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Agronomic response of soybean to first and second cropping season cultivation in different agro-climatic zones in Sierra Leone

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Key words: Soybean, Cropping season, Agro-climatic zone, Agronomic traits.

Abstract

Field experiments were conducted in 2012 and 2013 rainy season to evaluate the agronomic response of soybean to first and second cropping season cultivation in different agro-climatic zones in Sierra Leone. The experimental design was a randomized complete block in a split-plot arrangement with three replications. Cropping seasons (first and second) and soybean genotypes (TGx 1448-2E and TGx 1904-6F) were considered as the main and subplots respectively. Soybean seeds were planted on June 28 in the first season and September 05 in the second season. In both years, cropping season had a significant effect ($p < 0.05$) on the agronomic traits of soybean in all the locations. Shifting soybean cultivation from the first to second cropping season significantly decreased field emergence by 40.5-47.4%, number of nodules per plant by 28.6-32.5%, above-ground biomass by 42.5-49.1%, maturity by 11-14 DAP, grain yield by 57.8-64.5% and seed size (small seeds: seed size factor > 21). However, germination percentage significantly increased by 102.7-127.7%. Based on these results, cropping season posed a trade-off between first season producing better plant growth and high grain yield and second cropping season producing good seeds. For grain and seed production, cultivation of soybean in different agro-climatic zones in Sierra Leone should be done in the first and second cropping season respectively.

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Introduction

Soybean (*Glycine max* Merill L) grows within a wide range of agro-ecological zones worldwide (Scott, and Aldrich, 1983). However, individual soybean genotypes often show restricted adaptation to specific agro-climatic environments (Dlamini, 2015) as each soybean, genotype responds differently to changes in environmental conditions where the crop is been grown (Sadeghi, and Niyaki, 2013). Therefore, a slight change in the growing environment of soybean greatly affects the growth and development of its vegetative and reproductive components (Shegro *et al*, 2010). In this regard, the breeding unit of the International Institute of Tropical Agriculture (IITA) has made a remarkable improvement in the development of soybean genotypes with desirable agronomic traits within a range of maturity groups for cultivation mainly in the moist savannah, Sudan savannah and mid-altitude agro-ecological zones in Africa (Tefera, 2011). Sierra Leone falls within the humid tropics and its physical region is delineated by five agro-climatic zones (coastal plains, rain forest, savannah woodland, transitional rainforest, and hills and mountains) based on vegetation and the average duration of the rain-fed growing period (UNDP and FAO, 1979). The climate of Sierra Leone is tropical with a distinct dry season (November – April) and a rainy season (May – October). Farming activities are predominantly carried out during the rainy season as irrigation facilities are not in existence on smallholder farms. The rainy season is further divided into the first and second cropping season. The ideal planting time for the first cropping season is mid-May to mid-July. Long and short duration crops are cultivated during the first cropping season. The ideal planting time for the second cropping season is mid-August to mid-September. Short duration crops which require relatively dry periods at maturity are cultivated during the second cropping season.

The maturity period of soybean varieties in Sierra Leone ranges from 3.5–4.5 months. This permit one crop cycle of soybean within a year under rainfed conditions. Farmers in Sierra Leone plant soybean in the second cropping season, towards the end of August to early September. The quantity of water required for soybean growth and development under rain-fed conditions is determined by the amount of rainfall during its growth period. The total rainfall requirement for maximum productivity of soybean varies between 450 and 800 mm (Makbul *et al.*, 2011). Due to the consistent decline in rainfall, soybean plants cultivated during the second cropping season are subjected to soil moisture deficits and soil moisture deficits during.

The vegetative and reproductive growth stages in soybean can significantly affect field establishment, nodule formation, crop biomass, maturity period, grain yield and seed size (Mimi *et al.*, 2016). Research information in major soybean growing regions has shown that, planting soybean early, i.e. at that start of the rainy season increase soybean growth and yield when compared to late planting (Bruns, 2011, Ngalamu *et al.,* 2012 and Matsuo *et al.*, 2016). However, research information on the response of soybean agronomic traits to early planting i.e. first cropping season is limited in Sierra Leone. Therefore this study was conducted to determine the agronomic response of soybean genotypes to first and second cropping season cultivation in different agro-climatic zones in Sierra Leone.

Materials and methods

Experimental sites

The research was conducted at the Sierra Leone Agricultural Research Institute on-station sites in Rogbasha (N 08.76625°; W 011.98317°), Sumbuya (N 08.04088°; W 011.78955°) and Serabu (N 07.85249°; W 011,27757°) respectively, representing the savannah woodland (SW), transitional rain forest (TRF), and rainforest(RF) agro-climatic zones. Table 1 shows the major characteristics of the savannah woodland, transitional rainforest, and rainforest agro-climatic zones in Sierra Leone (UNDP and FAO, 1979).

The soils at the experimental sites were homogenous with no signs of physical degradation. The soils were loamy sand, acidic, low available phosphorus and soil organic carbon (Table 2).

Rainfall at the experimental sites was unimodal with the highest rainfall occurring in August. A standard rain gauge (Model: SRG, HyQuest Solutions) was mounted at each site to collect daily rainfall during the experimental period. The total and mean monthly rainfall for each year and site are presented in Table 2.

Table 1. Characteristics of the agro-climatic regions.

Characteristics	Agro-climatic Zones		
	Savannah woodland (SW)	Transitional rainforest (TRF)	Rainforest (RF)
Dominant landform	Drainage depressions, undulating plains, low plateau, and hills	Plateau with undulating high-lying plains, rolling hills.	Plateau with undulating plains, rolling plains and hills.
Altitude (m)	150-300	150-300	300-600
Mean temperature. (OC)	28.2	28.5	28.6
Average length of growing period (days)	255 ± 10	270 – 300	314 ± 9
Dominant vegetation	Lophira Savannah, Savannah woodland, mixed tree Savannah upland grassland and forest regrowth.	Savannah woodland, montane grassland and forest regrowth	Forest and forest regrowth

Table 2. Soil properties and rainfall distribution at the experimental sites.

Soil properties and rainfall distribution	Rogbasha (SW)		Serabu (RF)		Sumbuya (TRF)	
	2012	2013	2012	2013	2012	2013
Soil properties						
Texture	Loamy sand	Loamy sand	Loamy sand	Loamy sand	Loamy sand	Loamy sand
Soil organic carbon (%)	1.2	1.4	1.3	2.1	2.3	1.9
pH (1:2:5)	4.8	4.9	5.2	5.0	4.7	4.9
Available phosphorus(µgPg-1)	6.5	5.1	2.3	2.7	5.4	4.9
Rainfall (mm)						
June	201	247	103	334	171	263
July	605	512	363	443	531	438
August	755	703	576	788	631	531
September	476	389	527	568	387	474
October	392	288	344	200	321	286
November	114	26	186	35	188	15
December	0	0	10	37	8	0
Total	2543	2165	2109	2405	2237	2007

SW: savannah woodland, RF: rainforest, TRF: transitional rainforest.

Experimental design and treatments

The experiment was laid out in a randomized complete block design in a split-plot arrangement with three replications. Cropping seasons (first and second) and soybean genotypes (TGx 1448-2E and TGx 1904-6F) were considered as the main and subplots respectively. In 2012 and 2013, the soybean seeds were planted on the June 28 and September 05 in the first and second cropping season respectively. TGx 1904-6F and TGx 1448-2E are medium and late maturing soybean genotypes respectively. Each subplot was 12m^2 (3m x 4m).

Cultural practices

The land was prepared manually for planting. Each subplot consisted of six rows of soybean planted 0.5m between rows and 0.1m between plants. Two soybean seeds, inoculated with *Rhizobium* species were planted per hill, giving a population of 400.000 plants per hectare. Basal application of 30kg ha^{-1} of single super phosphate (SSP) was applied in a 2-cm deep trench, 10cm away from the planting line. The plots were kept weed-free by regular hoe weeding.

Data Collection

Field emergence in soybean was determined on the 14th day after planting by counting the number of emerged seedlings in the two middle rows in each treatment plot. The number of emerged seedlings were expressed as a percentage of the expected number of emerged seedlings. At mid podding, a sample area of 1m^2 (2m x 0.5m) was established 0.5m from each treatment plot to assess for nodulation and biomass. Ten plants were gently removed in a way that prevents the detachment of nodules. The average number of nodules per plant was determined by dividing the total number of nodules by 10. All the plants from the sample area were harvested and the mass (kg) determined using a sensitive digital scale (Model: SKX8200, OHAUS). 0.2kg sample of harvested plants was oven dried to constant mass for each treatment plot and the mass recorded. Above-ground biomass (kg ha^{-1}) was calculated as follows:

Above-ground biomass (kg ha^{-1})=

$$\frac{\text{MDS (kg) x MFH (kg) x10,000 m2}}{\text{0.2kg x 1m2 x 1ha}} \quad (1)$$

Where,

MDS = mass of the dry sample, MFH = mass of fresh sample from 1 m^2 sample area.

At full maturity, a sample area of 4m^2 (2m x 2m) was established, 0.5 m from each treatment plot borders to collect harvest data. Grains harvested from the sample area of each treatment plot were sun-dried to 10% moisture content and mass determined on a sensitive scale (Model: SKX8200, OHAUS). Grain yield was calculated as follows:

Grain yield (kg ha^{-1}) =

$$\frac{\text{Mass of sun−dried seeds x 10,000m2}}{\text{4m2 x 1ha}} \quad (2)$$

Seed size was determined by calculating the seed size factor. A seed size factor 15 (2,500 seeds per pound), 18 (3,000 seeds per pound) and 21 (3,500 seeds per pound) represent large, normal and small seeds respectively Casteel (2012). A sample of 0.1 kg from the sun-dried seeds of each treatment was counted and the number used to calculate the seed size factor as follows:

Seed size factor =

$$\frac{\text{0.453592kg x number of seeds 0.1kg−1 x 18}}{\text{0.1kg x 3,000}} \quad (3)$$

Where: 0.453592 = conversion ratio from pounds to grams, 18 = seed size factor for normal seeds, 3,000 = number of normal seeds per pound, 100g = mass of the sampled seeds.

Seed germination was determined under laboratory conditions at the Njala Agricultural Research Centre. Four samples of 100 seeds each were randomly selected from each seed lot and placed in Petri dishes (diameter = 14cm) with moist filter paper for the germination test. Germination was determined as the percentage of seeds producing normal seedlings. Normal seedlings were those that produce a vigorous set of primary and secondary roots; have a healthy hypocotyl, epicotyl, and cotyledon; and produce a healthy shoot meristem. The number of germinated seeds was recorded on the 10th day and the germination percentage follows:

Germination (%) =

$$\frac{\text{Number of germinated seeds on the 10thday x 100\%}}{400} \quad (4)$$

Data analysis

Analysis of variance (ANOVA) was performed for each location using the PROC MIXED procedure of SAS 9.4. Year, cropping season, soybean genotypes and their interactions were considered as fixed effects in determining the expected mean square and appropriate F-test whilst replication was considered as a random effect. Means were separated using the LSMEANS statement of PROC Mixed code of SAS with option pdiff at $P \leq 0.05$ which calculates the standard error of the difference (SED) between two least square means. PROC CORR of SAS 9.4 (SAS Institute, 2012) was used to calculate Pearson's correlation coefficient among the agronomic traits measured.

Results and discussion

Field emergence (%)

At each location, year and cropping season had a significant effect on soybean emergence on the 14th day after planting, however, the effect of genotypes was not significant ($P > 0.05$). Field emergence of soybean seedlings in 2012 was significantly higher than in 2013. Shifting soybean cultivation from the first to the second cropping season decreased the soybean emergence by 44.4% at Rogbasha, 47.4% at Serabu and 40.5% at Sumbuya (Table 3).

Similar results of a decrease in soybean emergence due to late planting in the second season have been reported (Egli and Cornelius, 2009). Soybean germination and emergence can be higher under favourable soil conditions of temperature, moisture, and oxygen. These conditions are highly influenced by the amount of rainfall at the time of planting and seedling establishment. The soil conditions in the first cropping season may have favoured soybean germination and emergence. The onset of the second cropping season i.e. end of August to early September coincides with high rainfall resulting in excess moisture in the pore spaces in the soil. This condition does not favour optimum germination and emergence of soybean. Optimal levels of soil moisture could maximise soybean seedling emergence (Chen, and Wiatrak, 2010).

Table 3. Effect of year and cropping season on field establishment (%) of soybean.

Treatments	Rogbasha (SW)	Serabu (RF)	Sumbuya (TRF)
Year			
2012	72.4	69.4	71.0
2013	65.9	65.8	64.8
F-test (p value)	0.0072	0.0265	0.0255
SED	2.1	1.5	2.5
Cropping season			
First	88.9	88.6	85.2
Second	49.4	46.6	50.7
F-test (p value)	<.0001	<.0001	<.0001
SED	2.1	1.5	2.5

SW: savannah woodland, RF: rainforest, TRF: transitional rainforest, SED: standard error of the difference between two least square means at 5% probability.

Nodulation at mid-podding

At each location, cropping season had a significant effect on soybean nodulation. The average number of nodules in the first season was higher than the second season. Shifting soybean cultivation from the first to second cropping season decreased the number of nodules per plant by 32.5% at Rogbasha, 30.4% at Serabu and 28.6% at Sumbuya (Table 4). Similar reductions in the number of nodules per plant due to late planting have also been reported in another study (Asim *et al*, 2003).

The significant reduction in the number of nodules per plant in the second cropping season could be associated with water deficit. Water deficit during growth and development in soybean can negatively affect nodulation and nitrogen fixation (Serraj and Sinclair, 1998). The soybean plants cultivated during the second cropping season were exposed to soil water deficit, due to the gradual decline in rainfall in September and subsequent months, thus subjecting the soybean plants to soil water deficit.

Table 4. Effect of cropping season on soybean nodulation and above-ground biomass at each location.

	Nodulation (average module plant^{-1})			Above ground biomass (kg ha^{-1})		
Cropping season	Rogbasha (SW)	Serabu (RF)	Sumbuya (TRF)	Rogbasha (SW)	Serabu (RF)	Sumbuya (TRF)
First	51.0	50.9	49.5	3598.7	3551.5	3464.2
Second	34.4	35.4	35.3	1830.2	2042.4	1767.9
F-test (P value)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
SED	1.3	0.8	1.3	159	278	327

SW: savannah woodland, RF: rainforest, TRF: transitional rainforest, SED: standard error of the difference between two least square means at 5% probability.

Above-ground biomass at mid-podding

At each location, the above-ground biomass in soybean at mid-podding was significantly affected by cropping season. In comparison to the first cropping season cultivation, the above-ground biomass in soybean decreased significantly by 49.1% at Rogbasha, 42.5% at Serabu and 49.0% at Sumbuya when cultivated in the second cropping season (Table 4).

Research finding has earlier shown that early-planted soybean produced higher biomass than the late-planted ones (Pedersen and Lauer, 2004 and Shegro *et al.* 2010). The decrease in soybean biomass when cultivated in the second cropping season could be associated with the change in the climatic environment during the growth cycle of the crop.

In the second cropping season, rainfall consistently declined after the month of August (Table 2) at each location which may have caused water deficit in the soil. Soybean is very sensitive to water stress, soil water deficits during vegetative to pod formation stage can significantly reduce dry matter accumulation (Mimi *et al.*, 2016). In addition, the above-ground biomass in soybean was significant and positively correlated to field establishment ($p < 0.0001$, $r = 0.73$) and nodulation ($p < 0.0001$, $r = 0.74$). The decrease in the value of these traits when cultivated in the second cropping season may have also contributed to the lower above-ground biomass.

Maturity

The maturity period of soybean at each location was significantly influenced by year ($p < 0.0001$), cropping season ($p < 0.0001$), genotype ($p < 0.01$), and the interaction between cropping season and genotype ($p < 0.0001$). At each location, TGx 1448-2E took a significantly longer time to mature than TGx 1904-6F when cultivated in the first cropping season. In the second cropping season, however, the maturity period of both soybean genotypes was not significantly different. Shifting soybean cultivation from the first to the second cropping season significantly decreased the maturity period of TGx 1448-2E by approximately 14 days in Rogbasha and 11 days in Serabu and Sumbuya, whilst the maturity period of TGx 1904-6F decreased by approximately 10 days in Rogbasha and 7 days in Serabu and Sumbuya (Fig. 1). Decrease in the maturity period of soybean due to late planting during the rainy season has been reported in other research findings (Shegro *et al.* 2010 and Shah and Hatam, 1989). The differences in the number of days between TGx 1448-2E and TGx 1904-6W could be attributed to the variability in the genetic attributes between the soybean genotypes. TGx 1448-2E and TGx 1904-6F are late and medium maturing soybean genotypes respectively. The similarity in the number of days to maturity for TGx 1448-2E and TGx 1904-6F, when planted in the second cropping season could be associated with drought stress as rainfall declined towards the end of the growing season at each location. Water stress during the later phases of reproductive stages could reduce the duration of the seed filling stage and consequently shortened the maturation period in late-planted soybean (Meckel *et al.* 1984).

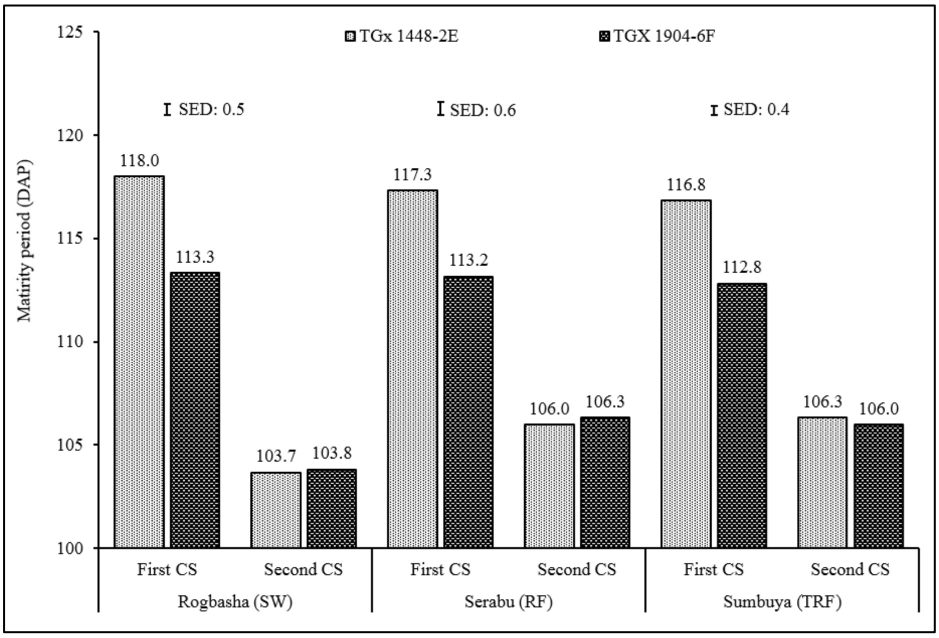

Fig. 1, Maturity period of soybean genotypes in the first and second cropping seasons at each location. SED: standard error of the difference between two least square means at 5% of probability, CS: cropping season, SW: savannah woodland, RF: rainforest, TRF: transitional rainforest.

Grain yield

The grain yield of soybean at each location was significantly influenced by cropping season ($p < 0.0001$). Shifting soybean cultivation from the first to the second cropping season significantly decreased grain yield by 57.8% at Rogbasha, 64.5% at Serabu and 59.1% at Sumbuya (Fig. 2). This result agrees with other research findings of soybean yield decrease due to late planting Popp *et al.* 2002, Khan *et al.*, 2004and Rahman *et al.*, 2006). The significant decrease in grain yield in the second season cultivated soybeans could be associated with the reduction in the field emergence and above ground biomass in soybean. Grain yield was significantly correlated with field emergence ($p < 0.0001$, $r = 0.90$), above-ground biomass ($p < 0.0001$, $r = 0.76$) and maturity period ($p < 0.0001$, $r = 0.77$).

These traits are actually influenced by the agro-climatic factors within the growing environment and any factor that cause a reduction in these traits could also cause a reduction in grain yield.

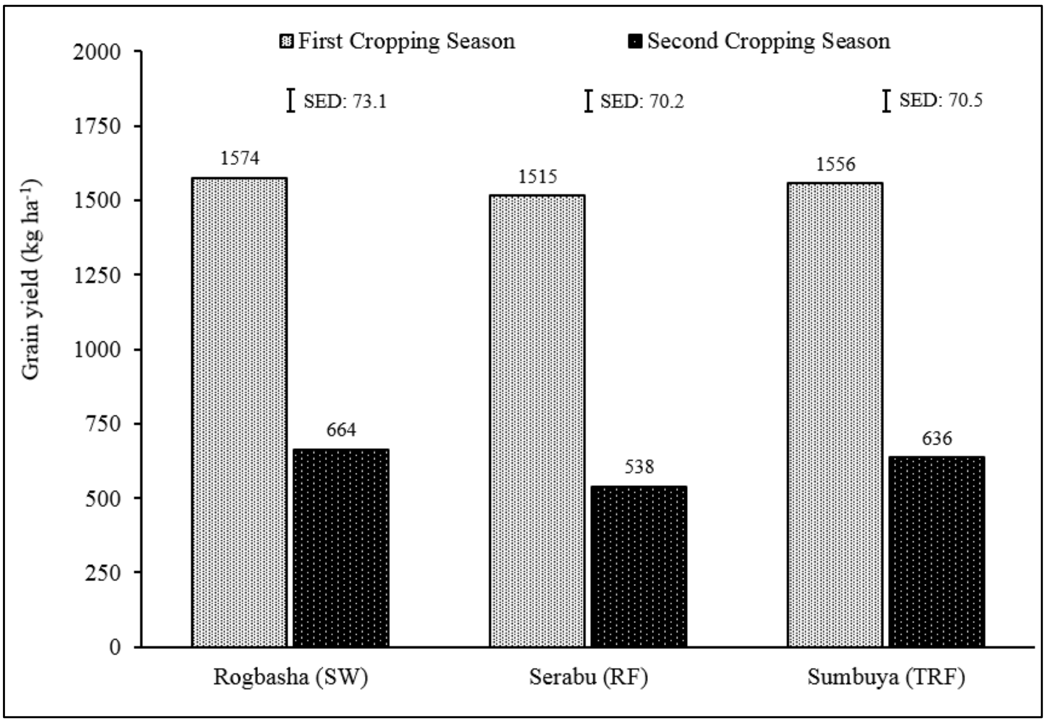

Fig. 2. Grain yield of soybean in the first and second cropping seasons at each location. SED: standard error of the difference between two least square means at 5% of probability, CS: cropping season, SW: savannah woodland, RF: rainforest, TRF: transitional rainforest.

Seed size and germination

Seed size

At each location, soybean seed size factor was significantly influenced by cropping season ($p < 0.0001$) and year ($p < 0.05$). Genotype and the interactive effect of year and cropping season on the seed size factor were however not significant ($p > 0.05$) at each location. Soybean cultivated in the first season produced normal seeds (seed size factor ≈ 18), while smaller seeds (seed size factor: > 21) were produced by those cultivated in the second cropping season (Table 5). Other studies have shown that time of planting could significantly affect the seed size in soybean with the maximum seed size obtained from the earliest planting date (Sadeghi and Niyaki, 2013). The reduction in soybean seed size was probably due to the late season drought, which affected seed development. Reduction in seed size could be associated with moisture deficit during the seed development stage in soybean. Water deficit during the grain-filling stage can negatively affect photosynthesis, sugar production, and translocation of phosphorus to the seed, which may cause a reduction in seed size (Westgate, and Peterson, 1993).

Table 5. Interactive effect of year and cropping season on soybean seed size factor and germination at each location.

	Seed size factor			Seed germination (%)		
Treatments	First CS	Second CS	Mean	First CS	Second CS	Mean
Rogbasha (SW)						
2012	17.9	20.8	19.4	26.7	89.3	58.0
2013	18.6	21.9	20.3	50.3	86.0	68.2
Mean	18.3	21.3		38.5	87.7	
SED (Y)		0.25			2.03	
SED (CS)		0.25			2.03	
SED (Y x CS)		0.36			2.88	
Serabu (RF)						
2012	18.3	20.9	19.6	37.7	89.5	63.6
2013	18.7	21.9	20.3	50.0	88.2	69.1
Mean	18.5	21.4		43.8	88.8	
SED (Y)		0.29			2.80	
SED (CS)		0.29			2.80	
SED (Y x CS)		0.41			3.97	
Sumbuya (TRF)						
2012	17.8	20.9	19.4	36.2	91.3	63.8
2013	18.7	21.8	20.2	49.8	89.0	69.4
Mean	18.2	21.4		43.0	90.2	
SED (Y)		0.09			3.02	
SED (CS)		0.09			3.02	
SED (Y x CS)		0.13			4.27	

CS: cropping season, SW: savannah woodland, RF: rainforest, TRF: transitional rainforest, SED: standard error of the difference between two least square means at 5% probability.

Germination

At each location, germination of soybean seeds was significantly influenced by year ($p < 0.0001$), cropping season ($p < 0.01$) and their interaction ($p < 0.05$). The effect of genotype was however not significant ($p > 0.05$). The germination percentage of the soybean seeds harvested from the second season cultivation significantly increased by 127.7% in Rogbasha, 102.7% in Serabu and 109.7% in Sumbuya when compared to those seeds harvested from the first season (Table 5).

Other research findings also show that the time of planting could severely affect soybean germination (Khalil *et al.,* 2001) and the germination percentage of late planted soybean seeds could be higher than those planted early (Kundu, *et al.,* 2016). The increase in germination percentage of seeds harvested from the second cropping season could be associated with climatic conditions during maturity. Soybean cultivated in the first season reached maturity during high rainfall periods. Repeated wetting and drying of soybean seeds before harvest favour the development of *Phomopsis* seed decay which can significantly affect seed germination Khan *et al.,* 2011).

Conclusions

Cropping season significantly affected the agronomic traits of soybean. Cultivating soybean in the first cropping season led to better field emergence, nodulation, above-ground biomass and grain yield and size whilst second cropping season cultivation produced seeds with high germination percentage. The maturity period of the soybean genotypes was dependent on cropping season. Based on these results, cropping season posed a trade-off between first season producing better plant growth and high grain yield and second cropping season producing seeds with high germination percentage. Therefore, for grain and seed production cultivation of soybean should be respectively done in the first and second season in different agro-climatic zones in Sierra Leone.

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