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Research Article

Climatic Suitability Mapping of Whole-Crop Rye Cultivation in the Republic of Korea

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ABSTRACT

This study was conducted to perform the suitability analysis of whole-crop rye (*Secale cereale* L.) based on the climatic information in the Republic of Korea to present useful information for producers and policy makers to determine the site-selection for the cultivation of the whole-crop rye. The criteria to analyze the climatic suitability of whole-crop rye was developed firstly. Then, the climatic suitability map for spatial analysis was developed through weighted overlaying the raster layers of climatic items in the evaluation criteria. Meanwhile, 16 geographically representative weather stations were selected to show examples of the calculation process of the climatic suitability score of a specific cultivation area. The results of the climatic suitability mapping indicated that the climatic conditions in most arable lands of the Republic of Korea such as the coastal, southern, western areas in the southern region of the Korean Peninsula and central areas in Jeju Island are suitable for the cultivation of whole-crop rye. The climatic suitability scores of the 16 weather stations were all in line with the results of the climatic suitability map.

(**Key words**: whole-crop rye, evaluation criteria, climatic suitability analysis, mapping)

Ⅰ. INTRODUCTION

Whole-crop rye (*Secale cereale* L.) is a popular winter forage crop in the Republic of Korea (Kim et al., 2010). It has good cold tolerance and could be cultivated in poorer soils compared to other cereal grains (Altpeter, 2006; Geiger and Miedaner, 2009). Meanwhile, the cold tolerance of rye is strong and it is recently preferred in Korea (Hurry et al., 1995; Seo, 2016). The cultivation area of whole-crop rye had reached to 40,000 ha in 2014 from 13,900 ha in 2007 in the Republic of Korea (Seo, 2016). Responding to the significant increase in its cultivation demand, it was thought that proper site-selection for the cultivation of the whole-crop rye needs an urgent attention. Therefore, suitability analysis of the environment factors for the whole-crop rye production in the Republic of Korea is thought to be necessary. Some studies on the suitable region detection for the cultivation of rice and cash plants had been done in Korea, however, similar research have been rarely performed for the forage crops and grasses (Yun, 2003; Kim et al., 2009). Among the environmental factors, climatic factors are of paramount importance to the growth of crops (Chung, 2007; Lobell et al., 2011). The global climate change has leaded to the increase of average temperature in many areas worldwide and this was thought to have a great effects on the agricultural production (Howden et al., 2007; Lobell and Burke, 2008; Rosenzweig et al., 2014). Especially, in the Republic of Korea, the average temperature has increased by 1.5℃ in the last century (Kim et al., 2010). Plants, including forage crops, might face more environmental stresses and subsequently the responding strategies to the changing climatic environments are necessary for the future agricultural production (Hatfield *et al*., 2011). Specially, the production of high quality forage crops plays the key role in the safety of livestock products supply (Seré et al., 1996; Kallenbach et al., 2006).

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To recommend the climatically suitable region for the cultivation of whole-crop rye in the Republic of Korea, this study was conducted to develop a suitability evaluation criteria of whole-crop rye to climatic conditions based on previous cultivation standards and experts' opinion, and subsequently generate the suitability map of whole-crop rye considering regional climate conditions in the Republic of Korea through weighted overlaying the raster data of basic climatic items.

Ⅱ. Materials and Methods

1. Developing the evaluation criteria of climatic suitability for whole-crop rye

To develop the evaluation criteria of climatic suitability for a whole-crop rye in the Republic of Korea, the Standard Farming Handbook - 91: Guide for Forages Production (RDA, 2005) was studied and referenced to contribute a standard frame. Then the frame was detailed enriched into the climatic suitability evaluation criteria (Table 1) with the consultation from forage crop experts. Temperature and precipitation related climatic variables were considered as predominantly attributing to the growth and development of whole-crop rye. Thereafter, three temperature related climatic variables and two precipitation related climatic variables were selected. The three temperature related climatic variables were minimum temperature in January which is related to the overwintering of the winter forage crops, number of days with daily mean temperature greater than 5 ℃ during September to December in the seeding year which determines whether the crops could get sufficient accumulated temperature after autumnal seeding for overwintering, and mean temperature during March to May in the next year which are related to the proper temperature for the yield production of forage crops (Peng et al., 2016). The two precipitation related climatic variables are number of days with precipitation and accumulated precipitation from last October to May since sufficient water supply plays an important physiological role in the yield production of forage crops (Peng et al., 2016). Each of the above climatic items was classified into three levels including improper, possible, and proper with a given level score 0.5, 0.8, and 1, respectively. Furthermore, based on references and the comments from forage experts, the weights of the five climatic variables are given (Table 1). To derive the climatic suitability score, the obtained level score of each item multiply with the weight of the item will be summed.

2. Preparation of the raster data of the climatic items

The raster data of the climatic items in the climatic suitability evaluation criteria were developed through overlaying the raster data of the basic climatic data such as daily temperature and daily precipitation from 1981 to 2010. Then, according to the climatic suitability criteria, the raster data of the climatic items were converted to the raster data of the suitability level scores. Meanwhile, 16 geographically representative weather stations as shown in Fig. 1 were selected to show examples of the calculation process of the climatic suitability score of a specific cultivation area.

3. Generation of the whole-crop rye climatic suitability map

With the numerical data of the climatic items in the climatic suitability evaluation criteria, the climatic suitability scores of

Table 1. The climatic suitability evaluation criteria for whole-crop rye cultivation

Climatic items	Improper (0.5)	Possible (0.8)	Proper (1)	Weight (%)	Suitability score
Minimum temperature in January (℃)	< -14	-14 ~ -10	> -10	10	
Mean temperature during March to May (℃)	<1	1 ~ 10	>10	20	
Number of days with daily mean temperature >5 ℃ (September - December)	< 30	30 ~ 50	> 50	20	
Number of days with precipitation (October - May)	< 45	45 ~ 70	> 70	25	
Accumulated precipitation (mm) (October - May)	< 346.5	346.5 ~ 539	> 539	25	
Total				100	

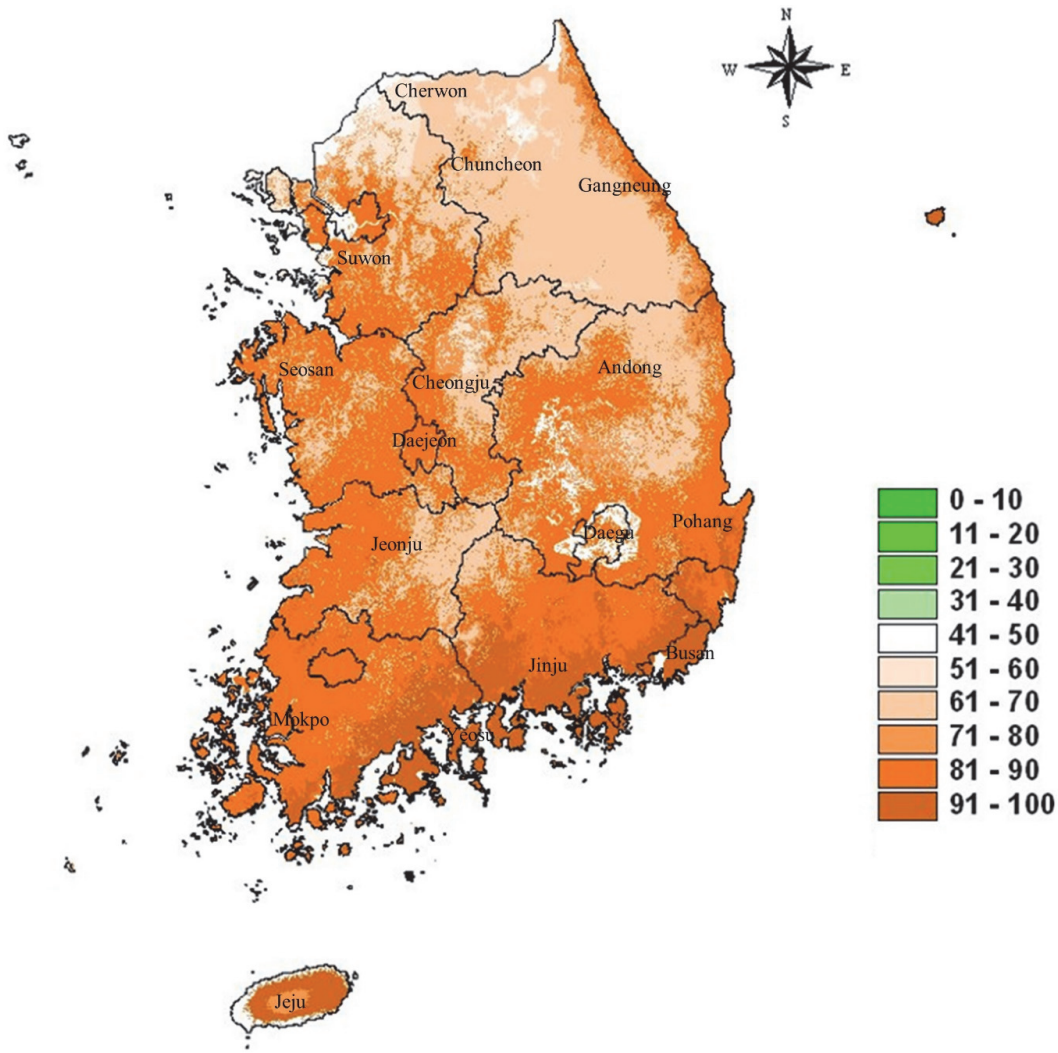

Fig. 1. The climatic suitability map of whole-crop rye and the geographical locations of the 16 selected representative weather stations in the Republic of Korea.

whole-crop rye was calculated via the following equation:

Where C_k refers to the level score of each climatic item and W_k is the weight of each climatic item. Meanwhile, the climatic suitability map with suitability scores of whole-crop rye was generated via weighted overlaying the generated raster data of the suitability level scores of five climatic items using ArcView 3.2 provided by a training program hosted by the national center for meteorology.

The climatic suitability scores were classified into three levels: proper (90 - 100), possible (70 - 89), poor (50 - 69), and improper (less than 50) based on previous research (RDA, 2005; Taddese, 2014) and experts' opinion. The proper level means the climatic condition of a specific area is favorable for the cultivation of whole-crop rye, the possible level means the climatic condition of an area is possible for the cultivation of whole-crop rye, and if a specific area has a climatic suitability score less than 70, the climatic condition there is poor or improper for the production of whole-crop rye.

Ⅲ. Results and Discussion

The brown and dark brown areas whose climatic suitability score is greater than 70 on the climatic suitability map of whole-crop rye were considered as the possible and proper regions for the cultivation of rye (Fig. 1). Therefore, the results on the climatic suitability map indicated that most arable lands in the Republic of Korea such as the coastal, southern, and

Table 2. Average climatic data of 16 weather stations in South Korea

Weather Stations	Climatic items				
	C1[1)]	C2	C3	C4	C5
Cherwon	−11.5	10	74	63	367.5
Chuncheon	−9.9	11.1	75	71	363.7
Gangneung	−3.2	12.3	94	64	561.6
Suwon	−7.4	11.3	78	97	382.5
Seosan	−6.4	10.6	85	97	420.3
Cheongju	−7	12.1	81	107	384.3
Andong	−7.4	11.6	77	72	338.8
Daejeon	−5.5	12.5	86	94	428.4
Pohang	−2	13.3	102	67	411.5
Daegu	−3.6	13.7	92	68	323.5
Jeonju	−4.6	12.4	89	108	437.2
Busan	−0.6	13.3	113	62	587.3
Jinju	−5.8	12.4	88	59	506.8
Mokpo	−1.5	12.1	102	105	420.3
Yeosu	−0.8	12.9	104	69	518.4
Jeju	3.2	13.7	122	119	596.4

1) C1, Minimum temperature in January (℃); C2, Mean temperature during March to May (℃); C3, Number of days with daily mean temperature >5℃ during September to December (d); C4, Number of days with precipitation during October to May (d); C5, Accumulated precipitation during October to May (mm).

western areas in the southern region of the Korean Peninsula and the central areas in Jeju Island are possible or proper regions for the cultivation of whole-crop rye. Meanwhile, as shown in Table 3, the climatic suitability scores of all the 16 weather stations are greater than 70 which is consistent with the results on the climatic suitability map. Furthermore, the climatic suitability scores of whole-crop rye in Gangneung, Pohang, Busan, Jinju, Mokpo, Jeonju, Seosan, Daejeon, Cheongju, Suwon, and Chuncheon are all greater than 90. For Chuncheon, though it is located in the north mountainous area, it has a high suitability score. This result is in line with the result on the suitability map that Chuncheon area showed dark brown color. This might be explained by that Chuncheon is a river basin area with better climatic conditions for agriculture than other mountainous areas. The rest weather stations are all located in the coastal, southern, and western areas in the southern region of the Korean Peninsula and Jeju Island. Their suitability scores are higher and the results are also consistent with the results on the climatic suitability map. Among the 16 weather stations, the climatic suitability scores of whole crop rye in Cherwon, Andong, and Daegu are lower than 90 but are all greater than 70 which are consistent with the results on the climatic suitability map and indicate that whole-crop rye could be cultivated almost all the arable lands in the Republic of Korea since its strong cold tolerance (Altpeter, 2006; Geiger and Miedaner, 2009).

Forage crop and grasses production is the foundation for the livestock production and subsequently the foundation for partial food supply (Wirsenius, 2000). Responding to the changing environments, the climatic suitability analysis could help for producers and policy makers to get a better understanding of the climatic impacts on agricultural production (Zabel et al., 2014). Furthermore, since most areas in the Korea are mountainous regions, this research may also aid the land utilization strategies via bring more possible lands for forage production or grazing by livestock.

In the future research, the results of this study was supposed to be combined with the soil suitability analysis and provide a comprehensive suitability analysis map for the producer and policy makers. Meanwhile, limitations in this research such as

Table 3. Calculation of suitability scores of whole-crop rye in cases of the 16 weather stations

Weather Station	Climatic items					
	C1[1)]	C2	C3	C4	C5	Suitability Score
Cherwon	8	16	20	20	20	84
Chuncheon	10	20	20	25	20	95
Gangneung	10	20	20	20	25	95
Suwon	10	20	20	25	20	95
Seosan	10	20	20	25	20	95
Cheongju	10	20	20	25	20	95
Andong	10	20	20	25	12.5	87.5
Daejeon	10	20	20	25	20	95
Pohang	10	20	20	20	20	90
Daegu	10	20	20	20	12.5	82.5
Jeonju	10	20	20	25	20	95
Busan	10	20	20	20	25	95
Jinju	10	20	20	20	20	90
Mokpo	10	20	20	25	20	95
Yeosu	10	20	20	20	20	90
Jeju	10	20	20	25	25	100

1) C1, Minimum temperature in January (℃); C2, Mean temperature during March to May (℃); C3, Number of days with daily mean temperature >5℃ during September to December (d); C4, Number of days with precipitation during October to May (d); C5, Accumulated precipitation during October to May (mm).

not considering the geomorphologic situation was also supposed to be amended. Furthermore, combing the suitability analysis with the field productivity of whole-crop rye and other forage crops is also with great significance to be investigated.

This study contributed a climatic algorithm for developing the climatic suitability map of whole-crop rye using the collected public climatic information. The results indicated that the climatic conditions in most arable lands of the Republic of Korea such as the coastal, southern, western areas in the southern region of the Korean Peninsula and central areas in Jeju Island are suitable for the cultivation of whole-crop rye. The results of this study are supposed to be useful for producers and policy makers to perform the determination on the site-selection for cultivating whole-crop rye.

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