Comparison of Causality of Temperature and Precipitation on Italian Ryegrass (*Lolium multiflorum* Lam.) Yield between Cultivation Fields via Multi-Group Structural Equation Model Analysis in the Republic of Korea

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Comparison of causality of temperature and precipitation on Italian ryegrass (*Lolium Multiflorum* Lam.) yield between cultivation fields via multi-group structural equation model analysis in the Republic of Korea

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Key words: Italian ryegrass; climatic factors; cultivation field types; multi-group structure equation model

Abstract
This study aimed to compare the causality of climatic factors affecting the yield of Italian ryegrass (IRG) between upland fields and paddy fields, by multi-group structure equation modeling. The raw data (n = 728) on forage contains both yield, field type, and the plantation address were collected from the Rural Development Administration, Republic of Korea. The climatic factors were: growing days, temperature and precipitation - in autumn and next spring seasons - from the climate big data of the weather information system of Korean Meteorology Administration. In the result, the composition of climatic factors was similar, but the causality by the paths was different between upland fields and paddy fields. In particular, yield in the paddy fields was sensitive to autumn precipitation due to short growing days in the rice-rotation system. In the paddy fields, the precipitation effect in both autumn and the next spring indirectly affected yield through temperature. The autumn temperature effect on yield in the paddy fields was 2.82 times greater than in the upland fields, between the two field types, the spring temperature effect was somewhat similar after wintering; thus, IRG cultivation in paddy fields should be limited to the south. However, there is greater suitability for IRG in the upland fields in the autumn, where the benefits of higher temperatures accumulate to offset effectively the short growing days. This study will assist in checking areas suitable for IRG cultivation as a winter forage crop in the Republic of Korea. The structure is being expanded by adding variables related to soil physical properties from soil information system and cultivation management from survey sheets, respectively, to the structure established in this study. This paper was published in the journal, Agriculture (MDPI), last December (Kim and Sung, 2019).

Introduction
Italian ryegrass (*Lolium multiflorum* Lam., IRG) is the most important winter forage crop because of its high feed value for livestock (Ghesquière et al., 1996; Ishii et al., 2005), and its cultivation in rice-paddy fields has been carried out tentatively in East Asia (Yang et al., 2008). In the growing system, IRG is cultivated continuously before the rice emerges, which alleviates the shortage of forage and contributes to an increase in rice yield. In the Republic of Korea, IRG has mainly been cultivated in paddy fields under the rice-rotation system, accounting for 81.4% of the total IRG cultivation areas (21,700 ha) in 2007 (Kim et al., 2009). IRG utilization has expanded gradually to 56.3% of the total area used for forage production, and the area is restricted to warm places because of poor cold resistance (Shin et al., 2012).

Since the 1990s, countries such as The Netherlands, the United States, and Australia have developed a model for precise prediction of crop productivity, such as the erosion-productivity impact calculator (EPIC) (Williams, 1990), the decision support system for agro-technology transfer, cropping system model (DSSA-CSM) (Jones et al., 2003), the agricultural production system simulator (APSIM) (Basso et al., 2013). These models have the advantage of using various and precise indicators, but the module focuses on calculations to make accurate predictions instead of describing the relationships between the indicators. Therefore, in this study, we focused on various relationships between variables rather than on the variable generation.

To identify complex causality, structural equation modeling (SEM) is a powerful statistical framework consisting of various cause-and-effects, unlike classic regression modeling which is a simple structure that considers only one response variable (Arbuckle, 2009; Kim et al., 2014; Kim et al., 2016; Kim et al., 2019). Furthermore, multi-group SEM has been performed to compare the causality between two or more groups.

Therefore, this study aimed to compare the causality of temperature and precipitation on IRG yield between upland fields and paddy fields. Additionally, IRG cultivation suitability classification of both fields was carried out based on mapping the most sensitive climatic factors.

Methods and Study Site

The IRG-climate dataset consisted of forage metadata and climate big data. The raw metadata (n = 728) were collected from reports by the National Agricultural Cooperative Federation on the adaptability test of imported varieties of forage crops (1998–2017). The data contained field types (upland fields and paddy fields), cultivar, seeding date, harvesting date, year, address, fresh matter yield (FMY, kg/ha), DMY (kg/ha), etc. Here, location based on the plantation address was limited to the southern areas of the Korean Peninsula (33°37′36″ N–36°36′55″ N). In order to compare causality of climatic factors, the growing days, temperature, and precipitation were divided by growing season as follows: autumn growing days (AGD, day), autumn accumulated temperature (AAT, °C), autumn precipitation days (APD, day), autumn precipitation amount (APA, mm), spring growing days (SGD, day), spring accumulated temperature (SAT, °C), spring precipitation days (SPD, day), and spring precipitation (SPA, mm), where the end of autumn and beginning of spring were defined as the first dates to record continuous temperature below 5 °C and above 5 °C, respectively.

SEM was performed in AMOS 23.0 (IBM crop.), and comparison was performed in R 3.6.4.

Results

As a result of the t-test to check differences between upland fields and paddy fields (Table 1), all variables were different ($p < 0.05$). For IRG yield, the mean DMY and FMY were 10,916.4 kg/ha and 58,315.7 kg/ha in the upland field and 8033.3 kg/ha and 38,927.2 kg/ha in the paddy field, respectively.

Table 1. Comparison of characteristics of climatic and yield variables for Italian ryegrass between upland and paddy fields.

Variable (Unit)	Upland (n = 586)		Paddy (n = 142)		t-Value
	Mean	SE	Mean	SE	
Dry matter yield (kg/ha)	10,916.41	178.20	8033.33	273.42	14.15 *
Fresh matter yield (kg/ha)	58,315.71	826.65	38,927.22	1231.94	12.86 *
Autumn growing days (day)	84.25	0.52	69.00	1.09	20.58 *
Autumn accumulated temperature (°C)	878.91	8.62	632.07	16.23	25.72 *
Autumn precipitation amount (mm)	114.21	3.18	78.54	4.46	6.62 *
Autumn precipitation days (day)	18.54	0.21	16.97	0.38	4.15 *
Spring growing days (day)	119.42	0.85	93.75	1.03	13.21 *
Spring accumulated temperature (°C)	1199.8	13.24	725.41	13.02	10.39 *
Spring precipitation amount (mm)	313.83	4.34	222.03	5.47	7.42 *
Spring precipitation days (day)	43.22	0.46	34.96	0.66	13.17 *

SE: standard error, * $p < 0.05$.

The structure contains climatic factors, and the yield was set as in Figure 2. There were: seasonal effects between autumn and the next spring (green-colored paths), precipitation affecting yield through temperature in both autumn and next spring seasons (blue-colored paths), and all climatic factors directly affecting the yield factor (red-colored paths). These individual cause-and-effect relationships generated a different causality structure between upland fields and paddy fields. The paths related to precipitation are noticeable. In the paddy fields, only precipitation was effective in yield through indirect paths that exist with temperature in both the autumn and the next spring.

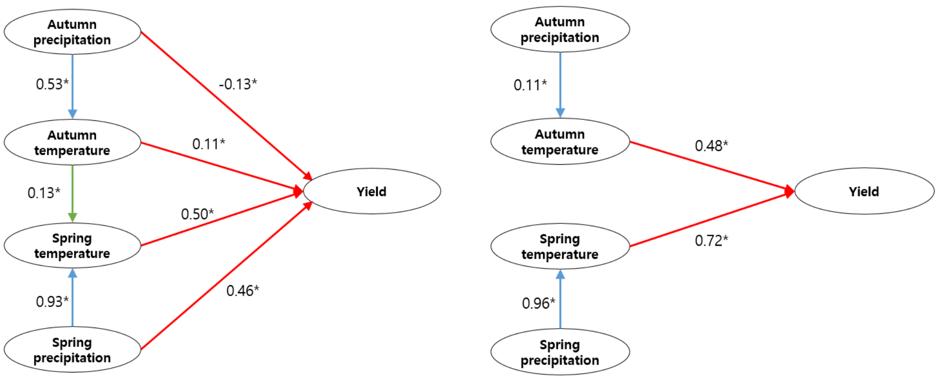
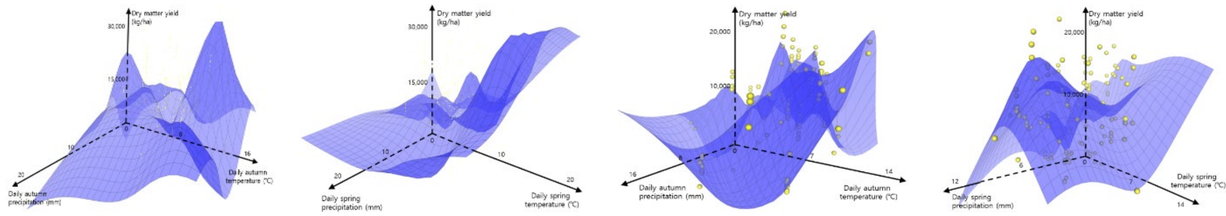


Figure 2. Path diagram of climatic factors on Italian ryegrass yield in structural part (left is upland fields, right is paddy fields): direct effects from climate to yield (red), from precipitation to temperature (blue), seasonal effect from autumn to next spring (green), *p<0.05.

According to the distribution of DMY and considering the daily temperature and precipitation in the upland fields (Figure 3A,B), the DMY was distributed to the right, representing high temperatures and low precipitation. This clear tendency was, therefore, certain to reflect both direct and indirect effects on yield in the upland fields. In the paddy field (Figure 3C,D), there were peaks with high yield in several places, not in certain locations. Especially in the autumn, DMY showed a tendency to increase in range of 7–14 of the daily temperature, but the trend stopped increasing because the daily temperature was not wide as spring temperature. Thus, yield fluctuations, which tend to increase IRG yield with increasing precipitation at high temperatures, were not clear and the yield trends were inconsistent in autumn and spring.



(A) (B) (C) (D)

Figure 3. 3D-contour plots of dry matter yield with daily temperature and precipitation for 20 years (1998–2017): (A) autumn in upland fields, (B) spring in upland fields, (C) autumn in paddy fields, (D) spring in paddy fields.

Figure 4 shows the mapping of the suitability line of IRG cultivation based on the autumn accumulated temperature within the upland fields and paddy fields; the line of the upland field was set by the first quartile (741.70 °C), and the line of the paddy field was calculated as 1.39 times the first quartile (1030.96 °C). Therefore, IRG cultivation under the rice-rotation system in the area between the suitability lines of the upland field (blue-colored) and the paddy field (red-colored) seems to be unstable due to insufficient growing days in the autumn. Based on the topography map, IRG can be cultivated in both fields in the west, where there are mainly plains; however, it is difficult to cultivate in the east where the Taebaek Mountains are located. Furthermore, the lines between fields are divided by the Sobaek Mountains located in the southern area.

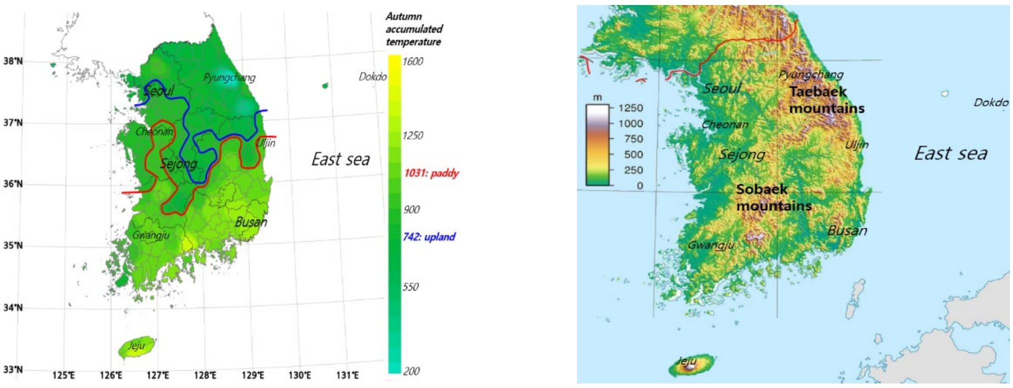


Figure 4. Maps of cultivation suitability classification of Italian ryegrass based on autumn accumulated temperature (red: paddy fields, blue: upland fields) and topography in the Republic of Korea (left is cultivation suitability map, right is topography map).

Discussion [Conclusions/Implications]

This study was carried out to compare the direct/indirect effects of temperature and precipitation on IRG yield between upland fields and paddy fields in the Republic of Korea via multi-group SEM. Although the results were focused on the Korean areas, the method of this study could be proposed to the research community outside Korea that is interested in the following conditions: The first is to cultivate in different environments that can be compared, such as upland fields and paddy fields with rice-winter crop rotation system. Unfortunately, the rice-winter crop rotation system is popular only in southern China, Japan, and Korea. If not, it is proposed to explore other groups that could be applicable to the same structures, such as climate classification, terrain classification. The second is the distinct seasonal role of the cropping system, such as autumn seeding, overwintering, and spring harvesting. Otherwise, growth stages may be used for the purpose of dividing the whole growth period instead of the seasons. The final condition is to construct complex causality structures with various cause-and-effect relationships. SEM is effective when many variables are linked continuously through three or more cause-and-effect relationships that the direct/indirect effects can be estimated. As a form of group, it also could be considered as a multi-group SEM that aims to be compared, as well as a multi-level SEM that can be entered as an explanatory variable to estimate its effect rather than a classification, and a multi-stage SEM that can identify the flow according to an ordered group.

In general, the structure of the SEM can be applied to various studies depending on the characteristics of measurements. For example, it is expected that if the measurements are related to agricultural economic feasibility, such as income, production costs, import prices, distribution costs, etc., part of the agricultural economic system can be structured. In this study, cultivation field types were considered for classification purposes; however, there was a limitation in that they could not be included in the structure as a variable. To overcome this limitation, it will be necessary to select and develop various measurements that can reflect the characteristics of the field types as a quantitative variable. Meanwhile, it is planned to expand the structure by adding variables related to soil physical properties from soil information system and related to cultivation management collected from the survey sheet to the structure centered on climatic variables.

Acknowledgements

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