, **Significant at 0.05 and 0.01 probability levels, respectively; ns: non significant.



Different letters over bars indicate differences among treatments ($p < 0.05$).

Figure 3. Grain yield of rice with different N rates in Parral, pooled data for 2007-2008 and 2008-2009 seasons.



Different letters over bars indicate differences among treatments ($p < 0.05$).

Figure 4. Grain yield of rice with different N rates in San Carlos, pooled data for 2007-2008 and 2008-2009 seasons.

Table 7a. Yield components for rice crop in both locations for five N rates evaluated in the 2007-2008 season.

Location	N rates	Ste-G	Stle-G	Fill-G	T-G	W-S
	kg ha^{-1}	%				g
Parral	0	5.01	12.14	83.40	94.90	36.03
	80	4.51a	11.7a	88.3ab	100.1ab	36.1a
	100	6.61a	12.5a	88.3ab	100.9ab	36.2a
	120	8.05a	12.1a	90.5a	103.0a	36.6a
	140	6.80a	11.8a	89.8a	102.1a	36.2a
	160	6.53a	10.9a	81.0b	91.1b	36.2a
CV (%)		57.0	17.6	9.6	9.4	1.6
San Carlos	0	1.42	7.78	61.03	66.40	37.13
	80	1.31a	7.5b	65.7a	71.3a	37.9a
	100	1.30a	7.8ab	67.7a	73.6a	37.4a
	120	1.00a	8.7ab	70.0a	76.7a	37.8a
	140	1.23a	8.9ab	65.7a	72.1a	37.8a
	160	1.33a	10.7a	66.7a	74.7a	37.2a
CV (%)		51.7	22.2	9.3	9.8	2.0

For N treatments (80 to 160 kg ha^{-1}), means in a column followed by the same letter for a location are not different, LSD ($p < 0.05$).

Table 7b. Yield components for rice crop in both locations for five N rates evaluated in the 2008-2009 season.

Location	N rates	Ste-G	Stle-G	Fill-G	T-G	W-S
	kg ha^{-1}	%				g
Parral	0	2.83	7.43	48.73	52.67	36.44
	80	2.43b	9.7b	53.7a	59.5a	35.4ab
	100	3.48ab	12.6a	52.3a	59.9a	34.8abc
	120	4.24a	12.9a	50.3a	57.9a	35.4a
	140	2.97ab	12.2ab	53.5a	61.0a	34.7bc
	160	3.41ab	12.2ab	51.7a	59.0a	34.6c
CV (%)		53.6	23.7	11.7	11.2	1.7
San Carlos	0	2.81	17.13	41.40	50.27	35.96
	80	2.82c	18.0c	47.5a	57.9b	36.4a
	100	4.63b	31.6ab	46.0a	67.0a	35.5b
	120	4.38b	22.1bc	49.1a	63.2ab	35.6b
	140	5.21b	33.2a	43.9a	66.0a	35.6b
	160	6.67a	32.4ab	44.7a	66.7a	35.5b
CV (%)		45.1	24.0	11.3	10.3	2.0

For N treatments (80 to 160 kg ha^{-1}), means in a column followed by the same letter for a location are not different, LSD ($p < 0.05$).
Ste-G: Stained grains; Stle-G: Sterile grains; Fill-G: Filled grains; T-G: Total grains per panicle; W-G: 1000-seed weight.

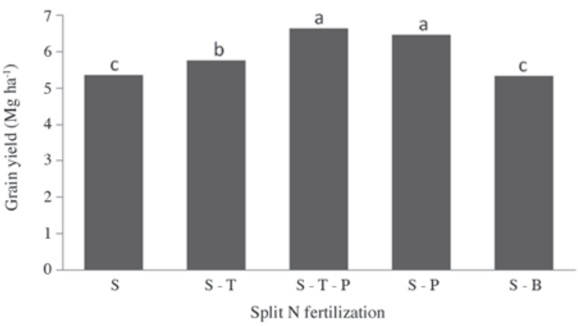
Locality of Parral

Grain yield obtained with N fertilization treatments was significantly higher than the control without N in both seasons (Table 2), indicating that evaluated N rates positively affected grain yield, as also demonstrated by Ortega (2007) and Artacho *et al*. (2009). Grain yield fluctuated from 5.47 to 6.34 Mg ha^{-1} for different N rates (Figure 3) and from 5.33 to 6.64 Mg ha^{-1} (Figure 5) for different evaluated split N fertilization. These grain yields were slightly lower than those indicated by Artacho *et al.* (2009) and similar to those indicated by Ortega (2007) for the same cultivar used in the Chilean experiment. For similar N rates used in experiments conducted in China, Xiang-long *et al.* (2007) and Huang *et al.* (2008) reported lower grain yield.

Results indicated that there was no interaction between evaluated N rates × split N fertilization ($p > 0.05$) in either season under experimental conditions, although rice yield was affected by both N rates and split N (Figures 3 and 5). Moreover, N rates affected the number of grains and filled grains per panicle only in the first season (Tables 3 and 4).

Evaluated N rates affected grain yield (Figure 3) and the best values were obtained with the highest evaluated rates. Jing (2007) also reported the effect of N rates on grain yield and 1000-seed weight, although N rates were different. Beşer (2001) indicate that optimum N rates for Turkish rice cultivars range between 140 and 160, and that N should be split at least twice. On the other hand, split N fertilization increased grain yield as compared with adding all of the fertilization at sowing time (Figure 5). Grain yield was higher in the first season (data not shown) because of the temperature decrease during the flowering period of the second season, which generated an average decrease of 2.96 Mg ha^{-1}.

Yield components (Tables 3 and 4) were affected by N rates in a different way given that in the first season both filled and total grains per panicle were affected, while the percentage of sterile grains and grain weight were affected in the second season. The highest N rate negatively affected filled and total grains per panicle in the first season (Table 3), while the lowest N rate generated the lowest percentage of sterile grains and grain weight in the second season (Table 4). In a study with the same cultivar and different N rates (0, 60, 120, 180, and 240 kg ha^{-1}) in central Chile, spikelet sterility was directly affected by the applied N rate, and the highest values were obtained with 180 and 240 kg N ha^{-1} (Ortega, 2007). In the same study, spikelet sterility fluctuated between 9.4 and 16.1% in the season with normal temperature during flowering, and 55.2 to 77.2 in the season with the lowest temperature during the same phenological period.



Different letters over bars indicate differences among treatments ($p < 0.05$).
S: 100% of N at sowing; S – T: 50% of N at sowing and 50% at tillering; S – T – P: 33% of N at sowing, 33% at tillering and 34% at panicle initiation; S – P: 50% of N at sowing and 50% at panicle initiation; S – B: 50% of N at sowing and 50% at the boot stage.

Figure 5. Grain yield of rice with different N applications in Parral, pooled data for 2007-2008 and 2008-2009 seasons.

The values obtained for stained grains fluctuated between 4.51 and 8.05% in the first season and between 2.43 and 4.24% in the second season, while filled grains fluctuated between 81.0 and 90.5 in the first season and 50.3 and 53.7 in the second (Tables 7a and 7b). On the other hand, total grains per panicle varied between 91 and 103 in the first season and between 60 and 61 in the second. Thus, the percentage of stained grains, filled grains, and total grains per panicle exhibited the greatest variations, while seed weight varied between 36.1 and 36.6 in the first season and 34.6 and 35.4 g in the second. Although statistical differences were obtained in all the analyzed yield components, in general, there was no consistent relationship with the N rates used (Tables 7a and 7b).

For split N fertilization there was a significant effect ($p < 0.05$) on the grain yield and the highest values were obtained with (1) 33% N at sowing, 33% at tillering, and 34% at panicle initiation and (2) 50% N at sowing and 50% at panicle initiation (Figure 5). Similar results were reported by Jing (2007) for 150 kg N ha^{-1}. With reference to this, Ida *et al.* (2009) indicated that N applications in the heading stage improved both N accumulated in the panicles and rice grain yield, supporting the practice of applying a fraction of the N rate at the time of panicle initiation. Beşer (2001) suggests that split N fertilization must incorporate N use in the boot stage.

Split N fertilization did not affect yield components in the first season, while a greater effect and higher variations in the results were exhibited in the second season (Tables 3 and 4). The highest values of sterile grains, filled grains, and total grains per panicle were obtained with split N fertilization in 33% N at sowing, 33% at tillering, and 34% at panicle initiation; and 50% N at sowing and 50% at panicle initiation. For the stained grains per panicle and 1000-seed weight components, the highest values were obtained with split N fertilization in 100% N at sowing, and 50% N at sowing and 50% at the boot stage.

Stained grains fluctuated between 2.32 and 5.28% and significantly higher when N was applied 50% at sowing and 50% at the boot stage (Tables 8a and 8b). Sterile grains varied between 10.2 and 13.7%, filled grains per panicle 49.7 and 58.9%, and total grains 52.5 and 68.3%. These three parameters were significantly higher when N was applied 50% at sowing and 50% at panicle initiation, or when N was split 33% at sowing, 33% at tillering, and 34% at the boot stage. The 1000-seed weight fluctuated between 34.3 and 37.0 g and was significantly greater when N was split 50% at sowing and 50% at the boot stage. Although statistical differences were obtained in all the analyzed yield components, in general, there was no consistent relationship with the split N fertilization used. Moreover, filled and total grains per panicle increased with (1) 33% N at sowing, 33% at tillering, and 34% at panicle initiation, and (2) 50% N at sowing and 50% at panicle initiation (Tables 8a and 8b).

Table 8a. Yield components for rice crop in both locations for five N partialities evaluated in the 2007-2008 season.

Location	Fertilization N split	Ste-G	Stle-G	Fill-G	T-G	W-S
		——— % ———				g
Parral	S	6.80a	11.7a	87.5a	99.3a	36.2a
	S – T	5.66a	12.2a	96.3a	98.5a	36.4a
	S – T – P	8.01a	12.2a	88.5a	100.8a	36.1a
	S – P	6.17a	11.4a	90.1a	101.7a	36.2a
	S – B	5.86a	11.7a	85.3a	96.8a	36.4a
CV (%)		65.2	18.7	9.8	9.4	1.3
San Carlos	S	1.01a	7.7c	67.8a	73.5abc	37.3c
	S – T	1.45a	8.3bc	65.3a	71.1bc	37.1c
	S – T – P	1.09a	9.5ab	69.1a	76.4ab	37.5bc
	S – P	1.47a	10.6a	68.2a	76.5a	38.0ab
	S – B	1.17a	7.6c	65.5a	70.7c	38.1a
CV (%)		36.2	24.9	7.3	8.0	1.8

Means in a column followed by the same letter for a location are not different LSD ($p < 0.05$).
S: 100% of N at sowing; S – T: 50% of N at sowing and 50% at tillering; S – T – P: 33% of N at sowing, 33% at tillering, and 34% at panicle initiation; S – P: 50% of N at sowing and 50% at panicle initiation; S – B: 50% of N at sowing and 50% at the boot stage; Ste-G: Stained grains per panicle; Stle-G: Sterile grains per panicle; Fill-G: Filled grains per panicle; T-G: Total grains per panicle; W-G: 1000-seed weight.

Table 8b. Yield components for rice crop in both locations for five N partialities evaluated in the 2008-2009 season.

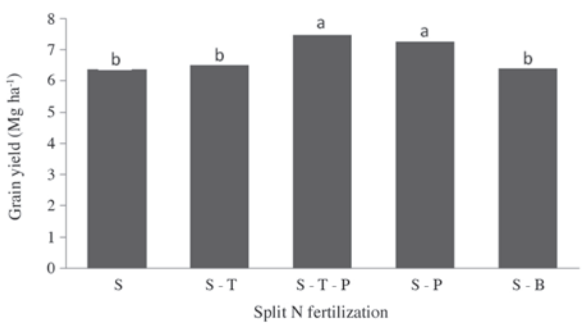
Location	Fertilization N split	Ste-G	Stle-G	Fill-G	T-G	W-S
		——— % ———				g
Parral	S	2.32b	10.2b	50.4b	56.1b	35.0b
	S – T	2.80b	10.7b	49.7b	55.7b	35.0b
	S – T – P	2.93b	13.6a	56.0a	64.7a	34.3c
	S – P	3.21b	13.7a	58.9a	68.3a	34.3c
	S – B	5.28a	11.4b	46.6b	52.5b	36.5a
CV (%)		64.7	17.5	12.3	11.3	1.9
San Carlos	S	4.16bc	28.1a	45.5ab	64.1ab	35.3bc
	S – T	5.08ab	29.5a	44.2b	62.8ab	34.9c
	S – T – P	5.09ab	26.5a	48.3a	66.2a	35.7a
	S – P	3.25c	27.1a	48.4a	67.3a	35.5b
	S – B	6.13a	25.9a	44.5b	60.3b	35.3bc
CV (%)		49.7	23.8	14.0	10.0	1.8

Means in a column followed by the same letter for a location are not different LSD ($p < 0.05$).
S: 100% of N at sowing; S – T: 50% of N at sowing and 50% at tillering; S – T – P: 33% of N at sowing, 33% at tillering, and 34% at panicle initiation; S – P: 50% of N at sowing and 50% at panicle initiation; S – B: 50% of N at sowing and 50% at the boot stage; Ste-G: Stained grains per panicle; Stle-G: Sterile grains per panicle; Fill-G: Filled grains per panicle; T-G: Total grains per panicle; W-G: 1000-seed weight.

Locality of San Carlos

At San Carlos, results showed a lack of interaction between N rates and split N fertilization in both seasons ($p > 0.05$) (Tables 5 and 6). However, N rates evaluated in this experiment consistently affected the percentage of sterile grains and 1000-seed weight in both seasons. These results are similar to those obtained by Jing (2007); moreover, N rates affected the number of grains per panicle only in the second season. Split N fertilization consistently affected 1000-seed weight in both seasons, as well as the number of grains per panicle, the percentage of stained grains in the second season, and the percentage of sterile grains in the first season (Tables 5 and 6), results matching those indicated by Jing (2007). The decrease in grain yield in San Carlos was similar to that obtained in Parral, about 1.45 Mg ha^{-1} in the second season compared to the first season (data not shown), which was associated with the temperature decrease during flowering (Figure 2). Grain yield fluctuated from 6.40 to 7.13 Mg ha^{-1} (Figure 4) and from 6.37 to 7.49 Mg ha^{-1} (Figure 5) for the different N rates and evaluated splits, respectively; these were significantly higher than the control without N in both seasons (Table 2). Though similar to the results in Parral, these results were slightly lower than those reported by Artacho *et al.* (2009), similar to those indicated by Ortega (2007), and higher than those indicated by Xiang-long *et al.* (2007) and Huang *et al.* (2008). For evaluated N rates, the highest grain yield was obtained with 120 to 160 kg N ha^{-1} (Figure 4), suggesting that the 120 kg ha^{-1} N rate is adequate for the rice crop under these conditions. This N rate value is lower than the one pointed out by Ortega (2007) in the same rice cultivar. For split N fertilization, results were similar to those in Parral, and the highest yield was obtained with the same two treatments: (1) 33% N at sowing, 33% at tillering, and 34% at panicle initiation, and (2) 50% N at sowing and 50% at panicle initiation (Figure 6). On the other hand, only split N fertilization consistently affected the 1000-seed weight in both seasons (Tables 8a and 8b). Similar results were obtained by Jing (2007).

For the effect of N rates on yield components, values obtained during the first season did not exhibit any differences and fluctuated between 1.00 and 1.33% for stained grains, 7.5 and 10.7% for sterile grains, 65.7 and 70.0 for filled grains per panicle, 71.3 and 74.7 for total grains per panicle, 37.2 and 37.9 g for 1000-seed weight (Table 7a). However, only the value for filled grains per panicle was stable and varied between 50.3 and 53.7 in the second season, while all other components



Different letters over bars indicate differences among treatments ($p < 0.05$).
S: 100% of N at sowing; S – T: 50% of N at sowing and 50% at tillering; S – T – P: 33% of N at sowing, 33% at tillering and 34% at panicle initiation; S – P: 50% of N at sowing and 50% at panicle initiation; S – B: 50% of N at sowing and 50% at the boot stage.

Figure 6. Grain yield of rice with different N applications in San Carlos, pooled data for 2007-2008 and 2008-2009 seasons.

were affected by the treatments (Table 7b). Thus, results varied between 2.82 and 6.67% for stained grains, 18.0 and 33.2% for sterile grains per panicle, 57.9 and 67.0 for total grains per panicle, and 35.5 and 36.4 g for 1000-grain weight. As observed in Parral, there was no clear relationship between N rates and the effect on yield components. Results indicate that none of the evaluated N rates had a consistent effect on yield components directly associated with the grain (filled grains, total grains per panicle, and 1000-seed weight).

For split N fertilization, results for the first season indicated that only stained grains and filled grains were not affected, while in the second season there was no effect on the percentage of sterile grains (Tables 8a and 8b). In the first season, sterile grains fluctuated between 7.6 and 10.6%, 70.7 and 76.5 for total grains per panicle, and 37.1 and 38.1 g for 1000-grain weight (Table 8a). In the second season, stained grains fluctuated between 3.25 and 6.15%, 44.2 and 48.4 for filled grains, 60.3 and 67.3 for total grains per panicle, and 34.9 and 35.7 g for 1000-grain weight (Table 8b). In general, just as in Parral, there was no relationship between split N fertilization and the effect obtained in the yield components in San Carlos (Tables 8a and 8b). Moreover, 1000-seed weight increased with the last N application (boot stage), as indicated by Beşer (2001). In general, in the second season, split N fertilization in (1) 33% N at sowing, 33% at tillering, and 34% at panicle initiation generated the highest number of filled grains and total grains per panicle, as well as the highest1000-seed weight. Finally, N rates and split N fertilization exhibited a different effect on the variations in yield components; N rates also exhibited a higher variation in both stained and sterile grains per panicle (Tables 7 and 8). The effect of both N rates and split N fertilization on yield components was also different in both locations and stained grains per panicle was consistently the least affected parameter (Tables 7 and 8).

CONCLUSIONS

The N rates used in this experiment showed a positive effect on grain yield as compared to the control without N. The relationship between locations and seasons indicates that grain yield increased with higher N rates; moreover, these results suggest that adequate N rates were 120 and 140 kg N ha^{-1} in San Carlos and Parral, respectively.

For split N fertilization in flooded rice crop conditions in Chile, the highest productivity was obtained with two strategies (1) 33% N at sowing, 33% at tillering, and 34% at panicle initiation, or (2) 50% N at sowing and 50% at panicle initiation.

Yield components were erratically affected by both N rates and split N fertilization, but splitting N generated lower variability in stained grains per panicle.

Efecto de dosis de nitrógeno y parcialización de la fertilización nitrogenada sobre el rendimiento de grano y componentes de rendimiento en arroz. El manejo nutricional del cultivo de arroz (*Oryza sativa* L.) está principalmente asociado con la fertilización nitrogenada, difícil de ajustar en condiciones de campo debido a variaciones en tipo de suelo y condiciones climáticas. El área cultivada con arroz en Chile comprende entre 28 000 y 46 000 ha por año y como los beneficios económicos dependen del costo de fertilización, se realizó un experimento de campo en dos localidades durante dos temporadas consecutivas (2007 a 2009) para determinar el efecto de la dosis y parcialización del N sobre el rendimiento de grano y sus componentes, evaluando 5 dosis de N y 5 estrategias de parcialización. Las localidades fueron Parral (36º2' S; 72º08' W, Vertisol) y San Carlos (36°19' S; 71°59' W, Inceptisol), con dosis de N de 80, 100, 120, 140 y 160 kg ha^{-1} aplicadas en diferentes estados de desarrollo como siembra, macolla, inicio de panícula y estado de bota. Los resultados indican efecto de la temporada sobre el rendimiento de grano, y un rendimiento maximizado con dosis de 120 y 140 kg N ha^{-1} en San Carlos y Parral, respectivamente. La mayor productividad asociada a la parcialización del N se obtuvo con (1) 33% de N a la siembra, 33% al momento de macolla y 34% al inicio de panícula (2) 50% del N a la siembra y 50% al inicio de panícula. Los componentes de rendimiento con mayor efecto sobre la productividad fueron afectados por la estrategia de parcialización de N. Las mayores dosis de N incrementaron el porcentaje de granos manchados y estériles por panícula.

Palabras clave: Arroz regado, manejo del nitrógeno, productividad del arroz, *Oryza sativa*.

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