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Evaluation of soybean genotypes under moisture stress conditions

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ABSTRACT

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Seed yield in soybean (*Glycine max* L.) is a function of moisture availability and is highly related to environmental conditions such as rainfall and irrigation. This study aimed to investigate differences among soybean lines and varieties in terms of phenology, above ground dry matter, seed yield, and yield components under different moisture regimes conditions, and to analyze the relationship between phenological characteristics and seed yield. Forty soybean genotypes were grown in two field experiments exposed to different irrigation regimes for three growing seasons (2010–2012). Results showed that variation in the duration of phenological stages was a determinant factor in increasing seed yield. There was a positive linear relationship between days to flowering and number of pods per plant, explaining 79 and 74% of the variation in seed yield under control and stress conditions, respectively. For both control and stress conditions, number of seeds m^{-2} was correlated with days to flowering and pod set. There were both linear positive and polynomial relationships between days to maturity and above ground dry matter at maturity, explaining 84 and 74% of the variation under control and stress conditions, respectively. These results suggest that' soybean breeding programs in Iran should focus more on the duration of phenological stages in developing superior soybean genotypes for both stress and optimal conditions.

Keywords: above ground dry matter, developmental stage, drought, flowering, seed yield.

INTRODUCTION

The three main approaches for minimizing the negative impact of water deficit on crop production are: conservation of soil water, access to more water, and overcoming special water-deficit sensitivities. Genetically improving crops for drought tolerance requires knowledge of the physiological mechanisms at different developmental stages and employment of suitable variety screening techniques. Recently, this strategy has gained considerable attention because of its efficiency, feasibility, and effectiveness. For soybean, pod and seed number are the most important yield components. Leaf area index (LAI), Leaf area duration (LAD), and dry matter accumulation and portioning strongly influence seed yield (SY) and its components.

As global populations and food demands increase, there will be a greater need to increase yields of crops subjected to water deficits. In recent years, substantial progress has been made in understanding water deficit limitations on soybean yields using model assessments, physiological investigations, and plant breeding (Sadok and Sinclair, 2011). Better water acquisition is most likely to be achieved by greater depth of rooting or greater root length density deep in the soil. Although promising genetic variability has been identified, further efforts to breed for these rooting traits is required (Xin *et al.,* 2012).

Limited observations of soybean transpiration rate responses to water stress conditions have indicated the existence of genotypes with nearly constant transpiration rates at high vapor pressure deficit. Sadok and Sinclair (2009) characterized 22 soybean genotypes for vapor pressure deficit response and their results offered some encouragement that the vapor pressure deficit at which plants limit transpiration rate might vary, thus the trait could be tailored to maximize potential yield in various water deficit environments.

In forage soybean, dry matter production was linearly correlated with water use, resulting in a production function slope of 21.2 kg ha^{-1} mm^{-1} (Nielsen, 2011). Average estimated dry matter yield was 5890 kg ha^{-1}, with a range of 2437 to 9432 kg ha^{-1}, thus it was concluded that forage soybean should be considered as a viable alternative crop for dryland cropping systems.

Xiaobing *et al.* (2005) investigated traits within 16 soybean genotypes from three maturity groups in Hailun, China, overtwo years. The maturity groups were selected to differ by approximately seven days in mean days to R_7 stage. Late maturity genotypes were higher yielding than early ones. Both pod number and seed number were higher in high yielding genotypes in each group. Significant variations were found for LAI, LAD, and above ground dry matter (ADM) within each maturity group. A higher accumulation of dry matter, higher LAI and LAD during reproductive stages were found to be closely related to high yields. No relationship was found between harvest index and SY (Xiaobing *et al*., 2005).

In Golestan province, drought stress can occur during any growth stage of soybean and causes severe damage to SY. This study aimed to investigate difference between soybean lines and varieties in terms of phenology, ADM, and SY and its components under two irrigation conditions, and to analyze the relationship between the phenological characteristics and seed yield.

MATERIALS AND METHODS

Two field experiments were conducted at the Agricultural Research Station of Gorgan, Golestan province, Iran, during the 2010, 2011, and 2012 growing seasons. Two separate experiments with different soybean genotypes were conducted; each useda randomized complete block arrangement with three replications. In first experiment (2010 and 2011), all soybean genotypes were irrigated based on 50, 100, and 150 mm evaporation from aclass A evaporation pan, but for the second experiment (2011 and 2012), soybean genotypes were irrigated based on 50 and 120 mm evaporation from aclass A evaporation pan. A summary of the treatments, statistical design, and genotypes are presented in Table 1.

Table 1. Summary of treatments, statistical design and genotype name/code used.

Growing season	Experiment	Genotypes
2010-11	Three separate experiments, each experiment as RCBD. In the first exp., all soybean genotypes were irrigated based on 50 mm evaporation from evaporation pan, but in the second and third experiments, the irrigation was based on 100 and 150 mm, respectively.	Gorgan3, Sahar, Williams, Katol, 033, Sari, Ds2, PE10, DW1, M7, L17, Hobbit × Century, Williams × A3935, M9, SG20, L14, SF, L504, HT2, WE6
2011-12	Two separate experiments, each experiment as RCBD. In the first exp., all soybean genotypes were irrigated based on 50 mm evaporation from evaporation pan, but in the second experiment the irrigation was based on 120 mm.	Williams × Crawford(1), Williams × Diana(1), Fora × Epps(1), Sahar × Collombus(4), Sahar ×Collombus(13), Sahar × Crawford(1), Crawford × Diana(2), Black Williams × Lan(4), Black Williams × Epps(10), Sahar × K188(5), Sahar × Hamilton(1), Sahar × LBK(1), DPX × Fora(1), DPX × K778(7), DPX × K778(10), DPX × K188(6), DPX × Sepideh(5), DPX × Sepideh(10), Sari, Katool

According to the Coupen classification, this region has a moderate and humid climate. Prior to sowing, soil samples were taken at depths of 0-30 and 30-60 cm. In accordance with the soil test results, pre-planting fertilizers of urea (25 kg N ha^{-1}), triple super phosphate (50 kg P_2O_5 ha^{-1}), and potassium sulphate (50 kg K_2O ha^{-1}) were applied. The soil was clay with pH of 7.9, and an electrical conductivity of 1.44 dS/m.

Experimental plots were regularly hand weeded. After seedling establishment, plants were thinned to obtain the desired plant population of 50×10 cm. From each plot, aboveground dry matterand other necessary samples were taken from 10 plants during the growth season. Flood-irrigation was used to replenish soil water in the root zone to the level of field capacity.

Agronomic traits (number of pods per plant, NPP, and number of seeds per square meter, NSS) and phonological traits (days to flowering, duration of flowering, and days to maturity) were measured and recorded following Fehr and Caviness (1977). Analyses of variance were performed for phenological data, SY and its components using SAS (SAS Institute, Inc., 1996). For control and stress conditions, the regression functions were fitted to the data of genotypes, over years and experiments (SAS Institute Inc., 1996). Weather data (Table 2) was obtained from a nearby weather station at Hashem Abad, Gorgan.

RESULTS AND DISCUSSION

Increasing duration of phenological stages was a good determinant factor for increasing yield components and SY (Fig. 1). Under both control and stress conditions, NPP was affected by days from sowing to flowering (R_1) and pod set (R_3), which became more significant when genotypes were exposed to lower temperatures during these periods. There was a positive linear relationship between days to flowering and NPP, explaining 79 and 74% of the variation under control and stress conditions, respectively (Fig. 1). For each day increase in days from sowing to flowering, NPP increased by 1.213 and 1.04 pods per plant under control and stress conditions, respectively.There was also a linear relationship between days to pod setand NPP, explaining 78 and 67% of the variation under control

Table 2. Monthly weather data for Gorgan Agricultural Research Station during the 2010-2012 growing seasons.

	2010			2011			2012		
Month	Mean temp. (°C)	Rainfall (mm)	Potential evap. (mm)	Mean temp. (°C)	Rainfall (mm)	Potential evap. (mm)	Mean temp. (°C)	Rainfall (mm)	Potential evap. (mm)
June	27.5	0.0	253	25.7	24.5	190	26.6	41.1	253
July	30.7	15.8	268	28.9	51.2	218	27.3	137	177
Aug.	30.2	0.0	293	30.3	43.3	246	29.6	0.0	227
Sep.	27.0	29.3	198	25.2	49.3	153	26.8	37.5	183
Oct.	23.7	35.5	144	21.1	1334	124	23.2	94.5	128
Nov.	16.5	9.2	62.8	11.6	67.6	47.2	18.0	34.1	73.0
Dec.	14.4	22.8	63.9	7.2	50.8	23.0	11.3	65.5	38.0

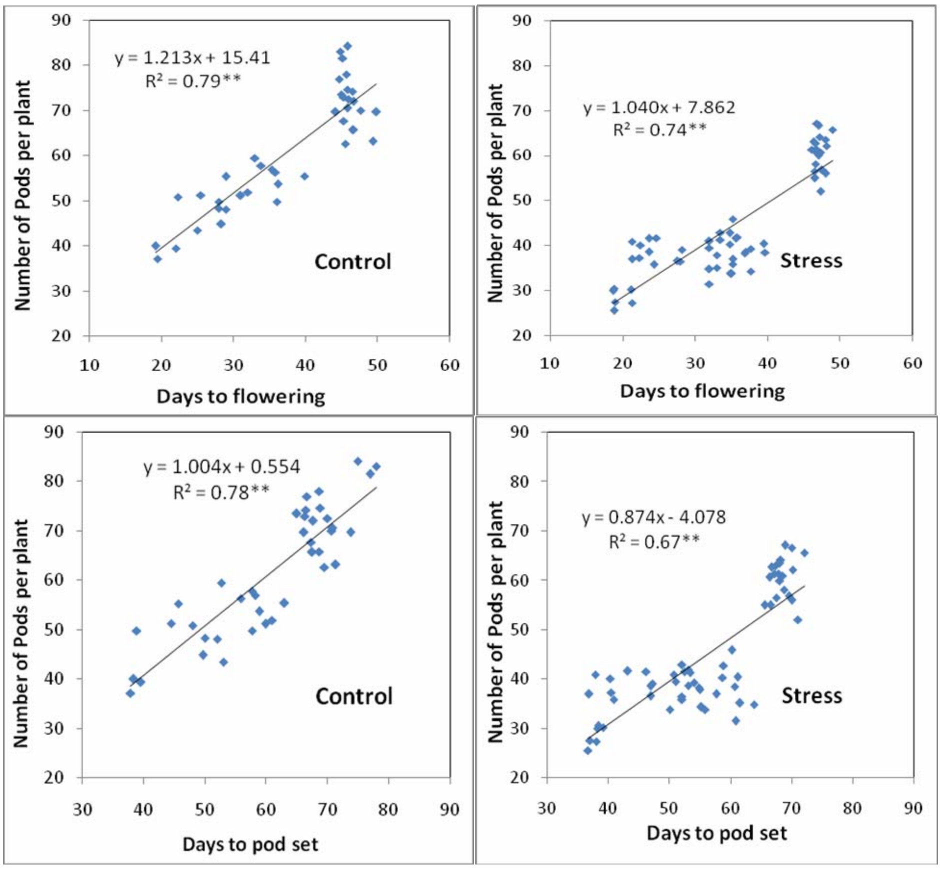

Fig. 1. Relationships between number of pods per plant and days to flowering and pod setunder control and stress conditions.

and stress conditions, respectively (Fig. 1). For each day increase in days from sowing to pod set, NPP increased by 1.004 and 0.874 pods per plant under control and stress conditions, respectively. There was a greater tendency for pod number to increase under control conditions, compared to stress conditions.

Under both control and stress conditions, NSS was affected by days from sowing to flowering and sowing to pod set (Fig. 2). There was a positive linear relationship between days to flowering and NSS, explaining 73 and 77% of the variation under control and stress conditions, respectively. For each day increase in days from sowing to flowering, NSS increased by 66.19 and 58.47 seeds m^{-2} under control and stress conditions, respectively, indicating a greater response of NSS to increases in phenological duration under control conditions (compared to stress conditions). There was also a linear relationship between days to pod setand NSS, explaining 72 and 70% of the variation under control and stress conditions, respectively (Fig. 2). For each day increase in days from sowing to pod set, seed number increased by 55.07 and 49.11 seeds m^{-2} under control and stress conditions, respectively.

There was a positive linear relationship between duration of flowering and NPP, explaining 80 and 78% of the variation under control and stress conditions, respectively (Fig. 3). For each day increase in flowering duration, NPP increased by 3.586 and 2.839 pods per plant under control and stress conditions, respectively indicating a greater response of pod number per plantto increase in flowering duration under control conditions. There

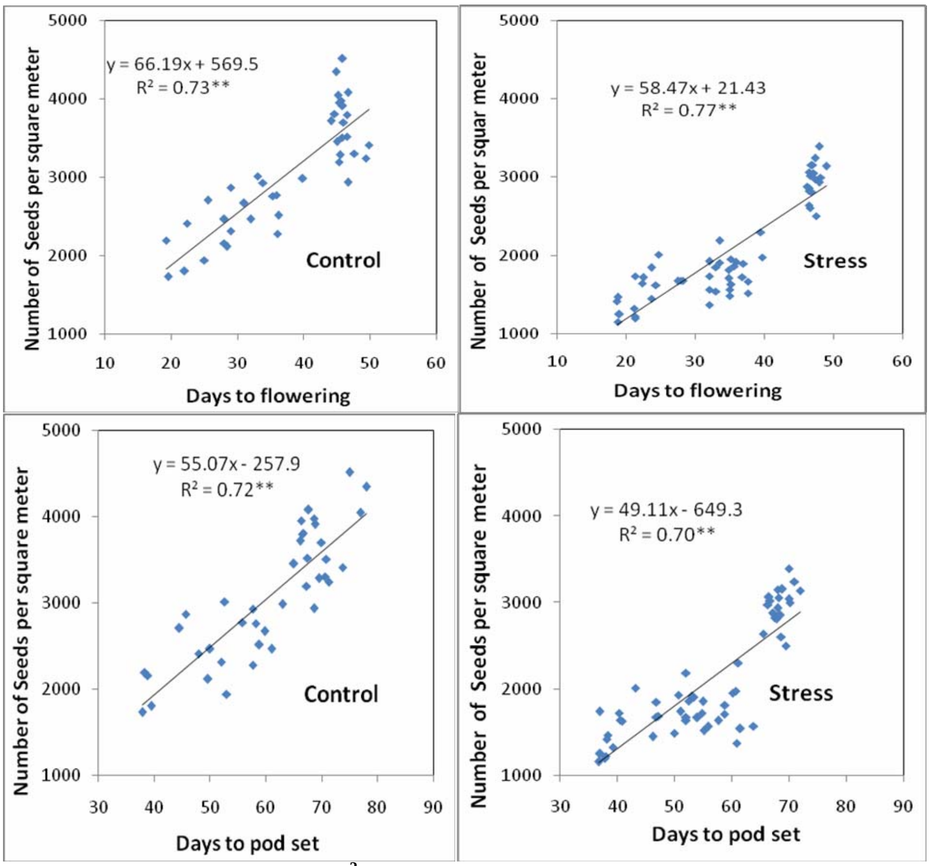

Fig. 2. Relationships between number of seeds m^{-2} and days to flowering and pod set under control and stress conditions.

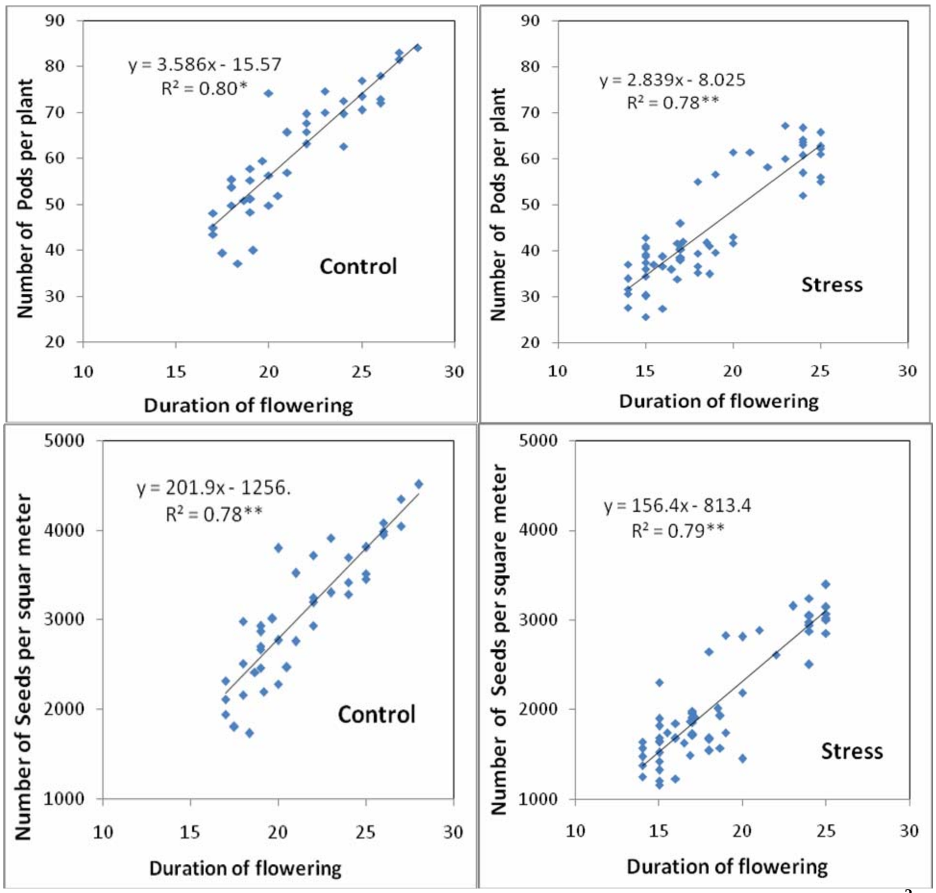

Fig. 3. Relationship between duration of flowering with number of pods per plantand number of seeds m^{-2} under control and stress conditions.

was also a linear relationship between the number of days to pod setand NSS, explaining 78 and 79% of the variation under control and stress conditions, respectively (Fig 3). For each day increase in flowering duration, NSS increased by 201.9 and 156.4 seeds m^{-2} under control and stress conditions, respectively, showing a greater response of soybean genotypes NSS to increases in flowering duration under control conditions.

There were positive linear and polynomial relationships between days to maturity and ADM at maturity, explaining 84 and 74% of the variation under control and stress conditions, respectively (Fig. 4). Under control conditions for each day increase in days to maturity, ADM increased by 67.07 kg ha^{-1}. Under stress conditions, the relationship between days to maturity and ADM was not linear; ADM decreased again in some late maturity genotypes. Under control conditions, the logarithmic relationship between SY and days to maturity was strong, explaining 85% of the variation (Fig. 4). However, under stress conditions, the equation between SY and days to maturity was a polynomial, explaining 76% of the variation (Fig. 4).

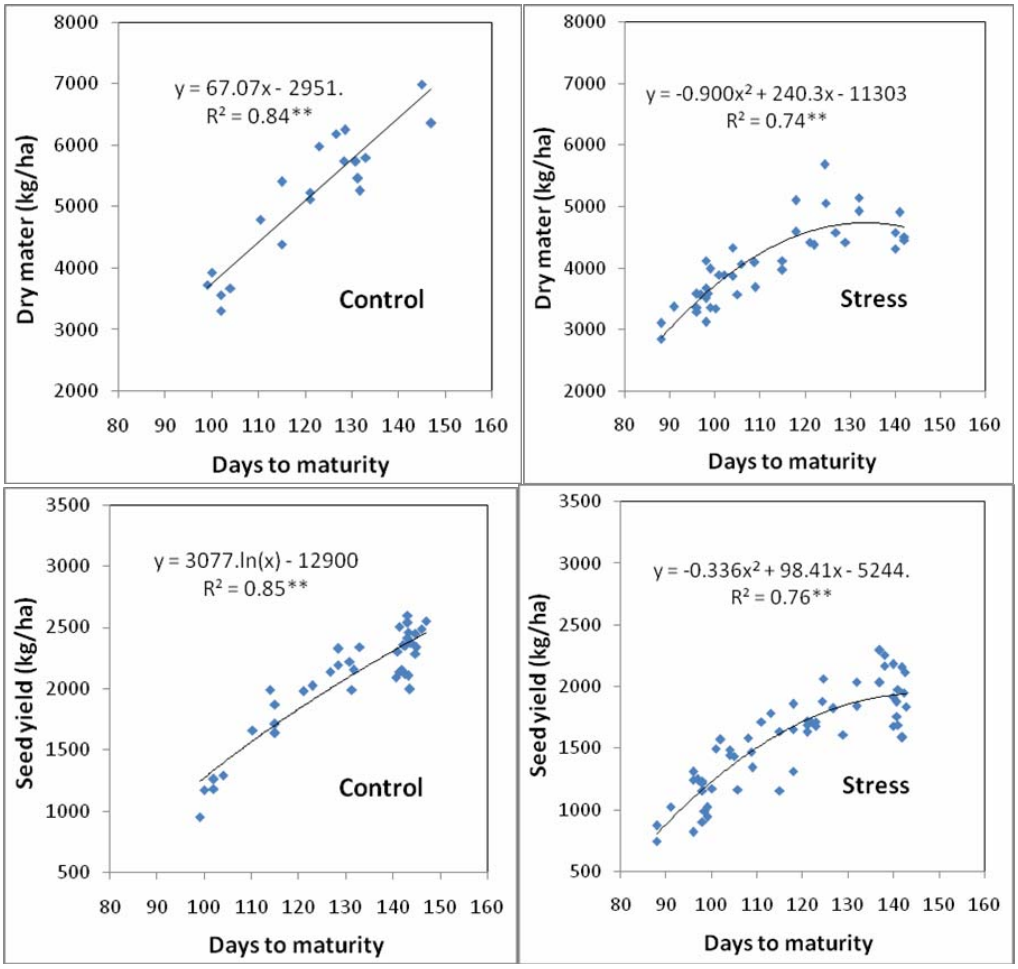

Fig. 4. Relationship between days to maturity with above ground dry matterat maturity and seed yield under control and stress conditions.

Water deficit is the primary limiting factor in soybean production in semi-arid regions. Therefore, increasing soybean SY requires the selection of cultivars tolerant and/or adapted to water deficit conditions. Zare *et al.* (2004), showed that drought tolerance and stress susceptibility explained a total of 94% of variation of soybean SY. The most tolerant cultivar was ‘Williams’, while ‘Delsoy’ and ‘Linford’ were the cultivars that exhibited potential SY in both environments. Kargar *et al.* (2004) studied 49 soybean genotypes to determine the most effective traits as well as drought tolerance indices for identifying tolerant soybean genotypes under drought conditions. They attributed reductions in SY to seed abortion under drought stress, thus leading to reduced NPP and NSS.

Daneshian *et al*. (2009) also studied growth and yield of 19 soybean genotypes under deficit irrigation conditions during three separate experiments in Karaj, Iran. Deficit irrigation had a significant effect on the number of nodes, plant height, number of branches, NPP, NSS, SY, and pod index (pod dry weight/total dry weight). Severe stress conditions had the greatest effect on reducing branch number, NPP, SY, and pod index.

In soybean, ADM production and SY are related to management practices and environmental conditions during the growth season. Under deficit irrigation conditions, selection for longer maturity period genotypes increase ADM and SY (Egli, 2004; Ashraf *et al*., 2011). However, increasing the days to maturity may be the most promising avenue to obtain higher soybean yields under non-stress conditions. Moisture deficit and warmer temperatures increase the rate of plant development and thus reduce days to maturity and SY potential. However, the direct effects of temperature depend on the genotype and its adaptability. In canola, lower air temperatures during the growth season appeared to be responsible for lengthening the duration, probably allowing more assimilates to accumulate and resulting in higher SY (Faraji *et al*., 2009; Faraji 2010, 2011). This probably resulted from increased photosynthesis under higher radiation (Adamsen and Coffelt, 2005).

Environmental stresses are responsible for limiting crop productivity and quality (Pahlavani *et al*., 2007; Faraji *et al*., 2009; Sinha *et al*., 2010). An empirical model with inputs accessible to growers, e.g. sowing date, soil depth, row distance, plant density, soil water at emergence, rainfall between emergence and R1 and between R1 and R5, was used to determine probability distributions of soybean yield at three locations during a 30-year series (Calvino *et al*., 2003). The data set included 125 crops covering a wide range of environmental conditions and management practices including sowing dates, inter-row spacing, seasonal water supply from 230 to 610 mm, average temperature and solar radiation at different stages, and soil depth. Sowing date was the variable with the largest effect on crop yield (r^2=0.59). The relationship between yield and sowing date was non-linear, with large yield reductions for delays in sowing dates yields of crops in deep soils averaged 2.4 t ha^{-1} for sowings on 25 December, and 1.5 t ha^{-1} for sowings on 10 January.

One of the greatest challenges for agriculture is to develop technology or agronomic options to improve SY (Turner, 2004). SY is partially a function of crop adaptation to environmental conditions, so favorable agronomic managements are very important. Blum (2005) concluded that when water use was the same for two cultivars, water use efficiency was higher for the higher yielding variety due to relative differences in dry matter production. However, determining optimum conditions can be a complex task since environmental variables interact with plant growth in different pathways.

CONCLUSIONS

Wheat–soybean double cropping is a common agronomic system in Golestan province, northern Iran. Environmental conditions and the intensity of drought stress can directly affect soybean growth under this system through the combined effects of the phenological duration and dry matter accumulation and portioning. Further increases in SY could be obtained through genetic improvements and/or better crop management. Results of this study suggest that soybean breeding programs in Iran should focus more on the duration of phonological stages for developing superior soybean genotypes for both stress and control conditions.

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