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Research Article

Exogenous application of potassium fertilizer alleviates the detrimental effect of waterlogging on soybean

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ABSTRACT

A field trial was laid out to mitigate the detrimental consequences of waterlogging (WL) on morpho-physiology and productivity of soybeans through potassium (K) application. Soybean genotypes AGS383 and G00166 were tested against 4 days of WL at the flowering stage. The K fertilizer was applied as (i) basal (full dose) and (ii) basal (50%) + top dress (50%) after the termination of a flood. The experiment's results showed that the WL negatively affected leaf greenness, water and chlorophyll (Chl) content, plant height, nodule and pod production, and soybean seed yield. However, the split application of K fertilizer minimized the detrimental effect of WL in the case of AGS383. This genotype produced taller plants, contained more Chl and water, higher nodules, bold seeds, and accumulated higher amounts of mineral nutrients in their grains under WL condition with K as basal + top dress after the termination of a flood.

Introduction

Soybean (*Glycine max* L.), an important legume and oilseed crop, contains protein, oil, carbohydrate, Ca, P, and vitamins (Mannan and Mamun, 2018; Yasmin et al., 2022; Dola et al., 2022). Phenolics, vitamins, antioxidants, dietary fiber, flavonoids, minerals, pigments, protein, and carbohydrates can be obtained from plant sources (Fatema et al., 2023). It has good nitrogen (N)-fixing ability (17-127 kg N ha^{-1} $year^{-1}$), which plays an irreplaceable role in the sustainable agricultural system (Messina, 1997). Soybean seeds also contain macronutrients, minerals, vitamins, folic acids, and secondary metabolites (Saki and Kogiso, 2008). Consuming soybeans reduces cancer, cholesterol, osteoporosis, and heart disease (Birt et al., 2004). Due to its wide range of adaptability and commercial value,the role of soybean in oilseed production increased from 160 million (m) tons on 70 m ha in 1998 to 350 m tons on 125 m ha in 2018 worldwide (FAOStats, 2021).

In Bangladesh, it has been cultivated since early 1970s in the greater Noakhaliand the area under soybeancultivation has expandedtragicallyfrom only 5000ha in 2005 to 62508ha in 2018-2019 (BBS, 2020)in the districts of Bhola, Patuakhali, Faridpur, and even in the northernpart of Bangladesh. It is mostly sown in January and harvested in April (Akand et al., 2018). However, the crop suffers from excess soil moisture due to a change in rainfall pattern, which is the consequence of recent climate change. Cyclone *Nada* in early November of 2016 caused heavy rains, which delayed soybean sowing. Similarly, soybean was damaged due to heavy rains in April 2017. In 2020, cyclone Amphan hit the southern part of Bangladesh on 20th March and damaged standing crops seriously.

Waterlogging (WL) is a critical problem in some parts of Jashore, Satkhira, Khulna, Bhola, Patuakhali, and Faridpur districts of Bangladesh. Monsoon rains are

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responsible for WL in crop fields of these southern districts, which causes widespread damage to crops. The growth and development of soybean is restricted under WL condition. WL also causes chlorosis and stunting, resulting in yield loss of soybeans (Tewari and Arora, 2016). Soil WL primarily inhibits crop growth and yield by initiating hypoxia conditions (Yin et al., 2009). Under hypoxia conditions, the growth pattern of plants depends onspecies type and survival mechanism (Nagai et al., 2010). Abiotic stress deteriorates the productivity of crops by producing oxidative damage and the creation of reactive oxygen species (ROS), which eventually cause damage in membrane, DNA, and proteins, create an imbalance in nutrients, and attenuation of photosynthetic rates and change color pigments (Sarker and Oba, 2020). The plant under stress conditions has boosted enzymatic and non-enzymatic antioxidants to alleviate ROS (Hassan et al., 2022).

Linkemer et al. (1998) observed a 30% yield loss at the early growth stage and a 93% yield loss at the reproductive stage. The WL hindered growth, dry matter production, and pod formation, resulting in lower yield (Hasanuzzaman et al., 2016). It also inhibited photosynthesis by closing stomata, degrading Chl leaf senescence (Ahmed et al., 2013). WL at the vegetative stage caused a yield loss of up to 18% worldwide (Komatsu et al., 2013).

Nutrient element K has a significant role in increasing the tolerant capacity of plants against various environmental stresses. It helps the plants overcome stress, disease, and pest infestation and take balanced nutrients. Plants deficient in K cannot efficiently use water and other nutrients from soil or fertilizer and are less tolerant to stress conditions. Strategic application of K in plants before hypoxia conditions may alleviate nutrient deficiency and can recover from flood damage. It maintains cell turgidity, starch formation and translocation, synthesis of protein and water, and nutrient uptake. It enhances the photosynthesis, translocation of photosynthates and activates enzymes during nodulation (Divitoand Sadras, 2014). It improves productivity (Emmanuel et al., 2021) and grain quality through better uptake of N and P in plants. Under the WL conditions, K uptake is significantly reduced in plants due to root damage (Amin et al., 2017). Therefore, the exogenous application of K after the flood recession might recover the WL damage in soybeans. Keeping these above considerations in view, the present study has aimed to determine the morpho-physiological changes of soybean plants due to WL and to find out the effect of K application after the flood water recession on soybeans' yield performance.

Materials and Methods

Experimental site

An experiment was conducted at the agronomy research field of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur (24°09′ N and 90°26′ E), Bangladesh, from December 2019 to April 2020 (Rabi season). The experimental site was situated at an elevation of 8.4 m from the sea level.

The temperature of the site increases gradually from January to June. Total monthly precipitation was high during January and April, while the minimum was during December, February, and March (Fig. 1). Before experimentation, the soil was analyzed to determine its physicochemical properties of the soil.

Soil pH was measured with a glass electrode in a soil-water mixture with a ratio of 1:2.5 (w/v) (Kalra and Maynard, 1991). Soil organic matter was determined by the Wlkley-Black method (Walkley and Black, 1934); total soil N by the micro-Kjeldahl method (Yoshida et al., 1976);available P by Olsen method (Olsen et al., 1954); exchangeable K by NH_4O-AC extraction method (Helmke and Sparks, 1996); and available S ($CaCl_2$-S) was determined by extracting the soil with 0.15 $CaCl_2$ (Williams and Steinbergs, 1959).

The field contains 40%, 45%, and 15% clay, silt, and sand, respectively, and is classified as silty clay. The soil has pH 6.1, organic matter 1.20%, total N 0.11%, available P 7.21 ppm, exchangeable K 0.19 meq/100 g soil, and available S 11 ppm.

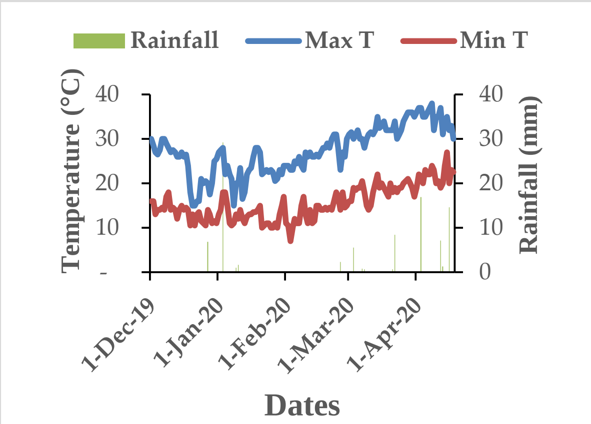

Fig. 1. Temperature and precipitation of the site during the experimental period

Cultural practice and experimental treatments combination

The site was prepared well before seed sowing. The soil was fertilized with urea, triple superphosphate, muriate of potash (MoP), gypsum, and zinc sulfate @ 60, 170, 100, 100, and 10 kg ha^{-1}, respectively. After application, they were incorporated into the soil.

The MoP was applied according to the treatment combination. The size of each plot was 3´4 m^2. Polythene was used to make a ridgearound the plot to restrict lateral water movement. The treatments were Factor A (soybean genotypes): i. AGS383 and ii. G00166, Factor B (WL): i. control (no water logging) and ii. WL for 4 days at the flowering stage), and Factor C (K application): i. basal (100%) and ii. basal (50%) + top dress (50%) after the termination of water logging. A randomized complete block design with three replications was used to conduct the experiment. AGS383 is a bold-grained and medium-statured soybean genotype. This genotype requires 100 to 105 days for maturity. Similarly, genotype G00166 is a short-stature and medium-grained genotype, which takes 80 to 85 days for maturity.

Sowing soybean seeds

Soybean seeds were sown manually in lines, maintaining 30´5 cm spacing. After sowing, the plots were lightly irrigated to confirm uniform seed germination. Thinning was done at the trifoliate leaf stage to maintain uniform and healthy crop growth. Weeding was done to keep the crop free from weeds and pulverized the soil crust for better aeration and conservation of soil moisture. Irrigation was done as and when necessary.

Creation of WL condition

The WL plots were surrounded by 30 cm deep polythene to hold water. The WLtreatment was created at the soybean's flowering stage (60 DAS). The height of flood water was 5 cm above the ground level. The treatments were continued for up to 4 days, and water was drained out. The air temperature was recorded during water logging period. As the duration of WL was 4 days, the measurement was taken from the second day. The data were taken twice daily (9 am and 4 pm).

Collection of leaf greenness, lodging, and growth data

After the termination of flood water, leaf greenness was determined following the method adopted by Akter et al. (2021). Lodging of plants after the recession of water was estimated based on visual observation following the standard evaluation system of IRRI (1988). Data were collected on plant height, soil plant analysis development (SPAD), leaf and stem dry matter (DM), and yield contributing characters were determined. A SPAD meter (model: SPAD-502, Minolta Co. Ltd., Japan) was used to record the SPAD value. A SPAD meter is a meter for determining leaf greenness. The measurements were taken after the recession of flood water. For each treatment, three plants were identified from each replication for taking the SPAD value. The uppermost fully expanded leaveswere selected for taking measurements. Three readings were taken at the basal, middle portion, and terminal part of the leaf and averaged. For growth and DM, estimation sampling was done after the termination of the WL condition. A 100 cm measuring scale was used to record plant height. The leaves plant^{-1} was recorded from the average of five plants.

The leaf fresh weight (FW), turgid weight (TW), and dry weight (DW) were recorded.

To record DM of leaf, nodule and stem parts were dried at 70 °C for 72 h. Relative water content

(RWC) and water saturation deficit (WSD) were determined according to Sangakkara et al. (1996).

$$RWC = \frac{FW - DW}{TW - DW} \times 100$$

$$WSD = \frac{TW - FW.}{TW - DW.} \times 100$$

Harvesting and quantification of yield data

The crop was harvested at physiological maturity when the pods turned brownish and got hard. To record yield components, five plants were collected from each plot. The first and last rows of the plot were avoided to reduce the border effect. The pods were separated and counted. The pod having at least one seed was counted as a filled pod. The length of ten pods was measured, andthe mean value was recorded. After separating the seeds from the pods, they were counted by hand. The weight of 100-seed was recorded for each genotype treatment-wise. The grain and straw yield data were collected from the 1.8 m^2 area of each plot. After collecting plants, seeds were separated, air dried, weighted by an electrical balance, and converted to t ha^{-1} at 14% moisture. The N, P, and K were determined from the collected grain samples. The grain sample was dried at 70 °C for 72 hrs and ground by Wiley Mill. The ground sample was digested in concentrated H_2PO_4, and the micro Kjeldahl method determined the total N concentration (Yoshida et al., 1976). P and K concentrations were analyzed by digesting a 0.2 g grain sample with 6 ml of 5:2 HNO_3: $HClO_4$ (Yoshida et al., 1976). Grain and straw samples from each plot (200 mg) were taken and separately oven-dried at 65 °C overnight to grind in a grinding machine.

Statistical analysis

Recorded data were analyzed using the CropStat 7.2 statistical package program. The treatment means were separated following DMRT at a 5% probability level (Gomez and Gomez, 1984).

Results and discussions

Plant height and dry matter production at the flowering stage

The plant height of AGS383 was 64.66 cm when K was top dressed in control and 55.77 cm when K was applied basally under the WL condition (Table 1). However, the plant height of G00166 was 31.88 cm when K was top dressed in control and 27.86 cm when K was applied basally under the WL condition. Both testing genotypes produced comparatively taller plants when K was top-dressed. However, AGS383 produced long-stature plants as compared to G00166 genotype. The genetic difference was responsible for the different plant heights of the two genotypes. The WL-induced decrease in plant height was noted in soybeans (Mamun et al., 2022). Kim et al. (2018) reported that the reduction in plant height under WL conditions was probably due to oxygen deficiency, anaerobic conditions, less root activity, and inhibition of synthesis and transport of photosynthetic assimilates.

The leaf number of AGS383 was 36.67 $plant^{-1}$ when K was applied basally under the WL condition and 32.00 when K was applied top dressed in control (Table 1). However, the leaf number of G00166 was 58.66 $plant^{-1}$ when K was applied top-dressed under the WL condition and 49.66 when K was applied basally under the WL condition. Under the WL conditions, the leaves' dry matter of both genotypes was higher than the control conditions. The leaf's dry matter of AGS383 was 10.72 g when K was applied basally under the WL condition and 7.40 g when K was applied basally in control. However, the leaf's dry matter of G00166 was 6.88 g when K was applied top dressed in control and 6.07 g when K was applied basally in control. The number of leaves $plant^{-1}$ decreased due to the imposition of WL treatment. However,G00166 produced more leaves than AGS383 under both growing conditions. The WL induced several physiological disturbances in growth (Hasanuzzaman et al., 2016).

However, the application of K after the recession of flood water provokes the production of more leaves $plant^{-1}$ (Table 1). The supplementation of K increased photosynthetic capacity and Chl content reported, resulting in more leaves plant^{-1}.

The nodules plant^{-1} of AGS383 was 39.66 when K was applied basally in control and 13.00 when K was applied basally under the WL conditions. However, the nodules plant^{-1} of G00166 was 24.33 when K was applied top dressed in control and 5.66 when K was applied basally under the WL conditions (Table 2). The nodule dry matter plant^{-1} of AGS383 was 0.29 g when K was applied top dressed in control and 0.06 g when K was applied basally under the WL conditions. However, the nodule dry matter plant^{-1} of G00166 was 0.32 g when K was applied top-dressed in control and 0.03 g when K was applied basally under the WL conditions.

The stem dry matter plant^{-1} of AGS383 was 6.04g when K was applied basally under the WL conditions and 4.71 g when K was applied basally in control. However, the stemdry matter plant^{-1} of G00166 was 3.09 g when K was applied top dressed in control and 2.68 g when K was applied basally in control. The nodule number drastically reduced under WL in both genotypes. However, the top dressing of K reduced the nodule production. The nodule production was reduced by 67 and 70% under basal K application, while 23 and 32% under a top dressing of K treatment in the case of AGS383 and G00166, respectively. The decrease in nodule production under the WL condition may be due to decreased oxygen transport and nutrition uptake and result in root destruction (Dennis et al., 2000).

Under hypoxia conditions, oxygen deficiency, anaerobic conditions, less root activity, and inhibition of synthesis and transport of photosynthetic assimilates are the probable causes of reduced nodule production. However, the top dressing of K fertilizer provoked the production of more nodules in soybean plants (Table 2).

Table 1. Effect of K application on growth of soybean at flowering stage

Soybean genotypes	Potassium application	Plant height (cm)		Leaves plant^{-1}		Leaf weight plant^{-1} (g)	
		Control	WL	Control	WL	Control	WL
AGS383	Basal	63.55^{a}	55.77^{a}	32.00^{b}	36.67^{b}	7.40^{a}	10.72^{a}
	Top dress	64.66^{a}	61.44^{a}	36.66^{b}	37.33^{b}	8.19^{a}	9.98^{a}
G00166	Basal	29.66^{b}	29.33^{b}	51.33^{a}	49.66^{a}	6.07^{b}	6.39^{b}
	Top dress	31.88^{b}	27.86^{b}	55.00^{a}	58.66^{a}	6.88^{b}	6.18^{b}

Similar letters in a column did not differ significantly at the 5% level. WL= Waterlagging.

Table 2. Effect of K application on dry matter production of soybean at flowering stage

Soybean genotypes	Potassium application	Nodule plant^{-1}		Nodule weight plant^{-1} (g)		Stem weight plant^{-1} (g)	
		Control	WL.	Control	WL.	Control	WL
AGS383	Basal	39.66^{a}	13.00^{b}	0.24^{abc}	0.06^{bc}	4.71^{a}	6.04^{a}
	Top dress	35.33^{a}	27.00^{b}	0.29^{ab}	0.11^{abc}	5.04^{a}	5.68^{a}
G00166	Basal	19.00^{b}	5.66^{b}	0.23^{abc}	0.03^{c}	2.68^{b}	2.75^{b}
	Top dress	24.33^{b}	16.33^{b}	0.32^{a}	0.22^{abc}	3.09^{b}	2.50^{b}

Similar letters in a column did not differ significantly at the 5% level. WL= Waterlagging

Leaf greenness and plant lodging after the termination of floodwater

Leaf greenness was observed 7 days after the termination of flood water. In the WL condition, leaf greenness was high in the case of G00166 with a top dressing of K fertilizer (Table 3). The lowest greenness was observed in AGS383 (5) when K was applied basally under the WL condition. AGS383 showed the highest lodging between the two genotypes under the WL condition with basal application of K fertilizer followed by a top dressing of K (Table 3). The lowest lodging was observed in the case of G00166 under the WL condition when K was top-dressed.

The soybean plants were sensitive to WL The symptom of leaf color varied from green to yellow within 4 days of WL stress. In WL condition, leaf greenness was high in G00166 with the dressing of K fertilizer. The greenness of adult leaves was significantly lower in WL condition. Fixing carbon by plant level is detrimental, leading to poorer growth (Zeng et al., 2013). The WL negatively affected soybean genotypes standing in nature. Among the genotypes, AGS383 (50%) showed the highest lodging, followed by G00166 (20%) with a top dressing of K fertilizer. The AGS383 is a taller genotype, while G00166 is a short-stature one. Taller soybean genotypes are more prone to lodging than shorter ones (Todaka et al., 2015).

Chlorophyll and relative water content at the flowering stage

Under both control and WL conditions, the Soil Plant Analysis Development (SPAD) of G00166 was higher than that of AGS383.

There was a general tendency of decreasing SPAD value due to WL irrespective of genotypes (Table 4). The SPAD of AGS383 was 34.86 when K was top-dressed in control. However, the SPAD of G00166 was decreased (35.66) when K was top dressed under the WL condition.

The Relative Water Content (RWC) did not show any clear trend due to the methods of the K application (Table 4). However, there was a general tendency of decreasing RWC due to WL irrespective of genotypes. The RWC of AGS383 was 81.92% when K was applied basally in control and 79.77% when K was applied basally under the WL condition. However, the RWC of G00166 was 83.33% when K was top-dressed in control and 70.88 when K was top-dressed under the WL condition. Under the WL conditions, the Water saturation deficit (WSD) of G00166 was higher than that of AGS383 in the case of both top-dressed and basally K applications. The WSD did not show any clear trend due to the methods of the K application. However, there was a general tendency to increase WSD due to WL irrespective of genotypes. The WSD of AGS383 was 20.23% when K was applied basally under the WL condition and 18.08% when K was applied basally in control. However, the WSD of G00166 was 29.12% when K was applied basally under the WL condition and 16.67% when K was top dressed in control.

Table 3. Effect of K application on leaf greenness and plant lodging of soybean after recession of flood water

Soybean genotypes	Potassium application	Leaf greenness score		Plant lodging score	
		Control	WL.	Control	WL
AGS383	Basal	2.0 (80)	5.0 (50)	0 (0)	5.0 (50)
	Top dress	1.0 (90)	4.0 (60)	0 (0)	3.5 (40)
G00166	Basal	2.0 (80)	4.0 (60)	0 (0)	2.7 (30)
	Top dress	1.0 (90)	3.0 (70)	0 (0)	1.0 (20)

Values within parentheses indicate percent greenness or lodging. WL= Waterlagging

The Chl content of the leaf is highly correlated with leaf greenness. The Soil Plant Analysis Development (SPAD) was measured 7 days after the recession of floodwater to observe the changes in Chl status in the leaves. Our result indicated that soybean leaf Chl content significantly decreased due to WL, resulting in leaf color variation. The general SPAD values were decreased due to 4-days WL Under the WL condition,G00166 had the highest SPAD, while AGS383 had the lowest during the measurement period. Under stress conditions, the Chl content was reduced compared to control (Ferdous et al., 2018).

Rocío et al. (2018) also observed a progressive decline in SPAD values of adult leaves under one week of WL.

This was also supported by the findings of Mondal (2013). The WL inhibits N absorption by the root system, resulting in decreased SPAD of the leaf (Bacanamwo and Purcell, 1999). Under the WL condition, AGS383 exhibited the highest RWC, while G00166 gave the lowest. Both genotypes showed numerically higher RWC under control than WL. It indicated that WL is detrimental to RWC in soybeans. However, the reduction of RWC of G00166 was much higher than that of AGS383 due to WL. It revealed that the RWC of AGS383was less affected by WL than G00166. Therefore, the absolute amount of plant water content decreased. G00166 exhibited the highest WSD under the WL condition, while AGS383 gave the lowest one in control. Both genotypes showed numerically higher WSD under the WL conditions, indicating that the plants are subjected to a greater water deficit. Sterling et al. (2018) found that lodging occurs under the WL condition that hinders water uptake by soybeans. However, water and nutrient uptake by plants was disturbed under the WL conditions, resulting in higher WSD. (Dennis et al., 2000).

Production of pods and seeds plant^{-1}

The pod of AGS383 was 39.66 plant^{-1} when K was top dressed in control and 30.33 plant^{-1} when K was applied basally under the WL conditions. However, the pod plant^{-1} of G00166 was 45.00 when K was applied top-dressed in control and 32.00 when K was top-dressed under the WL conditions (Table 5). The pod length of AGS383 was 4.25 cm when K was applied basally under the WL condition and 3.94 cm when K was applied basally in control. However, the pod length of G00166 was 4.34 cm when K was top-dressed in control and 3.66 cm when K was applied basally under the WL condition (Table 5). The seed number of AGS383 was 2.73 pod^{-1} when K was applied basally under the WL condition and 2.65 pod^{-1} when K was top dressed in control. However, the seed plant^{-1} of G00166 was 2.73 when K was top-dressed in control and 2.00 when K was applied basally under the WL condition.

Table 4. Effect of K application on chlorophyll, RWC, and WSD of soybean at flowering stage

Soybean genotypes	Potassium application	SPAD value		RWC (%)		WSD (%)	
		Control	WL.	Control	WL.	Control	WL
AGS383	Basal	34.66^{b}	32.60^{b}	81.92^{a}	79.77^{ab}	18.08^{a}	20.23^{ab}
	Top dress	34.86^{b}	33.60^{b}	79.93^{ab}	81.01^{ab}	20.07^{ab}	18.99^{ab}
G00166	Basal	39.06^{ab}	39.97^{a}	76.05^{ab}	74.51^{ab}	23.95^{ab}	25.49^{ab}
	Top dress	41.36^{a}	35.66^{b}	83.33^{a}	70.88^{a}	16.67^{a}	29.12^{a}

Similar letters in a column did not differ significantly at the 5% level. SPAD = Soil Plant Analysis Development; RWC = Relative Water Content; WSD = Water Saturation Deficit. WL= Waterlagging.

The number of pods and seeds plant^{-1} are the yield contributing characteristics of soybean. In this study, the production of pods and their length were reduced due to WL in soybeans. Growth and pod formation weredisturbed under WL conditions (Ahmed et al., 2020; Islam et al., 2014; Sathi et al., 2022). However, the genotype G00166 produced more pods plant^{-1} and longer-sized pods when K was applied after the flood recession. This finding was similar to Vyas et al. (2007) and Alam et al. (2009).

Grain and straw yield of soybean

The 100-seed weight of AGS383 was 19.94 g when K was top-dressed under the WL condition and 14.34 g when K was top-dressed under the control (Table 6). However, the 100-seed weight of G00166 was 11.81 g when K was applied basally under the WL condition and 9.66 g when K was top dressed in control.

Under the flooded condition, the 100-seed weight of soybean was more than the control condition when K was both top dressed and basally applied. This finding did not match the findings of Ara et al. (2016), who found that 100-seed weight decreased when the plants were subjected to WL stress. Ahmed et al. (2013) reported that the individual seed weight of maize and soybean was increased by 8 and 4%, respectively, under heavier K application. It may be due to increased plant photosynthetic activity and sink capacity by applying K, as reported by Alam et al. (2009) and Ahmed et al. (2020). However, the seed size of AGS383 was bigger than G00166. The weight of individual seeds is a genetically regulated character, and AGS383 has a bigger-sized seed.

The seed yield of AGS383 was higher under control than WL conditions in both modes of K application. The seed yieldof AGS383 was 2.61 t ha^{-1} when K was top dressed under the control condition and 1.52 t ha^{-1} with basal K application in WL. However, the seed yieldof G00166 was higher at 1.40 t ha^{-1} when K was applied basally in control and 1.05 t ha^{-1} when K was top dressed under the WL. The straw yieldof AGS383 was 1.56 t ha^{-1} when K was applied basally under the WL condition and 1.43 t ha^{-1} with basal K application in control. However, the straw yieldof G00166 was 0.79 when K was top dressed under the WL condition and 0.72 t ha^{-1} when K was applied basally under the WL condition (Table 6). Under the WL conditions, grain yield was drastically reduced. The reduction of yield contributing characters under WL resulted in lower yield. The yield components of mungbean were also affected by WL, as reported by Islam et al. (2014), resulting in lower yield (Amin et al., 2017). However, the split application of K improved grain yield in the case of AGS383 under both growing conditions. In this experiment, AGS383 produced 2 and 15% higher grain under the control and WL conditions, respectively, when K was applied after the recession of flood water. It indicated that the detrimental effect of flooding K fertilizer can be reduced. This finding also agreed with the result of Vyas et al. (2007). Application of K increased test weight and grain yield (Uddin et al., 2013) because photosynthetic activity, translocation, and metabolism of carbohydrates are influenced by K (Lu et al., 2016). The genotype AGS383 yielded 1.43 and 1.45 t ha^{-1} straw in the K basal and split application, respectively, under control.

Table 5. Effect of K application on pod and seed production of soybean at harvest

Soybean genotypes	Potassium application	Pod plant^{-1}		Pod length (cm)		Seeds pod^{-1}	
		Control	WL	Control	WL	Control	WL
AGS383	Basal	34.00^{a}	30.33^{ab}	3.94^{a}	4.25^{bcd}	2.66^{ab}	2.73^{a}
	Top dress	39.66^{ab}	34.00^{ab}	4.04^{ab}	4.24^{bcd}	2.65^{ab}	2.60^{abc}
G00166	Basal	44.00^{ab}	37.66^{ab}	3.76^{ab}	3.66^{cd}	2.26^{bcd}	2.00^{d}
	Top dress	45.00^{ab}	32.00^{b}	4.34^{abc}	3.81^{d}	2.73^{a}	2.20^{cd}

Similar letters in a column did not differ significantly at the 5% level. WL= Waterlagging

Nutrient concentration in soybean grain

The WL can lead to nutrient deficiency, particularly in N, K, and P in various plant species. Soil WL causes a significant decrease in K uptake in plants due to reduced root activity (Amin et al., 2017) as a reason the plant shows wilting. In this experiment, both genotypes absorbed more nutrients under the WL condition than control (Table 7).

The N concentration in the grains of AGS383 was 6.48 and 6.61% under the WL condition when K was applied basally and top dress, respectively. This genotype accumulated 5.48 and 5.35% N in grain when K was top dressed. Under the control condition, the P concentration was 0.44 and 0.46% in AGS383, while 0.49 and 0.58% in G00166 when K was applied basally and top dressing, respectively. G00166 absorbed 3.22 and 3.13% K under WL and 2.75 and 3.05% under control with basal and split application of K fertilizer, respectively (Table 7). The application of K improved the total amount of N in plants, as reported by Ahmed et al. (2013). Fixed ammonium ions were released from the soil in the presence of K, which favors plants to accumulate a higher amount of N. Therefore, plants' N, P, and K content increased due to applying K (Ali et al., 2019). Board (2008) reported that the effects of WL on P were not mentionable. Energy is essential in the root system for the active transportation of different nutrients (Mohammadi, 2009).

Under drought or WL conditions, the energy in the root system is reduced, and transportation of N, P, and K is suppressed (Rima et al., 2019; Vodnik et al., 2009). N, P, and K concentrations were higher under the WL condition in both genotypes. The exogenous application of K fertilizer improves N uptake when plants are subjected to WL conditions (Elzenga and Veen, 2010). Under the WL condition, plant growth, pigment content, and nutrient uptake by roots improve when K is applied as a supplement (Solaiman et al., 2007).

Table 6. Effect of K application on grain and straw yield of soybean at harvest

Soybean genotypes	Potassium application	100-seed weight (g)		Grain yield (t ha^{-1})		Straw yield (t ha^{-1})	
		Control	WL	Control	WL	Control	WL
AGS383	Basal	14.36^{b}	19.76^{a}	2.56^{a}	1.52^{c}	1.43^{a}	1.56^{a}
	Top dress	14.34^{b}	19.94^{a}	2.61^{a}	1.75^{b}	1.45^{a}	1.44^{a}
G00166	Basal	10.13^{cd}	11.81^{c}	1.40^{c}	1.06^{d}	0.76^{b}	0.72^{b}
	Top dress	9.66^{d}	11.02^{cd}	1.08^{d}	1.05^{d}	0.73^{b}	0.79^{b}

Similar letters in a column did not differ significantly at the 5% level. HL = Waterlogging.

Table 7. Effect of K application on the nutrient accumulation in grain of soybean at harvest

Soybean genotypes	Potassium application	Nitrogen (%)		Phosphorus (P, %)		Potassium (%)	
		Control	WL	Control	WL	Control	WL
AGS383	Basal	5.48^{c}	6.48^{b}	0.44^{b}	0.53^{ab}	2.75^{d}	2.83^{cd}
	Top dress	5.35^{d}	6.61^{a}	0.46^{ab}	0.45^{ab}	2.95^{c}	2.73^{d}
G00166	Basal	4.85^{c}	5.07^{c}	0.49^{ab}	0.52^{ab}	2.75^{d}	3.22^{a}
	Top dress	4.79^{c}	5.29^{d}	0.58^{a}	0.57^{ab}	3.05^{b}	3.13^{a}

Similar letters in a column did not differ significantly at the 5% level. WL= Waterlagging

Conclusions

Flooding negatively affected leaf greenness, chlorophyll content, relative water content, plant height, nodule, pod number, and grain and straw yield of soybeans. The detrimental effect of flooding was minimal when potassium was applied 50% during final land preparation and 50% after the recession of flood water. It could be concluded that AGS383 could be cultivated as a relatively high-yielding soybean genotype in waterlogging conditions for 4 days following potassium application as 50% during final land preparation and 50% after the recession of flood water.

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Declaration of conflicting interest

The authors have no conflicts of interest to declare.

Author's Contributions

MAA Mamun contributed to the conceptualization, supervision, data analysis, and manuscript drafting; M.M. Hossen carried out the field experiment, collected data, and prepared the table and graphs; M.M. Rahman and M.A. Karim contributed to the methodology and editing of the manuscript.

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