# Impact of Abnormal Climate Events on the Production of Italian Ryegrass as a Season in the Republic of Korea

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# Impact of abnormal climate events on the production of Italian ryegrass as a season in the Republic of Korea

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**Key words**: Italian ryegrass; autumn low-temperature; severe winter cold; spring drought; dry matte yield

## Abstract
This study aimed to assess the impact of abnormal climate events on the production of Italian ryegrass (IRG), such as autumn low-temperature, severe winter cold and spring droughts in the central inland, southern inland and southern coastal regions. Seasonal climatic variables, including temperature, precipitation, wind speed, relative humidity, and sunshine duration, were used to set the abnormal climate events using principal component analysis, and the abnormal climate events were distinguished from normal using Euclidean-distance cluster analysis. Furthermore, to estimate the impact caused by abnormal climate events, the dry matter yield (DMY) of IRG between abnormal and normal climate events was compared using a t-test with 5% significance level. As a result, the impact to the DMY of IRG by abnormal climate events in the central inland of Korea was significantly large in order of severe winter cold, spring drought, and autumn low-temperature. In the southern inland regions, severe winter cold was also the most serious abnormal event. These results indicate that the severe cold is critical to IRG in inland regions. Meanwhile, in the southern coastal regions, where severe cold weather is rare, the spring drought was the most serious abnormal climate event. In particular, since 2005, the frequency of spring droughts has tended to increase. In consideration of the trend and frequency of spring drought events, it is likely that drought becomes a NEW NORMAL during spring in Korea. This study was carried out to assess the impact of seasonal abnormal climate events on the DMY of IRG, and it can be helpful to make a guideline for its vulnerability. This study was accepted in the Journal of Animal Science and Technology in 02/NOV/2020.

## Introduction
Some abnormal/extreme climate events are becoming more extreme in East Asia, depending on the season, due to global warming and rapid climate change (Min et al., 2015). It has been reported that abnormal climate events causes great damage to agricultural industry and crops (Team et al., 2007; Rosenzweig et al., 2001). In particular, climate events are important for forage crops that can be provided with high quality feed for livestock. Winter forage crops are vulnerable to abnormal climate events during winter, which is significant for survival. Therefore, on the Korean Peninsula, which belongs to the temperate climate zone and has four distinct seasons, the representative abnormal climate events which are fatal and prone to happen to winter crops are as follows: First, low-temperature events, which can occur after seeding in autumn, impede the growth and development of winter crops, making it difficult for them to obtain the energy needed for wintering (Cooper, 1960). According to the report on the climate of the Korean Peninsula (Pachauri et al., 2014), the damage caused by low-temperatures in autumn is expected to decrease gradually as global warming increases summer temperatures and extends the summer period. However, low-temperature event can still be fatal due to the increase in frequency and intensity of late monsoon rain (Kaul-Changma) and typhoon. Second, considering the characteristics of Italian ryegrass (*Lolium multiflorum* Lam., IRG), which has weak cold resistance, there is no doubt that the severe cold in winter is the most critical factor despite its good growth and development in autumn (Kobayashi et al., 2008). According to Min et al. (2015), greenhouse warming has been assessed to lead to an increase in warm extremes and a decrease in cold extremes, but recent warming associated with Arctic sea ice-melting has tended to bring a cold snap to East Asia in winter. Therefore, the severe cold from warming is likely to become more deadly to IRG. Finally, if the spring drought persists for a long period, it causes a shortage of water resources following the winter dry season that damages the agricultural industry (Kim et al., 2005). According to Kim et al. (2011), there was a bimodal pattern of frequency between the short and long term for spring drought, which indicates the polarization of drought variation. Hence, as the dry season increases, spring drought will gradually emerge as an important abnormal climate event in the future.

IRG has been generally cultivated in the southern inland and coastal regions of the Korean Peninsula, but this has gradually expanded from the southern to the central regions, and it is now cultivated in most regions except for the northern and central mountainous regions. In general, IRG is vulnerable to the dry and cold conditions of the Korean winter due to lower cold and dry tolerance compared to other winter crops. IRG is cultivated popularly in rotation system with rice, a major food crop, which is helpful to income of farmer in the Republic of Korea. Furthermore, IRG is important winter forage crop in terms of feed value, such as feed nutritive and preference, on the southern and central regions of Korea. Unfortunately, studies related to the effects of climate change and climate events on IRG have been seldom carried out in the Republic of Korea, compared to the improvement of varieties and the development of cultivation techniques. Therefore, in this study, the impact of abnormal climate events on the IRG production was considered.

Therefore, this study aimed to assess the impact of seasonal abnormal climate events on IRG production considering various climate variables. Besides this, production trends by year were checked in consideration of significant abnormal climate events in different regions.

## Methods and Study Site

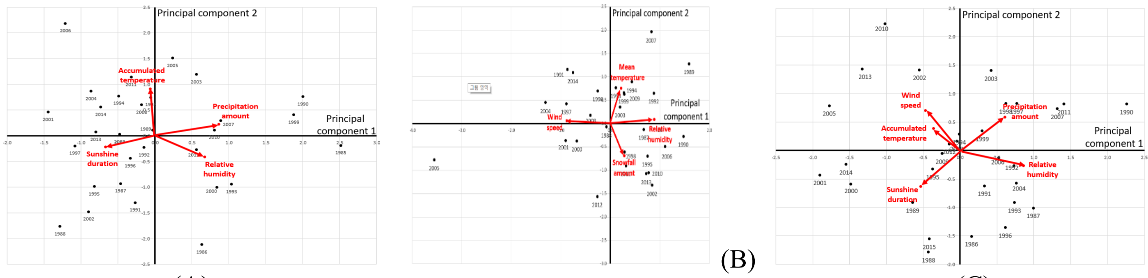
The IRG metadata (n=1,107) including location, year, cultivar, seeding and harvesting dates, height and dry matter yield (DMY, kg/ha) were collected from reports of the National Agricultural Cooperative Federation (NACF) and the Rural Development Administration (RDA) of the Republic of Korea from 1988 to 2013 (26 years). In general, abnormal/extreme climates in some regions may be normal in other regions; thus, it is necessary to classify the regions. In this study, the central inland, southern inland and coastal regions were selected because the northern inland and mountainous regions were not suitable for IRG cultivation. Suwon (latitude: 37° 25′ N, longitude: 126° 98′ E, n=321), Jeonju (latitude: 35° 84′ N, longitude: 127° 12′ E, n=107) and Jeju (latitude: 33° 51′ N, longitude: 126° 53′ E, n=135) were selected as representative locations for the central inland, southern inland and southern coastal regions, respectively.

Based on the location, the raw meteorological data contains daily mean temperature, wind speed, relative humidity, precipitation amount, snowfall amount and sunshine duration were collected by open-API (application programming interface) from the weather information system of KMA (1988-2013). To quantify the climate events for IRG, the season was divided into autumn, winter and next spring based on the earliest seeding date (03/September) and the latest harvesting date (12/June). In the Republic of Korea, IRG is generally sown between late September and early October and harvested in late May. Thus, growing periods were divided into autumn (September to November), winter (December to February), and next spring (March to May), respectively. To quantify abnormal climate events, the variables were temperature (℃), relative humidity (RH, %), precipitation amount (PA, mm), snowfall amount (SA, cm), sunshine duration (SD, hr) and wind speed (WS, m/s). Where, the temperature was: accumulated temperature (AT, ℃) over 5℃ in autumn and next spring, and mean temperature (MT, ℃) in winter. Where, the lower limitation of AT, 5℃ (41°F) was the base temperature of growing degree days for IRG. In general, abnormal climate can be defined by various criteria, including the type, intensity and frequency of climate variables. In this study, abnormal and normal climate scenarios for autumn, winter and next spring were categorized by seasonal climate variables using statistical analysis. Here, a category that satisfies climatic conditions favorable for survival, growth and development for the high IRG yield was defined as a normal climate scenario. Meanwhile, climatic characteristics unfavorable to the survival, growth and development of IRG at a specific season were reflected to the abnormal climate scenarios.

## Results

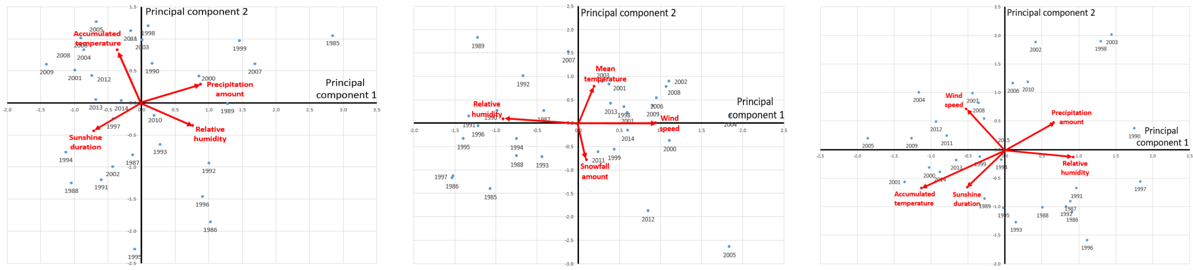
### *Classification of abnormal climate events by seasons*

Based on the climatic PCs, the year and climate variables were plotted together to classify abnormal climate events from normal (Figures 1–3). In the central inland regions (Figure 1), the autumn normal and low-temperature events could be divided into the second quadrant close to SD of PC1 and AT of PC2, and a fourth quadrant close to RH and PA of PC1 and far from AT of PC2, respectively. For winter, normal and severe cold events were placed in the first quadrant, where RH of PC1 and MT of PC2 were located, and the third quadrant, where WS of PC1 and SA of PC2 were located, respectively. For spring, normal and drought events were distributed on a right quadrant where RH and PA of PC1 were mainly arranged, and a left quadrant where WS, SD and AT of PC2 were arranged, respectively. The characteristics of climatic PCs of the southern inland region were similar to those of the central inland region (Figure 2). However, in winter, normal and severe cold events were located in the second and fourth quadrants, respectively; because the sign of climate variables in PC1 was opposite between central and southern inland regions. In the southern coastal regions (Figure 3), autumnal climate events were not classified as normal and low-temperature events. In the case of winter, it was difficult to distinguish severe cold from normal because of the ambiguous position of climate variables, although PCs were statistically distinct. The spring droughts were prominent in the third quadrant related to high AT, high SD and low PA.



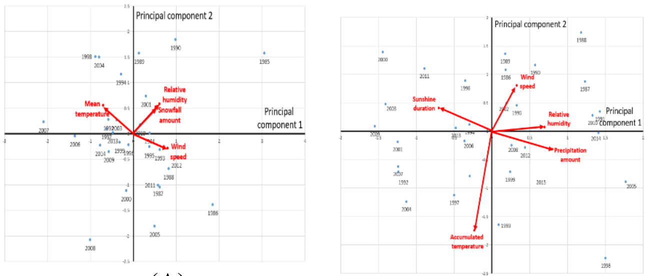

(A) (B) (C)

FIGURE 1. Scatter plots of year and climate variables to classify climate events in the central inland region: (A) autumn, (B) winter, (C) spring




(A) (B) (C)

FIGURE 2. Scatter plots of year and climate variables to classify climate events in the southern inland region: (A) autumn, (B) winter, (C) spring




(A) s(B)

FIGURE 3. Scatter plots of year and climate variables to classify climate events in the southern coastal region: (A) winter, (B) spring

***Comparison of climate variables and dry matter yield between climate events***

To assess the impact of abnormal climate events on IRG production, DMY was compared by t-test (Table 1). In the central inland, the difference in DMY was greater in order of severe winter cold (2,620 kg/ha), spring drought (2,048 kg/ha) and autumn low-temperature (1,452 kg/ha). In the southern inland region, the only severe winter cold reduced DMY by 4,127 kg/ha ($p < 0.05$). It was not expected that the damage was greater in the southern inland region than in the central inland region, where the MT was lower. In the southern coastal region, the low-temperature event was not outside of the normal range, and the severe winter cold event was not effective ($p = 0.61$).

## Discussion [Conclusions/Implications]

The study was carried out to assess the impact of abnormal climate events such as autumn low-temperature, severe winter cold and spring drought on the production of Italian ryegrass in the central inland, southern inland, and southern coastal regions of the Republic of Korea. The yield damage caused by severe winter cold event was serious in both inland regions; in particular, the damage was more fatal in the southern inland region, even though the frequency of events was lower. In consideration of the trend and frequency of spring drought events, it is likely that drought becomes a NEW NORMAL during spring in Korea. Finally, the damage caused by low-temperature events in autumn was lower than other abnormal events, although its tendency had changed since 2000. The greater the difference in climate characteristics by year, the more the production fluctuations tended to change rapidly. Therefore, for the abnormal climate events related to winter forage crops in the Republic of Korea, a strategic approach focusing on prediction and quick judgment is required, since we cannot be routinely prepared to the characteristics of rare events.

TABLE 3. Comparison of dry matter yield between climate events for Italian ryegrass based on regions and seasons

| Regions | Seasons | Events | N | Dry matter yield (kg/ha) | t-Test |
|---|---|---|---|---|---|
| Central inland | Autumn | Normal | 162 | 10,698.40 ± 310.14 | 3.93* |
| | | Low-temperature | 159 | 9,246.88 ± 201.20 | |
| | Winter | Normal | 298 | 10,153.57 ± 195.39 | 3.66* |
| | | Severe cold | 23 | 7,533.83 ± 478.68 | |
| | Spring | Normal | 194 | 10,776.06 ± 253.86 | 5.79* |
| | | Drought | 127 | 8,728.23 ± 237.99 | |
| Southern inland | Autumn | Normal | 85 | 9,170.87 ± 361.30 | -1.65 (p = 0.10) |
| | | Low-temperature | 22 | 8,334.09 ± 355.37 | |
| | Winter | Normal | 93 | 9,538.85 ± 291.65 | -5.23* |
| | | Severe cold | 14 | 5,411.50 ± 609.22 | |
| | Spring | Normal | 70 | 9,140.99 ± 422.63 | -0.78 (p = 0.44) |
| | | Drought | 37 | 8,729.86 ± 319.28 | |
| Southern coast | Autumn | Normal | | Not classified | |
| | | Low-temperature | | | |
| | Winter | Normal | 127 | 14,403.50 ± 1769.99 | 0.53 (p = 0.61) |
| | | Severe cold | 8 | 13,424.76 ± 483.68 | |
| | Spring | Normal | 52 | 14,749.92 ± 515.27 | 5.89* |
| | | Drought | 83 | 12.688.87 ± 673.40 | |

*p < 0.05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