Screening of soybean genotypes to short period of flooding

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Abstract

High soil moisture stress owing to heavy rainfall during the early growth stage is the most limiting factor affecting the growth and productivity of soybean in the Terai region of Nepal. This study was conducted to identify the soybean cultivars suitable for high soil moisture stress condition. Sixteen cultivars of soybean were planted under two soil moisture conditions namely, (a) short term flooded and (b) normal growing conditions in two consecutive years 2018 and 2019. Six stress tolerance indices like stress tolerance (TOL), stress susceptibility index (SSI), yield stability index (YSI), yield index (YI), mean productivity (MP) and geometric mean productivity (GMP) were calculated based on seed yields under flooded and normal conditions. The combined analysis showed that soybean cultivar SBO–115 (1912 kg/ha) and TGX 1990–94F (1883 kg/ha) produced significantly the highest seed yield under normal and flooded conditions, respectively. These two cultivars TGX 1990–94F (YI =1.3) and SBO–115 (YI =1.2) also possess the highest value of yield index. In contrast, the yield stability index was found maximum in cultivar LS –77 –16 –16 with a value of 1.4. Similarly, correlation analysis showed that soybean yield under flooded condition had a significant and positive association with yield under normal condition, YI, MP and GMP, while negative association found with TOL and SSI. This study indicated that the cultivars TGX 1990 – 94F, G –1873 and Kavre found to be more stable in two different conditions, while cultivars TGX 1990–94F and SBO –115 found suitable for flooded condition. These cultivars can be used directly or further in the crossing program for breeding high moisture stress tolerance cultivars.

Keywords: Flooding, soybean, stress tolerance

Introduction

Soybean (*Glycine max* L. Merril) is the most important legume crop possessing very good food, nutritional, environmental and industrial values. It is widely cultivated from terai to hilly regions in Nepal, which is mainly grown during the rainy season. The majority of area under soybean cultivation found in hilly areas, but due to increasing its demands in livestock and poultry industries and high production potential, it is becoming popular in plain areas of Terai and inner terai geographical regions (Pokhrel *et al*., 2013). Nepal is importing about 62247 t soybean with an import value of 3 billion, annually (MoALD, 2018). Considering the importance of soybean, there is a need for increasing its production and productivity to ensure food, feed and nutritional security in addition to a means of increasing soil productivity. Though the growth rate of area (1.1%), production (3.6%) and productivity (2.5%) of soybean over 15 years period in the country showed an increasing trend, the productivity of soybean in Nepal (1.3 t/ha) is found substantially below than the World (2.8 t/ha) and the Asian (1.5 t/ha) regions (Pokhrel *et al*., 2018; FAOSTAT, 2020). The area and production of soybean in Nepal were 25179 ha and 31567 t, respectively in the year 2019 (FAOSTAT, 2020). Grain Legumes Research Program, NARC has released eight varieties of soybean such as Hardee, Hill, Ransom, Seti, Cobb, Lumle 1, Tarkari Bhatmas 1 and Puja, on which one variety named Hill has been denotified due to its low productivity (Pokhrel *et al*., 2018).

There are various factors for the low productivity of soybean, among them the soil waterlogging or flooding stress is common abiotic stress caused by heavy rainfall, prolonged periods of rains, excessive irrigation and low water infiltration rate of soils that influence soybean production in the monsoonal areas of Asian region (Kokubun, 2013; Ye *et al*., 2018). VanToai *et al*. (2010) reported as much as a 25% yield reduction of soybean in Asia due to flooding and flood irrigation. The poor seed germination (Wuebker *et* *al*., 2001), deprived nutrients availability (Steffens *et al*., 2005), reduction in the availability of oxygen to roots (Bailey-Serres and Voesenek, 2008), decreased in nodulation (Linkemer *et al*., 1998), leaf chlorosis (Jackson and Colmer, 2005) and increased susceptibility to diseases (Helms *et al*., 2007) are the major effects noted of high soil moisture stress condition resulting in a significant yield reduction in soybean (Linkemer *et al*., 1998). Poor performances of existing soybean varieties and loss of yield due to high soil moisture stress condition are the main concern of soybean cultivation, where the selection of suitable varieties of flooding tolerance is very crucial for obtaining higher yield. There are various quantitative criteria or stress indices such as stress tolerance (TOL), stress susceptible index (SSI), yield stability index (YSI), mean productivity (MP), geometric mean productivity (GMP) and yield index (YI) have been reported for the screening or identification of high soil moisture stress tolerance soybean cultivars (Choudhary *et al*., 2017). All these stress indices are measured based on the performance of soybean cultivars under both the stress and non-stress growing environmental conditions through the function of reducing yield under stress condition. Stress resistance is a relative yield of a cultivar as compared to other cultivars growing under the same growing condition, while the stress susceptibility of a cultivar is measured as the function of the yield reduction under stress condition (Choudhary *et al*., 2017).

Therefore, it is important to study the influence of high soil moisture stress on the yield of the different soybean cultivars under flooded condition. The main objective of this study is to analyze the stress indices for investigating the performance of different soybean cultivars under high soil moisture stress condition, which would help researcher and farmers to develop or choose suitable cultivars under high soil moisture growing environmental condition.

Methodology

The experiments were conducted at Grain Legumes Research Program (GLRP), Khajura, Banke located at 28° 06" 45' N latitude, 81° 35" 58' E longitude and 182 masl in the summer season of two consecutive years 2018 and 2019. Altogether, sixteen cultivars of soybean were used for the experiments. The experiment was laid out in randomized complete block design in two soil moisture conditions namely, (a) flooding or high soil moisture stress condition, maintaining more than 5 cm water level in the plots for 7 days at 30 days after sowing (DAS) and (b) non-stress condition, normal growing condition**.** Water was drained completely after the completion of flooding treatment of 7 days. The individual plot size was 3 m^2, where the soybean cultivars were planted maintaining 50 cm row to row and 10 cm plant to plant distances. Each of the experimental plots was replicated three times in each growing environments. Fertilizers were applied at the rate of 20:40:20 N: P_2O_5:K_2O kg/ha and weeding operation was done at 25 DAS in both the growing environments. The stress tolerance indices as adopted by Choudhary *et al*. (2017) and Anwar *et al*. (2011) were derived in the study as:

$$\text{Stress Tolerance (TOL)} = Y_{ns} - Y_s \quad (1)$$
$$\text{Stress Susceptibility Index (SSI)} = \{1 - (Y_s/Y_{ns})\} \,/\, \{1 - (\hat{Y}_s/\hat{Y}_{ns})\} \quad (2)$$
$$\text{Yield Stability Index (YSI)} = Y_s/Y_{ns} \quad (3)$$
$$\text{Mean Productivity (MP)} = (Y_s + Y_{ns})/2 \quad (4)$$
$$\text{Geometric Mean Productivity (GMP)} = (Y_s \times Y_{ns})^{1/2} \quad (5)$$
$$\text{Yield Index (YI)} = Y_s/\hat{Y}_s \quad (6)$$

Where, Y_s and Y_{ns} are the yields of each cultivar under high soil moisture stress and normal growing conditions, $\hat{Y}_s$ and $\hat{Y}_{ns}$ are the mean yields of all cultivars under stress and normal conditions, respectively.

Soil characteristics

The soil of the experimental plots was found sandy loam with neutral pH (6.7) that contains a low amount of organic matter (1.82%) and nitrogen (0.09%) but a high level of phosphorous (128.82 kg/ha) and potassium (291.01 kg/ha).

Climatic condition of the study area

During the study period from July to November, the study area received 114 mm (2018) and 563 mm (2019) rainfall, where October and November were the coolest months. The mean minimum temperature, maximum temperature and rainfall of the study area are presented in Table 1. Moreover, rainfall was not recorded during the time of application flooding treatment in both the experimental years.

Table 1. Average temperatures and rainfall during study periods of the years 2018 and 2019

Month	2018			2019		
	Min temp (ºC)	Max temp (ºC)	Rainfall (mm)	Min temp (ºC)	Max temp (ºC)	Rainfall (mm)
July	26.1	34.2	20.5	26.61	32.82	392.8
August	26.7	33.3	31.1	26.34	33.51	170.4
September	26.6	36.8	14.0	22.55	33.07	0.0
October	21.3	33.0	47.9	13.91	30.39	0.0
November	13.2	28.3	0.0	10.46	25.68	0.0

Statistical analysis

All the data on yield and stress indices of different soybean cultivars and the correlation coefficient between soybean yields under high soil moisture stress and normal growing conditions were analyzed statistically using statistical software SPSS version 16.0. The mean values of the parameters were tested for significant differences by using Tukey's honest significant difference tests. A probability level ≤ of 0.05 was considered for a statistically significant difference.

Results and Discussions

Growth and yield attributing parameters

The growth and yield attributing parameters of soybean cultivars under normal and high soil moisture stress growing environments are presented in Table 2. The overall means of yield attributing parameters like number of pods per plant, number of seeds per ten pods and hundred seed weight of soybean cultivars were found higher under the normal growing condition as compared to high soil moisture stress condition. In contrast, comparatively a shorter plant height of all the tested cultivars was noted in high soil moisture stress condition. These results are also in line with the findings of (Ara *et al.*, 2015). The tolerant soybean cultivars maintained a greater number of pods and seeds per plant, and seed weight under a high soil moisture stress condition than the sensitive cultivars.

Table 2. Growth and yield attributing parameters of soybean cultivars under short term flooded and normal growing conditions (combined of two years)

Cultivar	Days to flowering		Days to maturity		Plant height, cm		No. of pods per plant		No. of seeds per ten pods		Hundred seeds weight, g	
	Flooded	Normal	Flooded	Normal	Flooded	Normal	Flooded	Normal	Flooded	Normal	Flooded	Normal
TGX 1989–21F	67 [a]	65 [a]	123	121 [abc]	75	72 [bcde]	65	64 [ab]	21 [ab]	23 [ab]	8.7 [cd]	11.0 [abc]
PK 7394	61 [abcd]	59 [abc]	116	114 [c]	80	78 [abc]	81	80 [ab]	22 [ab]	20 [ab]	11.7 [abc]	11.0 [abc]
Kavre	65 [ab]	61 [ab]	121	124 [a]	98	81 [ab]	85	68 [ab]	21 [ab]	19 [ab]	11.3 [abcd]	10.7 [abc]
AGS–376	56 [def]	53 [cd]	122	123 [ab]	79	53 [defg]	62	64 [ab]	19 [ab]	21 [ab]	14.3 [a]	13.7 [a]
SBO–115	59 [bcde]	60 [abc]	119	115 [bc]	101	76 [bc]	84	83 [ab]	20 [ab]	22 [ab]	11.0 [abcd]	10.3 [bc]
LS–77–16–16	51 [f]	51 [d]	118	117 [abc]	80	41 [g]	57	70 [b]	16 [b]	17 [b]	10.0 [bcd]	11.7 [abc]

Cultivar	Days to flowering		Days to maturity		Plant height, cm		No. of pods per plant		No. of seeds per ten pods		Hundred seeds weight, g	
	Flooded	Normal	Flooded	Normal	Flooded	Normal	Flooded	Normal	Flooded	Normal	Flooded	Normal
IARS–87–1	54^{ef}	54^{bcd}	119	120^{acb}	87	51^{fg}	62	56^{b}	25^{a}	22^{ab}	12.3^{ab}	12.3^{abc}
F–778817	55^{def}	53^{bcd}	121	121^{abc}	82	53^{efg}	67	56^{b}	21^{ab}	20^{ab}	14.0^{a}	12.3^{abc}
TGX 1990–38F	59^{bcde}	64^{a}	120	121^{abc}	102	74^{bc}	78	88^{a}	20^{ab}	21^{ab}	10.0^{bcd}	9.3^{c}
Puja	52^{ef}	50^{d}	122	120^{abc}	73	57^{cdefg}	55	54^{b}	19^{ab}	21^{ab}	13.3^{ab}	13.3^{ab}
PI 94159	56^{def}	53^{cd}	121	119^{abc}	74	60^{cdefg}	63	54^{b}	18^{b}	20^{a}	11.3^{abcd}	13.0^{ab}
TGX 1990-94F	63^{qbc}	65^{a}	128	125^{a}	102	97^{a}	82	83^{ab}	20^{ab}	23^{ab}	8.3^{cd}	9.3^{c}
TGX 1987–62F	65^{ab}	63^{a}	118	114^{c}	80	74^{bcd}	91	84^{ab}	22^{ab}	23^{ab}	8.0^{c}	9.3^{c}
TGX 1485–ID	64^{abc}	59^{abc}	123	118^{abc}	79	65^{bcdef}	59	74^{ab}	18^{b}	22^{ab}	11.0^{abcd}	11.7^{abc}
G–1873	57^{cdef}	58^{abcd}	119	118^{abc}	82	66^{bcdef}	79	64^{ab}	18^{b}	20^{ab}	11.3^{abcd}	12.0^{abc}
Co 165	51^{f}	53^{cd}	119	118^{acb}	72	67^{bcdef}	68	65^{ab}	20^{ab}	21^{ab}	11.3^{abcd}	12.0^{abc}
GM	58	58	121	119	82	67	67	71	20	21	11.1	11.4
F-test	**	**	ns	**	ns	**	ns	**	**	*	**	**

Note: n*s indicates non-significance. * and ** indicate significance at $p < 0.05$ and $p < 0.01$, respectively. means followed by the same letter in each column do not differ by Tukey's honest significant difference tests at $P < 0.05$.*

Soybean yield

The effect of soil moisture condition on the yield of soybean cultivars both under the normal and high soil moisture stress conditions are presented in Table 3. The seed yield of the soybean cultivars significantly influenced in both the growing environments. Among the tested soybean cultivars, cultivars SBO–115 (1912 kg/ha), TGX 1990-94F (1886 kg/ha), PK 7394 (1658 kg/ha) and F–778817 (1658 kg/ha) produced the highest yield under normal growing condition, while the cultivars TGX 1990-94F (1883 kg/ha), SBO–115 (1699 kg/ha) and TGX 1987–62F (1603 kg/ha) were identified as the highest yielder in high soil moisture stress condition. The variation in seed yield of different soybean cultivars both under normal and stress environmental conditions was also reported by (Helms *et al*., 2007) and (Ara *et al*., 2015). The overall mean of the soybean cultivars was found higher in normal growing condition compared with high soil moisture stress condition. Although, the mean yield of all soybean cultivars was found higher in high soil moisture stress condition than the normal growing condition in the first year of the experiment, as the year received a very low amount of rainfall during the soybean growing season. In contrast, soybean yield was found about 16% more under the normal growing condition as compared to high soil moisture stress condition in the second year of the experiment. The result of this study is in line with the study of Ye *et al*. (2018) and Linkemer *et al*. (1998), where they noted a significant reduction in yield of soybean by 17% to 56% due to the effects of waterlogging stress. Similarly, Helms *et al*. (2007) also reported about a 20% yield reduction of soybean under three days of waterlogging condition during V_1 (first trifoliate) and V_2 (second trifoliate) stages. The reduction of yield under stress condition might be due to the reduction in root growth, nodule formation, nitrogen fixation, leaf chlorosis and carbon assimilation (Wu *et al*., 2017).

Table 3. Yield (kg/ha) of soybean cultivars under high soil moisture stress and normal growing conditions

Cultivars	Y_{ns}			Y_s		
	2018	2019	Mean	2018	2019	Mean
TGX 1989–21F	506 ef	2257 abc	1382 bc	946 cde	1989 a	1467 ab
PK 7394	997 abc	2319 abc	1658 abc	1396 abc	1710 ab	1553 ab
Kavre	722 cde	2371 abc	1547 abc	1107 bcd	1920 a	1513 ab
AGS–376	581 def	2080 abcd	1331 cd	818 de	1659 ab	1239 b
SBO–115	1250 a	2573 ab	1912 a	1361 abc	2038 a	1699 ab
LS–77–16–16	306 f	1394 d	850 d	573 ef	1824 a	1199 b
IARS–87–1	1030 abc	2054 abcd	1542 abc	999 bcde	1811 a	1405 ab
F–778817	1144 ab	2171 abcd	1658 abc	1191 bcd	1709 ab	1450 ab
TGX 1990–38F	840 abcde	2139 abcd	1489 abc	1467 abc	1771 a	1619 ab
Puja	810 bcde	1901 bcd	1355 cd	1237 bcd	1561 ab	1399 ab
PI 94159	884 abcde	1538 cd	1211 cd	1039 bcde	1522 ab	1280 b
TGX 1990 –94F	1011 abc	2761 a	1886 ab	1746 a	2021 a	1883 a
TGX 1987–62F	1013 abc	1912 bcd	1463 abc	1500 ab	1707 ab	1603 ab
TGX 1485–ID	969 abcd	1717 cd	1343 cd	1340 abc	1649 ab	1494 ab
G–1873	568 def	1956 abcd	1262 cd	978 bcde	1580 ab	1279 b
Co 165	473 ef	1797 bcd	1135 cd	353 f	1121 b	737 c
GM	819	2058	1439	1128	1724	1426
F-test	**	**	**	**	**	**

Note: Y_{ns}: *yield under normal condition.* Y_s: *yield under high soil moisture stress condition. ** indicates significance at p < 0.01. means followed by the same letter in each column do not differ by Tukey's honest significant difference tests at P < 0.05.*

High soil moisture stress indices

The high soil moisture stress indices of different soybean cultivars were calculated based on the seed yield under normal and stress conditions. The high soil moisture stress indices such as TOL, SSI, YSI, MP, GMP and YI of different soybean cultivars are presented in Table 4. A significant difference at $P < 0.05$ was found in YSI, while the variation at $P < 0.01$ was noted in MP, GMP and YI, among the tested soybean cultivars in the experiments. The result revealed that soybean cultivars are differing for the gene controlling seed yield and high moisture stress tolerance indices. The low value of TOL was found in cultivars TGX 1990-94F (2.8), G–1873 (-17.2), Kavre (33.3) and Puja (43.6), which indicates that these cultivars of soybean are more stable in both the growing conditions, stress and non-stress growing environments. The negative value of TOL showed that the higher yield of soybean cultivars under stress condition as compared to normal growing condition. Similarly, the lowest SSI index (-0.2) was found in soybean cultivar TGX 1990-94F, among the tested cultivars, which means that the cultivar is more resistant to a high soil moisture stress condition. In contrast, the highest YSI index was observed in cultivar LS–77–16–16 (1.4). The MP of the soybean cultivars ranged from 936.1 in Co 165 to 1884.7 in TGX 1990-94F. Likewise, a significantly higher GMP index was found in TGX 1990-94F (1881.2) and SBO–115 (1800.5) followed by PK 7394 (1601.2). The result of YI revealed that the soybean cultivar TGX 1990-94F and SBO–115 with the highest YI value of 1.3 and 1.2, respectively, possess the suitability of the cultivars under high moisture condition. In the line of this study, Shannon *et al.* (2005) also noted the variation in yield reduction between the flood-tolerant group of soybean cultivars and flood susceptible group of soybean cultivars in flooded environmental condition.

Table 4. High soil moisture stress tolerance indices of soybean cultivars (combined of two years)

SN	Cultivar	TOL	SSI	YSI	MP	GMP	YI
1	TGX 1989–21F	-85.70	-9.50	1.10 [ab]	1424.40 [c]	1417.90 [cd]	1.00 [abc]
2	PK 7394	105.00	5.90	0.90 [ab]	1605.30 [ab]	1601.20 [abc]	1.10 [abc]
3	Kavre	33.30	1.20	1.00 [ab]	1530.00 [bc]	1524.70 [bcd]	1.10 [abc]
4	AGS–376	91.90	7.90	0.90 [ab]	1284.60 [cd]	1283.10 [cde]	0.90 [bc]
5	SBO–115	212.10	11.70	0.90 [ab]	1805.50 [ab]	1800.50 [ab]	1.20 [ab]
6	LS–77–16–16	-348.30	-48.50	1.40 [a]	1024.30 [de]	1005.60 [ef]	0.80 [c]
7	IARS–87–1	137.20	9.30	0.90 [ab]	1473.60 [bc]	1471.40 [bcd]	1.00 [abc]
8	F–778817	207.70	13.30	0.90 [ab]	1553.90 [ab]	1548.80 [abcd]	1.00 [abc]
9	TGX 1990–38F	-129.40	-12.20	1.10 [ab]	1554.20 [ab]	1549.00 [abcd]	1.10 [abc]
10	Puja	-43.60	-3.10	1.00 [ab]	1377.10 [c]	1374.70 [cd]	1.00 [abc]
11	PI 94159	-69.40	-12.50	1.10 [ab]	1245.70 [cde]	1233.30 [de]	0.90 [bc]
12	TGX 1990–94F	2.80	-0.20	1.00 [ab]	1884.70 [a]	1881.20[a]	1.30 [a]
13	TGX 1987–62F	-140.80	-10.10	1.10 [ab]	1532.90 [bc]	1528.80 [bcd]	1.10[abc]
14	TGX 1485–ID	-151.50	-16.50	1.10 [ab]	1418.70 [c]	1409.70 [cd]	1.00 [abc]
15	G–1873	-17.20	-3.50	1.00 [ab]	1270.30 [cd]	1265.80 [cde]	0.90 [bc]
16	Co 165	397.80	37.40	0.7 [b]	936.10 [e]	911.80 [f]	0.50 [d]
	GM	-	-	1.00	1432.60	1425.50	1.00
	F-test	-	-	*	**	**	**

Note: *TOL: stress tolerance. SSI: stress susceptible index. YSI: yield stability index. MP: mean productivity. GMP: geometric mean productivity. YI: yield index. means followed by the same letter in each column do not differ by Tukey's honest significant difference tests at P < 0.05.*

Correlation among the stress indices

The correlation analysis between soybean yield under normal condition, yield under stress environment and stress indices were calculated to determine the most desirable high soil moisture stress tolerance index (Table 5). This analysis helps to identify the best indices for the selection of high moisture stress tolerance soybean cultivars. The soybean yield under high soil moisture stress condition had a strong positive correlation (r = 0.580) with the soybean yield under normal growing condition, imparting a high potential yield under normal or optimum growing condition also somehow results in improving yield in a high moisture stress environment. The soybean yield under both the growing environmental conditions had a significant correlation with all the indices of high soil moisture stress. Similar results were also recorded by (Choudhary *et al*., 2017) in fenugreek and (Anwar *et al*., 2011) in wheat crops.

Table 5. Correlation coefficients between soybean yields and high soil moisture tolerance indices

Variables	Y_s	Y_{ns}	TOL	MP	SSI	YI	GMP	YSI
Y_s	1							
Y_{ns}	0.580**	1						
TOL	-0.403**	0.511**	1					
MP	0.881**	0.896**	0.077	1				
SSI	-0.349*	0.532**	0.966**	0.119	1			
YI	0.991**	0.586**	-0.386**	0.881**	-0.331**	1		
GMP	0.880**	0.897**	0.080	1.000**	0.125	0.878**	1	
YSI	0.329*	-0.545**	-0.959**	-0.137	-0.993**	0.316*	-0.134	1

Note: Y_{ns}: *yield under normal condition.* Y_s: *yield under high soil moisture stress condition. TOL: stress tolerance. SSI: stress susceptible index. YSI: yield stability index. MP: mean productivity. GMP: geometric mean productivity. YI: yield index. * and ** indicate significance at p < 0.05 and p < 0.01, respectively.*

Conclusion

From this study, it can be concluded that soybean cultivars namely TGX 1990–94F, G–1873 and Kavre were more suitable in two different conditions (high and normal soil moisture). The cultivars TGX 1990–94F and LS–77–16–16 were resistant to high soil moisture stress or more stress tolerance, while SBO–115 and TGX 1990–94F found more suitable for high soil moisture stress condition. Moreover, the results of correlation indicate that the selection of soybean cultivars based on the stress indices MP, YI and GMP can be used in the selection of suitable cultivars for both the environmental conditions.

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