Vol. 12(34), pp. 835-848, 14 September, 2018
DOI: 10.5897/AJMR2018.8899
Article Number: 6923B1258679
ISSN: 1996-0808

http://www.academicjournals.org/AJMR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Microbiology Research

Full Length Research Paper

Predicting maize and soybean crops dry biomass through rhizobacteria microorganisms activity on foliar bio-fertilizer in an arid agro-climate: A multiple linear regression analysis

Noel Dougba Dago[1*], Nafan Diarrassouba[1], Martial Didier Yao Saraka[1], Jean-Luc Aboya Moroh[1], Inza Jesus Fofana[1], Lamine Baba-Moussa[2] and Adama Coulibaly[1]

[1]Unité de Formation et de Recherche (UFR) des Sciences Biologiques, Département de Biochimie-Génétique, Université Peleforo Gon Coulibaly BP 1328 Korhogo, Côte d'Ivoire.
[2]Faculté des Sciences et Techniques, Laboratoire de Biologie et de Typage Moléculaire en Microbiologie, Université d'Abomey-Calavi, Cotonou, Benin.

Received 22 May, 2018; Accepted 4 September, 2018

After previously showing rhizobacteria *Pseudomonas fluorescence* and foliar bio-fertilizer mixture as a suitable practice in improving maize and soybean crops development and dry biomass, this study thus embark on predicting the above-mentioned plants dry biomass feature through their yield and growth parameters by assessing *P. fluorescence* activities on foliar bio-fertilizer in an arid agro-climate. For this purpose, several scripts and functions from our previous computational statistic pipeline, developed in R programming environment were partially used for statistical survey. Several multiple linear regression models have been achieved aimed at understanding the links between maize and soybean crops (i) dry biomass, (ii) yield and (iii) growth features as well as highlights the synergic roles of rhizobacteria microorganisms and foliar bio-fertilizer on that relationship. Findings, revealed as expected, a significant difference in term of crops development between plants from seeds without treatment and those from seeds under (i) rhizobacteria, (ii) rhizobacteri + foliar bio-fertilizer mixture and (iii) foliar bio-fertilizer treatments ($p<0.05$). Also, yield parameters exhibited a substantial variability reacting to rhizobacteria microorganism as well as to rhizobacteria microorganism + foliar bio-fertilizer mixture as opposed to growth features. Hence, the present results clearly showed significant difference between rhizobacteria microorganism and foliar bio-fertilizer activities impacting both maize and soybean crops yield and growth features ($p<0.05$). Indeed, findings suggested a selective impact of rhizobacteria microorganisms (*P. fluorescence*) on processed plants yield features. The same findings exhibited *P. fluorescence* and foliar bio-fertilizer mixture, as adjusting the synergy between both processed crops growth and yield parameters by improving dry biomass feature ($p= 0.17$). Finally, this study emphasized rhizobacteria microorganism's activities on foliar bio-fertilizer in an arid agro-climate low fertile soil as a weighty promoter improving maize and soybean crops dry biomass by normalizing the relationship concerning growth and yield features.

Key words: Rhizobacteria (*Pseudomonas fluorescence*), growth and yield parameters, dry biomass, maize (*Zea mays.* L.) and soybean (*Glycine max*), computational statistic.

INTRODUCTION

Soil composition is generally conditioned by many factors such as vegetation, climate (agro-climate) and environmental factors as well as by microorganism including bacteria, fungi and variety of insects and worms alongside protozoa activities on the earth. Continued interactions between these features enable guaranteeing and maintaining long term soil productiveness. Plant development is strongly correlated with soil nutriment availability. So, for constant growth, plants need several macro-elements such as nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S). Also, deficiency of these inorganic chemical elements in soil intended for agricultural practices compel farmers to use chemical fertilizers that have been recovered over time to be potential environmental and water pollutants. Thus, cultivable soil composition dynamism strongly depend on farmers practices, due to the use of pesticides as well as fertilizers. For optimal plant growth, the soil must be capable of storing the above-mentioned nutrients and transporting them to the root surface for endorsement by plant. However, findings suggest that, one of the most important factors in the generation of high yields from cereal cultivars is nitrogen (N) fertilizer; hence, farmers keep applying high amounts of the fertilizers which is very expensive and make the environment perilous especially when used discriminately. In addition, more than 50% of the applied nitrogen (N) fertilizers are somehow lost through different processes which is not limited to cash loss by the farmers. N is lost through different mechanisms including ammonia volatilization, denitrification and leaching losses, causing environmental pollution problems (Choudhury and Kennedy, 2005). Crop scientists all over the world are facing this alarming situation and are trying to overcome this condition by exploring alternative sources which is cost effective and save the environment. Bio-fertilizer, an alternative source of N-fertilizer, especially plant growth promoting Rhizobacteria (PGPR) affects plant growth by producing and releasing secondary metabolites, facilitating the availability and uptake of certain nutrients from the root environment and inhibiting plant pathogenic organisms in the rhizosphere (Kumar et al., 2008). It is noteworthy to emphasize that PGPR are free living bacteria, isolated from the rhizosphere, which when applied to seeds or crops, enhance the growth of the plant or reduce the damage from soil borne plant pathogens. Plant growth promoting Rhizobacteria can on the one hand form a symbiotic relationship with the plants and on the other hand, freely live in the soil though are found near or even the roots of plants. Generally, the impact of rhizobacteria on plant growth and health may be classified as neutral, deleterious or beneficial. Beneficial free living bacteria referred to as plant growth promoting rhizobacteria are found in the rhizosphere of the roots of many different plants. Among the means available to achieve sustainability in agriculture production, bio-fertilizers plays an important and key role because it processes many desirable soil properties and exerts beneficial effect on the physical, chemical and biological characteristics of the soil. Based on this, bio-fertilizers because of its vital role in maintaining long term soil fertility could be requested for many agricultural soils (Khosro and Yousef, 2012; Biari et al., 2008). It has been fully sustained that intensive use of mineral fertilizers can cause problems as the flow of these fertilizers into rivers, lakes and streams constitutes a source of pollution (van Keulen and Breman, 1990, Umesha et al., 2014). It is therefore appropriate to find alternative solutions at the overuse of chemical fertilizers. Bio-fertilizer are found to positively contribute to soil fertility, resulting in an increase in crop yield without causing any environmental, water or soil pollution hazards (Umesha et al, 2014). Research work has already been undertaken on the potential effect of bio-fertilizers on crop yields. Hernandez et al. (2010) claimed that inoculation of maize seed with rhizobacteria in combination with a dose of 120 kg N ha^{-1} results in an increase of around 25% of returns compared to those obtained with the same dose of nitrogen but without inoculation with microorganisms. Also, the combination of rhizobacteria raised with a dose of 120 kg N ha^{-1} can increase over 60% the maize yields in comparison with those obtained in plots without nitrogen application or inoculation of bacteria (Hernandez et al. 2010). From the previous studies and others, a positive interaction between *Pseudomonas fluorescence* and foliar bio-fertilizer promoting rice (*Oryza sativa* L.), maize (*Zea mays* L.) and soybean (*Glycine max* L.) crops growth and yield was suspected, as well as enhancing the resistance against pathogens (Ahemad and Khan, 2011; Adolphe et al, 2012; Munees et al. 2013; Pérez-Montaño et al, 2014; Diarrassouba et al, 2015). Also, recent findings suggested that the combined use of *Pseudomonas fluorescence* bio-fertilizer as plant growth-promoting rhizobacteria (PGPR) and inorganic nitrogen fertilizer has been found promising not only in maintaining and sustaining high productivity but in providing stability to rice crop (*Oryza sativa* L.) production and minimizing the cost of inputs and environmental pollution (Nehal, 2015). Consequently, integrated use of PGPR *Pseudomonas* along with inorganic and organic nutrient sources provides a sustainable agricultural ecosystem. From the results and observations, it was necessary to evaluate *via* a computational bio-statistical survey, the interaction

*Corresponding author. E-mail: dgnoel7@gmail.com, noel.dago@upgc.edu.ci. Tel: (+39) 3381426596 or (+225) 48397811.

between rhizobacteria microorganisms (*P. fluorescence*) and foliar bio-fertilizer in promoting maize (*Zea mays.* L.) and soybean (*G. max*) growth and yield (development) as well as dry biomass features interaction in an arid agro-climate characterized by arid and low fertile soil.

MATERIALS AND METHODS

Maize (*Zea mays* L.) and soybean (*G. max*) plants features like growth, yield and dry bio-mass data used in the present study were recycled from previous works (Diarrassouba et al., 2015; Dago et al, 2016). Briefly, the study was conducted on farm in the Department of Korhogo (north of Côte d'Ivoire). The experimental site is located between an average altitude of 392 m between - 5° 34 '31" and - 5°29' 34 '' West longitude and between 9° 31 '23" and 9° 31' 32 '' latitude North. The climate in this area is characterized by two types of Sudanese seasons: a dry season, from November to April, punctuated by the Harmattan characterized a dry wind from the Sahel, and a rainy season from May to October. The climate of this area is the maritime sub-equatorial with the temperatures that range between 24 and 33°C and the annual precipitation varies between 1100mm and 1600 mm. It is also noteworthy to emphasize that the soil in this region is arid which would explain the strong erosions of the latter during the rainy season.

Maize and soybean seeds material and experimental design

Maize and soybean seed varieties used in this experimentation are available at the Centre National de Recherche Agronomique (CNRA of Côte d'Ivoire). The experimental design consisted of a block of 4 treatments and 4 replications. The two blocks corresponding to each variety of maize of soybean plants were divided into 16 basic plots corresponding to the four different treatments (T_0, T_1, T_2 and T_3). The space between the ridges was 75 cm between rows and 40 cm between bunches with 2 plants per hill after thinning. The various treatments have covered each elementary plot of 4 m × 4 m (16 m²). Each elementary plot contained 4 lines of 4 m long. The four treatments were as follows: T_0: plots planted without *P. fluorescence* and without foliar fertilizer (pots planted in soil standard condition); T_1: subdivision sown with the seed inoculated with *P. fluorescence* only; T_2: land sown with the seed inoculated with *P. fluorescence* and foliar bio-fertilizer and T3: subdivision sown with foliar fertilizer only. Moreover, a regular weeding (once a month) was made for the maintenance of the plot. The present experimental design has been performed in the raining season when no watering was made on the analyzed maize and soybean plants outside the rain. In total, 20 samples in each considered experimental site for each processed treatment and replicate with regards to both maize and soybean crops yield and growth as well as dry biomass features were handled for the different statistical surveys.

Preparation of inoculums and seed inoculation

Rizofos Liq Maize bio-fertilizer manufacture requires the strain of bacterium *P. fluorescence* specifically selected for its phosphorus solubilizing ability. If stored under the recommended conditions (cool below 25°C), the product contains 1×109 CFU/ml in manufacturing. The inoculums were prepared from 500 ml Rizofos Liq Maize Premax-R + 200 ml of Premax-R for 100 kg of maize seed. The needed amount of Premax-R was put in a container and then the required amount of Rizofos Liq Maize was added. It was mixed until a homogeneous mixture was obtained before inoculation of the required amount of seed. This is followed by planting of seeds, and making holes about 3 cm deep, in which two inoculated seed of maize are deposited. The same experimental protocol was applied to soybean with the only difference being that the inoculums were prepared from Rizo Liq Top inoculant or bio-fertilizer for soybean culture, containing nitrogen-fixing bacteria (*Bradyrhizobium* sp). If stored under the recommended conditions (cool place less than 25°C), this product contains 1 × 1010UFC/ml. Inoculums were prepared from 50 ml Rizo-Liq Top + 20 ml Premax R; Soybean inoculant bacterial protector and adhesive for 10 kg of soybean seeds.

Foliar bio-fertilizer

Foliar bio-fertilizer composition enables high potential crops to aid plant growth in critical development stages (flowering, fertilization) without penalizing the latter’s metabolism. It acts as a pump for the plant and allows the best use of fertilizers conventional and soil mineral reserves. Foliar bio-fertilizer composition (g/L) is as follows: 140 g N; 70 g P_2O_5; 70g K_2O and trace elements. Nitrogen (N) total 14%; Phosphoric acid (P_2O_5) 7%; K_2O 7%; B 0.4 g / L; Mo 0.04 g/L; Cu 0.2 g/L; Zn 0.6 g/L; Mn 0.2 g/L and Fe 0.6 g/L. Foliar bio-fertilizer doses are as follows; (i) soybeans; 2 applications (3 L.ha^{-1}) at the beginning of the run and at the last visible leaf stage (ii) maize; 8 L.ha^{-1} at 5-10 leaf stage.

Growth and production measured parameters

During this study, growth and yield as well as dry biomass parameters were measured and calculated respectively, on each maize (*Z. mays* L.) and soybean (*G. max*) plants in the two considered experimental sites for each treatment (T_0, T_1, T_2 and T_3 treatments).

Growth parameters

Five features were evaluated during the growth phase (i) height of the plant, (ii) number of leaves, (iii) length of leaves, (iv) width of the leaves and (v) the diameter of the collar which has been measured using an electronic sliding caliper. The growth parameters were evaluated using centimeter as scale of measurement (cm). The height of the plants have been measured from the ground level to the end of the longest petiole. The number of leaves per plant was counted weekly.

Yield or production parameters

Five features were evaluated during the production phase (i) length of the ears and/or pods for (*Z. mays* L.) and soybean (*G. max*) plants respectively (ii) width of the ears for maize plant, (iii) geometric diameter of the ears for maize plants (iv) number of seed per ear or spike and/or pods for maize and soybean plants respectively and (v) number of ear (maize) and pods (soybean) per plant. Length, width and the geometric diameter parameters have been measured by using an electronic caliper using a centimeter as scale of measurement (cm).

Dry biomass

For estimation of dry biomass, the fresh weight of the vegetative

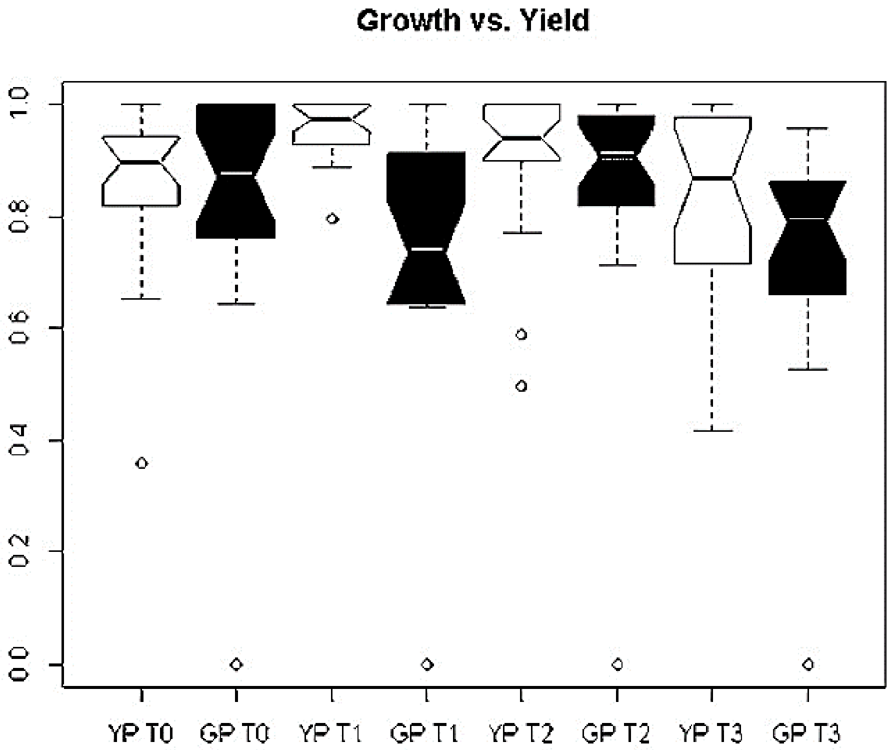

Figure 1. Box plot multivariate survey by weighting maize and soybean development dynamism under T_0, T_1, T_2 and T_3 treatments. (YP and GP acronyms were referred to growth and yield parameters respectively).

material for both maize and soybean separately were first determined and next the material was dried using an oven-dried for 48 h (at a temperature of 60°C: time and temperature required for a constant dry weight). The weights were measured using a precision balance 10^{-4} g (Toledo). Dry biomass was calculated using the following formula:

Dry biomass = [(Fresh weight of leaves) × (Dry weight of the leaf sample) / (Fresh weight of the leaf sample)] + [(Fresh weight rods) x (Dry weight of the sample rod) / (Wet weight of the sample rods)].

Statistical and computational statistical survey

Data normalization process

Data for the present experiment were statistically analyzed based on several scripts from R statistical package (R Core Team, 2014). Maize and soybean growth and yield parameters, because of their heterogeneity, were submitted to normalization by scaling between 0 and 1, since in statistics, normalization refers to the creation of shifted and scaled versions of statistics, where the intention is that these normalized values allow the comparison of corresponding normalized values for different datasets in a way that eliminates the effects of certain gross influences, as in an anomaly time series (Dodge, 2003).

Computational Pipeline content for statistical analysis

The present study developed computational statistical pipeline (computational pipeline) analyzing the relationship between (*Z. mays* L.) and soybean (*G. max*) plants growth and yield as well as dry biomass parameters based on several R version 3.4.3. Details as regards that computational statistical pipeline is reported in supplementary material chapter (Appendix).

RESULTS

Impact of rhizobacteria microorganism and foliar bio-fertilizer on maize (*Z. mays.* L.) and Soybean (*G. max*) plants development

Maize (*Z. mays.* L.) and soybean (*G. max*) seeds inoculated by *P. fluorescence*, *P. fluorescence* + Foliar bio-fertilizer mixture and foliar bio-fertilizer, exhibited different behavior in terms of cereals growth and yield features data distribution, when compared to T_0 treatment (seeds without *P. fluorescence* and foliar bio-fertilizer treatment and/or in soil standard condition) (Figure 1). Ratio value between growth and yield parameters under T_0 treatment resulted to around 0.97. The same ratio value concerning T_1, T_2 and T_3 treatments were 0.76, 0.97 and 0.91 respectively (Table 1). So, a substantial difference has been observed between analyzed cereals growth and yield parameters for all processed treatments (Figure 1, Table 1). Moreover, T_0 (soil standard condition) and T_2 treatments resulting in *P. fluorescence* + foliar bio-fertilizer mixture, exhibited the same ratio value by

Table 1. Descriptive statistic and variance ratio test estimation between both maize (*Zea mays* L.) and soybean (*G. max*) cereal crops yield and growth features.

Maize and soybean seeds treatments	Analyzed parameter	Mean	Median	Standard deviation (SD)	Ratio based on median value (growth/yield)	Variance ratio of F test to compare two variances
Seeds without rhizobacteria and foliar bio-fertilizer treatment (T0)	Growth	0.74	0.87	0.37	0.97***	0.16***
	Yield	0.85	0.90	0.15		
Seeds treated with Rhizobacteria treatment (T1)	Growth	0.67	0.73	0.05	0.76***	0.02***
	Yield	0.95	0.97	0.35		
Seeds treated with Rhizobacteria + foliar bio-fertilizer treatment (T2)	Growth	0.76	0.91	0.13	0.97**	0.11***
	Yield	0.9	0.94	0.37		
Seeds treated with foliar bio-fertilizer treatment (T3)	Growth	0.65	0.79	0.16	0.91***	0.24***
	Yield	0.83	0.87	0.33		

***p<0.05 (statistically significant test) and ** p>0.05 (non-significant difference).

comparing processed plants growth and yield data. This finding evoked normalization as well as a synergic impact of *P. fluorescence* + foliar bio-fertilizer mixture with regards both maize and soybean plants growth and yield features (Table 1 and Figure 1). Additionally, maize (*Z. mays* L.) and soybean (*Glycine max*) seeds under rhizobacteria microorganisms (p=2.57 4e-09) and rhizobacteria microorganism + Foliar bio-fertilizer mixture (p= 0.07) treatments, exhibited a positive impact by processing cereal yield parameters as opposed to the same seeds under foliar bio-fertilizer treatment (p = 0.6), when treatment T_0 and/or experimental site soil standard condition was considered as reference. Also, cereal seeds under T_1, T_2 and T_3 treatments induced a high dynamism for both maize and soybean crops yield parameters as opposed to their growth features (Figure 1). Taking everything into consideration, the present results confirmed the normalization effect of rhizobacteria microorganisms + Foliar bio-fertilizer mixture on processed plants yield and growth features.

Effect of rhizobacteria microorganism on maize (*Z. mays* L.) and Soybean (*G. max*) plants growth and yield parameters relationship

Cluster dendrogram graph based on Euclidian distance of Pearson correlation survey showed two distinct groups and/or tendencies (Figure 2). Indeed, processed parameters clustered disregarding rhizobacteria microorganisms (*P. fluorescence*), foliar bio-fertilizer as well as *P. fluorescence* + Foliar bio-fertilizer mixture treatments. However, findings suggested high variability of maize and soybean plants yield parameters with respect to growth features. In the same tendency, rhizobacteria microorganisms (*P. fluorescens*) treatment and rhizobacteria microorganisms (*P. fluorescens*) + Foliar bio-fertilizer mixture referred as T_2 treatment were recorded as inducing high variability in processed plants yield parameters (p<0.05) as opposed to T_0 and T_3 treatments (Figure 2). Also, the present result suggested a relative positive effect of both (i) *P. fluorescence* + Foliar bio-fertilizer mixture and (ii) rhizobacteria microorganism (*P. fluorescence*) treatment on maize (*Zea mays* L.) and soybean (*Glycine max*) plants growth parameters (Figure 2) as opposed to both T_0 and T_3 treatments. Further, findings exhibited no substantial difference between T_0 and T_3 treatments with regard to maize (*Zea mays* L.) and soybean (*Glycine max*) growth and yield parameters (Figure 2). Taking together, the present survey suggested a selective difference between (i) processed plants from seeds inoculated with *P. fluorescens* as well as with *P. fluorescens* + Foliar bio-fertilizer mixture referred as T_1 and T_2 treatments respectively and (ii) those from seeds in experimental site soil standard condition and with foliar bio-fertilizer inoculation denoted as T_0 and T_3 treatments respectively.

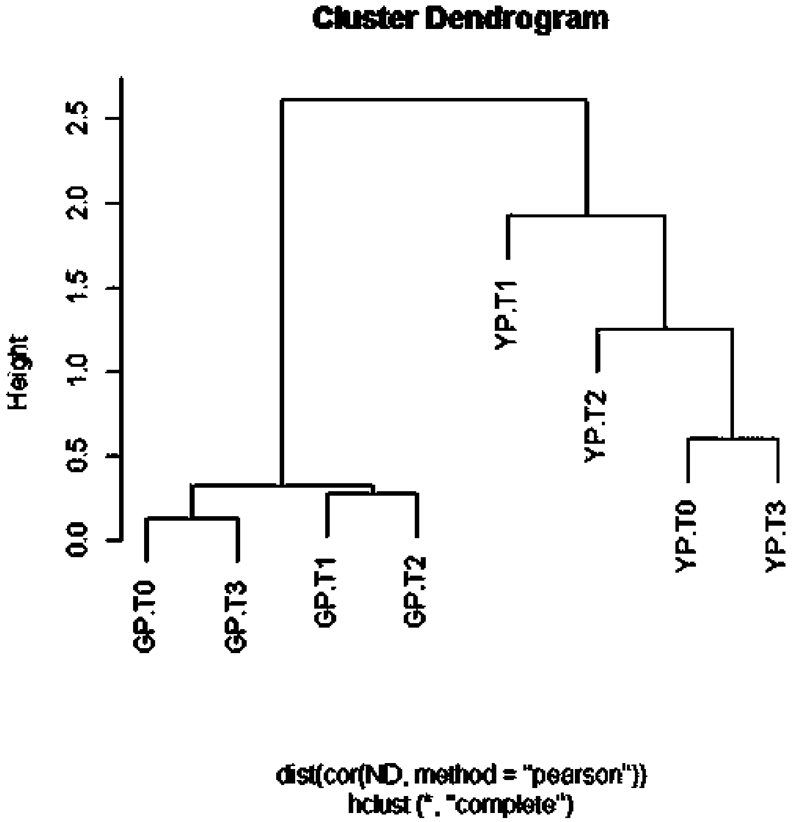

Figure 2. Euclidian distance assessing rhizobacteria microorganisms' and foliar bio-fertilizer impact on both maize (*Z. mays* L.) and soybean (*G. max*) growth (GP) and yield (YP) parameters relationship.

Performance assessment of rhizobacteria microorganisms' and foliar bio-fertilizer treatments impacting maize (*Z. mays* L) and Soybean (*G. max*) yield and growth features data dispersion

Findings suggested that one component (PC1) do not sufficiently explain the present process data dispersion (Figure 3). Data dispersion evidence has been highlighted by introducing and/or combining two principal component factors referred to as PC1 and PC2 (Figure 3). Furthermore, test of the hypothesis that 2 factors are sufficient (degrees of freedom for the model is 13) based on 22 observations, displayed a Chi Square value = 30.42 with an associated p value = 0.004. Also, the root mean square of the residuals of this model is 0.1 ($p<0.05$). Moreover, data distribution source became strongly evident by introducing a third component (PC3). Indeed, test of the hypothesis evaluating 3 factors and explaining processed data dispersion (degrees of freedom for the model is 7) based on 22 observations, exhibited a Chi Square value = 29.16 with an associated p value =0.0001. The root mean square of the residual associate to this model is 0.06 ($p<0.05$). These results suggested 3 component factors as strongly efficient in discriminating maize and soybean growth and yield features data dispersion source with respect to the other considered systems (Figure 3). Thus, Figure 3 clearly showed T_1 referred to yield and growth parameters of maize and soybean plants from seeds inoculated by *P. fluorescence* and T_2 referred to yield and growth features of maize and soybean plants from seeds under *P. fluorescence* and foliar bio-fertilizer mixture treatments as potential sources of presently analyzed data variability. Also, merging the present result (Figure 3) with the previous one (Figure 2); it seem obvious to deduce both maize (*Zea mays.* L.) and soybean (*Glycine max*) cereal plants yield attributes as significantly influenced by *P. fluorescence* as well as by *P. Fluorescence* microorganism activities on foliar bio-fertilizer (*P. Fluorescence* + Foliar bio-fertilizer mixture).

R fitting curve weighing rhizobacteria microorganism activities on foliar bio-fertilizer assessing the relationship between both maize and soybean plants yield features

Here, the performance of maize (*Z. mays* L) and soybean (*G. max*) yield parameters for seeds under rhizobactera microorganism's (*P. Fluorescence*) and rhizobactera

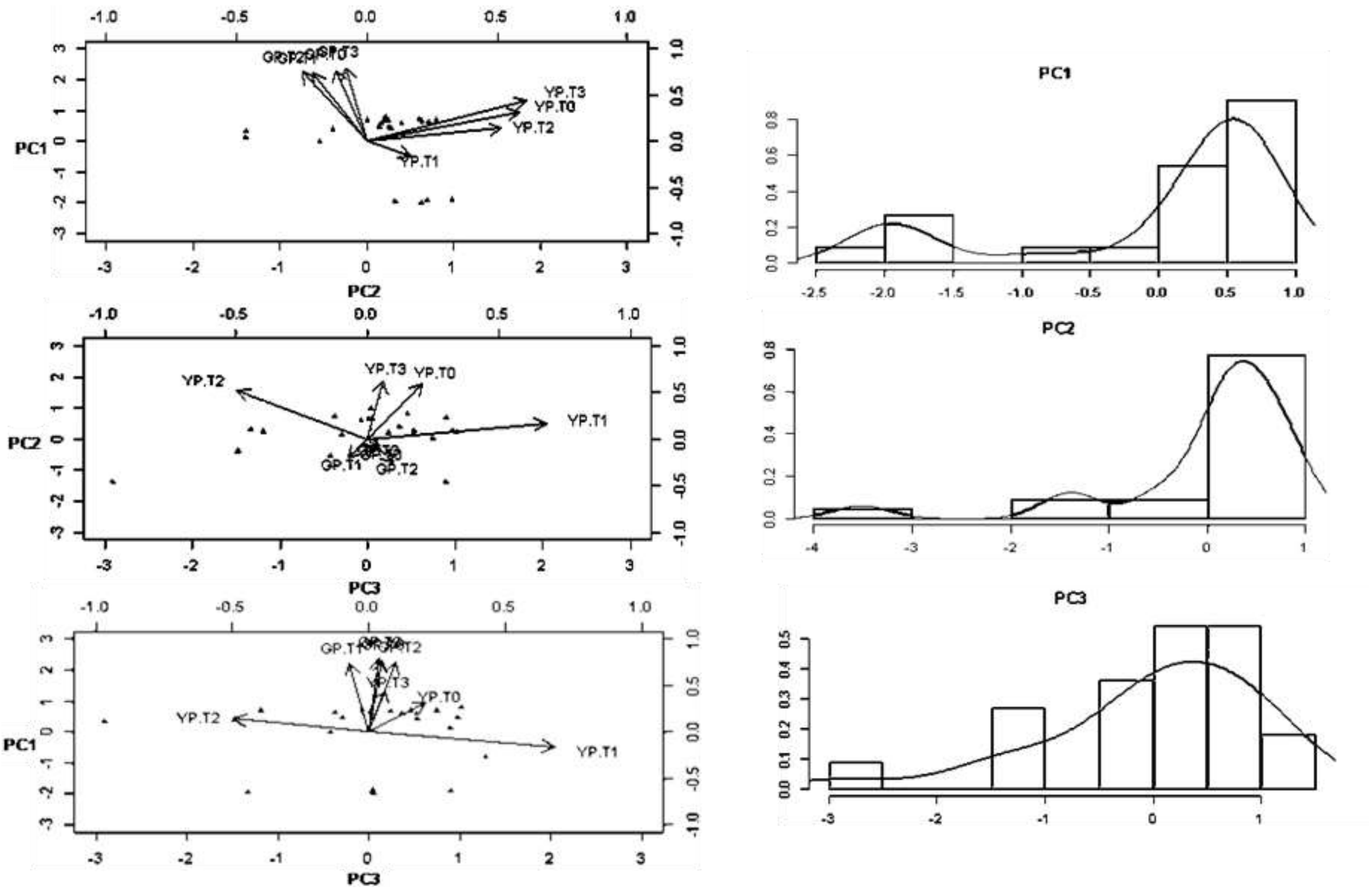

Figure 3. Principal component analysis weighing processed maize (*Z. mays* L.) and soybean (*G. max*) plants growth and yield parameters data dispersion source.

microorganism + Foliar bio-fertilizer treatments was assessed assuming plants from T_0 treatment as reference. Processed maize (*Z. mays* L.) and soybean (*G. max*) plants yield parameters from maize and soybean seeds inoculated by rhizobacteria micro-organisms (*P. fluorescence*), exhibited a heterogeneous behavior as opposed to those from seeds inoculated by rhizobacteria microorganisms (*P. fluorescence*) + Foliar bio-fertilizer mixture and foliar bio-fertilizer when experimental site soil standard condition was assumed as reference and/or benchmark. Interestingly, this analysis showed seeds inoculated by rhizobacteria micro-organisms + Foliar bio-fertilizer mixture, as improving and normalizing maize (*Z. mays* L.) and soybean (*G. max*) cereal plants yield parameters as opposed to plants from seeds inoculated by rhizobacteria microorganisms only (Figure 4). Overall, these findings suggested the implication of rhizobateria microorganisms (*P. fluorescence*) activity on foliar bio-fertilizer in the normalization procedure of both maize (*Z. mays* L.) and soybean (*G. max*) crops yield parameters improving plants development performances in an arid agro-climate low fertile soil.

ANOVAs and multiple linear regression survey linking T_0, T_1, and T_2 and T_3 treatments by handling maize and soybean plants yield features data

Results concerning the present analysis of variance, displayed 0.11 as residual standard error, on 18 degrees of freedom with a multiple R-squared value =0.52 (R^2= 0.52) and adjusted R-squared = 0.4452. Fisher test, associated to this variance analysis exhibited F-statistic = 6.618 on 3 and 18 Degree of Freedom (DF) with p=0.00, indicating that the null hypothesis that the yield parameter variables concerning maize and soybean plants from seeds inoculated by rhizobacteria microorganisms referred as T_1 treatment (YP.T_1), and rhizobacteria microorganisms + Foliar bio-fertilizer mixture yield denoted T_2 treatment (YP.T_2) and foliar bio-fertilizer (YP.T_3), collectively were not influenced by previous maize (*Z. mays.* L.) and soybean (*G. max*) seeds treatment should be clearly rejected. Results (Table 2) also showed cereal plants yield parameter from seeds under T_1 (p-value=0.91) and T_2 (p-value= 0.34) treatments, as not significantly controlling for yield parameter variable of the cereal plants from cereal seeds

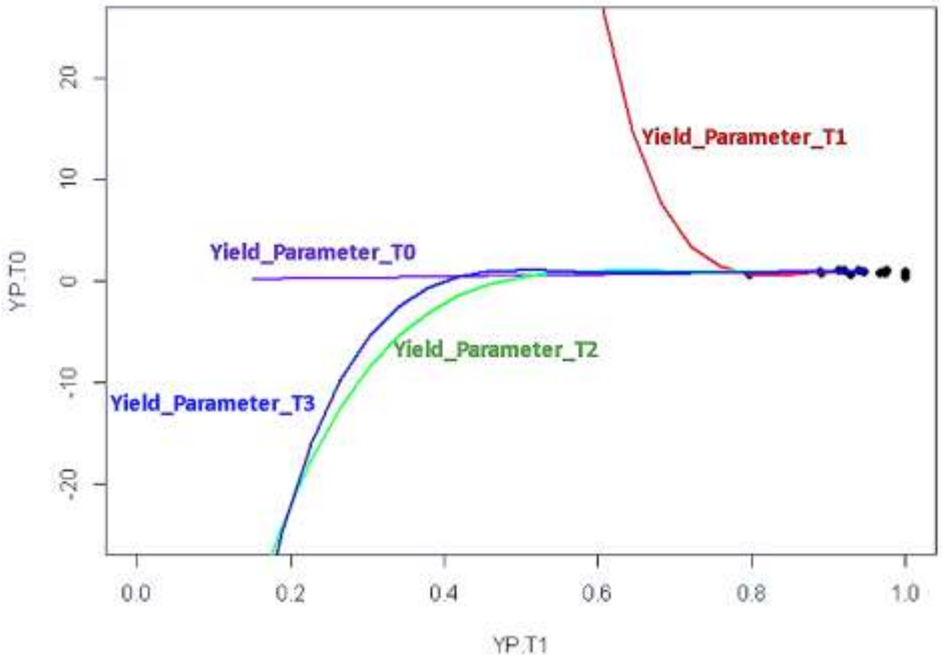

Figure 4. R fitting curve analyzing maize (*Z. mays.* L.) and soybean (*G. max*) yield performances by processing *P. fluorescence* microorganism's activities on foliar bio-fertilizer.

Table 2. Analysis of variance (ANOVA) table, linking T_0 treatment with T_1, and T_2 and T_3 treatments by processing cereals yield features.

Parameter	Estimated standard deviation	Error	t. value	Probability (Pr.>|t|)
Intercept values	0.48	0.54	0.90	0.38
Yield parameter under treatment T1	-0.06	0.50	-0.11	0.91
Yield parameter under treatment T2	-0.22	0.23	-0.97	0.34
Yield parameter under treatment T3	0.75	0.18	4.09	0.00***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

under T_3 treatment (p = 0.00). However, the same analysis exhibited processed maize and soybean plants yield parameter from seeds inoculated by foliar bio-fertilizer as controlling both maize and soybean cereal plants yield parameter under T_1 and T_2 treatments (p=0.00). Also, results of the partial analysis of variance have been reported as follows: F = 0.55 with p = 0.47. Thus, the null hypothesis (β_1= 0) at the 5% level of significance cannot be rejected. It seems that the variables YP.T_1 (p=0.46) and YP.T_2 (p=0.12) do not contribute significant information to maize (*Z.*

mays. L.) and soybean (*G. max*) treated seeds, once yield parameter variable from seeds under T_3 treatment (YP.T_3) has been taken into consideration. In other words, both maize (*Z. mays* L.) and soybean (*G. max*) seeds treated by rhizobacteria microorganism + Foliar bio-fertilizer mixture and rhizobacteria microorganism exhibited a contrast behavior among themselves and also with respect to seeds without inoculation plus seeds under foliar bio-fertilizer treatment. Altogether, these surveys are in agreement with the previous results (Figures 2 and 3).

Relationship between maize and soybean dry bio-mass and both yield and growth features evaluating *P. fluorescence* activity on foliar bio-fertilizer

Here, several multiple linear regression surveys aimed at understanding the relationship between maize (*Z. mays* L.) and soybean (*G. max*) plants dry bio-mass together with both yield and growth parameters were performed. Developed linear regression model based on maize and soybean plants from seeds without rhizobacteria microorganisms and foliar bio-fertilizer inoculation, was as follow; (E_1): *Dry Biomass=6.82*Yield parameter + 28.74*Growth parameter -398.95.* This equation evokes high contribution of cereals growth parameters in impacting cereals dry biomass attribute with respect to yield component. In other words, dry biomass of both maize and soybean plants from seeds without previous bio-fertilizer inoculation resulted to being highly influenced by plants growth features. However, intercept value (-398.95) concerning this model (E_1) seems to contrast with that estimated dry biomass performance. Unlike the previous considered model *(E1)*, the second developed multiple linear regression model; (E_2): *Dry Biomass=10.61*Yield parameter + 1.343*Growth parameter -34.65* from both maize and soybean cereal plants from seeds inoculated with rhizobacteria microorganisms, exhibited a high concordance between plants dry biomass and yield attribute. Moreover, multiple linear regression models based on (i) foliar bio-fertilizer, (*E3*): *Dry Biomass=0.43*Yield parameter + 0.76*Growth parameter + 6.26* and (ii) *P. fluorescence* + Foliar bio-fertilizer mixture, (E_4): *Dry Biomass=0.43*Yield parameter +1.92*Growth parameter -39.98*, suggested a reasonable synergy between both growth and yield features by improving processed maize and soybean plants dry biomass component. Furthermore, equation (*E3*), proposed foliar bio-fertilizer as having a relatively high influence on growth parameters with respect to yield attributes. Also, considering equation (E_4) as the resultant of both equations (E_2) and (E_3), we can suppose (i) rhizobacteria microorganisms and (ii) foliar bio-fertilizer treatment as influencing processed plants yield and growth parameters respectively. Next, the relationship between maize and soybean plants dry biomass, yield and growth parameters was analyzed by merging all processed treatments. Results of the developed multiple linear regression model was as follow; (E_5): *Dry Biomass=2.19*Yield parameter – 4.04*Growth parameter + 63.28*. This survey hypothesized a positive effect of yield parameters on analyzed plants dry biomass attribute as opposed to growth parameter. Also, equation E_5 suspected a potential drop of maize and soybean plants dry biomass by a strong upturn of cereal growth parameters (p=0.17). Collectively, these analysis suggested high fluctuation as regards analyzed plants dry biomass parameters for each considered treatments (Figure 5) and exhibited the combination between rhizobacteria microorganisms and foliar bio-fertilizer as a suitable practice normalizing the relationship among considered plants yield and growth features data by improving their dry biomass component, since high dry biomass value were recorded for processed plants from seeds inoculated by *P. fluorescence* + Foliar bio-fertilizer mixture (Table 3 and Figure 5).

Relationship between maize and soybean dry biomass features for seeds under *P. fluorescence* and foliar bio-fertilizer treatment by processing variable number of principal components

We performed a relationship analysis between considered plants dry bio-mass components was performed aimed at assessing rhizobacteria microorganism's activity on foliar bio-fertilizer through a principal component analysis by processing a variable number of principal component (Figure 6). As expected, the present analysis suggested 2 factors and/or components (Component 1 and 2) as enough for explaining the variability as well as the difference ratio among presently processed cereal plants dry biomass parameters (Figures 5 and 6). So, this analysis revealed Components 3 and 4 as unable to explain dry biomass data dispersion (Figure 6). Considering both Components 1 and 2 of Figure 6, our results suspected a high difference and/or an opposed behavior between both maize (*Z. mays* L) and soybean (*G. max*) plants dry biomass parameters for seeds under T_0 (plants from seeds without treatment) and T_3 (plants from seed inoculated by foliar bio-fertilizer) treatments (Figure 6). This result is in agreement with previous results reported in Table 3. Also, principal components 1 and 2 exhibited a relative difference in terms of data distribution with regards to dry biomass parameter referred to in both T_1 (maize and soybean seeds inoculated by *P. fluorescence* microorganisms) and T_2 (maize and soybean seeds under rhizobacteria microorganism + Foliar bio-fertilizer mixture inoculation) treatments (Figure 6). However, considering soil standard condition as benchmark, the present findings supported the high normalization aptitude of rhizobacteria microorganism + Foliar bio- fertilizer mixture treatment,

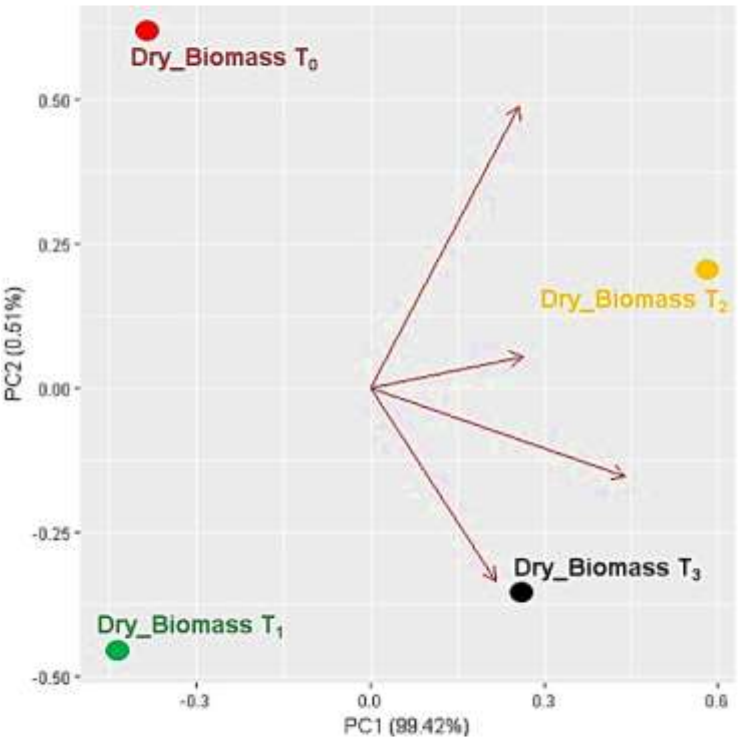

Figure 5. PCA graph assessing maize and soybean plants dry biomass features data dispersion evaluating *P. fluorescence* activities on foliar bio-fertilizer in an arid and low fertile soil.

Table 3. Summary of processed maize and soybean plants dry biomass data features by processing T_0, T_1, T_2 and T_3 treatments.

Descriptive statistic parameter	**Dry biomass treatment T_0**	**Dry biomass treatment T_1**	**Dry biomass treatment T_2**	**Dry biomass treatment T_3**
Mean	11.72 (p=0.99)*	14.15 (p=0.76)*	**21.12 (p=0.28)** *	12.53 (p=0.78) *
Median	10.72	12.57	19.05	11.44
¼ Quartile	4.66	5.64	6.52	5.08
¾ Quartile	17.79	21.08	33.65	18.88
Maximum	21.88	26.87	41.28	25.34
Minimum	3.58	4.61	5.12	1.9
Standard deviation	8.89	10.72	17.91	10.57

* The p was calculated by performing a Student exact test assuming mean value of dry biomass of both maize and soybean plants of plants in experimental site soil standard condition as benchmark value.

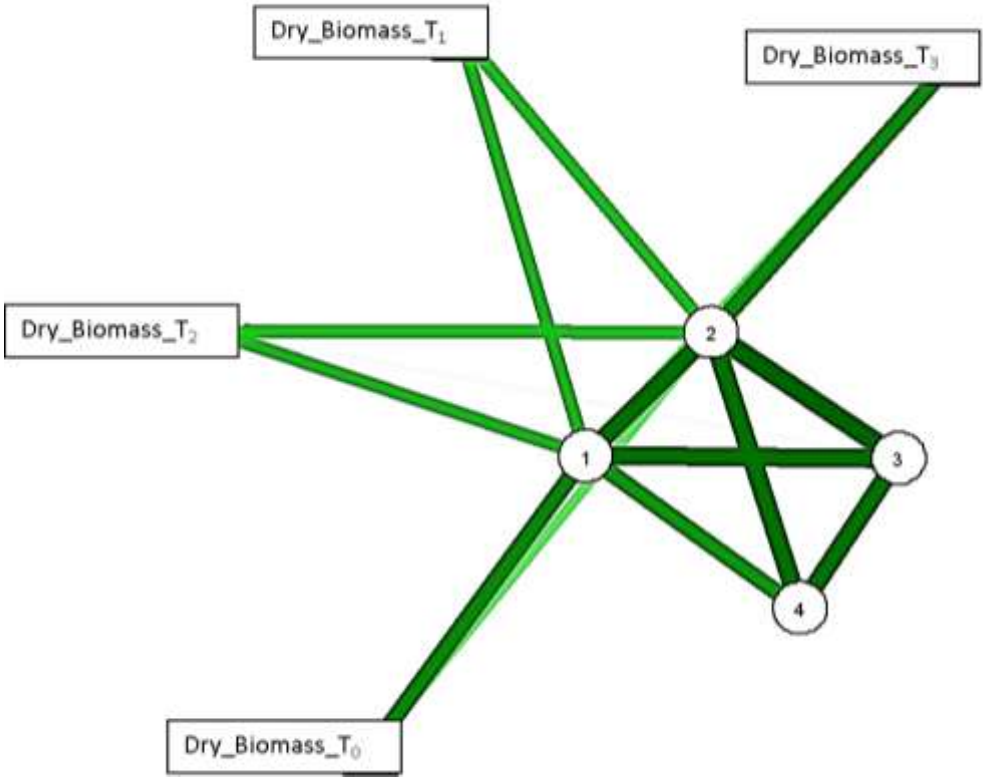

Figure 6. Relationship between both maize (*Z. mays* L) and soybean (*G. max*) dry biomass parameters through 4 principal components by assessing *P. fluorescence* activity on foliar bio-fertilizer.

on maize (*Z. mays* L) and soybean (*Glycine max*) growth and yield features data as opposed to T_1 and T_3 treatments (Figure 6). Combining this result with those of Tables 3, we can suggest rhizobacterium microorganism's activities on leaf bio-fertilizer, as being responsible for the adjustment of the synergy between growth and yield parameters, while improving the dry bio-mass features.

DISCUSSION

The inoculation of plant growth promotor rhizobacteria *P. fluorescence* in cereal plant may increase number of panicles, number of grains panicle, percentage of filled grains because of enhancement of plant biomass, root elongation, uptake of NPK and ultimately increase all characters without deteriorating soil health. Subsequently, they act as potential bio-fertilizers and antagonistic agents to save synthetic chemical fertilizers and pesticides, respectively and become an ecofriendly alternative in upcoming days (Khorshidi et al., 2011; Kumar and Dangar, 2013). This study examined the interaction between Rhizobacteria microorganism (*P. fluorescence*) and foliar bio-fertilizer with the purpose to highlight their influences and/or interference on maize and soybean crops performance in an arid agro-climate low fertile soil. The study revealed a consistent normalization effect of *P. fluorescence* + Foliar bio-fertilizer mixture on both processed maize and soybean growth and yield attributes. Also our findings showed that rhizobacteria microorganism improved cereal production (Khorshidi et al., 2011) unlike foliar bio-fertilizer, which would appear to have an impact on the considered plants growth process. Indeed, several studies showed that the interaction effect of rhizobacterium and different soil macronutrients (P, N) levels significantly influenced cereals plants yield feature data (Hossein et al., 2015).

Then, the high performance of rizhobacteria microorganism (*P. fluorescence*) + Foliar bio-fertilizer mixture in presently considered agricultural practice can be attributed to the interaction effect between the latter's increasing soil macronutrient. This finding is in agreement with Alam et al. (2008) who reported that cereal plants yield attributes increased as the levels of macronutrients (P, N) increased. Further, findings showed significant variation between both maize and soybean plants yield and growth attributes for seeds inoculated with rhizobacteria microorganism alone as well as foliar bio-fertilizer. However, results suggested a high instability in processed plants yield features data as opposed to growth attributes ($p\text{-value}<0.05$) (Diarrassouba et al., 2015; Noel et al., 2016). In addition, our findings showed a high susceptibility of maize and soybean cereal plants yield parameters by replying to rhizobacteria microorganisms (*P. fluorescence*) + Foliar bio-fertilizer mixture as well as rhizobacteria microorganisms (*P. fluorescence*) stimulus. These results suspected rhizobacteria microorganism activities in arid soil as improving maize and soybean crops yield attributes. In the other words, our findings linked the performance of processed plants yield attribute to the rhizobacteria microorganism's activities on foliar bio-fertilizer. Indeed, Hernandez et al. (2010) showed that inoculation of maize cereal seed with rhizobacteria in combination with nitrogen (N), enabled increase in maize yield attribute in comparison with those obtained with the same dose of nitrogen but without inoculation with microorganisms. Also, our finding suspected plants yield parameters from seeds inoculated with rhizobacteria microorganism (*P. fluorescence*) + Foliar bio-fertilizer mixture and rhizobacteria microorganisms alone as a source of data variability, suggesting the consistent impact of the former's and the latter's on that plants yield attributes. Therefore, we showed both maize and soybean plants yield attributes as significantly influenced by *P. fluorescence* microorganism as well as by *P. fluorescence* microorganisms activities on foliar bio-fertilizer. Several studies suggested a significant variation of the effects of different levels of soil macronutrient on cereal yield parameters (Hossein et al. 2015). Based on these evidences and others (Hernandez et al, 2010), the interaction between rhizobacteria microorganism and foliar bio-fertilizer as increasing soil macronutrients can be suggested, allowing the correct development of cereal plants. Shaharoona et al. (2006) showed the efficiency of *Pseudomonas* increasing significantly maize plant growth and production when adequate quantity of nitrate has been provided. Previous studies showed that rhizobacteria improve maize productivity increasing the absorption of nitrate, phosphate, potassium, zinc, manganese, copper and iron (Biari et al., 2008). Our findings *via* an R fitting curve survey highlighted the strong normalization effect of rhizobacteria microorganism and foliar bio-fertilizer mixture on yield attributes of both analyzed maize and soybean plants. The same analysis suggested a high instability of rhizobacteria microorganism's *vis-à-vis* of analyzed plants yield parameter as opposed to both (i) rhizobacteria microorganisms and foliar bio-fertilizer mixture and (ii) foliar bio-fertilizer treatments when soil standard condition referred as T_0 treatment was assumed as benchmark. Also, performed ANOVA analysis showed that, maize and soybean plants from seeds inoculated with *P. fluorescens* + Foliar bio-fertilizer mixture and rhizobacteria microorganism exhibited a contrast behavior among themselves as well as with respect to plants from seeds without inoculation and with seeds inoculated with foliar bio-fertilizer in term of processed plants yield attributes. Interestingly, our developed multiple linear regression analysis suggested a selective effect of rhizobacteria microorganism and foliar bio-fertilizer on maize and soybean plants yield and growth attributes respectively. The same survey evoked a high fluctuation as regards analyzed plants dry biomass parameters for each considered seeds treatments and exhibited the combination between rhizobacteria microorganisms and foliar bio-fertilizer as a suitable practice in normalizing the relationship among considered plants yield and growth feature data (Dago et al., 2015) by improving dry biomass component, since high dry biomass value were recorded for plants from seeds inoculated by *P. fluorescence* + Foliar bio-fertilizer mixture. Also, findings referring to above mentioned developed multiple regression survey, linked presently analyzed cereals plants dry biomass attribute with yield component. Principal component analysis based on multiple component factors enhanced normalization and synergic aptitude of rhizobacteria activity on foliar bio-fertilizer on both maize and soybean plants yield and growth attributes. Lack of knowledge with regards to chemical composition of considered experimental earth site represented a limit to the present work, since chemical characterization of the former could help to clearly understand the interaction between rhizobacteria microorganisms (*P. fluorescence*) and foliar bio-fertilizer in improving maize (*Z. mays.* L.) and soybean (*G. max*) growth and yield features.

Conclusion

This study assessed the interaction relationship between rhizobacteria microorganism (*P. fluorescence*) and foliar bio-fertilizer improving maize and soybean crops dry biomass by processing a computational statistical survey. Findings exhibited rhizobacteria microorganisms (*P. fluorescence*) and foliar bio-fertilizer as influencing both processed plants yield and growth attributes respectively. Rhizobacteria microorganism's activities on foliar bio-fertilizer was suspected to trigger the high proportion of dry bio-mass by normalizing the synergic relationship among analyzed maize (*Z. mays.* L.) and soybean (*G. max*) plants growth and yield parameters.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Adolphe A, Pacôme AN, Rachidatou S, Marcellin A, Henriette GH, Koya KD, Boniface Y, Romain GK et Lamine BM (2012). Effets des rhizobactéries PGPR sur le rendement et les teneurs en macroéléments du maïs sur sol ferralitique non dégradé au Sud-Bénin. International Journal Biological and Chemical Sciences 6(1):279-288.

Ahemad M, Khan MS (2011). Plant growth promoting fungicide tolerant

Rhizobium improves growth and symbiotic characteristics of lentil (Lens esculent us) in fungicide-applied soil. Journal of Plant Growth Regulation 30(3):334-342.

Alam M, Talukder N, Islam M, Sarkar A, Hossain M (2008). Phosphate solubilizing rhizoplane bacteria on growth and yield of transplant a man rice. Journal of Agroforestry and Environment 59(2):19-22.

Biari A, Gholami A, Rahmani HA (2008). Growth promotion and enhanced nutrient uptake of maize (*Zea mays* L.) by application of plant growth promoting rhizobacteria in arid region of Iran. Journal of Biological Sciences 8(6):1015-1020.

Choudhury ATMA, Kennedy IR (2005). Nitrogen fertilizer losses from rice soils and control of environmental pollution problems. Communications in Soil Science and Plant Analysis 36(11):1625-1639.

Dago DN, Silué PD, Fofana IJ, Diarrassouba N, Lallié HD, Coulibaly A (2015). Development of a Statistical Model Predicting Rice Production by Rain Precipitation Intensity and Water Harvesting. International Journal of Recent Scientific Research 6(9):6270-6276.

Dago ND, Diarrassouba N, Nguessan AK, Lamine BM (2016). Computational statistics assessing the relationship between different rhizobacteria (*Pseudomonas fluorescence*) treatments in cereal cultivation. American Journal of Bioinformatics Research 6(1):1-13.

Diarrassouba N, Dago DN, Soro S, Fofana IJ, Silué S, Coulibaly A (2015). Multi-Variant statistical analysis evaluating the impact of rhizobacteria *(Pseudomonas fluorescens)* on growth and yield parameters of two varieties of maize (*Zea mays* L.). International Journal of Contemporary Applied Sciences 2(7):206-224.

Dodge Y (2003). The Oxford Dictionary of Statistical Terms, OUP. ISBN 0-19-920613-9 entry for normalization of scores.

Hernández RA, Heydrich PM, Diallo B, El JM, Vandeputte OM (2010). Cell-free culture medium of *Burkholderia cepacia* improves seed germination and seedling growth in maize (Zea mays) and rice (Oryza sativa). Plant Growth Regulation 60(3):191-197.

Hossein EC, Esmaeil Y, Hemmatollah P (2015). Response of yield and yield components of rice (*Oryza sativa L*. cv. *Shiroodi*) to different phosphate solubilizing microorganisms and mineral phosphorous. International Journal of Biosciences 6(3): 70-75.

Khorshidi YR, Ardakani MR, Ramezanpour MR, Khavazi K, Zargari K (2011). Response of yield and yield components of rice (*Oryza sativa L*.) to *Pseudomonas flouresence* and *Azospirillum lipoferum* under different nitrogen levels. American-Eurasian Journal of Agricultural and Environmental. Sciences 10(3): 387-395.

Khosro M, Yousef S (2012). Bacterial bio-fertilizers for sustainable crop production: A review. APRN Journal of Agricultural and Biological Science 7(5): 237-308.

Kumar KV, Singh N, Behl HM, Srivastava S (2008). Influence of plant growth promoting bacteria and its mutant on heavy metal toxicity in Brassica juncea grown in fly ash amended soil. Chemosphere 72(4):678-683.

Kumar U, Dangar TK (2013). Functional Role of Plant Growth Promoting Endo- and Rhizobacteria in Major Cereal Crops. Kheti 1(1):37-40.

Munees A, Mulugeta K (2013). Mechanisms and applications of plant growth promoting rhizobacteria: Current perspective. Journal of King Saud University-Science 26(1):1-20.

Nehal ME (2015). Efficiency of *Pseudomonas fluorescence* as plant growth-promoting rhizobacteria (PGPR) for the enhancement of seedling vigor, nitrogen uptake, yield and its attributes of rice (*Oryza sativa L*.). International Journal of Scientific Research in Agricultural Sciences 2(Proceedings):057-067.

Noel DD, Nafan D, Souleymane S, Jean-Luc MA, Jesus F, Lamine BM (2016). Combination of rizhobacteria and foliar bio-fertilizer accelerating maize and soybean crop plants growth process in arid soil. Academia Journal of Agricultural Research 4(7):446-456.

Pérez-Montaño F, Alías-Villegas C, Bellogín RA, Del Cerro P, Espuny MR, Jiménez-Guerrero I, López-Baena FJ, Ollero FJ, Cubo T (2014). Plant growth promotion in cereal and leguminous agricultural important plants: From microorganism capacities to crop production. Microbiological Research 169(5-6):325-336.

R Core Team (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Shaharoona AAZ, Muhammad AB, AzeemKalid A (2006). Performance of *Pseudomonas* spp. containing ACC deaminase for improving growth and yield of maize (*Zea mays* L.) in the presence of nitrogenous fertilizer. Soil Biology and Biochemistry 38(9):2971-2975.

Umesha S, Divya M, Prasanna KS, Lakshmipathi RN, Sreeramulu KR (2014). Comparative effect of organic and bio-fertilizer on growth and yield of maize (*Zea mays. L*). Current Agriculture Research Journal 2(1):55-62.

van Keulen H, Breman H (1990). Agriculture development in the West Africa Sahelian region: a cure against land hunger. Agriculture Ecosystems and Environment 32(3-4):177-197.

APPENDIX

Supplementary Material

Data loading step. We loaded data previously prepared as a matrix table in Microsoft Excel environment with “*txt”* extension (e.g. loaded_file.txt), by applying R following script:

```
my_data<-read.delim("loaded_file.txt").
```

Next, we substituted a decimal coma “**,**” in each numbers by dot “**.**”, converting the former’s (transformed numbers) in numeric as well as transforming loaded data table into a matrix, by applying the following function:

`file_name<-as.matrix(data.frame (YP.T0=as.numeric(gsub(",",".",my_data[,1]), GP.T0=as.numeric(gsub(",",".",my_data[,2]),…)))`function and/or script.

We performed a multivariate statistical analysis assessing cereals growth and yield data distribution by applying boxplot script as following:

```
boxplot (file_name, data=file_name, notch=TRUE, col=(c ("whit”, “black")), main="Growth vs. Yield", xlab="Seeds_Treatment").
```

Next we performed a clustering analysis based on Euclidian distance of Pearson correlation values by weighting the influence of T_0, T_1, T_2 and T_3 treatments on both processed maize and soybean cereals growth and yield and dry biomass features *via* the following script:

```
plot (hc = hclust(dist(cor(file_name,method="pearson")))).
```

We executed a principal component survey with the purpose to discriminating variation source on analyzed feature data by (i) loading psych library (library(psych)) and (ii) running the following script series:

```
cities.pca.unrot<-principal((file_name), nfactors = 2, rotate = "none")
biplot(cities.pca.unrot)
cities.pca.unrot<-principal((file_name), nfactors = 3, rotate = "none")
biplot(cities.pca.unrot)
```

Next we evaluated the link and/or relationship between yield parameters under T_0, T_1, T_2 and T_3 treatments through R fitting curve analysis, assuming treatment T_0 as reference (first component). Scripts as regards that survey were as following:

```
fit <- lm (GP.T0~poly(GP.T0,4,raw=TRUE))
fit1 <- lm (GP.T0~poly(GP.T1,4,raw=TRUE))
fit2 <- lm(GP.T0~poly(GP.T2,4,raw=TRUE))
fit3 <- lm(GP.T0~poly(GP.T3,4,raw=TRUE))
xx<- seq(0.15,0.95, length=22)
plot(GP.T1,GP.T0,pch=19,ylim=c(-15,5), xlim=c(0,1),col="black")
lines(xx, predict(fit, data.frame(GP.T0=xx)), col="red",lwd=2)
lines(xx, predict(fit1, data.frame(GP.T1=xx)), col="yellow",lwd=2)
lines(xx, predict(fit2, data.frame(GP.T2=xx)), col="blue",lwd=2)
lines(xx, predict(fit3, data.frame(T3=xx)), col="green",lwd=2)
```

Where, i.e. “*YP.*T_0”and/or “*GP.*T_0”acronym,indicate numeric vectors with regard yield and growth parameters respectively of both processed maize and soybean seeds without rhizobacteria microorganism as well as foliar bio-fertilizer treatment. Next we focused on analysis of variance summarized in “*ANOVAs”* script with the purpose to perform variance analysis assessing the relationship with regards processed maize and soybean plants growth and yield and dry bio-mass parameters:

```
result_anova = anova(lm(Dry_biomass.T0 ~ GP.T0 + YP.T0 , data=file_name))
```

Multiple linear regression models have been developed by executing *lm* script.

```
result_lm= lm (Dry_biomass.T0 ~ GP.T0 + YP.T0, data=file_name)
```

To conclude we assessed maize and soybean dry biomass variability, weighing T_0, T_1, T_2 and T_3 treatments in each elementary plot by several principal component analysis (PCA) approaches.