Improved black soybean performances grown on selected highly weathered soils by using bio-nano-ortho silicic acid

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Abstract. The objectives of the study were to determine the potential use of bio-nano-ortho silicic acid (OSA) originated from locally mineral enriched with silica-solubilizing microbes to improve yield, reduce chemical fertilizer dosage, and increase water use efficiency (WUE) of black soybean grown on selected highly weathered soils. The first-year (2017) study was conducted at Majalengka and Natar area and arranged in a random block design (RBD) with three replicates, using a Detam-1 variety. Treatments of NPK fertilizers were 0, 50, 75, and 100% of standard recommended dosages in combination with 0, 2, 4, and 6 L bio-nano OSA Ha⁻¹. In general, application of 4 L bio-nano OSA Ha⁻¹ saved 32% NPK fertilizer dosage and improved growth and yield of Detam-1. The second year (2018) trials consisted of no fertilization (P0), farmer standard NPK fertilization (P1), P1 + organic matter (P2), 4 L bio-nano OSA Ha⁻¹ + NPK (P1), 50% (P3); and 75% (P4) respectively, arranged in a RBD with three replicates at three regions, i.e. Majalengka (Alfisols), Natar (Ultisols), and Indramayu (Alfisols). The results confirmed that the application of bio-nano OSA at 4 L Ha⁻¹ improved nutrient use and WUE as well as yield of Detam-1 on all three soils studied.

1. Introduction

Among main commodity crops in Indonesia, soybean is the third biggest consumed agricultural crop after rice and corn. However, national production so far is still deficit to satisfy the needs and therefore import is one most immediate option. Low productivity and/or limited growing area are two main factors causing this phenomenon. On the other hand, a considerably large area is available for development of soybean, such as those in Lampung [1] and West Java, especially for black soybean to supply the growing soy-sauce industry in these regions which are dominated by highly weathered soils [2]. The use of so-called marginally suitable non-irrigated soils for agricultural crops will face a major constraint, i.e. intensive drought period due to excessive evapotranspiration [3] [4]. On top of that, strong soil acidity plays important role on aluminum (Al) saturation capable of nutrient adsorption especially phosphate (P) [5]. On the other hand, silica (Si) has been shown to be able to improve plant drought tolerant as it controls stomata openings, and competes in Al adsorption releasing P available for plants [6] [7]. Reference [8] found that plants adsorb Si as much as other macro nutrients although it has not been considered as a macro nutrient yet. It has been reported also that Si readily available to plant is in the form of silicic acid (H₄SiO₄) or mono-silicic acid [Si (OH)₄] only [9] and soil Si solubility depends on particle size of bearing material [3]. This is the reason why in highly weathered soils with relatively high Si content show positive response on Si fertilizer as the soil Si is mostly
dominated by inert compounds (SiO₂). Many Si fertilizers are currently available, however, very limited of those containing high water-soluble ortho-silicic acid (H₄SiO₄) are available in the market.

In order to provide with an efficient technology, a newly constructed Si fertilizer formula was introduced in combination with Si-solubilizing microbes [10] and evaluated on black soybean grown on three different highly weathered soils in Lampung and West Java, Indonesia. The formula so-called bio-nano-ortho silicic acid (bio-nano OSA) was derived from quartz sand originated from Bangka-Belitung islands containing > 5% H₄SiO₄ with average particle size of 18 nm [11] [12]. Previous results indicated that the application of the bio-nano OSA improved drought tolerant of oil palm seedlings [13], growth and yield of mature oil palm in Central Kalimantan [14]. By using 4-6 L Ha⁻¹ of bio-nano OSA the yield of black soybean improved 36.7%, reduced 32% chemical fertilizer dosage, and tended to increase water use efficiency (WUE) up to 65% [15]. This article reports the effects of bio-nano OSA application on the yield, nutrient use, and WUE of a Detam-1 black soybean variety grown on Natar Ultisols (Lampung), Jatitujuh Alfisols (West Java), and Bantarwaru Alfisols (West Java).

2. Materials and Methods
This paper reports a two-years field experiments in Natar, Lampung Tengah, Lampung, and Jatitujuh, Majalengka, West Java, in 2017 and with an additional area in Bantarwaru, Indramayu, West Java, in 2018, on Ultisols and Alfisols soils. According to Soil Taxonomy [16], the Ultisols of Natar and belongs to Udults, whereas Alfisols of both Jatitujuh and Bantarwaru shows a vertic characteristics, i.e. significant cracks during dry season. The soils used were food crop (Natar), sugarcane (Jatitujuh), and rice field (Bantarwaru) area.

2.1. Materials
Bio-nano OSA was prepared by using method reported earlier containing 9% H₄SiO₄ which enriched with selected Si-solubilizing microbes, i.e. Aeromonas punctata, Burkholderia cenocepacia, B. vietnamiensis, and Aspergillus niger [10] [11]. Black soybean variety used was Detam-1 originated from Balitkabi, Malang. Liming with CaO was applied prior to planting. Urea, TSP, and KCl were single NPK fertilizers used in these experiments. To enhance seed germination and rhizobium infection, the Detam-1 seeds were inoculated with RhiPhosAnt, a commercial rhizobium inoculant enriched with P-solubilizing microbes [17].

2.2. Methods
The bio-nano OSA was prepared by employing the method described earlier by Santi et al. (2017). A randomized block design was used to examine six treatments with three replicates and plot size of 300 m². The treatments consisted of (i) blank/untreated (P0), (ii) NPK farmer standard practice (P1), (iii) P1 + 2 ton farmyard manure Ha⁻¹ (P2), (iv) 50% P1 + 4 L bio-nano OSA Ha⁻¹ (P3), (v) 75% P1 + 4 L bio-nano OSA Ha⁻¹ (P4), and (vi) 100% P1 + 4 L bio-nano OSA Ha⁻¹ (P5). Black soybean var. Detam-1 was sown in hole at 40 cm x 20 cm planting distances which has been limed previously with 500 kg CaO Ha⁻¹ (equivalent to 1500 kg dolomite). Standard fertilization used was 75 kg urea + 100 kg TSP + 100 kg KCl and applied two weeks before planting. The soybean seeds were inoculated with N-fixing and P-solubilizing microbes by using a commercial product, i.e. RhiPhosAnt, to enhance initial plant growth [17] [18]. Bio-nano OSA was applied twice by spraying to the soil after diluting the formula 100x with fresh water at 28 and 45 day after planting (DAP). Standard crop maintenance was performed including weed, pest, and disease control during the experiment period. Parameters observed include growth and yield of the plants as well as the water consumption and water use efficiency (WUE). General soil analyses were performed prior and after experimentations by using standard methods described by [19] [20]. A ring sample was taken at harvest day to determine water contents at different suction pressures to set a pF curve of each treatment plot.

Water consumption was determined based on evapotranspiration data following [21] [22] [23] employing formula ETc = ETo x Kc, where ETc is plant water consumption (mm plant⁻¹), ETo is
potential evapotranspiration, and Kc is crop coefficient for black soybean. Kc value was calculated based on the data collected at 56 DAP by using the following formula [24]:

\[
Kc = \frac{(WCfc - WCpwp)}{(WCsat - WCpwp)},
\]

where:

- Kc : crop coefficient for black soybean
- WCfc : water content at field capacity
- WCpwp : water content at permanent wilting point and
- WCsat : water content at saturated condition.

Potential evapotranspiration (ETo) data was determined from climatic data for the last four months and calculated by using FAO-CROPWAT 8.0 computer program [25] [26]. Plant transpiration of each plot was measured using a porometer at 58 days after planting [27] [28] [29]. Water use efficiency (WUE) was calculated based on the volume of water used by the crop to produce a unit weight of black soybean yield employing the formula described by [30] [31].

3. Results

During the first-year activity, a simpler production technology of bio-nano OSA yielding min. 5% of OSA content was successfully developed and further enriched with selected SSM as bio-nano OSA formula. The trials reported here are from second year results and indicated that bio-nano OSA improved the yield of Detam-1 (Figure 1-3). In general, application of 4 L bio-nano OSA Ha\(^{-1}\) saved 32% NPK fertilizer dosage, particularly on Jatitujuh and Bantarwaru Alfisols. On the other hand, the pattern was a bit different on a less fertile soils, i.e. Natar Ultisols. The lower yields obtained from Jatitujuh experiment was due to an intensive dry season when the trial commenced. However, the results confirmed that the application of bio-nano OSA at 4 L Ha\(^{-1}\) improved nutrient use and WUE as well as yield of Detam-1 black soybean on all three soils studied. The improved efficiency in nutrients used are shown especially in Jatitujuh (Figure 1) and Bantarwaru (Figure 3) where the optimum yields were achieved at 32 and 49 % reduced dosages of NPK, respectively. Black soybean drops in Jatitujuh required water higher than the other two areas under P0-P3 treatments and lower corresponding WUE values (Table 1). However, the addition of bio-nano OSA at 4L Ha\(^{-1}\) dosage improved their WUE values when combined with 25% reduced NPK fertilizer dosage or with 100% dosage of the fertilizers.

![Figure 1](image.png)

**Figure 1.** The relationship between NPK fertilizer dosages and yield of black soybean Detam-1 var. using 4 L Ha-1 bio-Nano OSA on Jatitujuh Alfisols.
Figure 2. The relationship between NPK fertilizer dosages and yield of black soybean Detam-1 var. using 4 L Ha\(^{-1}\) Bio-Nano OSA on Natar Ultisols.

![Graph showing the relationship between NPK fertilizer dosages and yield of black soybean Detam-1 var. using 4 L Ha\(^{-1}\) Bio-Nano OSA on Natar Ultisols.]

\[ y = 0.0445x^2 - 1.0075x + 957.57 \quad R^2 = 0.941^* \]

Figure 3. The relationship between NPK fertilizer dosages and yield of black soybean Detam-1 var. using 4 L Ha\(^{-1}\) Bio-Nano OSA on Bantarwaru Alfisols.

![Graph showing the relationship between NPK fertilizer dosages and yield of black soybean Detam-1 var. using 4 L Ha\(^{-1}\) Bio-Nano OSA on Bantarwaru Alfisols.]

\[ y = -0.4925x^2 + 50.339x + 2218.5 \quad R^2 = 0.941^* \]

Table 1. Water use efficiency (WUE) of black soybean var. Detam-1 with NPK fertilizer dosages and Bio-Nano OSA at three sites of experiments.

| Treatments                                      | Water Requirement (mm day\(^{-1}\)) | WUE (g mm\(^{-1}\) crop\(^{-1}\)) |
|------------------------------------------------|------------------------------------|-----------------------------------|
|                                                | KP, Natar                          | Jatitujuh | Bantarwaru | KP, Natar | Jatitujuh | Bantarwaru | KP, Natar | Jatitujuh | Bantarwaru |
| Blank (no fertilizer) (P0)                      | 4.59 ab                           | 8.95 a    | 4.31 c     | 1.731 a   | 1.36 c    | 2.09 ab    |
| 100% NPK fertilizer dosages (P1)                | 4.55 ab                           | 8.82 a    | 4.34 c     | 2.121 a   | 1.19 c    | 3.04 a     |
| 100% NPK fertilizer dosages + 20 kg Ha\(^{-1}\)  Organic Matter (P2) | 4.61 ab                           | 7.72 a    | 4.32 c     | 2.108 a   | 1.37 c    | 2.26 ab    |
| 50% NPK fertilizer dosages + 4 L Bio-Nano OSA Ha\(^{-1}\) (P3) | 4.10 b                            | 7.02 a    | 4.49 b     | 2.122 a   | 1.97 bc   | 2.80 a     |
| 75% NPK fertilizer dosages + 4 L Bio-Nano OSA Ha\(^{-1}\) (P4) | 4.13 b                            | 3.31 b    | 4.54 b     | 2.234 a   | 3.95 a    | 2.55 a     |
| 100% NPK fertilizer dosages + 4 L Bio-Nano OSA Ha\(^{-1}\) (P5) | 4.89 a                            | 3.86 b    | 4.65 a     | 2.236 a   | 2.79 b    | 1.52 b     |

\(^n\)Numbers in the same column followed by the same letter(s) are not significantly different according to Duncan’s Multiple Range Test (P<0.05).
4. Discussion
All soils used in this experiment were acidic in reaction with very low water-soluble Si ($H_4SiO_4$) contents (< 5 ppm). In comparison, agricultural soils in South Korea are freed from Si fertilizer application is when the plant-available Si above 157 ppm. Therefore, it is understood that the Si addition on these three soils with very low available Si-contents responded positively to Si application. Si has been considerably long understood of having several benefits on improving nutrient efficiency, especially when it competes for aluminum (Al) in the soils, then it will free phosphate and become readily available to plants. In addition, the role of Si in controlling stomatal openings have been widely reported [15] which in turn leads to a lower evapotranspiration rate as indicated by a more efficient WUE. These evidences were then assumed to benefit the plants in absorbing other nutrients, i.e. nitrogen (N) and potassium (K) so then the dosage of chemical fertilizers could be reduced significantly without affecting yield reduction [32].

5. Conclusion
The application of bio-nano OSA on an Ultisols and Alfisol soil under acidic in reaction with very low water-soluble Si ($H_4SiO_4$), promoted better growth and yield performances of Detam-1 black soybean variety. Application of 4 L Ha$^{-1}$ bio-nano OSA can reduce NPK fertilizer dosages up to 50%. However, further study is needed to confirm these results, under different location or ecosystems and a wider application.

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References
[1] Ritung S, Suryani E, Subardja D, Sukarman, Nugroho K, Suparto, Hilmatullah, Mulyani A, Tafakresno C, Sulaeman Y, Subandiono R E, Wahyunto, Ponidi, Prasodjo N, Suryana U, Hidayat H, Priyono dan Supriyatna W 2015 Sumberdaya Lahan Pertanian Indonesia. Luas, Penyebaran, dan Potensi Ketersediaan. Dalam: Husen E, Agus F, Nursyamsi D (Eds.). IAARD-PRESS.
[2] Goenadi D H 2017 E-Journal Menara Perk 85(1) p 44-52.
[3] Diedrich T, Dybowska A, Schott J, Valsami-Jones E and Oelkers E H 2012 Environ Sci Technol 46(9) p 4909-4915.
[4] Cristancho R J A and Restrepo F 2014 Silicon in agriculture – New development in Latin America (2014) 6th Internat. Conf Silicon in Agric 26-30 August 2014 Stockholm Sweden.
[5] Ashraf M and Harris P J C 2013 Photosynthesis under stressful environments: An overview. Photosynthetica 51(2) p 163-190.
[6] Farooq M, Wahid A, Kobayashi N, Fujita D and Basra S M A 2009 Agron Sustain Dev 29 p 185–212.
[7] Santi L P, Haris N and Mulyanto D 2016 Peningkatan Ketahanan Kelapa Sawit terhadap Cekaman Kekeciran melalui Aplikasi Bio-Silika (Bio-Si) Laporan Kemajuan Grand Research Sawit.Pusat Penelitian Bioteknologi dan Bioindustri Indonesia. 23 halaman.
[8] Chi drawar J N S, Thorat V, Shah P and Rao V 2014 Ortho silicic acid (OSA) based formulations facilitates improvement in plant growth and development 6th Internat. Conf. Silicon in Agric. 26-30 August 2014 Stockholm Sweden.
[9] Heckman J 2013 Silicon: A Beneficial Substance Better Crops 97(4), 14-16.
[10] Santi L P and Goenadi D H 2017 Solubilization of silicate from quartz mineral by potential silicate solubilizing bacteria *Menara Perkebunan* 85(2) 96-104.

[11] Santi L P, Mulyanto D and Goenadi D H 2017 Double acid-base extraction of silicic acid from quartz sand *J Minerals and Materials Charact Eng* 5(6) 362-373.

[12] Goenadi D H, Santi L P, Barus and Dariah A 2018 Bio-silifikasi sel dan imobilisasi aluminium oleh bio-nano OSA untuk efisiensi penggunaan air dan hara kedelai hitam di lahan kering masam Laporan Akhir Kegiatan KP4S Tahun 2018. 69 hal.

[13] Amanah D M, Haris N and Santi L P 2019 Physiological responses of bio-silica-treated oil palm seedlings to drought stress *Menara Perkebunan* 87(1) 20-30.

[14] Santi L P, Haris N and Mulyanto D 2018a Pemanfaatan Bio-Silika untuk Meningkatkan Produktivitas dan Ketahanan Terhadap Cekaman Kekekaningan pada Kelapa Sawit. Makalah pada Pekan Riset Sawit Indonesia (PERISAI) II, Bandung, 13-15 Februari 2018.

[15] Santi L P, Goenadi D H, Barus J and Dariah A 2018b Pengaruh bio-nano silika terhadap hasil dan efisiensi penggunaan air kedelai hitam di lahan kering masam *Jurnal Tanah dan Iklim* 42(1) 43-52.

[16] Soil Survey Division Staff 2010 Keys to Soil Taxonomy. 11th Edition. United States Department of Agriculture. Natural Resources Conservation Service, Washington DC.

[17] Goenadi D H and Santi L P, 2009 Introduction of microbial inoculants to improve functional relationship between above- and below-ground bio-diversity *Menara Perkebunan* 77(1)58-67.

[18] Purwaningish O, Indradewa D, Karibun S and Shiddiq D 2012 Tanggapan tanaman kedelai terhadap inokulasi rhizobium *Agrotop* 2(1) 25-32.

[19] Balai Penelitian Tanah 2009 Analisis Kimia Tanah, Tanaman, Air, dan Pupuk ISBN 978-602-8039-21-5. Bogor Balai Penelitian Tanah. 234p.

[20] Survey Laboratory Methods Manual Soil Survey Investigations Report No. 42 Version 5.0. 2014. United States Department of Agriculture. 998p.

[21] Songsri P, Vorasoot N, Jogloy S, Kemsma T, Akkasaeng C, Patanothai and Holbrook C C 2009 Evaluation of yield and reproductive efficiency in peanut (*Arachis hypogaea* L.) under different available soil water *Asian Journal of Plant Sciences* 8(7) 465-473.

[22] Jangpromma N, Thammasirirak S, Jaisil P and Songsri P 2012 Effects of drought and recovery from drought stress on above ground and root growth, and water use efficiency in sugarcane (*Saccharum officinarum* L.) *Australian J Crop Sci* 6(8) 1298-1304.

[23] Suryanti S, Indradewa D, Sudira P and Widada J 2015 Kebutuhan air, efisiensi penggunaan air dan ketahanan kekeringan kultivar kedelai Agritech 35(1) 114-120.

[24] Dwijopuspito T 1986 Soil Moisture Prediction. *Dissertation*. Univ. Phillippines at Los Banos, Phillippines.

[25] Surendran U, Sushanth C M, Mammen G and Joseph E J 2015 Modelling the crop water requirement using FAO-CROPWAT and assessment of water resources for sustainable water resource management: A case study in Palakkad district of humid tropical Kerala, India *Aquatic Procedia* 4 1211-1219.

[26] Prastowo D R, Manik T K and Rosadi R A B 2016 Penggunaan model Cropwat untuk menduga evapotranspirasi standar dan penyusunan neraca air tanaman kedelai (*Glycine Max* (L) Merril) di dua lokasi berbeda. *J Teknik Pertanian Lampung* 5(1) 1-12.

[27] Ansley R J, Dugas W A, Heuer M L and Trevino B A 1994 Steam flow and perometer measurements of transpiration from honey mesquite *J Experimental Botany* 45(275) 847 – 856.

[28] Yang Y, Tang M, Sulpice R, Chen H, Tian S and Ban Y 2014 Arbuscular mycorrhizal fungi alter fractal dimension characteristics of *Robinia pseudacacia* L. seedlings through regulating plant growth, leaf water status, photosynthesis, and nutrient concentration under drought stress *J. Plant growth Regul* 33(3) 612-625.
[29] Anggraini N, Faridah E dan Indrioko 2015 Pengaruh cekaman kekeringan terhadap perilaku fisiologis pertumbuhan bibit Black Locust J Ilmu Kehutanan 9 (1) 43-56.

[30] Anyia A O and Herzog H 2014 Water-use efficiency, leaf area and leaf gas exchange of cowpeas under mid-season drought European J Agron 20(4) 327-339.

[31] Singh A K, Madramootoo C and Smith D L 2014 Impact of different water management scenarios on corn water use efficiency Am Soc Agric Biol Eng 57(5) 1319-1328.

[32] Guntzer F, Keller C and Meunier J D 2012 Benefits of plant silicon for crops: a review. Agron Sustain Dev 32:201–213.