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The Optimum Seeding and Harvesting Dates of Sorghum-Sudangrass Hybrid (*Sorghum bicolor* L.) via Optimum Moving Response Surface Methodology

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Key words: sorghum-sudangrass hybrid; seeding and harvesting dates; optimum point; optimum moving response surface methodology

Abstract

This study aimed to detect the optimum seeding and harvesting dates, and to verify the variation of dry matter yield (DMY) for sorghum-sudangrass hybrid (SSH) via optimum moving RSM proposed to optimize the RSM in metadata. For detecting the optimum point, a response surface methodology (RSM) has been known well in agricultural science. The SSH metadata (n = 856) consists of individual experiments that could be performed to check the optimum seeding and harvesting dates by classic RSM. However, the SSH metadata failed to produce an effective single equation which can be detected the optimum seeding and harvesting dates due to different characteristics of the experimental design. Therefore, RSM were optimized by moving to an optimum point, it was called the optimum moving RSM in this study. As a result, the optimum seeding and harvesting dates were obvious based on a single quadratic function. The maximum DMY at the optimum seeding and harvesting dates (4th of May and 23th of September, respectively) were 25,404.50 kg/ha and 23,697.01 kg/ha, respectively. The SSH yield was rapidly decreased after 10 days from the optimum date, and the seeding and harvesting should be performed within 5 days to ensure a stable yield. Furthermore, the optimum moving RSM was expected to be useful to detect the optimum point in the metadata. About 11 hours grazing time was suggested focused on milk fatty acid and yield (27 kg/d) for Holstein cows as the optimum through eco-pastoral system. This study will be helpful to select a time of grazing in alpine grassland for farmers who want to produce good quality milk. This paper was published in the journal, Grassland Science (Wiley), in March (Kim et al, 2020).

Introduction

Sorghum-sudangrass hybrid (*Sorghum bicolor* L., SSH) has been suggested as a summer forage crop due to its drought resistance and regrowth ability in the most regions of the Republic of Korea. The annual mean dry matter yield (DMY) of SSH is 10.6 to 13.8 t/ha with two or more harvests over 20 weeks from May to September (Hwang, 2019). According to Harris (1996), DMY of the SSH is proportional to the rate at which the seedlings emerge for 25 days after the seeding date, and performance is successful when the soil dries slowly or the seeds germinate and emerge quickly. The harvesting time was found also to be important to forage quality, yield and composition (Atis et al., 2012); in particular, the appropriate harvesting time contributes to high yield and fodder quality in the physiological maturity stage and in the dough stage as lignin content increases.

The response surface methodology (RSM) is popular method for finding the optimum point related to screening, steepest ascent and modeling as an experimental strategy, based on linear functions with one or more explanatory variables as an experimental strategy (Box and Wilson, 1951; Buyske and Trout, 2001). According to Khuri (2017), while the approach in RSM may be difficult in an agricultural environment where experiments are typically conducted over for a long period of time between steps, there is an advantage to be obtained by using certain techniques. Therefore, RSM was suitable to detect the optimum seeding and harvesting dates and to check the DMY variation of SSH according to the date changes in this study.

Metadata are structured data that are descriptive, structural, administrative, referencing and statistical and are called data about data (Riley, 2017). To model the time series characteristic of the metadata, the yield trend by year was checked with climatic variables and/or weather events for summer forage crops (Chemere et al., 2019; Kim et al, 2019). Because of the different variables contained in the metadata, the causal relationship of climatic variables affecting yield was identified by longitudinal structural equation modeling for winter forage crops (Kim et al, 2014; Kim et al., 2016). Since cultivation experiments were carried out in various places, the yield prediction was modeled based on the cultivated location in order to ensure data homogeneity (Kim et al., 2017; Peng et al., 2017).

This study aimed to detect the optimum date to seed and harvest for SSH, check the DMY variation of SSH and propose the optimum moving RSM to modify the RSM in the metadata.

Methods and Study Site

The metadata were collected from various reports ($n = 856$) across a period of 35 years, for experiments on SSH (1979–2013), including the cultivar (Jumbo, SX17, Dentaka, etc.), year, location, seeding date, number of harvestings, harvesting dates by harvesting times and DMY (kg/ha) where SSH was harvested at a height of 120–150 mm (RDA, 2011). In the metadata, individual experiments for SD and HD were combined. HD was fixed when the optimum SD was detected. Every experiment exploring the optimum SD was carried out with seeding three or more times on different dates and one harvesting on the same day. The metadata consisted of K individual experiments to find the optimum SD, as shown in Figure 1. The levels of SD and HD in the metadata were the sum of individual level ($\sum_{i=1}^K L_i$) and the number of experiments (K), respectively. Therefore, it was necessary to confirm the academic friction concerning the interaction effect caused by the difference between the design of individual experiments and the composition of metadata. Furthermore, the level of SD had different numbers and intervals according to individual experiments; hence, the optimum moving transformation based on centralization and standardization as a way to modify the SD was used for RSM in this study.

Figure 1. Configuration of metadata for seeding date combined by individual experiments

SD: seeding date, HD: harvesting date, K: # of experiment, L: # of level, M: # of replication

RSM and optimum moving RSM were performed by Proc OPTEX and Proc RSREG in SAS 9.4. The optimum moving transformation was carried out by R 3.6.0.

Results

To check the optimum seeding and harvesting dates by response surface methodology

According to the descriptive characteristics of the variables (Table 1), the mean DMY was 16,628.80 kg/ha, similar to the median. The 10th and 90th percentile DMY (kg/ha) were 10,653.00 and 24,846.90, respectively. The mean SD and HD (day) were 129.73 and 263.12 respectively, equal to the 9th of May and 20th of September, respectively.

Table 1. The characteristics of variables of sorghum-sudangrass hybrid in the metadata

Variables (Abbreviation, unit)	Mean	Standard Error	Median	Percentile	
				10th	90th
Dry matter yield (DMY, kg/ha)	16,628.80	239.39	16,768.00	10,653.00	24,846.90
Seeding days from 01 Jan (SD, day)	129.73	0.47	127.00	119.00	148.00
Harvesting days from 01 Jan (HD, day)	263.12	0.50	262.50	249.00	280.00

Table 2. The estimation of a quadratic function to detect the optimum seeding and harvesting dates for dry matter yield of sorghum-sudangrass hybrid via response surface methodology

Parameters	Coefficient	P-value	D-effects	F-value	R2
Constant	-996,644.00	< 0.05			
SD†	532.96	0.86			
HD‡	7,327.38	< 0.05	33.77	33.60	0.25
SD*SD	-7.21	0.11		(P < 0.05)	
HD*SD	4.50	0.56			
HD*HD	-14.65	< 0.05			

†SD: seeding days from the first of January, ‡HD: harvesting days from the first of January

Furthermore, the optimum point and maximum were effectively displayed based on the contour and up-convex shape of the response surface plots (Figure 2); however, the model fitted poorly to the metadata ($R^2 = 0.25$), and the optimum effect was somewhat low (D -effects < 0.5).

Figure 2. Response surface plots for dry matter yield by seeding harvesting dates for sorghum-sudangrass hybrid (left is response contour, right is 3D-response surface)

To check the optimum seeding and harvesting dates by optimum moving response surface methodology

From the metadata, although all quadratic functions appeared clearly up-convex, they had different vertex positions and gradients in both SD|HD and HD|SD. The model fitness (R^2) of SD|HD and HD|SD was 0.25 and 0.10, respectively (Figure 3).

Figure 3. Individual quadratic functions of dry matter yield by seeding and harvesting dates for sorghum-sudangrass hybrid (left is seeding date, right is harvesting date)

In addition, the outliers of SD|HD (3 models) and HD|SD (1 model) were eliminated based on the coefficient of the quadratic term ($\beta_{ii,k}$). Then, the single quadratic function of SD|HD (or HD|SD) was estimated as the final step in optimum moving RSM (Table 3). The optimum SD|HD and HD|SD were -2.02 and 0.00, respectively. By summing the optimum and mean, the optimum days could be calculated at 124.18 and 266.29 respectively, equal to 4th of May and 23rd of September, respectively. Both models fitted well ($R^2 \geq 0.7$), and optimization was effective (D -effects ≥ 0.5). The maximum DMY (kg/ha) was 24,495.50 for SD|HD, and 21,915.01 for HD|SD. The DMY variation (kg/ha) was 677.00, 2105.00 (10 % loss) and 4282.50 (20 % loss) at ± 5 , ± 10 and ± 15 days from the optimum seeding date, respectively. For the optimum harvesting date, the DMY variation (kg/ha) was 1353.43, 1948.94 (10 % loss) and 4385.12 (20 % loss) at ± 5 , ± 6 and ± 9 days, respectively. Furthermore, the coefficient of the quadratic term of HD|SD was 3.6 times greater than that of SD|HD.

Table 3. The estimation of a quadratic function and optimum point for seeding and harvesting dates for sorghum-sudangrass hybrid via optimum moving response surface analysis

Model	Parameters	Coefficient	R^2	F-value	Optimum point	D-effects	Maximum yield
SD† HD‡	Quadratic (β_{ii})	-14.99 (P < 0.05)	0.71	29.04 (P < 0.05)	-2.02	52.19	-910
	Linear (β_{ii})	-60.46 (P < 0.05)					
	Constant (β_0)	-971.43 (P < 0.05)					
HD SD	Quadratic (β_{ii})	-54.14 (P < 0.05)	0.70	29.16 (p < 0.05)	0.00	52.86	-1,782
	Linear (β_{ii})	27.50 (P = 0.64)					
	Constant (β_0)	-1,782.56 (P < 0.05)					

†SD: seeding days from the first of January, ‡HD: harvesting days from the first of January

Discussion [Conclusions/Implications]

This study was carried out to determine the optimum seeding and final harvesting dates, and to confirm the DMY variation of the SSH. The optimum SD and HD by RSM (1st of May and 25th of September, respectively), and the optimum moving RSM (4th of May and 23rd of September, respectively) were found to be similar. According to RDA (2011), SSH sown in early May is harvested for the first time in early-mid July, second in early-mid August, and last in mid-late September. Even though the optimum date is appropriate regardless of the methodology, the fitness and optimum effect of RSM is worse than that of the optimum moving RSM. In particular, the critical drawback of RSM is that it is difficult to apply to metadata due to poor fitness. Therefore, we propose that the optimum moving RSM is useful in the following two conditions:

- Generating an individual model representing a clear optimum point by the RSM in the metadata.
- Setting a fixed variable that can be considered as a given effect to others.

We expected that the optimum moving response surface methodology would be useful for detecting the optimum point in the metadata. However, dry matter yield variation of the sorghum-sudangrass hybrid was more sensitive to the harvesting date than the seeding date. Accordingly, farmers should sow and harvest within 9 and 6 days of the optimum seeding and harvesting dates for stable yield, respectively. Considering the good weather conditions in the Republic of Korea, the optimum seeding and harvesting times are early May and late September, respectively.

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