Korean Journal Of Agricultural Science

pISSN : 2466-2402
eISSN : 2466-2410

FOOD & CHEMISTRY

Excessive soil water stress responses of sesame (*Sesamum indicum* L.) and perilla (*Perilla frutescens* L.) cultivated from paddy fields with different topographic features

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Abstract

In Korea, the largest agricultural lands are paddy fields which have poor infiltration and drainage properties. Recently, the Korean government has pursued cultivating upland crops in paddy fields to reduce overproduced rice in Korea. For this policy to succeed, it is critical to understand the topographic information of paddy fields and its effects on upland crops cultivated in the soils of paddy fields. The objective of this study was to characterize the growth properties of sesame and perilla from paddy fields with three soil topographic features and soil water effects which were induced by the topographic features of the sesame and perilla. The crops were planted in paddy fields located in Miryang, Gyeongnam with different topographies: mountain foot slope, local valley and alluvial plain. Soil water contents and groundwater levels were measured every hour during the growing season. The paddy field of the mountain foot slope was significantly effective in alleviating wet injury for the sesame and perilla in the paddy fields. The paddy field of the mountain foot slope had a decreased average soil water content and groundwater level during cultivation. Stress day index (SDI) from the alluvial plain paddy field had the greatest values from both crops and the smallest from the ones from the paddy field of the mountain foot slope. This result means that sesame and perilla had the smallest stress from the soil water content of the paddy field on the mountain foot slope and the greatest stress from the soil water content of the alluvial plain. It is important to consider the topography of paddy fields to reduce wet injury and to increase crop yields.

Keywords: paddy field, perilla, Sesame, soil water content, stress day index

Citation: Ryu J, Baek I, Kwak K, Han W, Bae J, Park J, Chun HC. 2018. Excessive soil water stress responses of sesame (*Sesamum indicum* L.) and perilla (*Perilla frutescens* L.) cultivated from paddy fields with different topographic features. Korean Journal of Agricultural Science. https://doi.org/10.7744/kjoas.20180074

DOI: https://doi.org/10.7744/kjoas.20180074

Received: June 11, 2018

Revised: September 19, 2018

Accepted: September 27, 2018

Introduction

Recently, the Korean government promotes utilizing paddy fields to cultivate upland crops instead of rice in order to reduce overproducing rice. The self-sufficiency rate of upland crops is 23.7% and the Korea government is trying to increase the self-sufficiency rate up to 50.0% by 2022 (NSO, 2016). In order to succeed this policy, it is important to optimization of paddy field properties for upland crop cultivation.

Korean land is consist of 55% of paddy fields among arable lands. Typical paddy field soils have poor infiltration and high groundwater table because rice is cultivated under flooding condition and paddy field soils need to prevent water drainage (Jung et al., 2011). Paddy field soils tend to have excessive soil water condition easily because of capillary rise of soil water from high groundwater (Benz et al., 1984; Meyer et al., 1989). Soil water contents are affected by many soil properties, such as soil drainage class, soil texture, soil slope, topography, etc. Anderson and Kneale (1980) reported that topography is the most important factor that affects soil water variation among soil properties. Jung et al. (2013) found that crop yields were strongly affected by soil water contents and geography of paddy fields after investigating crop yields and soil water variations across paddy fields with different geographical information.

Excessive soil water creates less oxygen in soil and this phenomena creates negative effects to crop growths and yields (Jo et al., 1996; Ji et al., 2009; Lee et al., 2010). Inadequate oxygen in soil interrupts root respiration and absorbance of nutrition uptake. This condition causes toxic matters in soils and promotes growth inhibition, root rot disease and accelerating aging in crops. These factors restrict cultivation of upland crops in paddy fields since upland crops are vulnerable to excessive soil water condition. Therefore it is important to manage soil water to produce optimal yields of upland crops in paddy fields.

In case of excessive soil - water conditions, Hiler (1969) introduced the stress day index (SDI) to quantify the cumulative stresses of water imposed on crops. This SDI is based on crop susceptibility (CS) factors (Hiler and Clark, 1971; Hardjoamidjojo et al., 1982). CS factors describe the plant susceptibility (or response) to environmental stresses and depend upon the species and the stage of development of a given crop. CS factors have been investigated for various physiological growth stages of corn and soybean under excessive soil - water or flooded conditions from various studies (Evans and Skaggs, 1984; Mukhtar et al., 1990; Purwanto et al., 1993). CS and SDI concepts have been applied to soybean cultivated in paddy fields in Korea (Jung et al., 2011), but there has been no attempt to use SDI model to soilcrops under excessive soil - water conditions.

Sesame and perilla are one of the most important oilseed crops in eastern Asia. These crops are widely used in food, nutraceutical, pharmaceutical and industry in Korea. Sesame (*Sesamum indicum* L.) is a member of the Pedaliaceae family (Ashri, 1998). Sesame seeds contain 50% fat, 20% protein, 15% carbohydrate and 0.5% lignan (Fukuda et al., 1985). Perilla (*Perilla frutescens* L.) contains 45% fat, 16 - 22% protein and many phenolic compounds (Lee et al., 2013). Previous studies reported that sesame and perilla are sensitive to environmental stresses, especially water stress (Ucan et al., 2007; Hagiwara et al., 2010). Chun et al. (2016) found that excessive soil water led to significant reduction in growth and yield of sesame and the highest reduction was observed at tillering stage. Hagiwara et al. (2010) concluded that growth and yield of perilla were affected by soil water and the intensity of soil water was not homogeneous to obtain optimal growth and yield. These studies concluded that growth and yield of sesame and perilla were highly affected by soil water contents, but there has been no investigation of a relation between soil water variation by topography and growth or yield of sesame or perilla.

The hypotheses of this study was that different topographic paddy fields might affect growth characteristics and yield of sesame and perilla. The objectives of this study were characterizing growth properties of sesame and perilla from paddy fields with three soil topographic features and soil water effects which were induced by topographic features on sesame and perilla.

Materials and Methods

Soil and crop

The field experiments were conducted at three paddy fields in Miryang, Gyeongnam (Fig. 1). Three paddy fields were selected based on geographical features; Mountain foot slopes, local valley and alluvial plains. Each paddy field cultivated rice until 2015. The whole experiment size of each paddy field was various. The experimental plot of each crop was 8 m by 20 m respectively throughout the three paddy fields. Soils from three paddy fields were tested for chemical and physical properties; pH, EC, organic matter, available P_2O_5, cations (K, Ca, Mg, Na), texture, drainage class, soil water and groundwater

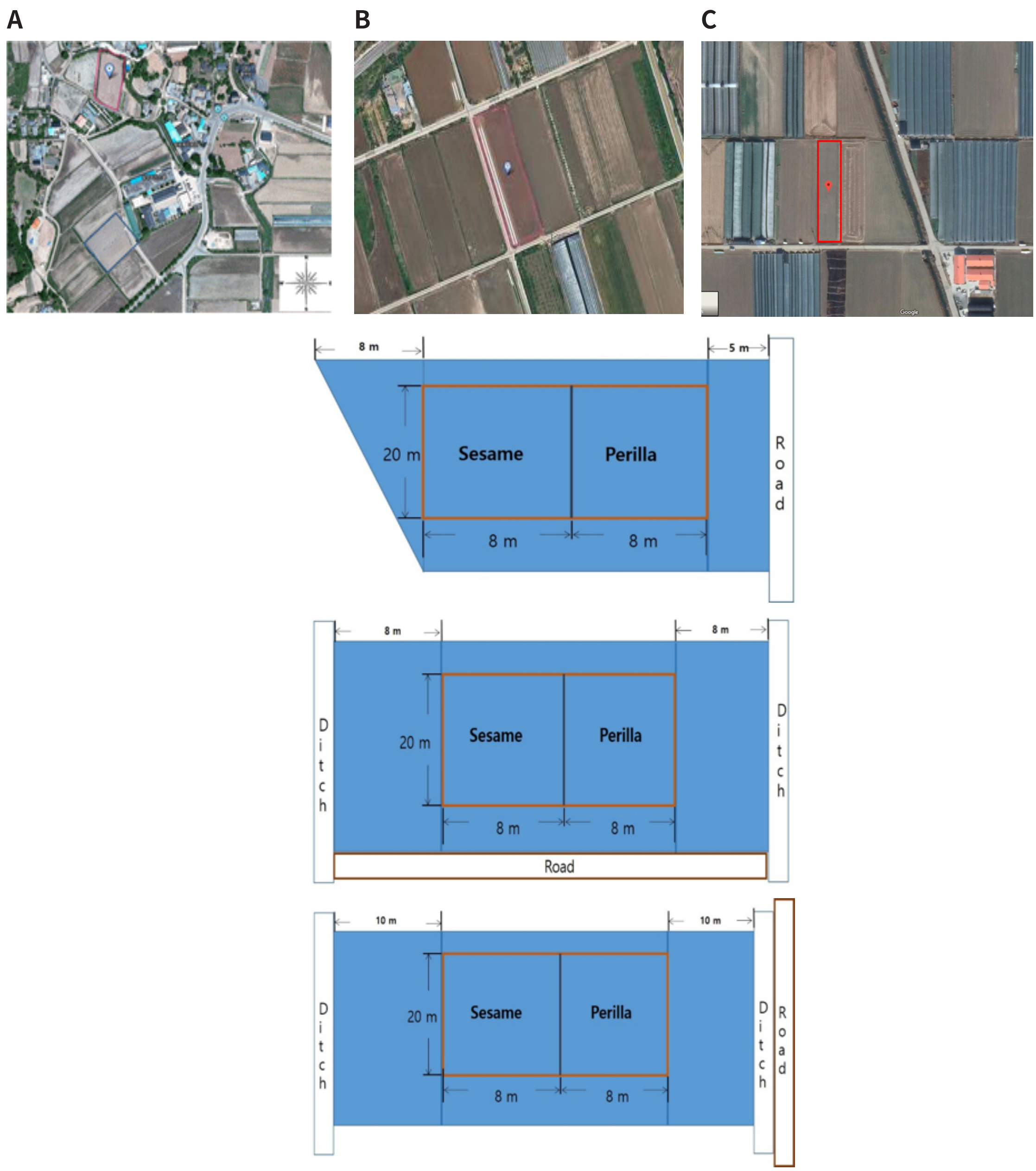

Fig. 1. Satellite images (top) and experiment plot diagram (bottom) from three paddy fields; A: Mountain foot slopes, B: Local valley and C: Alluvial plains.

level. All three paddy fields were cultivated rice until 2015. Each plot was fertilized followed by a standard amount of fertilizer for sesame and perilla before planting.

Sesame and perilla were cultivated at each paddy field from 2016 to 2017. Both crops were fertilized and cultivated by good agricultural practices (RDA, 2015). Sesame was planted with 70 × 20 cm planting intensity by end of May. Perilla was planted with 70 × 25 cm planting intensity by end of June. Geonback was selected as a sesame cultivar and Dayu was selected as a perilla cultivar, since two cultivars are one of the most popular oil crop cultivars cultivated in Korea. In each experimental site, soil water contents were measured by soil water probes (Easy AG, Sentek Pty. Ltd., Stepney, Australia) at 20 cm depth from the soil surface and levels of groundwater were measured by sensors with automatic water level recorders (Remote Data Systems, Inc., NC, USA) from 0 cm to 150 cm. Three soil water probes and one groundwater sensor were installed at the center of the experimental (Fig. 2). All measurements were measured every hour during growing seasons. Before harvest, leaf color was measured by SPAD chlorophyll meter (Minolta Corp. Ramsey, NJ, USA) to determine crop stress level. 10 measurements of SPAD chlorophyll meter were conducted from sampled crops. After harvest, growth and yield components were measured.

SDI (Stress-Day Index) model

The SDI concept is determined from a stress day (SD) factor and CS factor. The SD factor is a measure of the intensity and duration of stress. The CS factor is a measure of the crop susceptibility to a unit of stress and is a function of the crop species and its stage of development. Hiler (1969) defined the SDI as

$$\mathrm{SDI} = \sum_{i=1}^{n} \mathrm{SD}_i \times \mathrm{CS}_i \quad (1)$$

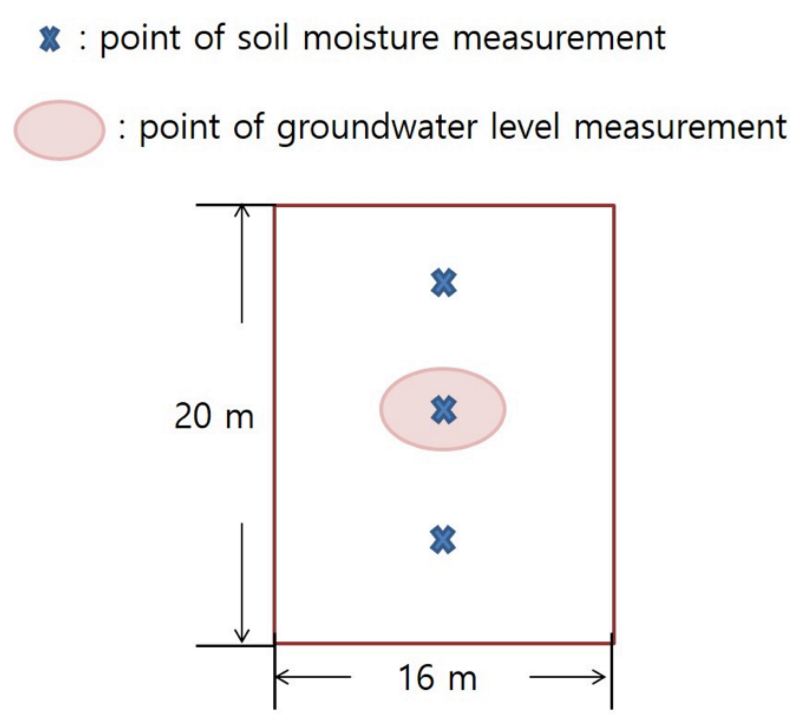

Fig. 2. Locations of soil water and groundwater level measurements from each experiment plot.

where n is the number of growth stages and SD and CS are the stress day and crop susceptibility factors for period *i*, respectively. The SD values can be replaced by SEW_{30} values. SEW_{30} (cm-day) represents the sum of groundwater level differences when it exceeds the depth of 30 cm, because Sieben (1964) considered the critical depth of 30 cm for excessive groundwater level for crops.

Sieben (1964) proposed crop yields to changes of groundwater table depths as

$$SEW_{30} = \sum_{i=1}^{n}(30 - x_i) \quad (2)$$

where x_i is the groundwater table depth below the soil surface on day *i*, and n is the number of days in the period being considered. The CS*i* is defined as the yield reduction ratio per unit of SD*i* at a given excessive soil water stress in *i*-th growth stage. Hiler (1969) expressed CSi as

$$CS_i = \frac{x - x_i}{x} \quad (3)$$

where X*i* is the yield from a treatment subjected to a unit water stress during *i*-th growth stage and X is yield when a crop is kept under no water stress throughout the season.

All data from measurements were analyzed statistically by analysis of variance (ANOVA) and Duncan's multiple range test at 95% using SPSS v20 (SPSS Inc., Chicago, IL, USA).

Results and Discussion

Soil characteristics

Soil properties of the three paddy fields are shown in Table 1. The chemical properties from all paddy fields did not have distinguishable difference except available P_2O_5 from the local valley paddy field. The available P_2O_5 values from all three paddy fields were above a proper range of available P_2O_5 (Kang et al., 2012). The values of K also were above a proper range of K content from paddy fields. However, the contents of Ca, Mg and Na were below a proper range. In physical properties, drainage classes were different across paddy fields. The paddy field of mountain foot slope had somewhat well drainage class, while the one of alluvial plains had poorly. These physical properties resulted in differences of soil water and groundwater levels across paddy fields.

Soil water and groundwater levels were measured during sesame and perilla cultivation. The paddy field with mountain

Table 1. Soil properties of three experimental sites.

Topography	Drainage class	Slope (%)	Texture	Gravel content (%)	Effective soil depth (cm)	Texture of subsoil	pH (1 : 5)	EC (ds/m, 1 : 5)	Organic matter (%)	Av.P_2O_5 (mg/kg)	Cations (cmolc/kg)			
											K	Ca	Mg	Na
Mountain foot slopes	Somewhat well	7 - 15	Sandy loam	0	50 - 100	Fine Loamy	5.1	0.3	2.0	406a	0.3	1.8	0.2	0.1
Local valley	Somewhat poorly	2 - 7	Silt Loam	0	> 100	Fine Silty	5.9	0.5	2.5	179b	0.5	2.9	0.4	0.1
Alluvial plains	Poorly	0 - 2	Silt Loam	0	> 100	Fine Silty	5.9	0.8	2.3	413a	0.4	1.5	0.2	0.1

a, b: letters represent statistical difference across paddy fields at 95% level.

foot slope had the smallest average soil water value as 10.52 ± 5.87 and the one with alluvial plains had the greatest one as 38.19 ± 10.25 ($p = 0.00$) (Fig. 3). Average groundwater level showed the smallest value from paddy fields of mountain foot slope as− 64.32 ± 32.22 cm (Fig. 3). Statically, the average groundwater levels from local valley and alluvial plains paddy fields did not show difference ($p > 0.05$), while ones from mountain foot sloes was significantly different from the other paddy fields ($p = 0.00$). Based on these soil water and groundwater level results, excessive soil water days were calculated by Eq. 2 (Fig. 3). Days of excessive soil water content were calculated based on days with average soil water over 30 % during sesame and perilla cultivation. Excessive soil water can be determined also when soil water content exceeds field capacity and this field capacity is affected by soil texture (McCarty et al., 2016). Ley et al. (1994) reported that field capacity of loamy soils was determined as 0.3 or 30%. Therefore, when soil water content was over 30% in these paddy fields whose textures were loamy soils, that day was counted as day of excessive soil water. Based on this calculation, days of excessive soil water from soil water contents were 17 day from paddy field of mountain foot slope, 36 day from one of local valley and 67 day from ones of alluvial plains. Days of excessive soil water from groundwater levels were calculated by SEW_{30} determined by Sieben (1964) (Eq. 2). The results of this calculation was 50 day from paddy field of mountain foot slope, 93 day from one of local valley and 94 day from ones of alluvial plains.

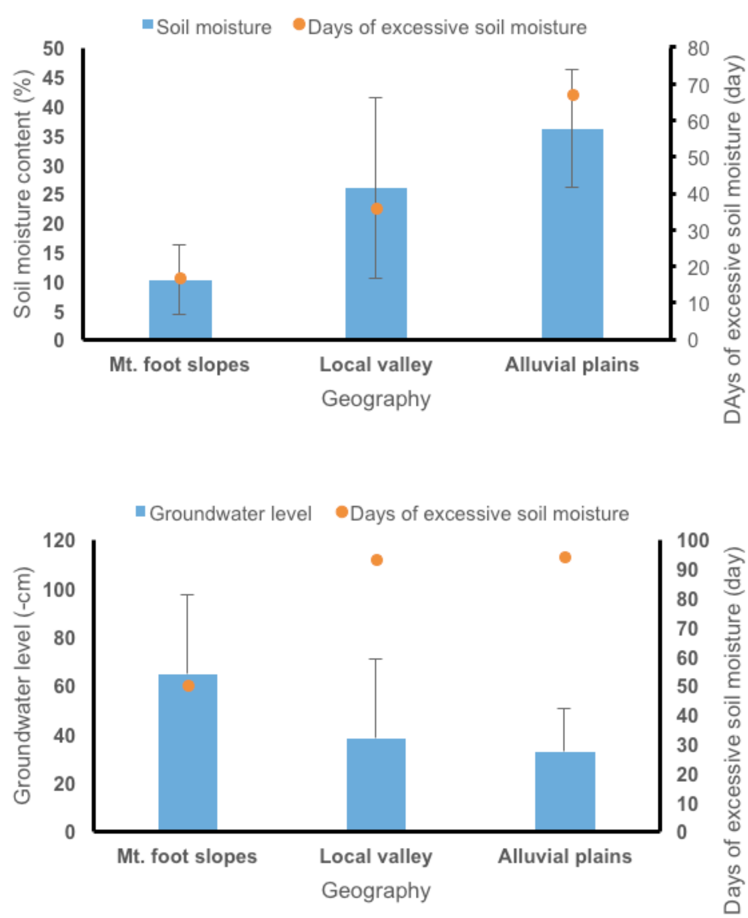

Fig. 3. Average and standard deviation values of soil water (top) and groundwater level (bottom) from three paddy fields (mountain foot slopes, local valley and alluvial plains). The points represent days of excessive soil water calculated from soil water content (top) and groundwater level (bottom).

Growth and yield characteristics

Sesame and perilla showed a similar trend in growth and yield characteristics across paddy fields (Table 2 and 3). The paddy field of mountain foot slopes had the greatest yields of sesame and perilla, while the paddy field of alluvial plains had the smallest ($p = 0.00$). The yield of sesame increased from the paddy field of mountain foot slopes up to 273% compared to ones from the paddy field of alluvial plains and 120% ones from local valley. An average yield of sesame which cultivated from upland soils was 119 ± 8.24 kg/10 a (RDA, 2015). This averaged yield from upland soils did not show significantly difference from the yield from mountain foot slopes. The yield of perilla from mountain foot slopes had the greatest value as 155.2 ± 5.5 kg/10 a, while ones from alluvial plains had the smallest as 33.6 ± 8.9 kg/10 a. The yield from paddy field of mountain foot slopes showed statistically no difference compared to an average yield of perilla from upland soils which was 144 ± 7.2 kg/10 a (RDA, 2015). The growth characteristics of sesame showed the similar trend as the yield results across paddy fields. Stem height, stem diameter, and capsule setting length showed the greatest values from the paddy field of mountain foot slopes and the smallest from the paddy field of alluvial plains. Some characteristics, such as capsule length and 1000 grain weight, did not show significant difference between the paddy field of mountain foot slopes and ones of local valley. The growth characteristics of perilla also showed the same trend of the yield results across the paddy fields. However, some characteristics did not show significant difference between the paddy field of mountain foot slopes and the ones of local valley.

Table 2. Growth and yield characteristics of sesame from three paddy fields; Mountain foot slopes, local valley, and alluvial plains.

Topography	Mt. foot slopes	Local valley	Alluvial plains
Stem height (cm)	161.7 ± 12.5a	125.4 ± 12.8b	100.1 ± 10.2c
Stem diameter (mm)	10.2 ± 1.6a	8.0 ± 1.3b	7.5 ± 1.1c
First setting pod node (order)	4.8 ± 1.2a	4.1 ± 1.3b	4.1 ± 1.4b
Capsule setting length (mm)	23.2 ± 4.3a	19.7 ± 4.1b	17.2 ± 4.5c
Capsule setting node (order)	28.7 ± 3.3a	26.4 ± 2.3b	27.2 ± 2.8b
Capsule length (mm)	28.7 ± 3.3a	26.4 ± 2.3b	27.2 ± 2.8b
Capsule width (mm)	8.0 ± 0.6b	7.9 ± 0.7b	8.4 ± 0.8a
1000 grain weight (g)	2.8 ± 0.1a	2.6 ± 0.0b	2.4 ± 0.1b
Yield (g)	109.1 ± 19.9a	60.7 ± 6.8b	29.2 ± 4.6c

a - c: letters represent statistical difference across paddy fields at 95% level.

Table 3. Growth and yield characteristics of perilla from three paddy fields; Mountain foot slopes, local valley, and alluvial plains.

Topography	Mt. foot slopes	Local valley	Alluvial plains
Stem height (cm)	68.0 ± 5.1a	57.7 ± 8.2b	36.6 ± 4.5c
Stem diameter (mm)	9.4 ± 1.6a	9.2 ± 1.7a	6.2 ± 1.0b
Number of branch	10.1 ± 1.2a	10.3 ± 2.2a	5.8 ± 1.4b
Number of node	9.2 ± 0.6b	9.5 ± 4.5a	7.3 ± 0.8c
Number of cluster	51.4 ± 12.8a	29.1 ± 14.5b	15.8 ± 5.9c
Cluster length (cm)	15.4 ± 1.7a	12.5 ± 2.3b	6.7 ± 0.7c
1000 grain weight (g)	4.4 ± 0.2a	4.2 ± 0.0a	2.3 ± 0.1b
Yield (g)	155.2 ± 5.5a	56.6 ± 4.8b	33.6 ± 8.9c

a - c: letters represent statistical difference across paddy fields at 95% level.

Table 4. Summary of SPAD chlorophyll meter and SDI results of sesame and perilla from three paddy fields; Mountain foot slopes, local valley, and alluvial plains.

Topography	SPAD		SDI	
	Sesame	Perilla	Sesame	Perilla
Mt. foot slopes	45.85 ± 3.91a	34.98 ± 4.30a	0	0
Local valley	49.51 ± 3.67a	27.35 ± 9.50a	5.4	7.5
Alluvial plains	38.92 ± 4.53b	20.54 ± 7.46b	212.8	497.7

SPAD, Soil Plant Analysis Development; SDI, stress-day index.
a, b: letters represent statistical difference across paddy fields at 95% level.

Water stress index analysis

In order to assess leaf physiological property under different soil water contents, a SPAD chlorophyll meter was used to acquire a rapid estimation of leaf chlorophyll content. Previous studies reported that soil water stress affects transpiration of plant leaves and this phenomena are reflected in leaf properties, such as specific leaf area and SPAD chlorophyll meter reading (Richardson et al., 2002; Songsri et al., 2009). The SDI measurements were also a good indicator of water stress to crops or plants (Evans et al., 1990; Kandil et al., 1995). The SDI calculations were done by Eq. (1) - (3). SPAD readings and SDI measurements are shown in Table 4. The SPAD meter results displayed that the SPAD values of sesame and perilla from the paddy fields of mountain foot slopes and local valley were greater than ones with alluvial plains ($p = 0.00$). However, SDI results showed different results than ones of SPAD values. Sesame and perilla from the paddy field of mountain foot slopes had a SDI value of 0 during cultivation. These results meant that both crops did not have any excessive soil-water stress during the cultivation. On the other hand, SDI values of sesame and perilla from the paddy field of alluvial plains had the greatest values than ones from other paddy fields. The SDI value of perilla from the paddy field of alluvial plains showed greater value than ones of sesame. This trend continued to ones from local valley.

Discussion

Sesame and perilla showed the greatest growths and yields from paddy fields of mountain foot slopes and the smallest ones from paddy fields of alluvial plains. Both crops showed a clear difference in growths, water stress responds and yields across different topography. Li et al. (2015) reported that agricultural productivity can be strongly affected by topographical characteristics and Chun et al. (2017) investigated important factors to sesame yields among various soil properties and concluded that soil topography and soil water characteristics are the most influential properties. It is reasonable to conclude that different topography resulted in different growths and yields of sesame and perilla. There have been studies which concluded that topographic features affected soil wetness and soil water content profile and lowland areas tended to have greater soil water contents (Qiu et al., 2001; Agren et al., 2014). Since topography and soil water content are closely related, investigating soil water effects on crops is important, especially cultivation in paddy fields. Based on these findings, certain topography, such as lowland or alluvial pains where soil wetness are greater than others created greater soil water stress to crops.

As the paddy field of alluvial plains had the greatest soil water content and the highest groundwater level during cultivation, growths and yields of sesame and perilla were the smallest, while the greatest growths and yields were occurred from the paddy field of mountain foot slopes, where the soil water contents were the smallest. This reflected that sesame and perilla from alluvial plain paddy field had greater soil water stress than ones from mountain foot slopes paddy field. These were shown in physiological responds such as SPAD and SDI results. Schlemmer et al. (2005) found that SPAD readings increased under adequate soil water contents, but the readings decreased under water stress condition. SDI has been applied to quantify soil water stress to crops (Hiler and Clark, 1971; Ahmad and Kanwar, 1989). Evans et al. (1991) and Purwanto et al. (1993) evaluated the SDI models of corns and soybeans to predict crop yields. Their best fitting results were range between r^2 = 60 - 80%, which meant that SDI values can be a good indicator of crop stress level and yield result. Kanwar (1988) studied SDI values from corns under different soil water contents and they concluded that SDI values increased as a degree of excessive soil water content increased. Based on these findings, it is reasonable to conclude that SPAD readings decrease and SDI values increase as soil water stress increases. In this study, the results of SPAD and SDI measurements showed as the paddy field of mountain foot slopes had the smallest SDI values of sesame and perilla and the greatest SPAD readings, where excessive soil water stress was the smallest. On the other hand, the paddy field of alluvial plains had the greatest stress of excessive soil water to both crops by the greatest SDI and the smallest SPAD values. In addition, the paddy field of mountain foot slopes had SDI value of 0 and it meant that there was no soil water stress. This result led to the yields of sesame and perilla were no smaller than ones from upland soils. Therefore all these measurement results concluded that the yields of sesame and perilla were the greatest from the paddy field of mountain foot slopes where soil water stress was the smallest and the yields from alluvial plains were the smallest due to the greatest water stress.

As mentioned above, one of the most hindrance factor in upland crop cultivation from paddy fields is excessive soil water condition and this soil water condition can be various by soil topography. It is important to consider soil topography, in order to succeed paddy field cultivation of upland crops and paddy fields of mountain foot slopes should be more favorable for cultivating upland crops in paddy fields.

Conclusions

Both sesame and perilla showed clear responses to different soil water contents induced by different topography. The growths and yields of both crops responded well to various soil topographic features; Paddy fields of mountain foot slopes would be better to grow upland crops in order to reduce wet injury of upland crops. On the other hand, paddy field with alluvial plains would be not favor with growing upland crops due to excessive soil water or bad drainage unless there is supportive drainage system. The results of this study would be helpful to Korean government policies to increase paddy field areas for upland crop cultivation.

Acknowledgement

This research was performed and funded by an Agenda project of Rural Development Administration (project number: PJ 01228601).

References

Ahmad N, Kanwar RS. 1989. Crop susceptibility factors for corn and their effect on the stress-day index. Transactions of the American Society of Agricultural Enginieers 32:1979-1986.

Agren AM, Lidberg W, Stromgren M, Ogilie J, Arp PA. 2014. Evaluating digital terrain indices for soil wetness mapping-a Swedish case study. Hydrology and Earth System Sciences 18:3623-3634.

Anderson MG, Kneale PE. 1980. Topography and hillslope soil water relationships in a catchment of low relief. Journal of Hydrology 47:1-2.

Ashri A. 1998. Sesame breeding. Plant Breeding Reviews 16:179-228.

Benz R, Conti F, Fioravanti R. 1984. Extrinsic charge movement in the squid giant axon membrane. Effect of pressure and temperature. European Biophysics Journal 11:51-59.

Chun HC, Jung KY, Choi YD, Lee SH, Kang HW. 2016. The growth and yield changes of foxtail millet (*Setaria italic* L.), proso millet (*Panicum miliaceum* L.), sorghum (*Sorghum bicolor* L.), adzuki bean (*Vigna angularis* L.), and sesame (*Sesamum indicum* L.) as affected by excessive soil-water. Korean Journal of Agricultural Science 43:547-559.

Chun HC, Jung KY, Choi YD, Lee SH. 2017. Improved method of suitability classification for sesame (*Sesamum indicum* L.) cultivation in paddy field soils. Korean Journal of Soil Science and Fertilizer 50:520-529. [in Korean]

Evans RO, Skaggs RW. 1984. Crop susceptibility factors for corn and soybeans to controlled flooding. ASAE Paper No. 84-2567, ASAE, St. Joseph, MI, USA.

Evans RO, Skaggs RW, Sneed RE. 1990. Normalized crop susceptibility factors for corn and soybean to excess water stress. Transactions of the American Society of Agricultural Enginieers 33:1153-1161.

Evans RO, Skaggs RW, Sneed RE. 1991. Stress day index models to predict corn and soybean relative yield under high water table conditions. Transactions of the American Society of Agricultural Enginieers 345:1997-2005.

Fukuda Y, Osawa T, Namiki M, Ozaki T. 1985. Studies on antioxidative substances in sesame seed. Agricultural and Biological Chemistry 49:301-306.

Hagiwara Y, Kachi N, Suzuki JI. 2010. Effects of temporal heterogeneity of water supply on the growth of Perilla frutescens depend on plant density. Annals of Botany 106:173-181.

Hardjoamidjojo S, Skaggs RW, Schwab GO. 1982. Corn yield response to excessive soil water conditions. Transactions of the American Society of Agricultural Enginieers 25:922-927.

Hiler EA. 1969. Quantative evaluation of crop-drainage requirments. Transactions of the American Society of Agricultural Enginieers 12:499-505.

Hiler EA, Clark RN. 1971. Stress day index to characterize effects of water stress on crop yields. Transactions of the American Society of Agricultural Enginieers 14:757-761.

Kandil HM, Skaggs RW, Dayem SA, Aiad Y. 1995. DRAINMOD-S: Water management model for irrigated arid lands, crop yield and applications. Irrigation and Drainage Systems 9:239-258.

Kanwar RS, Baker JL, Mukhtar S. 1988. Excessive soil water effects at various stages of development on the growth and yield of corn. Transactions of the American Society of Agricultural Enginieers 31:133-141.

Ji CH, Kim WH, Kim KY, Lee SH, Yoon SH, Lim YC. 2009. Effect of different drained conditions on growth, forage production and quality of silage corn at paddy field. Journal of the Korean Society of Grassland and Forage Science 29:329-336. [in Korean]

Jo JS, Kim CS, Won JY. 1996. Crop rotation of the Korean ginseng (Panax ginseng CA Meyer) and the rice in paddy field. Korean Journal of Medicinal Crop Science 4:19-26. [in Korean]

Jung KY, Yun ES, Park CY, Hwang JB, Choi YD, Park KD. 2011. Stress day index to predict soybean yield response by subsurface drainage in poorly drained sloping paddy fields. Korean Journal of Soil Science and Fertilizer 44:702-708. [in Korean]

Jung KY, Yun ES, Park CY, Hwang JB, Choi YD, Park KD. 2013. Study on pattern and cause of the wet injury of upland crops by cultivation condition on paddy soils. Korean Journal of Soil Science and Fertilizer 46:127-128. [in Korean]

Kang SS, Noh YS, Choi SC, Kim YS, Kim HJ, Choi MT, Ann BK, Kim HW, Kim HG, Park JH, Lee YH, Yang SH, Ryu JS, Zhang YS, Kim MS, Sonn YG, Lee CH, Ha SG, Lee DB, Kim YH. 2012. Status and changes in chemical properties of paddy soil in Korea. Korean Journal of Soil Science and Fertilizer 45:968-972. [in Korean]

Lee JE, Kim HS, Kwon YU, Jung GH, Lee CK, Yun HT, Kim CK. 2010. Responses of root growth characters to waterlogging in soybean [Glycine max (L.) Merrill]. Korean Journal of Crop Science 55:1-7. [in Korean]

Lee HL, Park KH, Lee MH, Kim HT, Seo WD, Kim JY, Baek IY, Jang DS, Ha TJ. 2013. Identification, characterization, and quantification of phenolic compounds in the antioxidant activity-containing fraction from the seeds of Korean perilla (perilla frutescens) cultivars. Food Chemistry 136:843-852. [in Korean]

Ley TW, Stevens RG. 1994. Pacific northwest publication No.475. Washington, Oregon, USA.

Li Y, Yang X, Cai H, Xiao L, Xu X, Liu L. 2015. Topographical characteristics of agricultural potential productivity during cropland transformation in China. Sustainability 7:96-110.

McCarty LB, Hubbard LR, Quisenberry V. 2016. Applied soil physical properties, drainage, and irrigation strategies. (pp. 1-72). Cham: Springer International Publishing, Germany.

Meyer SE, McArthur D, Jorgensen GL. 1989. Variation in germination response to temperature in rubber rabbitbrush (Chrysothamnus nauseosus: Asteraceae) and its ecological implications. American Journal of Botany 76:981-991.

Mukhtar S, Baker JL, Kanwar RS. 1990. Corn growth as affected by excess soil water. American Society of Agricultural Engineers 33:437-442.

NSO (National Statistical Office). 2016. Regional statistics yearbook. NSO, Seoul, Korea. [in Korean]

Purwanto MY, Hardjoamdjojo S, Nakamura R, Kubo N. 1993. Crop yield prediction by stress day indices under both excessive and deficient soil water conditions. Irrigation Engineering and Rural Planning

25:31-41.

Qiu Y, Fu B, Wang J, Chen L. 2001. Soil moisture variation in relation to topography and land use in a hillslope catchment of the Loess Plateau, China. Journal of Hydrology 240:243-263.

Richardson AD, Duigan SP, Berlyn GP. 2002. An evaluation of noninvasive methods to estimate foliar chlorophyll content. New Phytologist 153:185-194.

RDA (Rural Development Administration). 2015. Good practice of agricultural technology; oilseed crops. RDA, Jeonju, Korea. [in Korean]

Schlemmer MR, Francis DD, Shanahan JF, Schepers S. 2005. Remotely measuring chlorophyll content in corn leaves with differing nitrogen levels and relative water content. Agronomy Journal 97:106-112.

Sieben WH. 1964. Relation of drainage conditions and crop yields on young clay soils in the Yssellake polders. VanZee tot Land 40.

Songsri P, Jogloy S, Holbrook CC, Kesmala T, Vorasoot N, Akkasaeng C, Patanothai A. 2009. Association of root, specific leaf area and SPAD chlorophyll meter reading to water use efficiency of peanut under different available soil water. Agricultural Water Management 96:790-798.

Ucan F, Killi C, Gencoglan H, Merdun H. 2007. Effect of irrigation frequency and amount on water use efficiency and yield of sesame (*Sesamum indicum* L.) under field conditions. Field Crops Research 101:249-258.