INTRODUCTION

Crop growth models require plant parameters associated to characteristic of a variety to run the model. As a new variety is developed, a set of plant parameters associated to the respected variety need to be characterized. Some of required parameters, particularly by detail crop models, are photosynthetic parameters. Radiation is a driving force for photosynthesis (Gu et al., 2017; Strada & Unger, 2016). Hence, the response of photosynthesis to change in radiation, or specifically Photosynthetic Photon Flux Density (PPFD) has a high significance in crop growth model. Such a response is well known as Photosynthetic Light Response Curve (Herrmann, Schwartz, & Johnson, 2020; Johnson & Murchie, 2011; Lobo et al., 2013). There are two important parameters in the photosynthetic light response curve, i.e.: maximum photosynthesis ($P_{max}$), and initial light use efficiency, and in some cases is light compensation point. $P_{max}$ is a rate of photosynthesis by which increase in PPFD will no longer increasing photosynthesis rate; and initial light use efficiency is the slope of photosynthetic rate to light intensity at low light. These parameters are characterized in two new soybean varieties widely planted in Indonesia.

Anjasmoro and Dena-1 are two soybean varieties widely planted in Indonesia. Anjasmoro is preferred by farmers because it is suitable for tempe and tofu industry since it has yellow grain color, relatively big bean size, and high protein content (Isnaini, Rasyad, & Fianda, 2020; Krisnawati & Adie, 2017). Yellow and big grain soybean are good for tempe as it would give good color and high recovery of tempe. Of about 2.4 million ton per year soybean demand in Indonesia, 83.7% are used for tempe and tofu. In addition to its good quality grain, Anjasmoro also resistant to major disease.
in soybean such as leaf rust, and it is also logging resistant (Mahdiannoor, Istiqomah, & Syahbudin, 2017). Leaf rust of soybean, caused by *Phakopsora pachyrhizi* may cause yield loss up to 40 to 80%.

Dena-1 variety was released in 2015 particularly as shaded tolerant variety. In addition to some good characters such as yellow color, big grain, high protein content, and resistant to leaf rust, Dena-1 variety also tolerant up to 50% shading (Pratiwi & Artari, 2018). Hence, it is suitable for intercropping with young high estate crops, such as coconut, oil palm, and rubber. With large plantation area of those estate crops Indonesia, expansion of soybean crop to plantation area is promising. Dena-1 variety, along with Dena-2 variety as well, are considered as varieties suitable to be intercropped with young trees at community forest (Abidin, 2015)

Characterizing photosynthetic parameters of Dena-1 variety is also important to understand the physiological trait underlying the capacity of the variety to tolerate shading. More importantly, it will give physiological explanation up to which light condition this variety produce sufficient photosynthate for reasonable yield. Comparing the physiological trait of Dena-1 with that of Anjasmoro provides better understanding of why these varieties response differently to shading.

**MATERIALS AND METHODS**

The experiment was conducted in Tarowang farm, owned by a smallholder farmer in Tarowang village, district of Takalar, South Sulawesi province, Indonesia from August to November 2017. Tarowang is located at 119° 28′ East and 5° 39′ South with altitude of 15 m above sea level.

Photosynthetic performances were measured in an experiment designed to study the effect of *Actinomycetes* spp. on growth and yield of soybean. The experimental design was Factorial Design, in which soybean varieties as first factor that consist of Dena-1 (V1) and Anjasmoro (V2), and the second factor is *Actinomycetes* spp. application that consist of no *Actinomycetes* spp. (A0), and *Actinomycetes* spp. with concentration of 1 x 10^6 CFU/ml (A1). Each treatment combination was repeated three times and therefore there were 12 experimental units or plots in total. The plot size is 3 x 4 m, and two seeds per hole of soybeans were sowed in August 20, 2017 in a row of 20 x 40 cm.

The photosynthetic measurement was taken in October 15, 2017 using an open chamber portable photosynthetic system (LI-6400, LI-COR, Inc., Logan, NE, USA). Mature leaf exposed to full sunlight was flipped to the chamber. The size of the chamber used, or the area of leaf flipped in the chamber, is 2 x 3 cm, or 6 cm². To develop a light response curve, the photosynthesis was measured at variable Photosynthetically Active Radiation (PAR), i.e. 500; 1,000; 1,500; and 2,000 μmol (photon)/m²/s. Environment conditions during experiments were as follows: air temperature 25-27°C; block and leaf temperature 25-27°C; air flow rate 500 μmol/s; CO₂ concentration in sample cell 380–400 μmol CO₂/mol; and relative humidity in sample cell 56-70%. The measurements are repeated three times (once for each experimental unit). In each replication the system run for 5 second, and the data were registered every second, and therefore there are 15 data set available for each PAR level, or 60 data set for all replications and PAR levels. The parameters used are photosynthetic rate (Pn) (μmol CO₂/m²/s), intercellular CO₂ concentration (Ci) (μmol CO₂/mol air), and conductance to H₂O (mol H₂O/m²/s)

The photosynthetic light response curve (PN/I curve) was developed using Solver function of Microsoft Excel to fit it to the model suggested by Lobo et al. (2013). The Solver function fit the function by finding the least sum of square difference between data and model.

**RESULTS AND DISCUSSION**

Photosynthetic light response curves of Anjasmoro and Dena-1 varieties are shown in Fig. 1. Under normal condition or no *Actinomycetes* the curve of Dena-1 variety is higher than that of Anjasmoro (Fig. 1a). This indicates that Dena-1 responds better than Anjasmoro to light, as it has higher initial light use efficiency as well as higher maximum photosynthesis.
Fig. 1. Photosynthetic light response curve of Dena-1 and Anjasmoro variety under normal condition (a), and under Actinomycetes spp. treatment (b)

Maximum gross photosynthesis ($P_{\text{gmax}}$) of Dena-1 is 45.64 μmol (CO$_2$)/m$^2$/s, while Anjasmoro variety is only 34.81 μmol (CO$_2$)/m$^2$/s (Table 1). Reported maximum net photosynthesis ($P_{\text{nmax}}$) of other soybean varieties are 28.8 μmol (CO$_2$)/m$^2$/s (Yao et al., 2017), 29.9 μmol (CO$_2$)/m$^2$/s (Zhang, Hu, Luo, Chow, & Zhang, 2011), and 34.8 μmol (CO$_2$)/m$^2$/s (Sakoda, Tanaka, Long, & Shiraiwa, 2016). Net photosynthesis ($P_{\text{n}}$) is gross photosynthesis ($P_{\text{g}}$) minus dark respiration ($R_d$). The values of dark respiration are 3.19 μmol (CO$_2$)/m$^2$/s (Yao et al., 2017), and 6.72 μmol (CO$_2$)/m$^2$/s (Zhang, Hu, Luo, Chow, & Zhang, 2011). Along with high maximum photosynthesis, quantum yield at low light (initial light use efficiency) of Dena-1 variety is also higher with the value of 0.068 μmol (CO$_2$)/μmol (photons) compared to Anjasmoro 0.058 μmol (CO$_2$)/μmol (photons). Both Yao et al. (2017) and Zhang, Hu, Luo, Chow, & Zhang (2011) reported a similar quantum yield of soybean at 0.053 μmol (CO$_2$)/μmol (photons). Such a difference in $P_{\text{gmax}}$ and quantum yield between Dena-1 and Anjasmoro indicate Dena-1 is more tolerant to shading than Anjasmoro. As reported by Pratiwi & Artari (2018), Dena-1 variety is tolerant shading up to 50%. Quantum yield of Dena-1 both at light compensation point ($\phi(I_{\text{comp}})$) and at light between compensation point to 200 ($\phi(I_{200})$) is higher (0.07 and 0.05 μmol (CO$_2$)/μmol (photons)) than quantum
yield of Anjasmoro (0.06 and 0.04 μmol (CO₂)/μmol (photons)) (Table 1). In another word, photosynthesis at Dena-1 variety still occurs at acceptable rate even under low light or under shading.

Along with high maximum gross photosynthesis, initial light use efficiency, and quantum yield, the light saturation point of Dena-1 is consistently higher at percentile 50% all the way up to 95% than that of Anjasmoro. Light saturation point at 50% percentile of Dena-1 variety is 667 μmol (photons)/m²/s, while Anjasmoro is 603 μmol (photons)/m²/s. At 95 percentile, the light saturation point of Dena-1 variety is 6,004 μmol (photons)/m²/s, while Anjasmoro is 5,429 μmol (photons)/m²/s (Table 2). High light saturation point indicates that Dena-1 is not only tolerant to shading but also tolerant to high light. In another word, increase in light intensity can be accommodated by Dena-1 due to high capacity of its photosynthetic apparatus.

The photosynthetic light response curves of these two varieties change under Actinomycetes treatment. Under such condition the curve of Dena-1 is higher than that of Anjasmoro at the beginning or at low light. As light increase, the quantum yield is decreasing at a rate faster in Dena-1 than in Anjasmoro such that Dena-1 curve is surpassed by Anjasmoro curve at PAR 706 μmol (photon)/m²/s (Figure 1b). In another word, the photosynthetic light-response curve of Dena-1 is higher than Anjasmoro at PAR below 706 μmol (photon)/m²/s, but it is the other way round at PAR above 706 μmol (photon)/m²/s. Initial light use efficiency of Dena-1 is higher (0.096 μmol (CO₂)/μmol (photons)) than Anjasmoro (0.058 μmol (CO₂)/μmol (photons)). In contrast, the maximum photosynthesis (Pₚmax) is lower in Dena-1 (33.03 μmol (CO₂)/m²/s) than in Anjasmoro (48.77 μmol (CO₂)/m²/s) (Table 1). This indicates that Anjasmoro responds better to Actinomycetes spp. than Dena-1. The better response includes the conversion of additional nutrient from Actinomycetes spp. into the increase of the capacity of photosynthetic apparatus. With an increase in capacity of photosynthetic apparatus, photosynthesis rate increases along with increase in light, and so increase in light saturation point, and maximum photosynthesis (Table 1). Hence, the rate of decrease in quantum yield from light compensation point (Iₜ) to Iₚₚₚₚ is much higher in Dena-1 than in Anjasmoro, i.e. 40% (from 0.10 to 0.04) vs 17% (from 0.06 to 0.05).

Actinomycetes spp. play an important role in soil nutrient cycling (Bhatti, Haq, & Bhat, 2017), inorganic phosphates solubilizing (Ghorbani-Nasrabadi, Greiner, Alikhani, Hamedi, & Yakhchali, 2013; Pragya, Yasmin, & Anshula, 2012: Saif, Khan, Zaidi, & Ahmad, 2014), phytate hydrolyzing, a dominant form of organic P in soils (Ghorbani-Nasrabadi, Greiner, Alikhani, & Hamedi, 2012; Schneider, Cade-Menun, Lynch, & Voroney, 2016), and so improvement of nutrients availability (AbdElgawad et al., 2020; Hozzein et al., 2019) particularly phosphorus. Actinomycetes spp. is not only increasing the availability of phosphorus, but also nitrogen (AbdElgawad et al., 2020). Janati et al. (2021) also reported the importance of microbial P bio-solubilization such as Actinomycetes spp. as a pathway for improving biological nitrogen fixation (BNF) in grain legumes via P solubilizing microorganisms (PSM) and P solubilizing bacteria (PSB).

Increase the availability of phosphorus and nitrogen in the soil may increase crop growth and yield (Amule, Sirothiya, Rawat, & Mishra, 2018; Sahur, Ala, Patandjeng, & Syam’un, 2018; Soe, Bhromsiri, Karladee, & Yamakawa, 2012). Crop response to available nutrient, however, differs among species. Mahdiannoor, Istiqomah, & Syahbudin (2017) reported that growth and yield responses of Anjasmoro are much higher than local soybean variety to bio-fertilizer application. Similar result was also reported by Timotiwu, Nurmiaty, Pramono, & Maysarah (2020) that Anjasmoro responded better than Dena-1 to NPK fertilizer in term of plant height, biomass weight, number of pods, weight of 100 seeds, and yield. Research by AbdElgawad et al. (2020) may explain such a different in responses. They found that all tested legumes (soybean, kidney bean, chickpea, lentil, and pea crops) increase in its chlorophyll a and b content after enrichment with biologically active Actinomycetes spp. isolates. They further found that different plants responded differently to the same isolate. In relation to photosynthesis, phosphorus play an important role in energy transfer (Carstensen et al., 2018; Meng et al., 2021). Unfortunately, under P deficiency, P is allocated more to roots than to leaves (Muhammad, Abdullah, Saud, Shaharuddin, & Isa, 2021). An implication of this is that leaves and physiological processes occurring in leaves such as photosynthesis suffers more than other parts and physiological processes in the plants under deficient P. Anjasmoro seems to respond better than Dena-1 to Actinomycetes spp. treatment such that the more chlorophylls are available, energy transfers are more efficient in the photosynthetic system that in turn increase the capacity of photosynthetic metabolism to accommodate light (PAR) increase.
**Table 1.** Light response curve related parameters of Dena-1 and Anjasmoro varieties with and without Actinomycetes, i.e. Dena-1 – no Actinomycetes, Anjasmoro – no Actinomycetes, Dena-1 – Actinomycetes, Anjasmoro - Actinomycetes.

| Varieties and Actinomycetes Treatments | Maximum Photosynthesis | Quantum yield at I = 0 | Light saturation point at 50 percentile | Light saturated net CO\(_2\) uptake at 85 percentile | Light saturated net CO\(_2\) uptake at 90 percentile | Light saturated net CO\(_2\) uptake at 95 percentile | Quantum yield at LCP to I = 200 |
|---------------------------------------|------------------------|------------------------|----------------------------------------|--------------------------------------------|---------------------------------------------|---------------------------------------------|-------------------------------|
|                                       | Standard Parameters    | Light-saturated CO\(_2\) | Quantum yield at I = 200               | Light compensation point                  | Light compensation point                  | Light compensation point                  |                               |
|                                       |                        | (μmol (CO\(_2\))/m\(^2\)/s) | (μmol (CO\(_2\))/μmol photons) | (μmol photons)/m\(^2\)/s) | (μmol photons)/m\(^2\)/s) | (μmol photons)/m\(^2\)/s) | (μmol (CO\(_2\))/μmol photons) | (μmol (CO\(_2\))/μmol photons) |
| Anjasmoro – No Actinomycetes          | 34.81                  | 0.058                   | 603.26                                 | 3,418.47                                  | 5,429.33                                   | 11,461.92                                  | 26.59                         | 0.06                          | 0.04                          |
| Dena-1 – No Actinomycetes             | 45.64                  | 0.068                   | 667.17                                 | 3,780.66                                  | 6,004.57                                   | 12,676.32                                  | 34.01                         | 0.07                          | 0.05                          |
| Anjasmoro - Actinomycetes             | 48.77                  | 0.058                   | 843.63                                 | 4,780.60                                  | 7,592.71                                   | 16,029.06                                  | 34.04                         | 0.06                          | 0.05                          |
| Dena-1 – with Actinomycetes           | 33.03                  | 0.096                   | 343.41                                 | 1,945.97                                  | 3,090.66                                   | 6,524.73                                   | 28.09                         | 0.10                          | 0.06                          |
Beside the limitation of chlorophyll availability and energy transfer, photosynthesis at high light is apparently also limited by the availability of CO$_2$ as can be indicated by conductance to H$_2$O and internal CO$_2$ concentration. Under normal condition or no Actinomycetes treatment, Dena 1 has higher conductance (2.28 mol H$_2$O/m$^2$/s) than Anjasmoro (2.09 mol H$_2$O/m$^2$/s) and it increases faster with the increase of PAR from 500 to 2,000 μmol (photon)/m$^2$/s. Along with this increase, internal CO$_2$ concentration in Dena 1 decrease at a slower rate than in Anjasmoro (Table 2). This indicates that stomata of Dena 1 is more resilient to keep the internal CO$_2$ concentration higher than Anjasmoro when the demand for CO$_2$ increase.

It has been known widely that light affect stomatal opening, and so leaf conductance. The effect of light intensity to the stomatal response occurs in two ways. The first is through the decrease of intercellular CO$_2$ concentration due to increase in photosynthesis (Eyland, van Wesemael, Lawson, & Carpentier, 2021), and the second is through direct activation of guard cells (Driesen, Van den Ende, De Proft, & Saeyts, 2020; Elhaddad, Hunt, Sloan, & Gray, 2014; Ye et al., 2020). Unlike at normal condition, under Actinomycetes spp. treatment, the decrease in internal CO$_2$ concentration due to light increase in Dena 1 is faster than Anjasmoro. Limitation in availability of internal CO$_2$ at high light can be overcome by Actinomycetes spp. in Anjasmoro. A significant variation in the rapidity of stomatal responses amongst species to light change is existed (McAusland et al., 2016). For soybean, Bunce (2016) found 15 cultivars differed significantly in stomatal conductance. Variation in rapidity of stomatal responses to light could be altered by application of Actinomycetes spp.

### CONCLUSION

Initial light use efficiency and maximum photosynthesis of Dena-1 is 0.068 μmol (CO$_2$)/μmol (photons) and 45.64 μmol (CO$_2$)/m$^2$/s, respectively. While, Anjasmoro is 0.068 μmol (CO$_2$)/μmol (photons) and 34.81 μmol (CO$_2$)/m$^2$/s, respectively. High initial light use efficiency of Dena-1 could be one of the reasons that Dena 1 is tolerant to shading. Application of Actinomycetes spp. alters light response curve such that photosynthesis rate of Anjasmoro is higher than Dena-1 at PAR above 706 μmol (photon)/m$^2$/s and consequently, maximum photosynthesis ($P_{\text{max}}$) of Anjasmoro is also higher than Dena-1, i.e. 48.77 and 33.03 μmol (CO$_2$)/m$^2$/s, respectively. Such alteration could be brought about by higher increase in the capacity of photosynthetic apparatus of Anjasmoro than in Dena-1 under Actinomycetes spp. treatment.

### REFERENCES

AbdElgawad, H., Abuelsoud, W., Madany, M. M. Y., Selim, S., Zinta, G., Mousa, A. S. M., & Hozzein, W. N. (2020). Actinomycetes enrich soil rhizosphere and improve seed quality as well as productivity of legumes by boosting nitrogen availability and metabolism. *Biomolecules, 10*(12), 1675. https://doi.org/10.3390/biom10121675
Abidin, Z. (2015). Potensi pengembangan tanaman pangan pada kawasan hutan tanaman rakyat. *Jurnal Peneilan Dan Pengembangan Pertanian*, 34(2), 71-78. https://doi.org/10.21082/jp3.v34n2.2015.p71-78

Amule, F. C., Sirothiya, P., Rawat, A. K., & Mishra, U. S. (2018). Efficacy of actinomycetes, rhizobium and plant growth promoting rhizobacteria consortium inoculants on symbiotic traits, nodule leghemoglobin and yield of soybean in Central India. *International Journal of Chemical Studies*, 6(1), 593–596. Retrieved from https://www.chemijournal.com/archives/2018/vol6issue1/PartI/5-6-337-822.pdf

Bhatti, A. A., Haq, S., & Bhat, R. A. (2017). Actinomycetes benefaction role in soil and plant health. *Microbial Pathogenesis*, 111, 458–467. https://doi.org/10.1016/j.micpath.2017.09.036

Bunce, J. (2016). Variation among soybean cultivars in mesophyll conductance and leaf water use efficiency. *Plants*, 5(4), 44. https://doi.org/10.3390/plants5040044

Carstensen, A., Herdean, A., Schmidt, S. B., Sharma, A., Speta, C., Pribil, M., & Husted, S. (2018). The impacts of phosphorus deficiency on the photosynthetic electron transport chain. *Plant Physiology*, 177(1), 271–284. https://doi.org/10.1104/pp.17.01624

Driesen, E., Van den Ende, W., De Proft, M., & Saeyes, W. (2020). Influence of environmental factors light, CO2, temperature, and relative humidity on stomatal opening and development: A review. *Agronomy*, 10(12), 1975. https://doi.org/10.3390/agronomy10121975

Elhaddad, N. S., Hunt, L., Sloan, J., & Gray, J. E. (2014). Light-induced stomatal opening is affected by the guard cell protein kinase APK1b. *PLOS ONE*, 9(5), e97161. https://doi.org/10.1371/journal.pone.0097161

Eyland, D., van Wesemael, J., Lawson, T., & Carpenter, S. (2021). The impact of slow stomatal kinetics on photosynthesis and water use efficiency under fluctuating light. *Plant Physiology*, 2021, 1-15. https://doi.org/10.1093/plphys kiab114

Ghorbani-Nasrabadi, R., Greiner, R., Alikhani, H. A., Hamedi, J., & Yakhchali, B. (2013). Distribution of actinomycetes in different soil ecosystems and effect of media composition on extracellular phosphatase activity. *Journal of Soil Science and Plant Nutrition*, 13(1), 223–236. https://doi.org/10.4067/S0718-95162013005000020

Ghorbani-Nasrabadi, Reza, Greiner, R., Alikhani, H. A., & Hamedi, J. (2012). Identification and determination of extracellular phytate-degrading activity in actinomycetes. *World Journal of Microbiology and Biotechnology*, 28(7), 2601–2608. https://doi.org/10.1007/s11274-012-1069-3

Gu, J., Zhou, Z., Li, Z., Chen, Y., Wang, Z., Zhang, H., & Yang, J. (2017). Photosynthetic properties and potentials for improvement of photosynthesis in pale green leaf rice under high light conditions. *Frontiers in Plant Science*, 8, 1082. https://doi.org/10.3389/fpls.2017.01082

Herrmann, H. A., Schwartz, J.-M., & Johnson, G. N. (2020). From empirical to theoretical models of light response curves - linking photosynthetic and metabolic acclimation. *Photosynthesis Research*, 145(1), 5–14. https://doi.org/10.1007/s11120-019-00681-2

Hozzein, W. N., Abuelsoud, W., Wadaan, M. A. M., Shuikan, A. M., Selim, S., Al Jaouni, S., & AbdElGawad, H. (2019). Exploring the potential of actinomycetes in improving soil fertility and grain quality of economically important cereals. *Science of The Total Environment*, 651, 2787–2798. https://doi.org/10.1016/j.scitotenv.2018.10.048

Isnaini, Rasyad, A., & Fianda, D. O. (2020). Keragaan kedelai (*Glycine max* (L) merril) generasi M1 varietas anjasmoro hasil radiasi sinar gamma. *Jurnal Agroteknologi*, 1(1), 39–44. https://doi.org/10.24014/ja.v11i1.9345

Janati, W., Benmrid, B, Elhaissoufi, W., Zeroual, Y, Nasielski, J., & Bargaz, A. (2021). Will phosphate bio-solubilization stimulate biological nitrogen fixation in grain legumes? *Frontiers in Agronomy*, 2021, 637196. https://doi.org/10.3389/fagro.2021.637196

Johnson, G., & Murchie, E. (2011). Gas exchange measurements for the determination of photosynthetic efficiency in Arabidopsis leaves. In *Chloroplast Research in Arabidopsis. Methods in Molecular Biology (Methods and Protocols)* (Vol. 775, pp. 311–326). Totowa, NJ: Humana Press. https://doi.org/10.1007/978-1-61779-237-3_17

Krisnawati, A., & Adie, M. M. (2017). Protein and oil contents of several soybean genotypes under normal and drought stress environments at reproductive stage. *International Journal of Bioscience, Biochemistry and Bioinformatics*, 7(4), 252–261. https://doi.org/10.17706/ijbb.2017.7.4.252-261
Lobo, F. de A., de Barros, M. P., Dalmagro, H. J., Dalmolin, A. C., Pereira, W. E., de Souza, É. C., ... Rodriguez Ortiz, C. E. (2013). Fitting net photosynthetic light-response curves with Microsoft Excel — a critical look at the models. *Photosynthetica*, 51(3), 445–456. https://doi.org/10.1007/s11099-013-0045-y

Mahdiannoor, Istiqomah, N., & Syahbudin, S. (2017). Pertumbuhan dan hasil dua verietas kedelai (Glycine max L.) dengan pemberian pupuk hayati. *Ziraa’ah Majalaih Ilimiah Pertanian*, 42(3), 257–266. https://doi.org/10.31602/zmip.v42i3.898

McAusland, L., Viallet-Chabrand, S., Davey, P., Baker, N. R., Brendel, O., & Lawson, T. (2016). Effects of kinetics of light-induced stomatal responses on photosynthesis and water-use efficiency. *The New Phytologist*, 211(4), 1209–1220. https://doi.org/10.1111/nph.14000

Meng, X., Chen, W.-W, Wang, Y.-Y, Huang, Z.-R., Ye, X., Chen, L.-S, & Yang, L.-T. (2021). Effects of phosphorus deficiency on the absorption of mineral nutrients, photosynthetic system performance and antioxidant metabolism in *Citrus grandis*. *PLoS ONE*, 16(2), e0246944. https://doi.org/10.1371/journal.pone.0246944

Muhammad, I. I., Abdullah, S. N. A., Saud, H. M., Shaharuddin, N. A., & Isa, N. M. (2021). The dynamic responses of oil palm leaf and root metabolome to phosphorus deficiency. *Metabolites*, 11(4), 217-232. https://doi.org/10.3390/metabo11040217

Pragya, R., Yasmin, A., & Anshula, J. (2012). An insight into agricultural properties of actinomycetes. *International Journal of Research in BioScience*, 1(1), 7–12. Retrieved from https://www.idjsr.com/uploads/23/1246_pdf.pdf

Pratiwi, H., & Artari, R. (2018). Respon morfo-fisiologi genotipe kedelai terhadap naungan jagung dan ubikayu. *Jurnal Agronomi Indonesia*, 46(1), 48–56. https://doi.org/10.24831/jai.v46i1.15441

Sahur, A., Ala, A., Patandjengi, B., & Syam’un, E. (2018). Effect of seed inoculation with actinomycetes and rhizobium isolated from indigenous soybean and rhizosphere on nitrogen fixation, growth, and yield of soybean. *International Journal of Agricultural Science*, 80, 4371623. https://doi.org/10.1155/2018/4371623

Saif, S., Khan, M. S., Zaidi, A., & Ahmad, E. (2014). Role of phosphate-solubilizing actinomycetes in plant growth promotion: Current perspective. In Khan M., Zaidi A., & Musarrat J. (Eds.), *Phosphate Solubilizing Microorganisms* (pp. 137-156). Cham: Springer. https://doi.org/10.1007/978-3-319-08216-5_6

Sakoda, K., Tanaka, Y., Long, S. P., & Shiraishi, T. (2016). Genetic and physiological diversity in the leaf photosynthetic capacity of soybean. *Crop Science*, 56(5), 2731–2741. https://doio.org/10.2135/cropsci2016.02.0122

Schneider, K. D., Cade-Menun, B. J., Lynch, D. H., & Voroney, R. P. (2016). Soil phosphorus forms from organic and conventional forage fields. *Soil Science Society of America Journal*, 80(2), 328–340. https://doi.org/10.2136/ssaj2015.09.0340

Soe, K. M., Bhromsiri, A., Karladee, D., & Yamakata, T. (2012). Effects of endophytic actinomycetes and *Bradyrhizobium japonicum* strains on growth, nodulation, nitrogen fixation and seed weight of different soybean varieties. *Soil Science and Plant Nutrition*, 58(3), 319–325. https://doi.org/10.1080/00380768.2012.682044

Strada, S., & Unger, N. (2016). Potential sensitivity of photosynthesis and isoprene emission to direct radiative effects of atmospheric aerosol pollution. *Atmospheric Chemistry and Physics*, 16(7), 4213–4234. https://doi.org/10.5194/acp-16-4213-2016

Timotiwu, P. B., Nurmiyat, Y., Pramono, E., & Maysaroh, S. (2020). Growth and yield responses of four soybean (*Glycine max* (L.) Merrill.) cultivars to different methods of NPK fertilizer application. *Planta Tropika: Journal of Agrosains*, 43. https://doi.org/10.3389/fpls.2020.00374

Ye, Z.-P., Ling, Y., Yu, Q., Duan, H.-L., Kang, H.-J., Huang, G.-M., ... Zhou, S.-X. (2020). Quantifying light response of leaf-scale water-use efficiency and its interrelationships with photosynthesis and stomatal conductance in C3 and C4 species. *Frontiers in Plant Science*, 11, 374. https://doi.org/10.3389/fpls.2020.00374

Zhang, Y.-L., Hu, Y.-Y., Luo, H.-H., Chow, W. S., & Zhang, W.-F. (2011). Two distinct strategies of cotton and soybean differing in leaf movement to perform photosynthesis under drought in the field. *Functional Plant Biology*, 38(7), 567–575. https://doi.org/10.1071/FP11065