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学位論文全文に代わる要約
Extended Summary in Lieu of Dissertation

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学位論文題目：
Title of Dissertation

Yield and physiological responses of soybean to different soil moisture status and drip irrigation（異なる土壌水分条件および点滴灌がいに対するダイズの収量および生理反応）

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Dissertation Summary

Soybean cultivation is deleteriously affected by drought stress in different regions where rainfall or irrigation facilities are insufficient. Stress caused by water deficiency in soybean largely depends on soybean growth stages and time exposed to drought. Drought stress during the vegetative stage limits leaf expansion, accelerates leaf senescence, and yield reduction (Desclaux et al., 2000; Valliyodan et al., 2017). During the reproductive stages cause flower and pos abortion, decrease in seeds number per pod and individual seed weight, as well as unfilled pods on the upper nodes of the soybean plant resulting in the reduction of soybean yield potential (Sionit & Kramer, 1977; Desclaux et al., 2000; Brevedan & Egli, 2003). Additionally, recent soybean yield in Japan (1636 kg ha^{-1}, Ministry of Agriculture, Forestry and Fisheries 2020) is about half of that in the USA (3326 kg ha^{-1}, USDA-National Agricultural Statistics Service 2020), this is a large gap of soybean yield between Japan and the USA. Low yield in Japan may be due to disadvantageous climatic conditions for soybean cultivation. For instance, drought stress in soybean cultivation in southern Japan frequently decreases the germination rate and vegetative growth, increases flower and pod abortion, and reduces seed weight (Takeda & Sasaki, 2013). Severe water deficit is rare, but drought stress after the rainy season and typhoons reduces soybean yield in Japan (Fatichin et al., 2013; Matsuo et al., 2016). The quality and quantity of soybean yield depend on water needed for growth. Also, Japan's and Thailand's soybean demands were higher than the supply causing to rely on soybean imports. Hence more research, especially stress, under different conditions on soybean crop growth, development, and yield, as well as the occurring of the stress in their sensitive stages is necessary.

Besides, drip irrigation enables a more effective water supply to plants compared with other irrigation systems because of the ease of controlling watering (Dasberg & Or, 1999). Isoda et al. (2006) demonstrated a very high soybean yield with frequent and sufficient irrigation using a drip system in an arid area of central Asia.

Recently, narrow-row planting (ca. 0.3 m between rows) in soybean cultivation has become common in Japan (the standard in Japan is 10 to 20 plants m^{-2}, with 0.60 to 0.80 m between rows, 0.07 to 0.20 m between plants within the rows, and tilling between the rows), and high soybean yield using narrow-row planting has been reported (Maitree & Toyota, 2017). Furrow irrigation is common for the standard spatial arrangement of soybeans. In contrast, drip irrigation is well suited for narrow-row planting, which does not require tilling between rows during cultivation. In this research, the author focused on the drip irrigation system. Soybean crops need to be irrigated frequently in order to avoid yield and quality losses (Constable & Hearn, 1980). It has been reported that full irrigation after water stress during flowering increased growth and quality of soybean (Sutherland & Danileson, 1980). Irrigation in areas where water is deficient has also been known to significantly increase seed yield in soybean (Garcia y Garcia et al. 2010; Kadhem et al., 1985; Karam et al., 2005). Although the effect of irrigation on soybean cultivation in Japan is uncertain, soybean yield from irrigation was greater than that of rainfed cultivation in a year receiving low precipitation (Scott et al., 1987). Therefore, soybean yield under rainfed cultivation decreases in a year with low precipitation, and the effect of irrigation on soybean production appears more clearly in a region with low precipitation. To solve this problem, complementary irrigation in soybean cultivation could alleviate drought stress, even for a short period, and contribute to increasing yield. This study, therefore, has focused to investigate the effects of using drip irrigation on the growth, yield, and its components of soybean grown in a low precipitation region in Japan, as well as to evaluate the phenological and physiological responses and dry matter production under a wide range of irrigation levels in two Japanese soybean cultivars ‘Hatsusayaka’ and ‘Sachiyutaka’. ‘Sachiyutaka’ is one of the current leading soybean cultivars in Southwestern Japan and ‘Hatsusayaka’ is expected to become popular because of having equal productivity to or higher than that of ‘Sachiyutaka’ (Saruta et al., 2012). Irrigation treatment is set from the blooming to the full-seed stage (R1−R6 stages) due to drought stress during the reproductive stages severely decreases soybean yield as previously mentioned. According to the objective, the experiment has been divided into two experiments: field and pot experiment.

Three years of consecutive experiments (2016−2018) with two treatments (drip irrigation; Drip, and rainfed; Rainfed) were conducted to assess the response of soybean growth and yield under drip irrigation conditions at Kagawa prefecture due to the occurrence of the second-lowest precipitation in Japan. Three drip tubes with emitters every 0.3 m (Dripnet PC 12, Netafim Japan Ltd, Tokyo, Japan) were installed between the strands: the tube length was 5.0 m in 2016 and 5.5 m in 2017 and 2018. The amount of daily irrigation during treatment was determined based on the daily evapotranspiration measured by evapotranspiration simulators, located in the experimental field. Daily total solar radiation and daily precipitation were measured at the meteorological station of the Faculty of Agriculture, Kagawa University, which is located adjacent to the experimental field. We assumed effective rainfall (effective rainfall ≥ 5 mm d^{-1}) to be that according to the Ministry of Agriculture, Forestry and Fisheries (1982). Leaf water potential (Ψ_L) of the topmost fully expanded leaf from three plants of each treatment was measured weekly by using a pressure chamber (Model 600; PMS Instrument Company, Albany, USA). Leaf greenness (SPAD values) using a SPAD meter (SPAD-502; Konica Minolta Inc., Tokyo, Japan) was also measured on the leaves used for Ψ_L measurement. Samples were harvested at 2-week intervals. Yield and its component, the above-ground dry matter (AGDM), leaf area index (LAI), crop growth rate (CGR), net assimilation rate (NAR), and mean leaf area index (mLAI), radiation use efficiency (RUE) were estimated using the procedure given by Maitree and Toyota (2017). Seeds were classified into fine and nonconforming which includes seeds that were damaged by pests and diseases, that split, or showing other obvious defects by using a 7.3-mm sieve and weighed. The results showed that the changes in accumulated effective rainfall and accumulated ETa to estimate the plant water status of soybean in each year. Although effective rainfall during treatment in 2016 and 2017 was 23% and 34% lower than in 2018, the amount of rainfall and the occurrence of rain in this study varied by growth period and year. Accordingly, we compare total water input (sum of effective rainfall and irrigation) to identify the factors responsible for the variation in yield and its components among years, cultivars, and irrigation treatments. As a result, we found many significant correlations between total water input and seed yield or its components. These results indicated that total water input was the main factor affecting the variation of seed yield and its components among years as well as the higher total water input in Drip than in Rainfed contributed to higher yield and yield components in Drip than in Rainfed within each year. ANOVA revealed a significant effect of drip irrigation on total seed yield, AGDM at maturity, RUE, and numbers of branches, nodes, and fertile pods. Because seed yield is the product of AGDM at maturity and harvest index, the more closed linear relationship between total seed yield and AGDM rather than between total seed yield and harvest index indicated the greater contribution of AGDM to seed yield. AGDM has a significant correlation with the means of growth parameters (CGR, NAR, and mLAI) during treatment period, and CGR correlated with NAR more closely than with mLAI. Highly significant correlation coefficients among NAR, RUE, and Ψ_L suggested that maintaining plant water status higher by drip irrigation substantially increased the efficiency of dry matter production per unit leaf area and per intercepted solar radiation. On the other hand, the variation of fine seed yield was analyzed by correlation among yield components associated with the numbers (i.e., numbers of seeds, pods, nodes, and branches). The results revealed a significant correlation among fine seed yield, number of fine seeds, fertile pods, and branch pod ratio. Also, the results revealed the significant correlations between branch pod ratio and numbers of fine seeds and fertile pods suggested that increase of branch growth by drip irrigation contributed to increase number of pods in branch, which increased number of fine seeds in Drip. This result consistent with Frederick et al. (2001), who reported that drought stress during R1 to R5 decreased total seed yield primarily by reducing branch vegetative growth, which reduce branch seed number and branch seed yield, without reducing main stem seed yield. AGDM and LAI in Drip tended to be higher than in Rainfed throughout cultivation for both cultivars for all years. Although considerably high AGDM and LAI were observed in Drip in 2017, AGDM and LAI in 2016 and 2018, and those in Rainfed in 2017 were within the range of our previous study (Maitree &Toyota, 2017). ANOVA showed the significant effect of irrigation on CGR and NAR in the 2nd period. The highly significant correlation between CGR and NAR in the 2nd period suggested that large contribution of NAR to CGR. Although ANOVA showed significant effect of irrigation on mLAI from 2nd to 5th period, correlation between CGR and mLAI were only significant in 1st and 4th period. The significant correlation between Ψ_L and growth parameters suggested that using drip irrigation should avoid drought stress and maintaining plant water status which contribute to NAR. Previous studies have reported that a decrease in RUE during drought was caused by a decline in canopy photosynthesis as a consequence of senescence due to water stress (Jefferies & Mackerron, 1989; Kiniry et al., 1989; Li et al., 2008). In the present study, no severe water stress was observed that caused the leaf senescence. According to ANOVA, the effect of irrigation on RUE was highly significant, suggesting that using drip irrigation should increase RUE of soybean in areas where there is no severe water deficit, such as our experiment site. Garcia y Garcia et al. (2010) showed that response to yield and water use efficiency by drip irrigation in soybean was different among genotypes. In the present study, the mean numbers of branches and nodes across years and irrigations for Hatsusayaka were larger than for Sachiyutaka, whereas the mean of fine and total seed yield, and number of seed across years and irrigations for Sachiyutaka were larger than for Hatsusayaka. These morphological characteristics in Hatsusayaka and Sachiyutaka in this study are consistent with our previous study (Chomsang et al., 2020; Maitree & Toyota, 2017). The larger number of branches, nodes, and pods for Hatsusayaka support the ability to produce many branches of this cultivar compared with Sachiyutaka (Toyota et al., 2017). Probably due to the limitation of assimilate supply, however, a large proportion of pods and seeds were aborted or grew insufficiently in Hatsusayaka. The lower harvest index for Hatsusayaka than for Sachiyutaka could be attributed to the larger aborted pod and nonconforming seed in this cultivar. Total rainfall during the same growing season with this study (sown on July 10 and harvested on November 10) at the Faculty of Agriculture, Kagawa University from 2001 to 2019 was varied between 112 mm (2012) and 903 mm (2017), with a mean of 507 mm. The 95% confidence interval for the 19-year mean was 393 mm (lower) and 622 mm (upper). Total rainfall in 2017 was the highest among 19-year mean and that in 2018 was higher than the upper 95% confidence interval. Total rainfall in 2016 was lower than the 19-year mean but within the 95% confidence interval. There were six years during 19-years when total rainfall during the soybean cultivation season fell below the 95% confidence interval of the 19-year mean. The results of this study indicated that the use of drip irrigation suppresses the decrease of yield in years with rainfall as low as 2016. Therefore, the probability of avoiding a decrease in soybean yield in a drought year by using drip irrigation will be about once every three years. The probability will increase about once every 1.7 years (≒ two years) if we expect a significant effect of using drip irrigation in a year when rainfall is lower than the 19-year mean.

Pot experiment was designed a wide range of irrigation levels (100% of field capacity (control), 80%, 60%, 40%, and 20% of control) to compare dry matter production and physiological responses of two soybean cultivars. Both cultivars were grown in 1/2000a Wagner pots (well-drained loam soil) at a non-air-conditioned greenhouse. Irrigation consumption was monitored daily using a gravimetric method. In other words, the daily amounts of irrigation for control for each cultivar was calculated as $W_{i-1} - W_i$, where W_i and W_{i-1} are the weight of a pot at day i and day i−1, respectively. The daily amount of irrigation for i8, i6, i4, and i2 was determined based on iC. During the experiment, we measured soil moisture in volumetric water content (VWC) along the first 10 cm depth with TDR soil moisture sensor (2016) and ECH_2O moisture sensor (2017) on a daily basis, in a subsample of three pots under different irrigation treatments. The net photosynthesis rate (Pn), stomatal conductance (Gs), transpiration (E), and intercellular CO_2 (Ci) were measured with a Portable Photosynthesis System (Model LI-6400, LI-COR Inc., Lincoln, NE). The photosynthetically active radiation (PAR), provided by an LED light source, was set to 1500 μmol m^{-2} s^{-1}. The flow rate of air through the sample chamber was set at 500 μmol s^{-1}, and the leaf temperature was maintained at environment temperature. Carbon dioxide levels in the leaf chamber were controlled by using CO_2 cartridge and fixed flow rate at 500 μmol s^{-1}. The CO_2 concentration within the leaf chamber was fixed at 400 μmol mol^{-1}. The parameters were measured weekly from 10:00 am to 14:00 pm. Three plants were randomly chosen, and one of the most recently expanded leaves was selected from each plant three times. Then the leaf used for Pn measurement was subjected to measure Ψ_L and SPAD value. Water use efficiency (WUE) was calculated as Pn/E and mesophyll efficiency (Ci/Gs) was calculated as Ci/Gs (Agnihotri et al. 2009; Sheshshayee et al. 1996). The measurement method of yield and its components was the same as the field experiment. The results showed that the day to reach the R3, R6, and R8 stages were delayed proportionally with the amount of irrigation, and Hatsusayaka was delayed than Sachiyutaka in both years may be due to the unique characteristics of each cultivar. This finding agrees with Getachew (2014), who concluded that water deficit might hasten or delay phenological periods depending on the time it occurs, severity, rate of onset of the stress, and type of species involved. On the other hand, the days to reach the R8 stage in 2017 had longer delays than in 2016, probably due to delayed stem senescence. Harbach et al. (2016) reported that delayed stem senescence is caused by insect damage, the fungicide pyraclostrobin, the herbicide glyphosate, water deficits, or their interactions. In addition, the large amount of assimilate in vegetative organs remains in the late reproductive stages (Egli & Bruening, 2006). In this study, the large amount of remaining assimilate in vegetative organs due to the loss of destination sink organs (seeds were severely damaged by pest in 2017) was the major factor for delayed stem senescence, which contributed to the large delay in the R8 stage in 2017. The effects of irrigation levels were significant in seed yield, the response of seed yield to irrigation levels was increased proportionally with the amount of irrigation up to a certain level (at 80% of control), and after that, it reached a threshold. It has been reported that water deficit occurred during critical periods of plant development, resulting in yield reductions (Al-Tawaha et al., 2007; Kadhem et al., 1985; Korte et al., 1983; Kunert et al., 2016). Moreover, the proportional decrease in seed yield with irrigation levels of both cultivars in the present study was due to the lower number of pods and seeds. In general, assimilate supply to reproductive organ mainly determines the number of pods or seeds (Board & Tan, 1995; Egli, 2010; Jiang & Egli, 1993), in order that the higher TDM and Pn in higher irrigation levels might produce the higher number of flowers, pods, and seeds. Our data also suggested that the fertile pod number decreased with decrease in irrigation levels would result in quite a low pod set ratio. Moreover, our results showed that the proportional decrease in irrigation levels resulted in a decrease of stomatal conductance with decreasing leaf water potential, which contributed to the reduction of photosynthesis rate as well as low total dry matter production. The results are consistent with Egli & Yu (1991), Liu et al. (2004) and Schou et al. (1978) who reported that water stresses reduce photosynthetic activity during the reproductive stage, causing a reduction in yield and yield components. In addition to the inhibition of Pn, decreased carbohydrate metabolism in leaves caused by drought stress may also reduce the amount of assimilates available for export to the sink organs (Pelleschi et al., 1997). It has been reported that water stress, induced by controlled watering, causes a progressive and concomitant decrease in net photosynthesis and light-saturated stomatal conductance in soybean leaves (Ribas-Carbo et al., 2005). The severity of water stress has often been assessed by its effect on relative water content, Ψ_L, light-saturated stomatal conductance, or even net photosynthesis. Although Hatsusayaka had higher leaf water potential and total dry matter than Sachiyutaka in some irrigation levels, there is no significant effect on total dry matter, seed yield, Pn, SPAD, Ψ_L, WUE and Ci/Gs. These results indicated that there was no difference in drought-tolerance between Hatsusayaka and Sachiyutaka.

Overall, our results revealed that using drip irrigation for soybean cultivation at the experiment site would be suppressing yield decline in years with low rainfall rather than achieving a higher yield than standard in years with normal or high rainfall. More information is needed to estimate the rainfall-threshold, which is expected to have a significant effect on using drip irrigation in this region. Besides, seed yield response to irrigation levels increased proportionally with the amount of irrigation. It is worth noting that both experiments showed that maintaining plant water status is the main factor of mitigating drought stress and would be suppressing the decrease in soybean yield. Also, there is no clear evidence indicating the different response to drought tolerance between Hatsusayaka and Sachiyutaka. Moreover, the reduction of dry matter production and soybean seed yield by drought stress is likely to occur in the tropical wet-dry climate of Thailand as well as the temperate zone of Japan. Thus, understanding the interactive effects of drought stress on plant responses not only is needed for the current environmental conditions encountered in the field but is also for the future climate.

References

Agnihotri, R. K., Palni, L. M. S., Chandra, S., & Joshi, S. C. (2009). Gas exchange variability and water use efficiency of thirty landraces of rice still under cultivation in Kumaun region of the Indian Central Himalaya. *Physiology and Molecular Biology of Plants*, *15*(4), 303–310.

Al-Tawaha, A. M., Seguin, P., Smith, D. L., & Bonnell, R. B. (2007). Irrigation level affects isoflavone concentrations of early maturing soya bean cultivars. *Journal of Agronomy & Crop Science*, *193*(4), 238–246.

Board, J. E., & Tan, Q. (1995). Assimilatory capacity effects on soybean yield components and pod number. *Crop Science*, *35*(3), 846–851.

Brevedan, R. E., & Egli, D. B. (2003). Short periods of water stress during seed filling, leaf senescence, and yield of soybean. *Crop Science*, *43*(6), 2083–2088.

Chomsang, K., Morokuma, M., & Toyota, M. (2020). Dry matter production and physiological responses to a wide range of irrigation levels in two Japanese soybean cultivars. *Plant Production Science*, *23*(4), 490−503.

Constable, G. A., & Hearn, A. B. (1980). Irrigation for crops in a sub-humid environment. I. The effect of irrigation on the growth and yield of soybeans. *Irrigation Science*, *2*(1), 1–12.

Dasberg, S., & Or, D. (1999). *Drip irrigation*. Springer-Verlag Berlin Heidelberg.

Desclaux, D., Huynh, T. T., & Roumet, P. (2000). Identification of soybean plant characteristics that indicate the timing of drought stress. *Crop Science*, *40*(3), 716–722.

Egli, D. B., & Bruening, W. P. (2006). Depodding causes greenstem syndrome in soybean. *Crop Management*, *5*(1), 1–9.

Egli, D. B. (2010). Soybean Reproductive Sink Size and Short-term Reductions in Photosynthesis during

Flowering and Pod Set. *Crop Science*, *50*(5), 1972–1977.

Egli, D. B., & Yu, Z. W. (1991). Crop growth rate and seeds per unit area in soybean. *Crop Science*, *31*(2), 439–442.

Fatichin, Zheng, S. H., Narasaki, K., & Arima, S. (2013). Genotypic adaptation of soybean to late sowing in Southwestern Japan. *Plant Production Science*, *16*(2), 130–132.

Frederick, J. R., Camp, C. R. & Bauer, P. J. (2001). Drought-stress effects on branch and mainstem seed yield and yield components of determinate soybean. *Crop Science*, *41*(3), 759−750.

Garcia y Garcia, A., Persson, T., Guerra, G., & Hoogenbiim, G. (2010). Response of soybean to different irrigation regimes in a humid region of the southeastern USA. *Agricultural Water Management*, *97*(7), 981–989.

Getachew, M. (2014). Influence of soil water deficit and phosphorus application on phosphorus uptake and yield of soybean (*Glycine max* L.) at Dejen, North-West Ethiopia. *American Journal of Plant Sciences*, *5*(13), 1889–1906.

Harbach, C. J., Allen, T. W., Bowen, C. R., Davis, J. A., Hill, C. B., Leitman, M., Leonard, B. R., Mueller, D. S., Padgett, G. B., Phillips, X. A., Schneider, R. W., Sikora, E. J., Singh, A. K., & Hartman, G. L. (2016). Delayed senescence in soybean: Terminology, research update, and survey results from growers. *Plant Health Progress*, *17*(2), 76–83.

Isoda, A., Mori, M., Matsumoto, S., Li, Z., & Wang, P. (2006). High yielding performance of soybean in Northern Xinjiang, China. *Plant Production Science*, *9*(4), 401–407.

Jefferies, R. A., & Mackerron, D. K. L. (1989). Radiation interception and growth of irrigated and droughted potato (*Solanum tuberosum*). *Field Crops Research*, *22*(2), 101–112.

Jiang, H. & Egli, D. B. (1993). Shade induced changes in flower and pod number and flower and fruit abscission in soybean. *Agronomy Journal*, *85*(1), 221–225.

Kadhem, F. A., Specht, J. E., & Williams, J. H. (1985). Soybean irrigation serially timed during R1 to R6. II Yield component responses. *Agronomy Journal*, *77*(2), 299–304.

Karam F., Masaad R., Sfeir T., Mounzer O., & Rouphael Y. (2005). Evapotranspiration and seed yield of field grown soybean under deficit irrigation conditions. *Agricultural Water Management*, *75*(3), 226–244.

Kiniry, J. R., Jones, C. A., O'toole, J. C., Cabelguenne, M., & Spanel, D. A. (1989). Radiation-use efficiency in biomass accumulation prior to grain-filling for five grain-crop species. *Field Crops Research*, *20*(1), 51–64.

Korte, L. L., Williams, J. H., Specht, J. E., & Sorensen, R. C. (1983). Irrigation of soybean genotypes during reproductive ontogeny. I. Agronomic responses. *Crop Science*, *23*(3), 521–527.

Kunert, K. J., Vorster, B. J., Fenta, B. A., Kibido, T., Dionisio, G., & Foyer, C. H. (2016). Drought stress responses in soybean roots and nodules. *Frontiers in Plant Science*, *7*, 1–7.

Li, Q., Chen, Y., Liu, M., Zhou, X., Yu, S., & Dong, B. (2008). Effects of irrigation and planting patterns on radiation use efficiency and yield of winter wheat in North China. *Agricultural Water Management*, *95*(4), 469–476.

Liu, F., Jensen, C. R., & Andersen, M. N. (2004). Drought stress effect on carbohydrate concentration in soybean leaves and pods during early reproductive development: Its implication in altering pod set. *Field Crops Research*, 86, 1–13.

Maitree, L. & Toyota, M. (2017). A high seed yield and associated attributes of dry matter production achieved by recent Japanese soybean cultivars. *Plant Production Science*, *20*(2), 193–204.

Matsuo, N., Fukami, K., & Tsuchiya, S. (2016). Effects of early planting and cultivars on the yield and agronomic traits of soybeans grown in southwestern Japan. *Plant Production Science, 19*(3), 370–380.

Ministry of Agriculture, Forestry and Fisheries, 2020. Changes in cultivation area, yield per 10a and production of soybean. Data collection related to soybean. Retrieved April 4, 2020, from https://www.maff.go.jp/j/seisan/ryutu/daizu/d_data/attach/pdf/index-42.pdf

Pelleschi, S., Rocher, J. P., & Prioul, J. L. (1997). Effect of water restriction on carbohydrate metabolism and photosynthesis in mature maize leaves. *Plant, Cell and Environment*, 20, 493–503.

Ribas-Carbo, M., Taylor, N. L., Giles, L., Busquets, S., Finnegan, P. M., Day, D. A., Lambers, H., Medrano, H., Berry, J. A., & Flexas, J. (2005). Effects of water stress on respiration in soybean leaves. *Plant Physiology*, 139, 466–473.

Saruta, M., Takada, Y., Okabe, A., Kikuchi, A., Ono, S., Igita, K., Sakai, S., Matsunaga, R., Hajika, M., Takahashi, M., & Komatsu, K. (2012). [A new soybean cultivar 'Hatsusayaka', with tolerance of delayed leaf senescence and suitability for tofu processing]. Bulletin of NARO Western Region Agricultural Research Center, 11, 81–99. In Japanese with English abstract.

Schou, J. B., Jeffers, D. L., & Streeter, J. G. (1978). Effects of reflectors, black boards, or shades applied at different stages of plant development on yield of soybeans. *Crop Science*, 18, 29–34.

Scott, H. D., Ferguson, J. A., & Wood, L. S. (1987). Water use, yield, and dry matter accumulation by determinate soybean grown in a humid region. *Agronomy Journal*, *79*(5), 870–875.

Sheshshayee, M. S., Krishnaprasad, B. T., Nataraj, K.N., Shankar, A. G., Prasad T. G., & Udayakumar, M. (1996). Ratio of intercellular concentration to stomatal conductance is good reflection of mesophyll efficiency. *Current Science*, *70*(7), 672–675.

Sionit, N., & Kramer, P. J. (1977). Effect of water stress during different stages of growth of soybean. *Agronomy Journal*, 69, 274–278.

Skaggs, R. K. (2001). Predicting drip irrigation use and adoption in a desert region. *Agricultural Water Management*, *51*(2), 125–142.

Sutherland, P. L., & Danileson, R. E. (1980). Soybean response to evapotranspiration deficit. *Agronomy*. Abstract. pp. 192–193.

Takeda, H. & Sasaki, R. (2013). Effects of ground water level control on the establishment, growth and yield of soybeans seeded during and after the rainy season. *Japanese Journal of Crop Science*, *82*(3), 233–241. In Japanese with English abstract.

Toyota, M., Maitree, L., & Chomsang, K. (2017). Changes in radiation interception and R:FR over time and with canopy depth of two soybean cultivars with different branching characteristics. *Plant Production Science*, *20*(2), 205–214.

USDA-National Agricultural Statistics Service, 2020. SOYBEANS – YIELD, Statistics by Subject, Retrieved April 4, 2020, from https://www.nass.usda.gov/Statistics_by_Subject/

Valliyodan, B., Ye, H., Song, L., Murphy, M., Shannon, J. G. & Nguyen, H. T. (2017). Genetic diversity and genomic strategies for improving drought and waterlogging tolerance in soybeans. *Journal of Experimental Botany*, *68*(8), 1835–1849.