

Original Research Paper

Correlations between Growth and Yield Parameters of Soybean (*Glycine max* (L.) Merr.) under the Influence of *Bradyrhizobium japonicum* in Kipushi (The Democratic Republic of Congo)

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Abstract: This study aimed to evaluate the correlations between different agronomic parameters and their contribution to soybean performance under *Bradyrhizobium japonicum* influence. The experiment was carried out at Kanyameshi (Kipushi), following a Split Plot design, with three strains of *Bradyrhizobium japonicum* (GraphEx™, *Bradyrhizobium* sp and Sojapak © 50) and four soybean varieties (TGX 1740-7F: V1, PAN 1867: V2, TGX 1880-3E: V3 and LUKANGA: V4). The strongest correlations were obtained between fresh biomass and plant height, the number of stems and collar diameter, fresh biomass and collar diameter, number of stems and plant height, number of roots and number of stems, fresh biomass and number of roots, number of pods and number of leaves. The collar diameter is the most positively correlated parameter with both growth and soybean yield parameters. While lifting rate, collar diameter, plant height, number of stems, number of leaves, fresh biomass, number of nodules and number of pods are the most linked to soybean grain yield. A significant negative correlation was observed between number of leaves and the weight of 100g. Fresh biomass was found to be more predictable, whereas number of leaves is the growth parameter that contributes most to soybean fresh biomass. Based on their decreasing contribution to fresh biomass, the various parameters can be classified as follows: Number of leaves > number of root > plant height > collar diameter. Among examined agronomic parameters, only four contribute directly to the soybean yield, namely number of leaves, number of pods, fresh biomass and collar diameter. By applying *Bradyrhizobium japonicum* to the four soybean varieties, the correlations between observed parameters were enhanced. This study is a major contribution in the conduct of soybean cultivation as it identified the parameters on which the farmer should focus to maximize soybean grain yield.

Keywords: Agronomic Parameters, Soybean Yield, Correlations

Introduction

Soybean (*Glycine max* (L.) Merr.) is one of the most important and widely grown crops in the world. It accounts for 30% of the world's processed vegetable

oil (Graham and Vance, 2003) and provides to the body a range of unsaturated fatty acids important for vitamin intake (Mandimba, 1997; Javaheri and Baudoin, 2001; Javaheri and Baudoin, 2001; Giller and Dashiell, 2007).

Due to multiple constraints, soybean yield is very low in most cropping conditions in Africa. The national average yield varies from one country to other; in DR Congo, it was estimated at 0.56 t. ha⁻¹ in 2014 against to 2.1 t. ha⁻¹ in Zambia (FAO, 2017). A large literature is devoted to the issue through research-based solutions (Hungry and Bohrer, 2000; Hardarson and Broughton, 2003; Amin *et al.*, 2008; Tshibuyi and Kidinda, 2015), the establishment of appropriate strains in specific local conditions (e.g. Bruno *et al.*, 2003; Ferguson *et al.*, 2006; Abaidoo *et al.*, 2007; Ben Tshibuyi and Kidinda, 2015), nitrogen and phosphate fertilization (e.g., Fatima *et al.*, 2007), organic fertilization (e.g., Kasongo *et al.*, 2013) and optimization of planting date (e.g. Baboy *et al.*, 2015). The results of these studies are reported to improve soybean productivity in many countries.

Despite this progress, several uncertainties remain on the links between the different agronomic parameters influencing the performance of soybeans in the province of Upper Katanga, Democratic Republic of Congo. While the type and nature of the link between two variables are generally determined by studying the correlation coefficients. However, it is established that crop yield is complex and correlation studies alone are insufficient. The correlation coefficient is very important for measuring the degree and direction of linkage of different parameters that affect either positively or negatively the yield (Kumar *et al.*, 2013). The need remains to establish the linear regressions in order to obtain a clear understanding of the contribution of each parameter on the total genetic architecture of the yield. In other parts of the world, this theme is widely discussed (Khan *et al.*, 2000; Amanullah and Hatam, 2001; Peluzio *et al.*, 2005; Chandel *et al.*, 2014; Malik *et al.*, 2011; Mellendorf, 2011; Mbarek *et al.*, 2012; Sokoto *et al.*, 2012; Kuswanto, 2014; Panda *et al.*, 2015).

The objective of this paper is to highlight the correlations between the different agronomic parameters and the contribution of each parameter on the performance of soybean under *Bradyrhizobium japonicum* input. The study tries to answer the following questions: (i) what are the types of correlations between the different soybean growth and yield parameters? (ii) what are the most predictable agronomic parameters to soybean yield? (iii) can the contribution of *Bradyrhizobium japonicum* strengthen correlations among studied agronomic parameters?

Methodology

Study Area

The experimentation was carried out at the experimental site of the Institut National pour l'Étude et la Recherche Agronomique (INERA), located at Kaniameshi in Kipushi territory at 11°45'25' S and 27°16'59' E. Kipushi is located in the province of Upper

Katanga in the Democratic Republic of Congo and belongs to the climatic type Cw6 according to Köppen classification. Mean annual temperature varies around 20°C (Moulaert, 1992). The average annual humidity is 68% with monthly moisture levels ranging from a minimum of 47% in the dry season to a maximum of 86% during the rainy season.

Recent studies by Mukalay (2016), based on fine and detailed analyzes of soil profiles according to current WRB criteria (WRB: FAO, IUSS, 2014), showed that the Upper Katanga agricultural zone contains four soil groups, including the Acrisols found in Kipushi region.

Conduct of the Experiment

The experiment was installed using a Split Plot device with three replicates, using three strains of *Bradyrhizobium japonicum* (GraphExTM, *Bradyrhizobium* sp and Sojapak ® 50) and four soybean varieties (TGX 1740-7F: V1, PAN 1867: V2, TGX 1880-3E: V3 and LUKANGA: V4). The combination of the different strains and varieties resulted in 16 treatments. The planting density was 250000 plants ha⁻¹. Soybean seed inoculation was done at planting for concerned treatments. The follow-up of the experiment consisted of three weeding operations at an interval of two weeks from the planting date.

Statistics

Data from the experiment were submitted to a correlation analysis to determine the Pearson coefficient which defines the nature of the link between two variables. Positively and significantly correlated variables were subjected to linear regression analysis in order to quantify the contribution of each explanatory variable. The influence of *Bradyrhizobium japonicum* on the correlations between agronomic parameters was evaluated using a Principal Component Analysis (PCA). The correlation matrix, regression and PCR were performed using the Munitab17, Excel and Past software, respectively.

Results

Table 1 presents the types of correlations between the different soybean growth and yield parameters. It appears that some parameters are either positively or negatively correlated to others. Some positive correlations are significant while others are not. The same observation is made for negative correlations. The strongest correlations are obtained between FB and PH, NS and CD, FB and CD, NS and PH, NR and NS, FB and NR, NG and NF. This implies that value increase of one of this parameter leads to the increase of the parameter to which it is significantly correlated. In addition, the CD is the most positively correlated with both growth and yield parameters. While the most related to SY are LR, CD, PH, NS, NL, FB, NN and NG.

Table 1: Linear Correlations (Pearson coefficients) between growth and soybean yield parameters. LR: Lifting Rate; CD: Collar Diameter, PH: Plant High, NS: Number of Stems, NR: Number of Roots, NL: Number of Leaves, FB: Fresh Biomass, DB: Dry Biomass, W100g: Weight of 100 seed, NP: Number of Pods, SY: Soybean Seed Yield; NN: Number of Nodules

	LR	CD	PH	NS	NR	NL	FB	DB	W100g	NP	SY
CD	-0.24										
TH	-0.13	0.59***									
NS	-0.04	0.74***	0.72***								
NR	-0.04	0.55***	0.36*	0.71***							
NL	-0.49**	-0.02	0.22	0.23	-0.03						
FB	0.07	0.72***	0.72***	0.97***	0.74***	0.27					
DB	0.09	-0.17	-0.03	-0.08	0.04	0.06	-0.07				
W100g	-0.35*	0.40**	0.29	0.21	0.14	-0.40**	0.19	-0.06			
NP	0.47**	0.01	0.19	0.21	-0.14	0.72***	0.23	0.14	-0.14		
SY	0.35*	0.34*	0.41**	0.32*	0.11	0.48**	0.42**	-0.07	0.20	0.48**	
NN	0.05	0.14	0.29	0.25	0.05	0.19	0.24	-0.01	0.22	0.33*	0.43**

*Significant at $p \leq 0.05$; **Significant at $p \leq 0.01$; ***Significant at $p \leq 0.001$

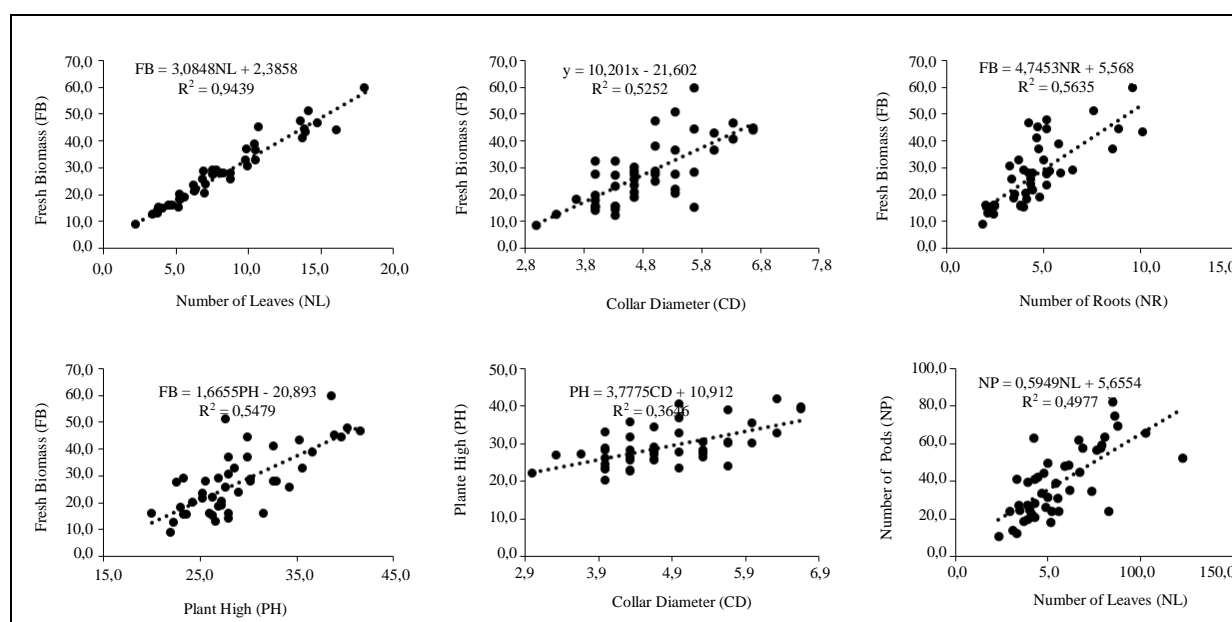


Fig. 1: Linear regression between different soybean growth parameters

A negative correlation is observed between NF and P100g indicating that if the value of one of this parameter increases, the other decreases. The same observation is made between LR and NL, LR and W100g. The results also show that NP and CD are completely independent, the two parameters are not dependent in this study. This concerns all correlations whose value is close to 0.

Figure 1 shows the linear regressions between different soybean growth parameters. As a result, Fresh Biomass (FB) is the most predictable parameter in this study. However, leaf number (NL) is the growth parameter that contributes most to soybean FB. The prediction power indicates that 94% of the FB is explained by the NL. This implies that only 6% of the variance of the FB is not explained by the NL. Another parameter explaining the FB is the Collar Diameter

(CD). This agronomic parameter contributes for more than 52% to FB, with about 48% of the variance of the parameter not explained by the CD. Moreover, the influence of the number of roots (NR) on the biomass is greater than that of the CD. Indeed, the regression coefficient obtained is 0.56. What implies the NR strongly explains the FB and is an important predictor. As for Plant High (PH), observations show that this parameter strongly influences FB, with a regression coefficient of ca. 0.54. This prediction power of the PH is associated with those of NL, CD and NR. These observations imply that improving the performance of these parameters is an effective way to increase soybean FB.

Moreover, PH being a predictor for FB is itself explained at 36% by the CD. Indeed, the CD contributes not only to FB but also the PH. Nevertheless, its contribution on the FB is much higher than that on the PH.

Concerning NL, a most important agronomic parameter of FB, the result indicates that this parameter also explains the Number of Pods (NP) obtained in this study. Indeed, the NP is explained to ca. 50% by the NL. Which implies that any increase in NL is an effective way to increase the number of soybean pods.

Figure 2 shows soybean agronomic parameters that effectively contribute to the crop yield. Indeed, among the agronomic parameters examined, four contribute directly to soybean yield, namely NL, NP, FB and CD. Although the predictive power of all these parameters is less than 25% while increasing their value would explain the yield of soybeans.

For NL, the regression coefficient obtained is 0.22, the increase in NP contributes 20% to soybean yield, whereas, the CD has a predictive power of 12%. FB, a most predictable parameter, appears to be unrelated to soybean yield in this study. The regression coefficient indicates that FB contributes only 4% to soybean SY.

Figure 3 shows the correlations between soybean growth and yield parameters on the one hand and the influence of the *Bradyrhizobium japonicum* and variety effect on these correlations on the other. This principle component analysis (ACP) provides 45% of the information on axis 1 and 25% on axis 2, which represents 70% of information for the entire projection. For the axis 1, the most explanatory variables are the

different treatments T6, T10, T9, T7, T11, T14, T13, T12 and T15. However, the most explicative variables of axis 2 are both the growth and yield parameters of soybean and other treatments including T5, T8, T2, T3 and T4 while T16 is strongly correlated to both axes. NR, CD and W100g are strongly correlated to each other and with axis 1, which implies that they are positively influenced by T16, T6, T14, T13 and T15 while being negatively influenced by T11, T7, T12, T9 and T10.

The DB, NN, SY and NR are strongly correlated to each other and to axis 2. This implies that these parameters are positively influenced by T16, T3 and T4 while being negatively influenced by T5 and T8. In addition, the results show that inoculum supply is an important factor that positively influences soybean growth and yield parameters. Indeed, in the absence of the inoculum, the different treatments negatively influence the growth and yield parameters of soya except for T13 which is positively correlated with axis 1. This implies T13 (control) positively influences NR, CD and W100g while T5 and T9 are negatively correlated to axis 1 and axis respectively. T5 then negatively influences DB, NN, SY, NR, CD and P100g while T9 is negatively correlated to NR, CD and P100g. Positively correlated treatments are similar in terms of their influence on soybean growth and yield parameters.

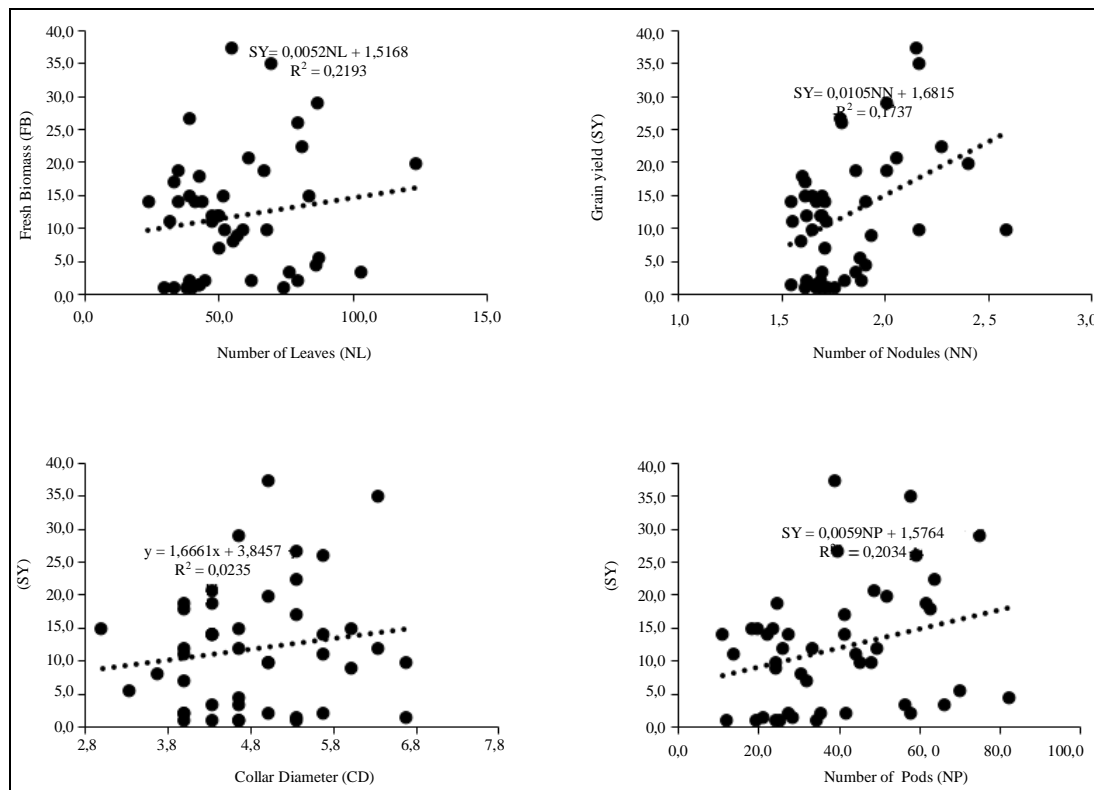


Fig. 2: Regression between some growth parameters and soybean yield

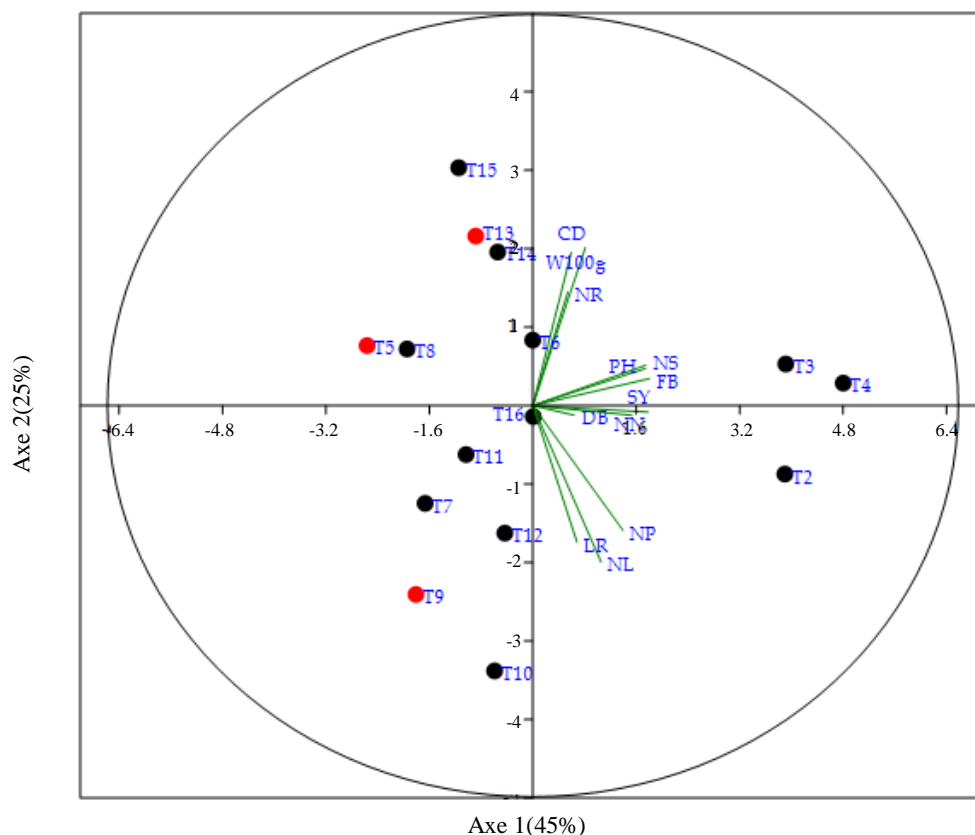


Fig. 3: Influence of inoculation on the correlations between growth and soybean yield parameters. T2: S1V1, T3: S2V1, T4: S3V1, T5: S0V2, T6: S1V2, T7: S2V2, T8: S3V2, T9: S0V3, T10: S1V3, T11: S2V3, T12: S3V3, T13: S0V4, T14: S1V4, T15: S2V4, T16: S3V4

Discussion

In this study, the strongest correlations are obtained between FB and PH, NS and CD, FB and CD, NS and PH, NR and NS, FB and NR, NP and NL. This implies that the value increase of one of this parameter leads to an increase in the parameter to which it is significantly correlated (Malik *et al.*, 2011). Indeed, the positive link between this parameter is an important indicator in the conduct of the soybean crop. From obtained results, the CD is the most positively correlated to both growth and yield parameters of soybean. While the parameters the most correlated to SY are LR, CD, PH, NS, NL, FB, NN and NP. Significant and positive correlations between SY and these parameters were reported by Karnwal and Singh (2009; Mehmet *et al.*, 2009; Maria *et al.*, 2009; Benedict and Uguru, 2011; Malik *et al.*, 2011; Machikowa and Laosuwan, 2011; El-Badawy and Mehasen, 2012; Sarutayophat, 2012; Chandel *et al.*, 2014) and Atanda *et al.* (2014). This implies that poor development of each parameter positively correlated to SY would negatively impact crop productivity.

Moreover, the negative correlation observed between NL and W100g indicates that if the value of one of this

parameter increases, the other decreases. In this context, the NL is the explanatory variable whereas W100g is the explained variable. The fact that an increase in NL that is not necessarily accompanied by efficient translocation of nutrients in seeds could explain this negative correlation. A large increase in NL implies a high utilization of the reproductive energy of the plant, which would limit the amount of energy intended for good seed formation. Other authors have found positive correlations between NL and W100g and explained this by the fact that the strong development of leaf biomass favors a strong interception of light which would result in a high photosynthetic efficiency and better formation of seeds (Kumar *et al.*, 2000; Subhani *et al.*, 2000; Esmail, 2003; Singh *et al.*, 2006; Bilgi, 2006). The observations made in this study would be attributed to environmental conditions that did not favor the synergy between NL and W100g. The results also showed that NP and CD are totally independent, the two parameters are not correlated in this study. This would indicate that regardless of the NP, this cannot be directly attributed to the CD.

Despite the fact that correlations provide necessary information on the types of linkages between variables, the meaning of the link and its quantification are not

clearly defined (Guler *et al.*, 2001; Ulukan *et al.*, 2003; Garcia del Moral *et al.*, 2005). It is thus important to use linear regression between an explanatory variable and an explained variable in order to quantify the extent of the contribution (Chandel *et al.*, 2014). This study showed that FB is the most predictable parameter whereas the NL is the growth parameter that contributes the most to soybean FB. Since FB is directly linked to the vegetative growth of the plant, it makes sense that any better expression of the growth parameters (mainly NL) contributes to the increase of its value. The more leaves there are in a plant, the higher its FB, because in soybean, for example, NL, NR and NS are the main components of FB. Another parameter explaining the FB is CD. This agronomic parameter contributes more than 52% to FB, with about 48% of the variance of the parameter not explained by the CD. Larger organs can store more carbohydrate stores, which are used by young plants at the beginning of the growing period (Chandel *et al.*, 2014). Based on their decreasing contribution on the FB, the various parameters can be classified as follows: NL > NR > PH > CD. This succession shows the most determinant parameters on FB.

For NL, a most important agronomic parameter of FB, the result indicates that this parameter contributes strongly to pod formation. Indeed, the NP obtained is explained to approximately 50% by the NL. Which implies any increase in NL is an effective way to increase the number of soybean pods. This is explained by the role played by leaves through photosynthesis, which would have favoured the formation of pods while disadvantaging the weight of seeds inside the pods. This paradox would be the result of the combination of the genotype and edapho-climatic conditions during the experiment.

Among the agronomic parameters examined, only four contribute directly to the yield of soybeans, NL, NP, FB and CD. Although, the predictive power of these parameters is less than 25%, increasing their value would explain the yield of soybeans. Based on their decreasing contribution, these parameters can be classified as follows: NL > NP > CD > FB. The influence of NL and NP on SY has been reported by several authors (Khan *et al.*, 2000; Mellendorf, 2011). The NL is a parameter that determines the photosynthetic efficiency of a plant and consequently its performance on SY. However, it is influenced by several factors including the environment (Talebi *et al.*, 2010; Mbarek *et al.*, 2012; Chandel *et al.* 2014; Mbah and Eke-Okoro, 2015). Furthermore, NP is one of the most important yield parameters that determine the number of seeds per plant. As for the CD, its contribution to SY would be linked to the fact that more plants are vigorous, more energy is available to be allocated to SY. The FB, a most predictable parameter, appears to be unrelated to soybean yield in this study. The regression coefficient indicates that FB contributes only 4% to SY. This would

be the proof that good vegetative growth is not always synonymous of high grain yield.

By applying *Bradyrhizobium japonicum* to four soybean varieties, the results showed that correlations between observed parameters were strengthened. Indeed, in the absence of the inoculum, the different treatments negatively influence the soybean growth and yield parameters except for T13 which is positively correlated to NR. These observations would be a major indicator of the importance of inoculation in soybean cultivation since, without soybean inoculum, soybean performance is compromised on several parameters. Positively correlated treatments are similar in terms of their influence on soybean growth and yield parameters. These similarities between treatments are the result of genetic factors of the varieties combined with environmental factors that define their expression (Ozveren Yucel *et al.*, 2006; Talebi *et al.*, 2010; Mbarek *et al.*, 2012; Chandel *et al.*, 2014; Mbah and Eke-Okoro, 2015).

Conclusion

This study aimed to evaluate the correlations between different agronomic parameters and their contribution to soybean performance under *Bradyrhizobium japonicum* influence. This study showed that some positive correlations are significant while others are not. The same observation is made for negative correlations. The strongest correlations are obtained between FB and PH, NS and CD, FB and CD, NS and PH, NR and NS, FB and NR, NP and NL. This study also showed that FB is the most predictable parameter whereas the NL is the growth parameter that contributes the most to soybean FB. From the agronomic parameters examined, only four contribute directly to the yield of soybeans, NL, NP, FB and CD. However, their predictive power is low because it accounts for less than 25% of the obtained yield. By applying the *Bradyrhizobium japonicum* to four soybean varieties, the correlations between observed parameters were strengthened.

This study is a major contribution to the conduct of soybean cultivation as it has identified the parameters on which the farmers should focus to maximize the yield of fresh biomass or grain soybean. However, more experiments are needed in other areas of the province of Upper Katanga to highlight the agronomic parameters more sensitive to environmental conditions.

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Author's Contribution

Ben Tshibuyi Kasu-Bandi: Contributed in paper preparation, development and publication.

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Germain Nyembo Kasendue: Contributed in paper preparation and development

Louis Baboy Longanza: Contributed in paper development

Kasongo Lenge Emery: Contributed in paper preparation and development

Antoine Kanyenga Lubobo: Contributed in paper preparation and development

Ethics

Authors declare that there not any conflict of interest or any other ethical issues that may arise after the publication of this manuscript. All data are original from experiments conducted by the Authors of this manuscript.

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