JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
Volume 9, Number 3 (April 2022):3445-3452, doi:10.15243/jdmlm.2022.093.3445
ISSN: 2339-076X (p); 2502-2458 (e), www.jdmlm.ub.ac.id

Research Article

Nitrogen-fixing bacteria and organic ameliorant for corn growth and yield increment in Inceptisols

Reginawanti Hindersah[1*], Nadia Nuraniya Kamaluddin[1], Shabrina Rahma Fauzia[2], Mieke Rochimi Setiawati[1], Tualar Simarmata[1]

[1] Department of Soil Science and Land Resources, Faculty of Agriculture, Universitas Padjadjaran, Jalan Raya Bandung-Sumedang Km. 21, Jatinangor, Sumedang 45363, Indonesia
[2] Agrotechnology Undergraduate Program, Faculty of Agriculture, Universitas Padjadjaran, Jalan Raya Bandung-Sumedang Km. 21, Jatinangor, Sumedang 45363, Indonesia

[*]corresponding author: reginawanti@unpad.ac.id

Article history:

Received 31 October 2021
Accepted 11 February 2022
Published 1 April 2022

Keywords:

corn waste
inorganic fertilizer
nitrogen-fixing bacteria
soil organic matter

Abstract

Since Inceptisols, in general, contain low soil organic matter and major plant nutrients, inorganic fertilizers are commonly added during corn cultivation. In order to maintain long-term soil health and fertility, biofertilizer and organic ameliorant application are suggested. The addition of nitrogen (N)-fixing bacteria (NFB) can benefit plant growth through the supply of available nitrogen for plant uptake. Organic ameliorants can enhance soil chemical and biological properties. A field trial had been performed to observe the effect of biofertilizer and organic ameliorant on corn growth, N status in soil and plant, and the yield and waste of corn. The experiment was designed in a Completely Randomized Block Design that consisted of four treatments and six replications. The treatments were 1.2 kg/ha N-fixing mixed biofertilizer, 2 t/ha organic ameliorant, and mixtures of biofertilizer and ameliorant. Control plants received neither biofertilizer nor ameliorant. The experiment results found that N-fixing biofertilizer and ameliorant increased plant height, fully-developed leaves number, soil reaction and N uptake of corn compared to the control. The total-N content was slightly increased after NFB inoculation with and without amelioration over other treatments. Plots treated with biofertilizer and ameliorant produced a higher grain weight compared to the control treatment. Corn wastes such as empty corn cob and husk weight were increased in plants treated with biofertilizer, ameliorant and a combination of both. This study suggested that the combined application of biofertilizer and ameliorant produced 66% more grain yield and 84 % more cob and husk waste compared to untreated plants.

To cite this article: Hindersah, R., Kamaluddin, N.N., Fauzia, S.R., Setiawati, M.R. and Simarmata, T. 2022. Nitrogen-fixing bacteria and organic ameliorant for corn growth and yield increment in Inceptisols. Journal of Degraded and Mining Lands Management 9(3):3445-3452, doi:10.15243/jdmlm.2022.093.3445.

Introduction

Corn (*Zea mays* L.) is an important grain for feed industries. In livestock production, corn grains are not the only useful part of animal diets, but their wastes, such as empty cob and husk, are beneficial for feedstock. Fermented and unfermented corn waste was included in the composition of ruminants feed (Defar et al., 2017; Widaningsih et al., 2018; Arwinsyah et al., 2019). Despite the increase in corn grain demand in Indonesia, corn cultivation areas reduce over time due to land use changes. The harvest area of corn in Indonesia in 2018 was 5.73 million and has decreased to 5.16 million ha in 2020. Nonetheless, corn productivity in 2020 was 5.47 t/ha, which is almost

5.4% higher than that in 2018, but it is much lower than the government plan to increase the corn productivity up to 8 to 9 t/ha. Furthermore, corn is still imported from other countries to fulfil national needs, so corn production should be enhanced to save the foreign exchange.

Nowadays, corn cultivation is shifted to low fertility and acidic soil like Inceptisols. The cultivation process in sub-optimum soil requires a high fertilization rate in order to compensate for the lack of nutrient availability in this type of soil. In Indonesia, Inceptisols have developed from volcanic materials that contained higher content of basalt (Neswati et al., 2019; Muslin et al., 2020) with low organic matter, acidic to slightly acidic reaction, and limited essential nutrients (Muslim et al., 2020; Safruddin et al., 2009; Syamsiyah et al., 2018). In the tropical region with high precipitation, Inceptisols are susceptible to nutrient and organic matter loss to become degraded soil. Long-term and high dose application of inorganic fertilizer leads to compacted layer formation that further decreases permeability, water availability and yield (Massah and Azadegan, 2016). In certain cases, intensive chemical fertilization may lower mineralization rate of soil organic matter from organic fertilizer as well as urease and catalase enzyme activity (Ning et al., 2017; Guo et al., 2019).

Following intensive fertilization, the organic matter and essential nutrient content of Inceptisols are possibly increased (Song et al., 2015), but without intensive and sufficient organic matter application, the soil will be further degraded. In mineral soil, the content of organic matter is only less than 7% but has an important effect on soil properties. Organic matter lower soil bulk density and increase porosity, allowing better root growth and, subsequently, nutrient uptake by the plant (Tanveera et al., 2016). The prominent role of organic matter in soil includes providing water-extractable N, which contribute to N availability for plant uptake (Wijanarko and Purwanto, 2017; Wang et al., 2019).

The nitrogen deficiency symptom is possibly one of the most frequent nutrient problems in agricultural practice. The chlorophyll content of leaf blades in cereal relates positively with N content that is important for photosynthesis and corn production (Fornari et al., 2020). Heterotrophic NFB in low-N soil has a prominent role in maintaining the nutrient cycle in soil. The enzymatic gaseous N transformation to ammonia is carried out by two NFB genera, Azotobacter and Azospirillum, providing 20 kg N/ha and 20-40 kg/ha, respectively (Sayyed et al., 2012; Jnawali et al., 2015). The free-living NFB in grain production contributes to 15.5 kg N/ha (Ladha et al., 2016). In the presence of glucose, Azotobacter fixed 8.14-8.46 mg N/g glucose (Bag et al., 2017).

Organic matter is one of the key components of soil for bacteria growth, especially heterotrophs since it depends on organic carbon as the main source of energy. Soil carbon content reduction can lead to dramatic shifts in the microbial diversity-biomass ratio, which may negatively affect soil enzymatic processes (Bastida et al., 2021). The water and organic matter contents were positively correlated with the diazotrophic bacteria population, but the abundance in NFB has negatively correlated to soil pH (Chen et al., 2019).

Soil ameliorant amendment is a way to improve soil fertility and thereby enhance plant growth. Both organic and inorganic ameliorants are considered as non-conventional fertilizers for better plant yield. The use of ameliorants, including composted sewage sludge, manure, biochar, weeds as well as a natural mineral has been reported to increase soil fertility and plant productivity in degraded and suboptimal soil (Maftu'ah et al., 2019; Subiksa and Husnain, 2019; Malyuta et al., 2020; Haryati et al., 2021).

Corn cultivation with biofertilizer inoculation followed by ameliorant application produce a higher grain yield. The sustained increase of corn yield during two decades was more prominent in the field with organic matter amendment combined with chemical fertilizer compared to field received only chemical fertilizer (Song et al., 2015). In a field experiment, biofertilizer combined with composted organic increased the NO_3^- and NH_4^+ contents in soil and hence the number of tillers over the control (Amanda et al., 2018). A mixture of NFB, phosphate solubilizing bacteria and compost produce 26% more corn cob weight (Kalay et al., 2020).

The degradation of Inceptisols should be prevented by organic matter application combined with chemical fertilizer and biofertilizer inoculation in order to sustain corn productivity and manage soil health. The objective of this field experiment was to observe the effect of biofertilizer and ameliorant on corn growth, N status in soil and plant, and the yield and waste of corn grown in Inceptisols with an average content of organic matter.

Materials and Methods

The research was carried out from January to April 2020 at the field experiment of the Center for the Development of Horticultural Seeds and Various Plants in Pasir Banteng, Tanjungsari, Sumedang Regency, West Java. The field experiment is located in the tropics at an altitude of ± 752 m above sea level with an annual temperature of 19 °C-30 °C and relative humidity of 39-84%.

The soil in the experimental field was silty clay loam Inceptisols with a slightly-acidic reaction (pH of 5.7). Soil properties verified that soil was average in organic carbon, total N, total P_2O_5 and total K_2O but low in available P_2O_5 (Table 1). The cation exchange capacity (CEC) was average due to low exchangeable K, Ca and Na; and the base saturation (BS) was low. The population of total NFB in soil was 2.14 x 10^7 Colony Forming Unit (CFU)/mL. The level of total Fe

(important metal for NFB) in soil was average up to 6.39 mg/kg.

The trial utilized a carrier-based biofertilizer composed of mixed NFB *Azotobacter* sp., *Azospirillum* sp., and endophytic bacteria isolated from the corn rhizosphere. The biofertilizer was formulated in an organic-based carrier enriched with organic substances. The population of each bacterium in solid biofertilizer were at least 10^7 CFU/g on 10 days after formulation. The composition of organic ameliorant was 50% composted bagasse, 20% biochar, 20% dolomite, 1% humic acid and 9% bat guano manure. The ameliorant contained 13.27% organic carbon and 0.52% total N, and have C:N ratio of 23.

Table 1. Chemical properties of Inceptisols before the experiment.

Parameter	Value
pH_{H2O} and pH_{KCl}	5.77 and 4.81
Organic C (%)	2.30
Total N (%)	0.21
C:N ratio	11
P_2O_5 HCl 25% (mg/100 g)	20.74
P_2O_5 Bray (mg/kg)	4.87
K_2O HCl 25% (mg/100 g)	25.92
Exchangeable cations:	
Potasium (cmol/kg)	0.25
Sodium (cmol/kg)	0.32
Calcium (cmol/kg)	4.02
Magnesium (cmol/kg)	1.96
Cation exchange capacity (cmol/kg)	23.61
Base saturation (%)	27.74
Total Fe (mg/kg)	6.39
Exchangeable Al (cmol/kg)	0
Exchangeable H (cmol/kg)	0.23
Al saturation (%)	0

Experimental design

The experiment was performed to test the effect of NFB biofertilizer and organic ameliorant on plant growth and yield of corn hybrid variety cv BISI-2. The field trial was set up in a Completely Randomized Block Design that consisted of four treatments, including control treatment; all treatments were replicated six times. The treatments were 1.2 kg solid NFB biofertilizer/ha, 2 t organic ameliorant/ha, and a mixture of similar doses of solid NFB and organic ameliorant. The control treatment received neither biofertilizer nor ameliorant. All experimental plots were treated with 300 kg Urea/ha, 200 kg SP-36/ha and 200 kg KCl/ha as basal fertilizers.

Field experiment establishment

The tillage of the field experiment was done by using a rotary hand tractor. The plot was divided into six replication units with the east-west orientation. The size of the experimental plot in all replications was 3 m x 2.5 m with a 50 cm distance between treatment plots and replications units. The organic ameliorant at the rate of 1,440 g per plot was mixed with the soil during field preparation.

Biofertilizer was applied by a seed coating method. Corn seeds were mixed with gum Arabic and water (1:2 v/v), then wet seeds were coated by the mixture of solid biofertilizer and organic ameliorant at the volume ratio of 1:4. The organic ameliorant as much as 36 g was put in each planting hole at a distance of 7.5 cm x 25 cm one week before sowing. Two biofertilizer-coated seeds were sown in 40 planting holes. Inorganic fertilizers were put in a 5 cm depth hole at a distance of 5 cm from the planting hole. Plants were treated with SP-36 at sowing time, while Urea and KCl were applied twice at 1 week and 4 weeks after sowing at the rate of 50% at each application.

At two weeks after sowing, one seedling in each planting hole was removed in order to maintain only one plant until harvest time. During the experiment, grasshoppers and armyworms (*Spodoptera litura*) attacked a few plants and caused leaf damage. Any pesticides did not apply, and the pest was mechanically eliminated by nipper.

Parameters and statistical analysis

The data of shoot height, stem diameter and leaves number were taken at six and eight weeks after sowing. Stem diameter was measured at 2 cm up the stem base by using a calliper, while leaves numbers were only counted for fully-developed leaves. At eight weeks after sowing (end of vegetative phase, before taseling), dry weight and N content of leaf blade, pH and total N of soil were analyzed. Nitrogen analysis and pH measurement was performed by the proximate analysis method determined by the Association of Official Agricultural Chemists (AOAC, 2019). The N uptake on the leaf blade was calculated by multiplying its dry weight by N content. The enumeration of NFB population in the corn rhizosphere was done at week eight by using the Serial Dilution Plate Method (Ben-David and Davidson, 2014) in James Nitrogen Free Malat Bromthymol Blue (Videira et al., 2012).

At harvest time (day 103), intact corn cobs were picked up from of individual plant and weighed. The corn husk was peeled, and the cobs were dried in the open air under sunlight for three days in order to decrease the water content up to 11%. Grain yield in a hectare was counted based on grain weight in a single plot. In order to analyze the volume of wastes from corn cultivation, empty corn cob and corn husk weight were calculated based on corn cob and grain weight. Data of each parameter was the average of five data taken up from plant sampling points which were not included border plants. All data were subjected to analysis of variance (ANOVA) at $p \leq 0.05$. The Duncan's Multiple Range Test at $p \leq 0.05$ was only performed for the significant parameter on Anova. Statistical analysis was carried out by Minitab ver 18.

Results and Discussion

Plant growth

Single and mixed application of NFB and organic ameliorant increased the shoot height but did not affect the stem diameter of corn at six and eight weeks after application (Table 2). At 8 weeks, the highest shoot was shown by corn inoculated by NFB with or without inoculation. The stems diameter of treated plants remained similar compared to the control. The increase of leave number was observed in corn treated with NFB and ameliorant in single or mixed application (Figure 1). At six weeks, the leaves number of plants with NFB and NFB + ameliorant were higher than with ameliorant only and the control. Application of NFB and ameliorant at sowing time resulted in the highest leave number at week 8, which was 46% more than the control. Surprisingly, the organic amendment had not affected the leaves number at the end of the vegetative phase.

Table 2. Effect of NFB and ameliorant on plant height and stem diameter at six and eight weeks after sowing.

Fertilizer Treatments	Shoot Height (cm)		Stem Diameter (cm)	
	6 weeks	8 weeks	6 weeks	8 weeks
Control	98.5 a	142.3 a	2.6 a	4.1 a
Consortia of NFB	119.4 c	188.2 c	2.9 a	4.5 a
Organic Ameliorant	112.0 b	172.6 b	2.8 a	4.4 a
NFB and Ameliorant	127.5 d	197.7 c	3.1 a	4.5 a

Remarks: Numbers followed by the different letters in a column are significantly different based on the Duncan Multiple Range Test at $p \leq 0.05$.

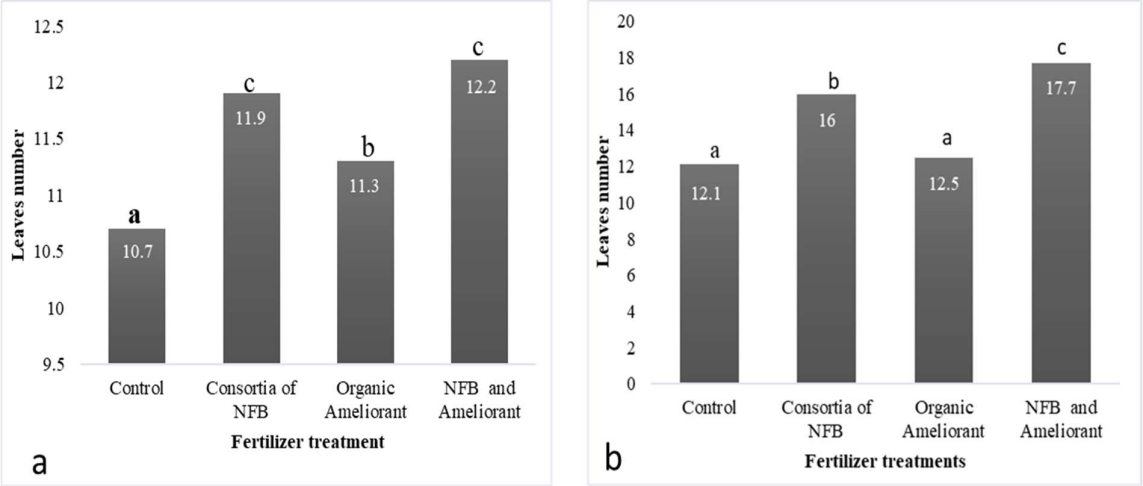

Figure 1. The leaves number of corns grown with various fertilizer treatments at six (a) and eight (b) weeks after sowing. Different letters in bars indicated the significant difference based on the Duncan Multiple Range Test at $p \leq 0.05$.

Nitrogen status in soil and plant

The experiment utilized medium acid soil with a soil reaction (pH-H_2O) of 5.77 (Table 1). At the end of the vegetative stage, the pH change to slightly acid and even to near neutral in the soil received NFB or/and ameliorant. Before the experiment, the soil contained 0.21% total N (Table 1), but after growing the corn, the total N in the control treatment and in soil with organic amendment slightly decreased. The result verified the highest total-N increment was in soil with a mix of NFB and ameliorant (Table 3). Fertilizer treatments did not influence N content and dry weight of leaf blade but increased its N uptake (Table 4). It is clearly shown that the highest N uptake was by plant inoculated with NFB combined with ameliorant. The increment of N uptake by the individual plant was 14.5-48 % over another treatment and control.

Nitrogen-fixing bacteria population

Before the experiment, the NFB in the rhizosphere was 2.14 x 10^7 CFU/mL, equal to 7.33 $\log_{10}$ of CFU/mL. The NFB count after either single or mixed application of NFB and ameliorant increased over the control (Figure 2). The highest NFB population was clearly recorded in corn rhizosphere grown with the NFB and ameliorant, which is 1.5-7.1% higher than another treatment and the control.

Table 3. Effect of NFB and ameliorant on acidity and total nitrogen in soil of corn at eight weeks after sowing.

Treatments	Soil Acidity	Total N (%)
Control	6.44 a	0.19 a
Consortia of NFB	6.79 bc	0.23 b
Organic Ameliorant	6.71 b	0.20 a
NFB and Ameliorant	6.91 c	0.27 c

Remarks: Numbers followed by the different letters in a column are significantly different based on the Duncan Multiple Range Test at $p \leq 0.05$.

Yield and corn waste

Corn cv. BISI-2 has two cobs in an individual plant. The weight of intact corn cob increased after NFB inoculation and ameliorant as well as their combination (Table 5). The results showed that the plots with fertilizer treatment have higher grain weight than the control. Estimated corn productivity verified that corn yield in the control plot was 26.3-40.0 % less than treated plots (Table 5). The combined application of NFB and ameliorant contributed to the highest intact corn cob and grain weight.

Table 4. Nitrogen content and uptake in the leaf blade of corn treated by various fertilizers at 8 weeks after sowing.

Fertilizer Treatments	N Content (%)	Blade Dry Weight (g)	N Uptake (g/plant)
Control	2.78	92.86	2.55 a
Consortia of NFB	3.10	106.95	3.30 b
Organic Ameliorant	3.00	96.25	2.87 a
NFB and Ameliorant	3.11	119.39	3.78 c

Remarks: Numbers followed by the different letters in a column are significantly different based on the Duncan Multiple Range Test at $p \leq 0.05$.

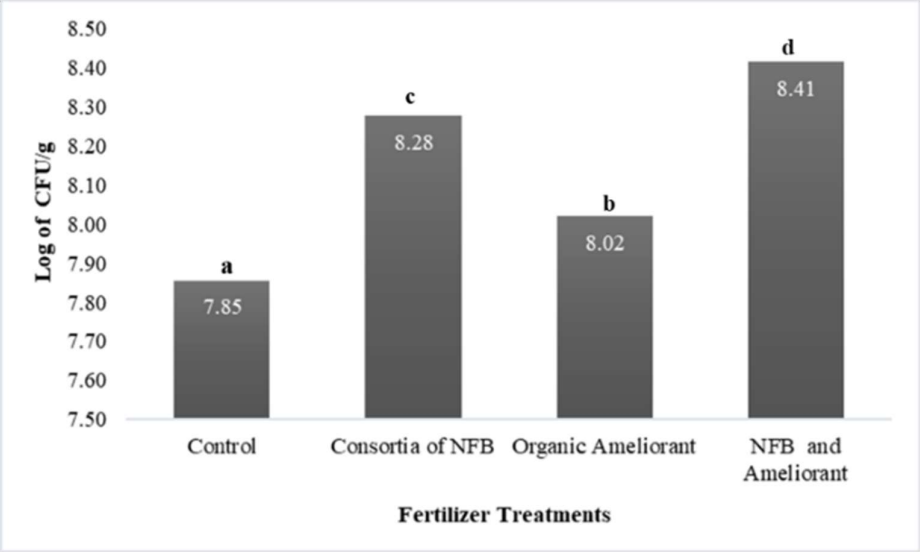

Figure 2. Change in nitrogen-fixing bacteria population in corn rhizosphere after application of various fertilizers. Different letters in bars indicated the significant difference based on the Duncan Multiple Range Test at $p \leq 0.05$.

Table 5. Effect of NFB and organic ameliorant on the weight of intact corn cob and grain weight of corn.

Fertilizer Treatments	Intact Corn Cob Weight (g/plant)	Grain Weight		Estimated Yield (t/ha)
		g/plant	kg/plot	
Control	223.85 a	136.20 a	5.45 a	7.26
Consortia of NFB	346.18 c	198.10 b	7.92 b	10.56
Organic Ameliorant	322.91 b	184.96 b	7.40 b	9.86
NFB and Ameliorant	389.33 d	227.20 c	9.09 c	12.11

Remarks: Numbers followed by the different letters in a column are significantly different based on the Duncan Multiple Range Test at $p \leq 0.05$.

Equivalent with corn yield, the corn waste produced in this field trial was enhanced in plots with fertilizer treatment. The weight of empty corn cob and husk counted from an individual plant in control plots were the lowest (Table 6). By calculating the waste for a hectare based on the value of a single plant, it was revealed that corn cultivation possibly produced empty corn cob up to 1.2 t/ha in control and 2.6-4.4 t/ha in the treated plot. While corn husk weight obtained from a hectare corn plantation could be 3.5 t/ha in control and 3.6-4.8 t/ha in treated plots.

Before growing the corn, the soil had an average content of organic carbon, N, total P_2O_5, total K_2O and CEC but low in available P_2O_5 and BS. Plant treated with consortia of NFB and ameliorant in the single and combined application had higher grain weight and resulted in grain yield increment in a plot. Estimated corn productivity in a hectare then increased in treated plots over control plots. The average grain yield of the Bisi-2 hybrid variety is 8.9 t/ha but will increase up to 13 t/ha with optimal inputs and cultivation method based on its description released by the Indonesia Ministry of Agriculture. We found that grain yield in the control plots (7.26 t/ha) was 18.4 % less than the average yield. A single application of NFB or ameliorant has increased the grain yield; furthermore, combined application of both inputs resulted in yield increment up to 12.11 t/ha.

Table 6. Effect of NFB and organic ameliorant on the weight of empty corn cob and husk.

Fertilizer Treatments	Waste Per Plant		Estimated Waste Per Plot	
	Empty Corn Cob (g)	Corn Husk (g)	Empty Corn Cob (kg)	Corn husk (kg)
Control	22.11 a	65.53 a	0.88	2.62
Consortia of NFB	80.58 c	67.50 a	3.22	2.70
Organic Ameliorant	48.61 b	89.34 b	1.94	3.57
NFB and Ameliorant	82.33 c	79.80 b	3.29	3.19

Remarks: Numbers followed by the different letters in a column are significantly different based on the Duncan Multiple Range Test at $p \leq 0.05$.

The yield increment is possibly caused by shoot height and leaves number increment at the end of the vegetative phase. Leaves are prominent organs for photosynthesis to produce carbohydrates and other photosynthates. The increase of soil reaction induced by the application of ameliorant containing dolomite was shown. The shifting of soil reaction from slightly acid before the experiment to neutral after NFB and amendment application benefits plant as well as bacterial growth. In general, plant enables to grow at the pH of 5.6-7.5, but soil reactions between 6.7-7.8 affect nutrient availability in soil and provide an optimal condition for nutrient uptake (Samson et al., 2017). Before the experiment, the soil contained total K_2O and P_2O_5 in average concentration; the increase of pH up to 6.91 in plots with NFB and ameliorant application may cause the increment of available P and K for root uptake. In neutral pH, trace elements adsorption by soil increases and become less available for plants (Neina, 2019), so we did not observe plant toxicity syndrome in all plots.

Increased NFB population in the rhizosphere after NFB inoculation and ameliorant amendment was demonstrated. Moreover, neutral soil reaction in treated soil assures NFB proliferation since Azotobacter and Azospirillum showed optimal cell propagation in a neutral environment (Verma et al., 2011; Mukhtar et al., 2018). All those NFB have been reported to produce phytohormones, mostly indole acetic acid (Zulaika et al., 2017; Puente et al., 2018; Woźniak et al., 2019) that enable to improve plant roots and hence might increase nutrients uptake, including N. Plant treated with NFB and organic ameliorant showed sufficient N (≥ 3%) but control plant had only 2.78% N. At 58 days, N content of all leaf blade is adequate in 3.0%, but deficient in 1.7% (Reuter and Robinson, 1988). The higher NFB count in the rhizosphere of corn grown in treated plots possibly contributed to the available N increment in the soil through N fixation, and hence N uptake by leaf blade.

The results showed that ameliorant application increased plant growth and grain yield. The organic matters in ameliorants are not only needed for bacterial proliferation but also provide nutrients for plant growth. Soil organic matter is composed of various substances, including simple molecules such as sugars and amino acids to polymeric molecules such as cellulose, protein, and lignin. The microbes mineralized organic compounds into inorganic and soluble molecules such as NH_4^+, NO_3^-, PO_4^-, PO_4^{2-}, and SO_4^{2-} for plant uptake. This transformation is an enzymatic process that depends on C:N ratio of organic matter and C:N ratio in the soil after the organic matter amendment (Grzyb et al., 2020). The C:N ratio of organic ameliorant was lower than 25 (Table 1), indicating that rapid immobilization of inorganic N did not occur.

Sufficient nutrients provided by inorganic fertilizer, NFB and ameliorant play a prominent role to enhance grain yield. This also indicated that photosynthate translocation from leaves to corn reproductive organs in treated plots was better for corn cob and grain development compared to the control

one. Single and mixed application of NFB inoculation and ameliorant in this field trial did not only increase the intact cob and grain weight but also produced a higher amount of waste. Ruminant productivity is affected by genetic factors and the feed, which is greenery. Fodder provision by utilizing corn waste that contains many hemicellulose and cellulose can overcome the limited availability of greenery in the dry season.

Conclusion

Inoculation of biofertilizer composed of NFB consortia combined with the amendment of organic ameliorant caused higher plant height, fully-developed leaves number and N uptake of corn grown in the field. A slight change of soil reaction from slightly acid to neutral was recorded in soil received biofertilizer and ameliorant compared to pH before the experiment, but total-N content was slightly reduced in soil with ameliorant. Single or mixed application of NFB biofertilizer clearly enhanced grain yield of corn cv BISI-2 in the plot, but the mixed application of both inputs produced the highest grain yield. The results showed that introducing NFB and organic ameliorants also produce a significant amount of corn cob waste. The increase of empty corn cob and corn husk was demonstrated in plots with NFB and ameliorant. This field experiment concluded that NFB biofertilizer inoculation combined with ameliorant enhance yield and the corn waste up to 66% and 84%, respectively, compared to control treatment.

Acknowledgements

The research was fully funded by the Academic Leadership Grant of Universitas Padjadjaran. The authors thank the Head of The Center for the Development of Horticultural Seeds and Various Plants, Department of Agriculture of West Java.

References

Amanda, A.P., Fitriatin, B.N. and Sofyan, E.T. 2018. Consortium of biological fertilizers and organic ameliorants on soil nitrogen and growth of rice (*Oryza sativa* L.) on Inceptisols. *Jurnal Agrotek Indonesia* 3(2):03-106. doi:10.33661/jai.v3i2.1373 (*in Indonesian*)

AOAC (Association of Official Analytical Chemists). 2019. Official Methods of Analysis of AOAC International, 21st Edition. AOAC International, Gaithersburg, MD.

Arwinsyah, Tafsin. M. and Yunilas. 2019. Effect of bio activator use on corn cobs as a complete feed on performance and digestibility of local sheep. *IOP Conference Series: Earth and Environmental Science* 260(2019):012047, doi:10.1088/1755-1315/260/1/012047.

Bag, P., Panda, P., Paramanik, B., Mahato, B. and Choudhury, A. 2017. Atmospheric nitrogen-fixing capacity of Azotobacter isolate from Cooch Behar and Jalpaiguri Districts soil of West Bengal. *International Journal of Current Microbiology and Applied Sciences* 6:1775-1788, doi:10.20546/ijcmas.2017.603.204.

Bastida, F., Eldridge, D.J., García, C., Png, G.K., Bardgett, R.D. and Delgado-Baquerizo, M. 2021. Soil microbial diversity–biomass relationships are driven by soil carbon content across global biomes. *ISME Journal* 15:2081–2091, doi:10.1038/s41396-021-00906-0.

Ben-David, A. and Davidson, C.E. 2014. Estimation method for serial dilution experiments. *Journal of Microbiological Methods* 107:214-221, doi:10.1016/j.mimet.2014.08.023.

Chen, J., Shen, W., Xu, H., Li, Y. and Luo, T. 2019. The composition of nitrogen-fixing microorganisms correlates with soil nitrogen content during reforestation: A comparison between legume and non-legume plantations. *Frontier in Microbiology* 10:508, doi:10.3389/fmicb.2019.00508.

Defar, G., Urgie, M. and Melaku, S. 2017. Effect of urea treatment and concentrate mix supplementations on feed intake and digestibility of Horro sheep fed cured maize husk (*Zea mays*) at Bako, Western Ethiopia. *African Journal of Agricultural Research* 2(17):1459-1465, doi:10.5897/AJAR2016.11883.

Fornari, E.Z., Gaviraghi, L., Basso, C.J. Pinheiro, M.V.M., Vian, Santi, A.L. 2020. Relationship between photosynthetic pigments and corn production under nitrogen sources. *Pesquisa Agropecuaria Tropical* 50: e63661.

Grzyb, A., Wolna-Maruwka, A. and Niewiadomska, A. 2020. Environmental factors affecting the mineralization of crop residues. *Agronomy* 10(12):1951, doi:10.1590/1983-40632020v5063661.

Guo, Z., Han, J., Li, J., Xu, Y. and Wang, X. 2019. Correction: Effects of long-term fertilization on soil organic carbon mineralization and microbial community structure. *PLOS ONE* 14(4):e0216006, doi:10.1371/journal.pone.0216006.

Haryati, U., Irawan and Maswar. 2021. Application of mulch and soil ameliorant for increasing soil productivity and its financial analysis on shallots farming in the upland. *IOP Conference Series: Earth and Environmental Science* 648 (2021): 012155, doi:10.1088/1755-1315/648/1/012155.

Jnawali, A.D., Ojha, R.B. and Marahatta, S. 2015. Role of Azotobacter in soil fertility and sustainability-A Review. *Advances in Plants & Agriculture Research* 2(6):1-5.

Kalay, A.M., Hindersah, R., Ngabalin, I.A., Jamlean, M. 2020. Utilization of biological fertilizers and organic matter on the growth and yield of sweet corn (*Zea mays* saccharata). Agric 32(2):129-138, doi:10.24246/agric.2020.v32.i2.p129-138 (*in Indonesian*).

Ladha, J.K., Padre, A., Reddy, C.K., Cassman, K., Verma, S., Powlson, D.S., van Kessel, C., Richter, D.D., Chakraborty, D. and Pathak, S. 2016. Global nitrogen budgets in cereals: a 50-year assessment for maize, rice and wheat production systems. *Science Reports* 6:19355, doi:10.1038/srep19355.

Maftu'ah, E., Susilawati, A. and Hayati, A. 2019. Effectiveness of ameliorant and fertilizer on improving soil fertility, growth and yields of red chili in degraded peatland. *IOP Conference Series: Earth Environmental Science* 393(2019):012011, doi:10.1088/1755-1315/393/1/012011.

Malyuta, O., Gordeeva, T. and Yatmanova, N. 2020. Non-traditional fertilizers as soil ameliorants: The study of

usefulness. *BIO Web Conferene* 17(2020):00120, doi:10.1051/bioconf/20201700120,

Massah, J. and Azadegan, B. 2016. Effect of chemical fertilizers on soil compaction and degradation. *Agricultural Mechanization in Asia, Africa & Latin America* 47(1):44-50,

Mukhtar, H., Bashir, H. and Nawaz, A. 2018. Optimization of growth conditions for Azotobacter species and their use as biofertilizer. *Journal of Bacteriology and Mycology* 6(5):274–278, doi:10.15406/jbmoa.2018.06.00217,

Muslim, R.Q., Kricella, P., Pratamaningsih, M.M., Purwanto, S., Suryani, E. and Ritung, S. 2020. Characteristics of Inceptisols derived from basaltic andesite from several locations in volcanic landform. *SAINS TANAH – Journal of Soil Science and Agroclimatology* 17(2):115-121, doi:10.20961/stjssa.v17i2.38221.

Neina, D. 2019. The Role of soil pH in plant nutrition and soil remediation. *Applied and Environmental Soil Science* 2019:5794869, doi:10.1155/2019/5794869.

Neswati, R., Lopulisa, C., Rivananda. and Basir, A. 2019. Characteristics and classification of soil formed from Banda recent volcanic ash on various topographic positions. *IOP Conference Series.: Earth and Environmental Science* 280:012017, doi:10.1088/1755-1315/280/1/012017.

Ning, C-C., Gao, P-D., Wang, B-Q, Lin, W-P, Jiang, N-H. and Cai, K-Z. 2017. Impacts of chemical fertilizer reduction and organic amendments supplementation on soil nutrient, enzyme activity and heavy metal content. *Journal of Integrative Agriculture* 16(8):1819-1831, doi:10.1016/S2095-3119(16)61476-4.

Puente, M.L., Gualpa, J.L., Lopez, G.A., Molina, R.M., Carletti, S.M. and Cassán, F.D. 2018. The benefits of foliar inoculation with *Azospirillum brasilense* in soybean are explained by an auxin signaling model. *Symbiosis* 76:41-49, doi:10.1007/s13199-017-0536-x.

Reuter, D.J and Robinson, J.B. 1988. *Plant Analysis and Interpretation Manual*. Ikata Press, Sydney. pp. 219.

Samson, R., Ningal, T., Tiwary, A., Grote, R., Fares, S., Saaroni, H., Hiemstra, J.A., Zhiyanski, M., Vilhar, U., Carinanos, P., Järvi, L., Przybysz, A., Moretti, M. and Zürcher, N. 2017. Species-Specific Information for Enhancing Ecosystem Services. In: Pearlmutter, D. et al. (eds.), *The Urban Forest, Future City*. Springer International Publishing AG., pp 111-132.

Sayyed, R.Z., Reddy, M.S., Kumar, K.V., Yellareddygari, S.K.R., Deshmukh, A.M., Patel, P.R. and Gangurde, N.S. 2012. Potential of plant growth-promoting rhizobacteria for sustainable agriculture bacteria. In: Maheshwari, D.K. (ed). *Bacteria in Agrobiology: Plant Probiotics*. Springer-Verlag Berlin Heidelberg, pp 287-313.

Song, Z., Gaob, H., Zhu, P., Peng, C., Denga, A., Zheng, C., Manna, M.A., Islam, M.N. and Zhang, W. 2015. Organic amendments increase corn yield by enhancing soil resilience to climate change. *The Crop Journal* 3(2):110-117, doi:0.1016/j.cj.2015.01.004.

Subiksa, I.G.M. and Husnain. 2019. Effect of organomineral soil amendment for acid upland on soil chemical properties and growth of maize. *Penelitian Pertanian Tanaman Pangan* 3(1):23-30. doi:10.21082/jpptp.v3n1.2019.p23-30 (*in Indonesian*).

Syafruddin, Rauf, M., Arvan, R.Y. and Akil, M. 2009. Requirements for N, P, and K fertilizers on Inceptisol Haplustepts soil. *Indonesian Journal of Agriculture* 2(1), 2009:77-84 77.

Syamsiyah, J., Sumarno, Suryono, Sari, W. and Anwar, M. 2018. Chemical properties of Inceptisol and rice yields applied with mixed source fertilizer (MSF). *Journal of Tropical Soils* 23(1):1-9, doi:10.5400/jts.2018.v23i1.1-9.

Tanveera, A., Kanth, T.A., Tali, P.A. and Naikoo, M. 2016. Relation of soil bulk density with texture, total organic matter content and porosity in the soils of Kandi area of Kashmir valley, India. *International Research Journal of Earth Sciences* 4(1):1-6, doi:10.9734/JGEESI/2016/21344.

Verma, R., Chourasia, S.K. and Jha, M.N. 2011. Population dynamics and identification of efficient strains of Azospirillum in maize ecosystems of Bihar (India). *3 Biotech* 1:247=253, doi:10.1007/s13205-011-0031-7.

Videira, S.S., Messias de Oliveira, D., Fiusa de Morais, R., Borges, W.L., Baldani, V.L.D. and Baldani, R.I. 2012. Genetic diversity and plant growth promoting traits of diazotrophic bacteria isolated from two *Pennisetum purpureum* Schum. genotypes grown in the field. *Plant and Soil* 356:51–66, doi:10.1007/s11104-011-1082-6.

Wang, X-W., Cai, H., Liu, Y-L., Li, C-L., Wan, Y-S., Song, F-P and Chen, W.F. 2019. Addition of organic fertilizer affects soil nitrogen availability in a salinized fluvo-aquic soil. *Environmental Pollutants and Bioavailability* 31(1):331-338, doi:10.1080/26395940.2019.1700827.

Widaningsih, N., Dharmawati, S. and Puspitasari, N. 2018. Crude protein and crude fiber contents of fermented corn cobs using different levels of buffalo rumen fluid. *Ziraa'ah* 43(3):255-265 (*in Indonesian*).

Wijanarko, A. and Purwanto, B.H. 2017. Effect of land use and organic matter on nitrogen and carbon labile fractions in a Typic Hapludult. *Journal of Degraded and Mining Lands Management* 4(3):837-843, doi:10.15243/jdmlm.2017.043.837.

Woźniak, M., Gałązka, A., Tyśkiewicz, R. and Jaroszuk-Ściseł, J. 2019. Endophytic bacteria potentially promote plant growth by synthesizing different metabolites and their phenotypic/physiological profiles in the Biolog GEN III MicroPlateTM Test. *International Journal of Molecular Science* 20(21):5283, doi:10.3390/ijms20215283.

Zulaika, E., Solikhah, F., Alami, N.H., Kuswytasari, N.D. and Shovitri, M. 2017. Viability of Azotobacter consortium in auxin production. *AIP Conference Proceedings* 1854:20041, doi:10.1063/1.4985432.