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Analysis of Rice Yield Differences for Inland and Coastal Regions in South Korea

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Abstract: Rice production improvement could be obtained with continuous efforts to overcome meteorological factors affecting crop growth. Meteorological factors and rice yield components were compared between inland (Chuncheon city) and coastal (Kangreung city) regions to illustrate the causes of the rice yield decrease in the coastal region. During the rice growing period from 1 May to 15 October, the difference in daily average air temperature between the two regions was not noticeable. However, diurnal range of temperature and solar radiation were higher at Chuncheon than at Kangreung. Average wind velocity was higher at Kangreung. Rice yield components, grains per panicle was lower by 16.7 and ripening ratio was lower by 4.9% at Kangreung. Thus, rice yield was lower at Kangreung (4,392 kg ha^{-1}) by 655 kg ha^{-1} than at Chuncheon (5,047 kg ha^{-1}). The correlation analyses revealed that the lower rice yield at Kangreung could be attributable mainly to lower diurnal range of air temperature and solar radiation during panicle development and ripening stages which cause the lower number of grains per panicle and the lower grain ripening. The results could provide rice researchers and farmers information about required cultivar characteristics to overcome the meteorological conditions in coastal regions.

Key words: Meteorological factors, yield components, rice growth stage

INTRODUCTION

Kangwon province is geographically divided into inland and coastal regions by the Taeback mountain range that runs from north to south in South Korea. These two regions show not only different meteorological characteristics but also different rice yields[1]. According to Kim[1], the inland plain region represented by Chuncheon shows about 10% higher rice yield than the east coastal region represented by Kangreung. Choi *et al.*[2] and Kim [1] reported that the primary reason for this yield difference was due to the difference of meteorological conditions rather than that of soil conditions between the two regions. They also reported that the plant factors for the yield difference were the decreased number of tillers, panicles and grains and the lowered grain ripening ratio. A unique meteorological condition in the east coastal region lying in the boundary of the Ohtsk anticyclone causes the decreased growth or the delayed development of rice frequently due to the chilling injury[2]. As a result of this meteorological condition, the east coastal region shows not only lower average rice yield than the inland region in Kangwon province but also uneven average rice yields from year to year. However, there have been few studies about the relations between rice yield and meteorological characteristics for this region.

The polished rice yield for 5 years from 1995 to 1999 was averaged at 4,570 kg ha^{-1} across the eleven counties and cities in the inland region of Kangwon province and at 4,270 kg ha^{-1} across the six counties and cities in the coastal region[3]. Miho[4] reported that the higher production regions in Japan showed more daily sunshine hours and greater diurnal temperature range, resulting in higher ripening ratio and grain weights than the lower production regions. Lee[5] reported that the meteorological conditions in Korea are not optimum for the preheading accumulation of carbohydrate in rice, due to the

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comparatively higher temperature, smaller diurnal temperature range and less sunshine hours from July to August. In Southeastern Asia, 80% of rice is cultivated in the monsoon or wet season. It causes comparatively lower productivity in rice due to less solar radiation than in the dry season[6].

Rice growth stage is classified into vegetative growth, panicle development and ripening stage[7]. During ripening stage high diurnal temperature range and sufficient sunshine hours are ideal for maintaining physiological activity[8-10]. There have been frequent cold injuries to rice, especially in the east coastal areas, that have caused low rice yields by delayed heading and poor ripening[11]. Chang[11] also pointed out that rice yield in the coastal region is negatively influenced by less daily sunshine hours and cold winds and the strong winds from August to September give injuries to flowering and fertility. Kim[12] reported that insufficient sunshine hours reduce transpiration and nutrient translocation.

The purpose of the research was to deduce the cause of the rice yield decrease in the east coastal region compared to the inland one in South Korea. Meteorological factors, yield and yield components were compared between Chuncheon and Kangreung, represented as inland and coastal region in Kangwon province, respectively. The relationships between the meteological factors and the rice yield component were analyzed and used to trace the major meteorological factors bringing about the rice yield decrease in the coastal region.

MATERIALS AND METHODS

Two experimental sites were chosen, one from Chuncheon city (74 m above sea level) as an inland region and the other from Kangreung city (14 m above sea level) as a coastal region in Kangwon province of South Korea. The fields were located at Kangwon Agricultural Research and Extension Services (KARES) in Chuncheon and at Coastal Experimental Station of KARES in Kangreung. The soils were a fine sandy loam for the inland field and a sandy for the coastal field.

Meteorological data: Climate data from 1995 to 1999 were obtained from the Chuncheon and Kangreung weather stations. The climatological analysis was carried out for the rice growing periods from 1 May to 15 October, which were broken down into the vegetative and the reproductive stages. The vegetative stage was divided into the rooting and the tillering periods. The rooting period was 10 days after transplanting, which was from 25 May to 3 June and the tillering period from 4 June to 14 July. The reproductive stage was classified into the panicle development period from 15 July to 14 August and the ripening period from 15 August to 31 September.

Rice growth and yield data: The rice varieties used were Odaebyeo, Jinmibyeo and Hwasungbyeo in both sites. Uniform seeds were selected and sterilized. After sprouting, the seeds were sown at 130 g per a 30x60 cm nursery tray on 25 April. Seedlings were grown in upland condition to make their root healthy. The seedlings were transplanted at the spacing of 30x14.3 cm with three seedlings per hill at Chuncheon and 30x13.3 cm with 4 to 5 seedlings per hill at Kangreung. The fertilizer was applied at a rate of 110-70-80 kg ha^{-1}, N-P_2O_5-K_2O, at Chuncheon and 110-100-110 kg ha^{-1} at Kangreung. Half of the N was applied prior to planting. Of the remaining N, 20% was applied at tillering, 20% at panicle formation and 10% at full heading stage. All of the phosphate fertilizer was applied prior to planting. Seventy percent of the potassium fertilizer was applied prior to planting and 30% at panicle formation stage. The other managements were done according to the standard cultivation method recommended by KARES[13].

The Randomized Block Design was used with three replications for each site. The measured yield components were as follows: panicles per hill or square meter, spikelets per panicle, percent grain ripening and 1,000 grain weight. Rice yields were measured with 100 hills harvested in the experiment plot.

Statistical analysis: The SAS software (SAS version 8.1, SAS Institute Inc. Cary, North Carolina) was used for statistical analyses such as Pearson correlation coefficient and Least Significant Difference (LSD) test. The correlations between the yield components and the meteorological factors for each growth period were analyzed by converting the yield components to indices according to the following formula:

$$\text{Index} = \frac{\text{Yield component of each variety for each year}}{\text{Five years average of each variety}} \qquad (1)$$

The indices were introduced to reduce the possible year-to-year variations of the yield components.

RESULTS AND DISCUSSION

Comparison of meteorological conditions: The meteorological conditions were compared between Chuncheon and Kangreung during the rice growing period from 1 May to 15 October both phenologically (Table 1) and daily (Fig. 1). No big difference was found

Table 1: Comparison of the meteorological conditions between Kangreung (coastal) and Chuncheon (inland) during the rice growing periods

Region	Period	Temperature (°C) Ave	Max	Min	Diunal range	Solar radiation (MJ m^{-2})	Precipitation (mm)	Wind speed (m sec^{-1})	Relative humidity (%)
Chuncheon	1 May-15 Oct.	20.7	26.5	16.0	10.5	14.8	1221.5	1.16	79.6
	Tillering	22.3	27.9	17.5	10.4	16.7	258.7	1.15	78.5
	Panicle development	25.4	30.2	21.7	8.5	13.9	494.0	1.19	84.7
	Ripening	21.0	27.0	16.8	10.2	13.9	308.5	1.01	82.4
Kangreung	1 May-15 Oct.	21.2	25.3	17.4	7.9	14.2	1015.0	2.00	72.3
	Tillering	21.4	24.9	18.1	6.8	14.3	202.7	1.71	76.2
	Panicle development	25.6	29.2	22.4	6.8	13.9	258.3	1.85	78.1
	Ripening	21.9	25.9	18.1	7.8	12.9	375.3	1.95	73.8

Table 2: Comparison of yield components and yield of rice between inland (Chuncheon) and east coastal (Kangreung) regions in Kangwon province

Region	Variety	Heading date	Panicles (m^{-2})	Grains (m^{-2})	Ripened grains (%)	1,000 grain weights (g^{-1})	Yields (kg ha^{-1})
Chuncheon	Odae	03 Aug.	387.5	32.232	83.8	25.0	5,101
	Jinmi	12 Aug.	360.4	35.496	86.9	22.1	5,021
	Hwasung	17 Aug.	402.5	31.191	89.8	22.2	5,020
	Mean	11 Aug.	383.5	32.973	86.8	23.1	5,047
Kangreung	Odae	10 Aug.	462.7	33.535	81.0	23.9	4,757
	Jinmi	13 Aug.	410.8	31.506	80.4	20.6	4,202
	Hwasung	21 Aug.	540.7	28.309	84.3	21.6	4,219
	Mean	15 Aug.	444.1	31.117	81.9	22.0	4,392
LSD (α = 0.05)	Between regions	-	27.9	ns	3.9	ns	301

on the average values of the daily air temperature, the daily total solar radiation and the relative humidity between the two regions during the whole rice growth period (Table 1). However, the diurnal range of temperature and the precipitation were higher at Chuncheon and the wind speed was higher at Kangreung. On the other hand, the daily total solar radiation at the tillering and the ripening stages showed somewhat differences between the two regions, being higher at Chuncheon. The precipitation was higher at Kangreung at the ripening stage, while it was higher at Chuncheon at the tillering and the panicle development stages. As some studies[1,2] pointed out, we could find some meteorological factors that might negatively affect rice production at Kangreung. These are the lower diurnal range of temperature and the higher wind speed during the whole growing period and the lower daily total solar radiation and the higher precipitation at the ripening stage as compared to Chuncheon.

When factors were ompared on the daily basis (Fig. 1), most of those described above were found with same trends for the daily total solar radiation, the precipitation and the wind speed. However, daily values of the average temperature at Kangreung were higher until May, lower in June and higher after late August than at Chuncheon. The trend of the daily minimum temperature was almost similar to this. It is considered that the lower temperatures at Chuncheon might be a factor of decreasing rice production.

Since solar radiation is an important factor on plants as their photosynthetic energy source, it was compared between the two regions as a function of time for the different growth stages (Fig. 2). Solar radiation was higher all day during the tillering stage at Chuncheon than at Kangreung; lower in the morning and higher in the afternoon during the panicle development stage and similar in the morning, but higher in the afternoon during the ripening stage. So, it appears that the lower solar radiation during the tillering and ripening stages might be a causal factor for the lower rice productions in the coastal regions.

Comparison of rice yield components and yields: In regions susceptible to severe weather injuries on rice, heading date is generally considered as an indirect indicator for these such as chilling injury[14]. Average heading dates were delayed by about four days (7 days for Odae) at Kangreung (Table 2). This makes possible to deduce that rice growth at Kangreung was influenced worse by some meteorological factors compared to that at Chuncheon.

The number of tillers were produced more by 60.6 m^{-2} at Kangreung. Chang[11] and Choi *et al.*[2] also reported that more tillers were secured in the coast region than the inland. The number of grains per panicle and the ripening ratio were significantly higher by 16.7 and 4.9%, respectively, at Chuncheon than at Kangreung. It is considered that these are the major components to cause the lower rice production in the coastal regions as compared to the inland regions. Rice yield was significantly higher by 13% (655 kg ha^{-1}) at Chuncheon than at Kangreung on average, the results being consistent in all varieties. These results are in general agreement with Choi *et al.*[2] and Kim[1].

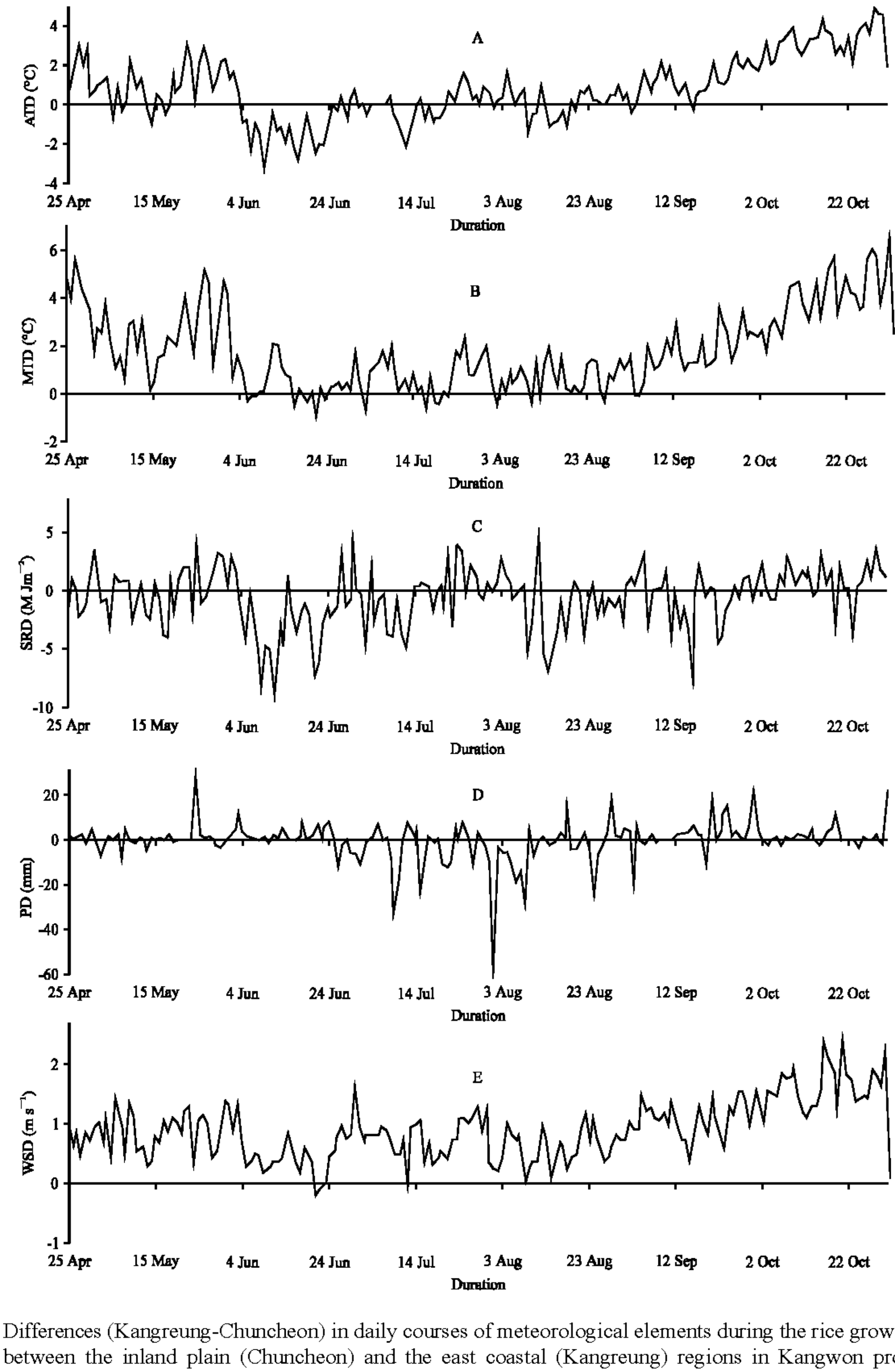

Fig. 1: Differences (Kangreung-Chuncheon) in daily courses of meteorological elements during the rice growing season between the inland plain (Chuncheon) and the east coastal (Kangreung) regions in Kangwon province. A. Average Temperature Differences (ATD); B. Minimum Temperature Differences (MTD); C. Solar Radiation Differences (SRD); D. Precipitation Differences (PD); E. Wind Speed Differences (WSD)

Table 3: Correlations between the indices of yield components and the average meteorological factors during the rice growth stage during which each yield component is determined

Yield component index	Tillering			Panicle development			Grain ripening		
	AT	DR	SR	AT	DR	SR	AT	DR	SR
Panicles/m	-0.097	-0.514**	-0.190	0.000	-0.541**	-0.090	-	-	-
Spikelets/panicle	0.185	0.409*	0.417*	0.426**	0.593**	0.687**	-	-	-
Percent ripened grain	-	-	-	-0.362*	0.276	-0.166	-0.108	0.712**	0.459**
1,000-grain weight	-	-	-	0.332	0.385*	0.471**	0.187	0.191	0.280

AT: Average Temperature (°C), DR: Diurnal temperature Range (°C), SR: Solar Radiation (MJ m^{-2}), * and **, significant at 0.05 and 0.01 levels, respectively

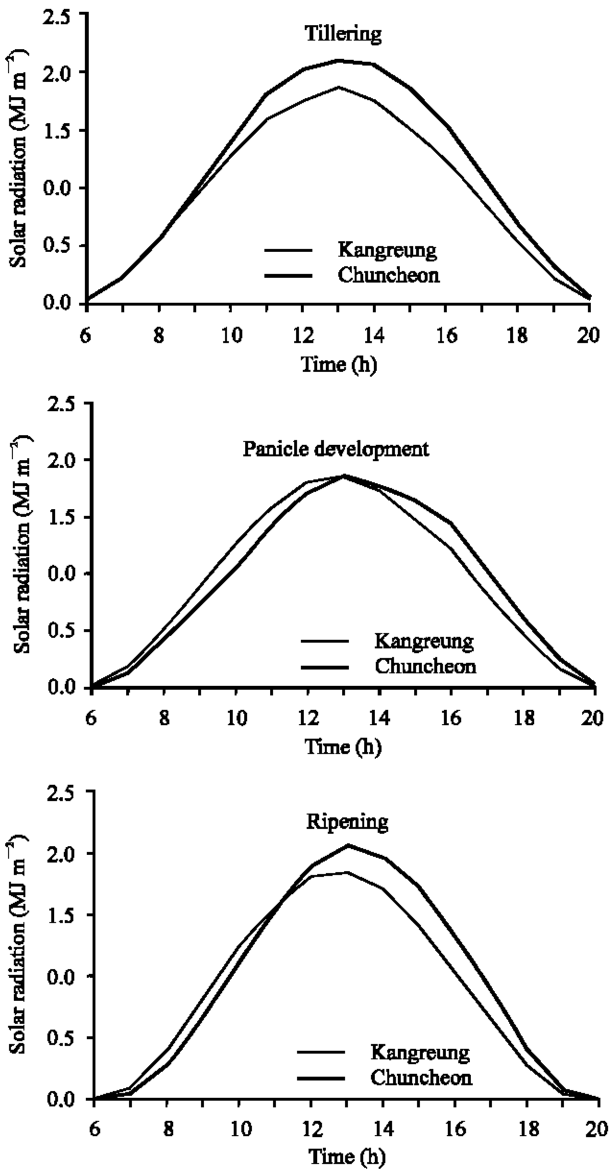

Fig. 2: Diurnal changes of solar radiation during each growth stage at Chuncheon and Kangreung

Correlations between the yield components and the meteorological factors: Correlation analyses were performed to figure out the major meteorological factors of each growing stage influencing on the yield components and causing lower yield (Table 3). During the tillering stage, there was a negative correlation between the number of panicles per m^2 and the diurnal temperature range. On the other hand, it appears that spikelets growth is indirectly influenced by the diurnal temperature and the solar radiation during this stage according to the correlations.

During the panicle development stage, the number of spikelets per panicle showed strong positive correlations with the diurnal temperature range and the solar radiation. During the ripening stage, there was a strong correlation between the percent ripening and the diurnal temperature range and a moderate correlation between the percent ripening and the solar radiation. Overall, smaller diurnal range of air temperature and lower solar radiation during the panicle development and the ripening stages at Kangreung would have resulted in smaller number of spikelets per panicle and poorer grain ripening compared to Chuncheon.

There have been previous studies dealing with meteorological factors affecting rice yield such as diurnal temperature range, solar radiation and wind[1,4-6,8-12,14]. Present results are in general agreements with many of their results. In addition to the above findings, this study presents more information about the effects of solar radiation and diurnal temperature range and their correlation with the yield components for each growing stage.

It is assumed that lower rice grain yields in the coastal regions are mainly caused by smaller diurnal temperature range and less solar radiation during the panicle development and ripening periods. The results could be used as basic information about the meteorological factors of causing lower rice production in coastal regions so that rice researchers and farmers could apply it to develop and choose appropriate rice varieties.

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