Effects of Bio-nano OSA Application on Fertilizer Use and Water Consumption Efficiencies of Black Soybean Grown on Rice-Field

Pengaruh Aplikasi Bio-nano OSA terhadap Efisiensi Penggunaan Pupuk dan Konsumsi Air Kedelai Hitam pada Sawah Tadah Hujan

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INFORMASI ARTIKEL

Riwayat artikel:

Diterima: 11 Maret 2019
Direview: 21 Maret 2019
Disetujui: 05 Juli 2019

Keywords:

Bio-nano ortho-silicic acid
Si solubilizing microbes
Black soybean
Crop water consumption
Fertilizer use efficiency

Kata kunci:

Bio-nano asam orto-silikat
Mikroba pelarut Si
Kedelai hitam
Kebutuhan air tanaman
Efisiensi penggunaan pupuk

Direview oleh:

Ai Dariah, Eni Maftuah

Abstract. Rice-field, during the dry season, offers promising potential as food crop production area particularly for secondary crops such as black soybean. However, rice-field have some limitations to support crop productivity economically, due to low fertilizer efficiency and/or water usage. Silicate (Si) fertilizer in the form of bio-nano ortho silicic acid (OSA) has been proven to improve yield and water use efficiency of black soybean on the upland, but not on rice field. This study aimed to determine the effects of bio-nano OSA application on yield, fertilizer and water use efficiencies of Detam-1 black soybean grown at a Bantarwaru rice-field, Indramayu, West Java. Experiment was undertaken from August to November 2018 with treatments consisting of : (i) control (P0), (ii) farmers' standard practice (P1), (iii) P1 + 2 ton organic fertilizer 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) P1 + 4 L bio-nano OSA ha^{-1} (P5), in a randomized block design with three replications. The soil belongs to Alfisols with vertic property, i.e. cracking during the dry season. The results show that the application of bio-nano OSA was capable of improving yield of Detam-1 black soybean up to 26%, increasing water use efficiency up to 37%, and reducing NPK fertilizer dosages up to 50%. The highest yields of Detam-1 black soybean was 2.4-2.5-ton bean ha^{-1}, achieved from the treatment of combination of 50-75% NPK fertilizer dosages and application of bio-nano OSA at 4 L ha^{-1} rate with optimum level of NPK dosage at 39.2%. By using bio-nano OSA and optimum dosage of NPK fertilizer, the farmer's profit increased IDR 4,152,340 ha^{-1} per season compared to standard practice.

Abstrak. Sawah tadah hujan pada musim kemarau menawarkan peluang yang prospektif untuk dimanfaatkan sebagai areal produksi tanaman pangan khususnya palawija seperti kedelai hitam. Namun, sawah tadah hujan secara umum memiliki masalah khusus untuk mendukung produktivitas tanaman di musim kemarau yaitu rendahnya efisiensi serapan hara dan/atau penggunaan air. Teknologi pupuk silika dalam formulasi bio-nano ortho-silicic acid (OSA) telah terbukti mampu meningkatkan hasil kedelai hitam dan efisiensi penggunaan air pada lahan tegalan tetapi tidak pada lahan sawah tadah hujan. Penelitian ini ditujukan untuk mempelajari pengaruh aplikasi pupuk Si (bio-nano OSA) terhadap produksi tanaman kedelai hitam Detam-1, efisiensi penggunaan pupuk, dan air pada sawah tadah hujan di Bantarwaru, Indramayu, Jawa Barat. Percobaan dilaksanakan di lahan petani pada bulan Agustus hingga Nopember 2018 dengan menguji perlakuan : (i) kontrol (P0), (ii) pemupukan standar petani (P1), (iii) P1 + 2 ton pupuk organik 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), dan (vi) 100% P1 + 4 L bio-nano OSA ha^{-1} (P5), dalam rancangan acak kelompok dengan ulangan tiga kali. Tanah di lokasi percobaan tergolong ordo Alfisol dengan sifat vertik seperti timbulnya retakan saat musim kemarau. Hasil percobaan menunjukkan bahwa aplikasi bio-nano OSA mampu meningkatkan produksi kedelai hitam varietas Detam-1 hingga 26%, meningkatkan efisiensi penggunaan air hingga 37%, dan menghemat dosis pupuk NPK hingga 50%. Produktivitas kedelai hitam tertinggi sebesar 2,4–2,5 ton biji kering ha^{-1} diperoleh pada perlakuan kombinasi pupuk NPK 50-75% dari standar petani dan aplikasi bio-nano OSA 4 L ha^{-1} dengan dosis optimum pupuk NPK pada 39,2%. Tambahan keuntungan usaha tani kedelai hitam Detam-1 di Bantarwaru dengan aplikasi bio-nano OSA dan pemupukan NPK yang optimum dapat mencapai IDR. 4.152.340 ha^{-1} per musim jika dibandingkan perlakuan dosis pupuk standar.

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ISSN 1410-7244

Introduction

Indonesia as many other countries in the world faces food security problems due to low productivity of food crops on highly weathered soils under intensive tropical climate. This situation to some extent creates shortage in commodity supply endangering the sustainability of related industry. A good example of this phenomenon is black soybean production to support mainly soy sauce industries. In order to tackle the low supply of black soybean, i.e. 100K ton soybean deficit in 2018, the Government of Indonesia undertakes an intensive program to boost national production and hence reducing import dependency. On top of the new variety with high yield potential, the program focuses on the use of acid upland soils. Lampung and West Java Provinces are two areas most available for soybean development, as these regions each has 2.7 million ha (Mha) where 0.99 Mha suitable for food crops, whereas those in West Java accounts to 1.5 Mha (Ritung *et al*. 2015) and about 16,275 ha rice-field located at soy sauce industry centers in Cirebon, Indramayu, and Majalengka, West Java.

Rice-field soil offers a huge potential for growing food crops during dry season, but it is handicapped by some limitations to support economic yields, especially for black soybean. In Lampung and northern coastal coast area of West Java, intensive dry season caused severe drought stress to the crops due to excessive evapotranspiration (Diedrich *et al*. 2012; Christancho and Restrepo 2014). Low nutrients availability and water use efficiency were also reported as common limiting factors (Hafif and Santi 2016; Moreira and Moraes 2016). On the other hand, silica (Si) has gained more attentions where crops are able to contend drought as Si regulates stomata opening and competes to bind Al releasing P to be readily available to the crops (Farooq *et al*. 2009; Santi *et al*. 2017a). In fact, plants absorb Si as much as other macro nutrients although Si has not been considered as macro nutrients (Djajadi 2013; Chidrawar *et al*. 2014) and predicted to be key factor for crop production in the future (Edward 2014). However, very limited products available in the market which have high water-soluble Si (H_4SiO_4-ortho silicic acid, OSA). Silicic acid or ortho-silicic acid ($Si(OH)_4$ or H_4SiO_4) refers to Si available for the plant (Heckman 2013).

Many nutrient-bearing minerals such as potassium, phosphorus, and silica were unreadily available nutrients for plants. However, the use of effective microbes could enhance nutrient solubility (Santi and Goenadi 2012 a&b; Goenadi and Santi 2013). Santi *et al*. (2017b) formulated a high available Si originating from quartz sand combined with Si-solubilizing microbes showed a significant effect in improving drought stress tolerance of oil palm seedlings. Application of the product so-called bio-nano OSA (with the particle diameter of 18 nm) on black soybean grown at acid dry land soils of Natar and Majalengka could significantly improve yield and efficiency of water and fertilizer use (Santi *et al*. 2018). As rice-field soil offers additional opportunities to extend black soybean growing area during dry season. It is important to evaluate the effectiveness of bio-nano OSA on black soybean yield in this soil. However, the performance of the bio-nano OSA on black soybean grown at rice field has not been available yet so far. The research aimed determined the effect of bio-nano OSA application on fertilizer use and water consumption efficiencies of black soybean grown on rice-field.

Materials and Methods

The experiment was carried out in Bantarwaru, Gantar, Indramayu District, West Java, located at $6^0$31’53,9” - $6^0$33’35” S and $107^0$53’47”- $107^0$54’48.9” E on August-November 2018. According to Soil Taxonomy (Soil Survey Staffs, 2014), the soil at experimental site was indicative of belonging to Udalf (Alfisols with udic moisture regime) with some vertic characteristics indicated by 1-2 cm cracking on the soil surface during dry season, argillic horizon, and base saturation >35% and with soil pH 5.8; sand 32.7%; silt 27.9%, clay 39.4%; P_2O_5 0.16%; K_2O 0.03%; CaO 0.32%; organic C 1.6%; Total SiO_2 13.9%; available Si 2.6 ppm; CEC 27.3 $cmol^+kg^{-1}$; Al-exchange 0.2 $cmol^+kg^{-1}$; Total Al 0.35 ppm; H-exchange 0.03 $cmol^+kg^{-1}$ and base saturation 69.5%. The experimental site can be classified as a dry climate since it has five wet and six dry months annual average (Table1). Based on Oldeman’s rainfall type classification the site belongs to D3 agroclimatic zone with 3-4 consecutive wet months and 4-6 dry months.

A randomized block design was used to examine six treatments with three replicates and each plot size were 300 m^2, occupying 5400 m^2 experimental total block area. The treatments consisted of (i) control/untreated (P0), (ii) NPK farmer standard practice (P1), (iii) P1 + 2-ton organic manure fertilizer 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). Bio-nano OSA was prepared by using method reported earlier containing 9% H_4SiO_4 which enriched with selected Si-solubilizing microbes, i.e. *Aeromonas punctata*, *Burkholderia cenocepacia, B. vietnamiensis*, and *Aspergillus niger* (Santi and Goenadi 2017; Santi *et al*. 2017b).

Black soybean var. Detam-1 was used and sown in hole at 20 cm x 40 cm planting distances which has been limed previously with 500 kg CaO ha^{-1} (equivalent to

Table 1. Rainfall data based on monthly average during 11 years (2008-2018) observation at Bantarwaru weather station

Tabel 1. Data curah hujan berdasarkan rata-rata per bulan selama 11 tahun pengamatan (2008-2018) di stasiun cuaca Bantarwaru

Month	Years										
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Jan	585	265	391	167	239	341	592	426	388.5	705.8	161.7
Feb	280	280	315	152	0	413	343	380	416.7	234.4	495.5
Mar	50	325	586	506	259	403	223	327	472.6	574.7	682.7
Apr	172	230	409	291	156	310	300	301	143.5	266.3	354.5
Mei	83	179	90	143	19	157	196	99	166.8	79.5	96.7
Jun	33	99	181	0	70	222	54	0	180.6	52	32.2
Jul	0	0	89	0	0	205	62	1	58.5	25.5	0.0
August	14	0	115	0	0	20	9	0.2	69	20	0.0
Sept	1	4	216	0	0	0	0	0.5	156.1	33.7	1.0
Oct	64	160	197	18	60	40	18	0	348	307.1	7.5
Nov	646	174	314	252	234	138	233	94.9	363	485.4	150.9
Des	663	584	274	397	234	552	442	420.3	312.5	294.7	201.2
M-Wet	4	5	7	4	4	7	6	5	6	7	4
M-Dry	8	7	5	8	8	5	6	7	6	5	8

1,500 kg dolomite). Standard fertilization used based on soil analysis were 75 kg urea + 100 kg SP-36 + 100 kg KCl ha^{-1} 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 (Hafif and Santi 2016). 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 Balai Penelitian Tanah (2009) and USDA (2014). 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 Songsri *et al*. (2009), Jangproma *et al*. (2012), and Suryanti *et al*. (2015), employing formula $ET_c = ET_o \times K_c$, where ET_c is plant water consumption (mm $plant^{-1}$), ET_o is potential evapotranspiration, and K_c is crop coefficient for black soybean. K_c value was calculated based on the data collected at 56 DAP by using the following formula of Dwidjopuspito (1986):

$$K_c = (WC_{fc}-WC_{pwp})/(WC_{sat}-WC_{pwp}),$$ where

K_c : crop coefficient for black soybean

WC_{fc} : water content at field capacity

WC_{pwp} : water content at permanent wilting point and

WC_{sat} : water content at saturated condition.

Potential evapotranspiration (ET_o) data was determined from climatic data for the last four months and calculated by using FAO-CROPWAT 8.0 computer program (Surendran *et al*. 2015; Prastowo *et al*. 2016). Plant transpiration of each plot was measured using a porometer at 56 DAP (Ansley *et al*. 1994; Yang *et al*. 2014; Anggraini *et al*. 2015). Water use efficiency (WUE) was calculated based on the volume of water used by the crop to produce a unit weight of black soy bean yield employing the formula described by Anyia and Herzog (2014) and Singh *et al*. (2014). Black soybean quality was determined on the basis of proximate analyses (AOAC 2005), i.e. protein, total fat, and anthocyanin. Further, fertilizer efficiency was determined by reducing standard dosage of N-P-K fertilizer.

Results and Discussion

Soil Characteristics

Effect of soils type on soybean are considerably well documented (Barrios *et a*l. 2006; Afrida *et al*. 2015; Dos

Santos *et al*. 2015; Kawasaki *et al*. 2016). In general, soybean yield is superior at fertile soils in temperate climate in comparison to those at less-fertile soil under tropical climate. The soil utilized in this experiment exhibits some characteristics of an Alfisols, i.e. relatively high clay content in the subsoil and base saturation > 35% (69.5%), low organic matter content (1.63%), rather acidic in reaction (pH H_2O 5.8 and KCl 4.6), high cation exchange capacity (CEC, 27.3 $cmol^{+}kg^{-1}$) (Balai Penelitian Tanah 2009), and low soluble Si (2.6 ppm) (Vasanthi *et al*. 2014). Vertic characteristics were indicated by significant crack on the soil surface when dry assuming dominant type of 2:1 clay mineral as reported by Righi *et al*. (1999). The soil analysis after harvest (Table 2) indicates that available Si increases 6.8-31.6% compared to standard practice, and the highest content achieved by P4 treatment (23.1 ppm). These phenomena indicate that Si was confirmed to be competitor for Al resulting in more P released into soil solution (Farooq *et al*. 2009). However, data of available P from this experiment were rather inconclusive although a slight increase was noticeable on P3 treatment (0.132%) compared to standard practice (0.110%). The effect of Si on P availability was initially thought to be related to Si influences on soil pH, when it was applied as calcium (Ca). The chemical similarity between phosphate ($H_2PO_4^-$) and silicate ($H_3SiO_4^-$) ions was believed to govern this interaction (Agostinho *et al*. 2017).

Effect of Bio-nano OSA on Plant Growth

Plant growth performances were evaluated on the basis of plant height, number of leaves, pod number, wet and dry weights of biomass, and Si leaf content (Table 3). In general, the parameters observed show significant effects due to treatments applied, except pod number. The data indicate that the reduction of NPK fertilizer dosages up to 50% did not significantly affect the growth performances of Detam-1 black soybean. These evidences confirm the assumption that Si promotes a healthy plant especially in combating water stress as reported by many researchers (Heckman, 2013; Chanchal *et a*l. 2016; Sapre and Vakharia 2016). Addition of Si did also induce the Si

Table 2. Chemical properties of the soil at a farmer rice-field in Bantarwaru, Indramayu, after harvesting period

Tabel 2. Sifat kimia tanah pada lahan sawah tadah hujan di Bantarwaru, Indramayu setelah panen

Treatments		pH-H_20	C-Organic (%)	N-Total (%)	HCl 25 % Extraction P_2O_5 (%)	Exchage Al ($Cmol^{+}Kg^{-1}$)	Available Si (ppm)
Blank (no fertilizer)	(P0)	6.1	1.59	0.17	0.10	1.05	2.40
100 % NPK fertilizer dosage	(P1)	5.8	1.67	0.22	0.11	1.58	17.55
100 % NPK fertilizer dosage + 20 kg organic matter	(P2)	6.0	2.08	0.18	0.10	1.74	19.01
50 % NPK fertilizer dosage + 4 L bio-nano OSA ha^{-1}	(P3)	5.9	1.87	0.20	0.13	0.80	18.74
75 % NPK fertilizer dosage + 4 L bio-nano OSA ha^{-1}	(P4)	5.8	2.05	0.22	0.12	0.95	23.10
100 % NPK fertilizer dosage + 4 L bio-nano OSA ha^{-1}	(P5)	5.9	1.97	0.20	0.10	1.60	22.03

Table 3. Plant growth performances of black soybean grown rice-field in Bantarwaru, Indramayu

Tabel 3. Keragaan pertumbuhan tanaman kedelai hitam pada lahan sawah tadah hujan di Bantarwaru, Indramayu

Treatments		Height (cm)	Number of Leaves	Number of Pods	Biomass (ton ha^{-1})	Content Si of Leaves (g kg^{-1})
Blank (no fertilizer)	(P0)	63.1 c[1]	16.8 bc	58.5 a	4.19 bc	0.042 b
100 % NPK fertilizer dosage	(P1)	71.6 b	24.8 b	71.5 a	4.49 abc	0.041 b
100 % NPK fertilizer dosage + 20 kg organic matter	(P2)	73.3 b	15.8 c	60.3 a	3.73 c	0.044 b
50 % NPK fertilizer dosage + 4 L ha^{-1} bio-nano OSA	(P3)	72.4 b	33.9 a	79.9 a	5.21 a	0.066 a
75 % NPK fertilizer dosage + 4 L ha^{-1} bio-nano OSA	(P4)	74.6 b	36.7 a	84.2 a	4.91 ab	0.049 b
100 % NPK fertilizer dosage + 4 L ha^{-1} bio-nano OSA	(P5)	85.1 a	19.9 bc	71.1 a	4.35 abc	0.049 b
Coefficient Variable (%)		2.2	12.7	15.1	7.5	12.2

[1] Numbers in the same column followed by similar letter(s) are not significantly different according to Duncan Multiple Range Test (P<0.05).

[1] Angka-angka dalam kolom yang sama yang diikuti oleh huruf yang sama tidak berbeda nyata menurut uji jarak ganda Duncan (P<0,05).

uptake as indicated by increasing Si leaf content. The highest Si uptake was obtained by applying 50% NPK fertilizers in combination with bio-nano OSA at 4 L ha^{-1} rate.

Effect of Bio-nano OSA on Black Soybean Yield

Data of Detam-1 soybean yields (dry bean, about 14% water content) from each treatment are presented in Figure 1. The values range from 1.57 (P5) to 2.37 (P4) which is in the range of genetic potential yield of 2.5-ton ha^{-1} (Adie *et al*. 2009). However, these values are significantly higher compared to those reported earlier by Santi *et al*. (2018). The differences are assumed to be as a result of different soil ecosystem. In the previous study, they grew Detam-1 black soybean on dry land soil, whereas the current study was on rice-field soil. These findings confirm that the productivity of the latter is much higher. Addition of organic matter (cattle farmyard manure) did not improve the yield and the yield was significantly lower than those obtained by bio-nano OSA addition combined with reduced rate of NPK fertilizers (50-75%). However, the reason why the combination of 100% NPK fertilizers with bio-nano OSA (P5) resulting in a lower yield compared the other treatments is unclear from this study.

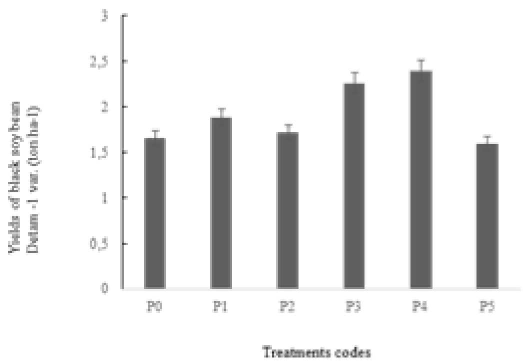

Figure 1. Effects of treatments (P0-P5) on the yield of black soybean Detam-1. 100% NPK = Urea (75 kg); SP36 (100 kg); and KCl (100 kg) ha^{-1}

Gambar 1. Pengaruh perlakuan (P0-P5) terhadap produktivitas kedelai hitam Detam-1. 100% NPK = Urea (75 kg); SP36 (100 kg); dan KCl (100 kg) ha^{-1}

Application of bio-nano OSA was found to be closely related with NPK fertilizers dosages. Figure 2 shows that the optimum yields (2.35-ton ha^{-1}) was achieved at 39.2% dosage of NPK fertilizers (R^2=0.8996**). This means that application of 4 L bio-nano OSA ha^{-1} rate could reduce fertilizer dosage up to 60%. Assuming the current price of single N-P-K fertilizers IDR 2,300; 2,600; 9,000 kg^{-1} respectively; black soy bean IDR 9,000 kg^{-1}; and bio-nano OSA IDR 150,000 L^{-1}, then the farmers could enjoy additional profit up to IDR 4,152,340 ha^{-1} per season compared to standard practice.

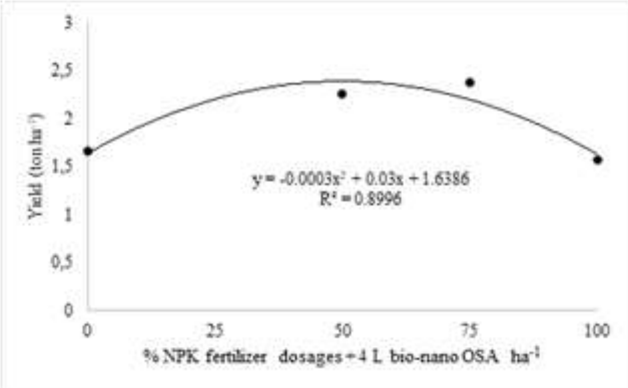

Figure 2. Relationships between NPK fertilizer dosages and yield of black soybean var Detam-1 grown at rice-field Alfisols soil in Bantarwaru, Indramayu. 100% NPK = Urea (75 kg); SP36 (100 kg); dan KCl (100 kg) ha^{-1}

Gambar 2. Hubungan antara dosis pupuk NPK terhadap produktivitas kedelai hitam var Detam-1 yang tumbuh di lahan sawah tadah hujan dengan jenis tanah Alfisol di Bantarwaru, Indramayu. 100% NPK = Urea (75 kg); SP36 (100 kg); dan KCl (100 kg) ha^{-1}

Water Consumption and Water Use Efficiency (WUE)

During research application of bio-nano OSA in August-November 2018 period, average monthly rainfall is less than 100 mm with RH 63.9-74.8%. Plant water use of each treatment and its corresponding WUE are presented in Table 4. Daily water usage by plant ranges between 4.31 (P0) and 4.65 (P5) mm day^{-1} with the highest value found at 100% NPK fertilizers + 4 L bio-nano OSA ha^{-1} treatment (P5). Meanwhile, WUE values range from 1.33 (P5) to 2.10 $g.mm^{-1}$ (P4). These values are in agreement with those reported previously by Santi *et al*. (2018). As reported by many researchers before (Farooq *et al*. 2009; Diedrich *et al*. 2012; Ashraf and Harris 2013), these evidences confirm also the assumption that Si promotes a better water usage hence the crops become more tolerance to drought stress. Mechanism of Si uptake by plants is assumed taken place after H_4SiO_4 is quickly deposited in the leaf cell wall which then plays important role in controlling stomatal reaction upon atmospheric humidity change and transpiration rate as a consequence. Malav and Ramani (2017) assumed that increased water use efficiency observed with the application of Si, probably might be due to prevention of excessive transpiration. It is unlikely that Si absorbed by plants with

Table 4. Water use and water use efficiency of black soybean Detam-1 var. from each treatment, grown on a dry climate rice-field Alfisols soil in Bantarwaru, Indramayu

Tabel 4. Kebutuhan air dan efisiensi penggunaan air kedelai hitam Detam-1 dari masing-masing perlakuan yang diuji pada lahan sawah beriklim kering jenis tanah Alfisols di Bantarwaru, Indramayu

Treatments		Plant Water Use (mm)	Water Use Efficiency (g mm^{-1})
Blank (no fertilizer)	(P0)	4.31 c [1]	1.5 c
100 % NPK fertilizer dosage	(P1)	4.34 c	1.7 abc
100 % NPK fertilizer dosage + 20 kg org. matter ha^{-1}	(P2)	4.32 c	1.6 bc
50 % NPK fertilizer dosage + 4 L bio-nano OSA ha^{-1}	(P3)	4.49 b	1.9 ab
75 % NPK fertilizer dosage + 4 L bio-nano OSA ha^{-1}	(P4)	4.54 b	2.1 a
100 % NPK fertilizer dosage + 4 L bio-nano OSA ha^{-1}	(P5)	4.65 a	1.3 c
Coefficient variable (%)		1.3	9.4

[1] *Numbers in the same column followed by similar letter(s) are not significantly different according to Duncan Multiple Range Test (P<0.05)*

[1] *Angka-angka dalam kolom yang sama yang diikuti oleh huruf yang sama tidak berbeda nyata menurut uji jarak ganda Duncan (P<0,05)*

Table 5. Effects on reduced rate of NPK fertilizers combined with bio-nano OSA on black soybean quality

Tabel 5. Pengaruh pengurangan dosis pupuk NPK yang dikombinasikan dengan bio-nano OSA terhadap kualitas kedelai hitam

Treatments		Total Fat (%)	Protein (%)	Anthocyanin (mg kg^{-1})
Blank (no fertilizer)	(P0)	17.6	39.4	49.9
100 % NPK fertilizer dosage	(P1)	17.7	39.8	99.4
100 % NPK fertilizer dosage + 20 kg org. fertilizer ha^{-1}	(P2)	17.7	40.1	416.3
50 % NPK fertilizer dosage + 4 L bio-nano OSA ha^{-1}	(P3)	17.5	40.2	367.9
75 % NPK fertilizer dosage + 4 L bio-nano OSA ha^{-1}	(P4)	18.5	38.9	309.1
100 % NPK fertilizer dosage + 4 L bio-nano OSA ha^{-1}	(P5)	17.7	40.3	445.7

preference as stated by Chidrawar *et al*. (2014) that plants absorbed Si as much as other macro elements although it has not been considered as a plant macro nutrient yet. The most efficient water used by crops was achieved by P4 treatment with 25% reduced dosage of NPK fertilizer. Additional NPK fertilizer increased plant water use, but not resulting in increasing yield which in turn reduced water use efficiency (Table 4). It is unclear yet from this study about this phenomenon.

Quality of Black Soybean

One of quality indicator for black soybean is proximate contents (AOAC 2005), consisting of amino acids (protein), fatty acids, and anthocyanin (Ganesan and Xu 2017). Table 5 shows these three substances in Detam-1 black soybean harvested from each treatment plots. The data show that in terms of total fat and protein contents there were no differences among treatments. On the other hand, there were remarkable differences in anthocyanin content, especially between bio-nano OSA treated plots (P3-P5) and untreated (P0) and standard fertilization practice (P1). Anthocyanin is a representative antioxidant of the flavonoid family found in plant tissues. Black soybean seed coats are an excellent source of anthocyanin. The mechanisms by which Si is so effective at promoting anthocyanin are not well-understood, but could include changes in soil conditions, increased root growth, photosynthesis and production anthocyanin (Shen *et al*. 2010). Abdelkader *et al*. (2016) report that anthocyanin concentration significantly increased by 16.3% as the applied Si rate increased from 0.00 to 5.25 kg Si ha^{-1}. In this research, application of 100% NPK fertilizer + 4 L bio-nano OSA ha^{-1} rate or 100 % NPK fertilizer dosage + 20 kg organic fertilizer ha^{-1} (Table 5) resulted in a relatively high anthocyanin content i.e. 445.7 and 416.3 mg kg^{-1} respectively. The reason for this phenomenon is unclear yet from this current study. The total fat and proteins contents generated from this research supporting analytical reported by Adie *et al.* (2009), i.e. 13.1% total fat and 45.4% protein respectively.

An interesting phenomenon is that the reduction of NPK fertilizers in combination with application of bio-nano OSA did not reduced the quality of black soy bean on a rice-field soil in term of anthocyanin content. Nurrahman (2015) reported that black soy bean var. Malika contains 14.5% fat, 39.1% protein, and anthocyanin 222.5 mg 100 g^{-1}. It is indicative, however, that anthocyanin contents among black soybean varieties were varied considerably as reported by Lee *et al*. (2016) where out of 56 Korean black soy bean varieties the values range from 198 to 14,204 ppm.

Conclusions

The effect of bio-nano OSA application on fertilizer use and water consumption efficiencies of black soybean grown on rice-field on Alfisols was shown to be effective in this study. Application of 4 L bio-nano OSA ha^{-1} reduced NPK fertilizer use up to 60%, and improved WUE up to 37%. The optimum yield of Detam-1 black soybean was 2.35-ton ha^{-1} at 40% NPK fertilizer dosage combined with 4 L bio-nano OSA ha^{-1}. The quality of soy- bean improved by the addition of bio-nano OSA. However, further study is still necessary to confirm the results particularly under different location or ecosystems.

Acknowledgements

We would like to extend our sincere gratitude to Strategic Agricultural Development (KP4S) Project-Ministry of Agriculture, for funding this research (Contract number: 31.64/PL.040/H.1/02/ 2018.K, 12 February 2018) and to farmers at Bantarwaru, for their kind cooperation in field implementation of this project.

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