Int.J.Curr.Microbiol.App.Sci (2023) *12*(07): 172-180

International Journal of Current Microbiology and Applied Sciences
***ISSN: 2319-7706* Volume 12 Number 7 (2023)**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2023.1207.019

Root and Leaf Phenomenons of C3 Plants Infected with Vesicular Arbuscula Mycorrhizal

Muh. Akhsan Akib[1]*, Syatrawati[2] and Retno Prayudyaningsih[3]

[1]Muhammadiyah University of Parepare, Jl. Jend Ahmad Yani km 6, Parepare, South Sulawesi - 91131, Indonesia
[2]Politeknik Pertanian Negeri, Jl. Poros Makassar - Parepare Km. 83, Mandalle, Pangkajene dan Kepulauan, South Sulawesi – 90761, Indonesia
[3]Center for Applied Microbiology Research, BRIN. Jl. Raya Jakarta-Bogor km 46, Cibinong, West Java – 16911, Indonesia

**Corresponding author*

Keywords

Colonization, leguminosae, mycorrhiza, root nodule, stomata

Article Info

Received:
04 June 2023
Accepted:
06 July 2023
Available Online:
10 July 2023

A B S T R A C T

The utilization of VAM in plants generally uses powder dosage forms and not yet used dosage forms of sachet and tablet. The research aimed to examine the phenomenon of the roots and leaves of C3 plants infected with VAM in different dosage forms at the screen house scale. The research was conducted at the Agrotechnology Laboratory and Screen House, Faculty of Agriculture, Animal Husbandry and Fisheries, Muhammadiyah University of Parepare, using factorial design. The first factor was the VAM dosage forms, namely powder/control, sachet, and tablet dosage forms. While, other factors were the C3 plant species, namely Puero (*Pueraria javanica*)/control, mung bean (*Vigna radiata*), and red spinach (*Amaranthus tricolor*). The parameter observations on the percentage of infected roots, root volume, leaf area, and stomata density. Data were analyzed using variance analysis. The results showed that the VAM dosage form had a significant effect on all parameters observed with various root and leaf phenomena so VAM in a sachet and tablet dosage form can be recommended as a new dosage form for VAM application in the field.

Introduction

The based on the photosynthetic pathway, plants are grouped into C3, C4, and CAM plants (Cousins *et al.*, 2020; Kumar *et al.*, 2017). C3 plants use the Calvin cycle as their photosynthetic pathway, the name C3 is obtained from the first molecule produced, namely the three-carbon (3C) molecule 3-phosphoglyceric acid in the first stage of carbon fixation (Muhie, 2022; Upadhyay *et al.*, 2020). C3

plants are the most common plant species on earth, with an estimated 85 percent of plant species being C3 plants (Kumar *et al.,* 2017; Sivaram *et al.,* 2020), including puero (*Pueraria javanica*), mung bean or green gram (*Vigna radiata*), and red spinach (*Amaranthus tricolor*). C3 plants have an adaptive ability in environments with high atmospheric CO2 content (Bhargava and Mitra, 2021; Wang *et al.,* 2020), however, the growth process of these plants is also influenced by climate, weeds, pest attacks, plant diseases, nutrient availability, and water (Anwar *et al.,* 2021; Skendzi *et al.,* 2021).

High availability of nutrients can be found in the topsoil layer containing dark-colored organic matter up to 25-35 cm (Gerke, 2022; Hoffland *et al.,* 2020). However, this topsoil layer has been lost a lot due to unwise tillage (Krauss *et al.,* 2022; Krauss *et al.,* 2020), excessive use of herbicides (Khangura *et al.,* 2023; Theint Theint Win *et al.,* 2020), land clearing without regard to conservation (Abdelrahman, 2023; Marpaung *et al.,* 2021), and eroded due to erosion (Feeney *et al.,* 2023; Halecki *et al.,* 2018), so an environmentally friendly technology is needed that can help plants to absorb bound nutrients and water in the ground.

Vesicles Arbuscular Mycorrhizal (VAM) is an environmentally friendly biological technology that can be in mutualistic symbiosis with plant roots (Anand *et al.,* 2022; Weng *et al.,* 2022) and has received attention from agronomists.

VAM has been proven to be used as an alternative technology to encourage plant growth (Begum *et al.,* 2019; Huey *et al.,* 2020), increase crop productivity and quality (Hristozkova and Orfanoudakis, 2023; Wu *et al.,* 2022) especially on dry land, acid soil, and land contaminated with heavy metals.

The utilization of VAM in plants generally uses powder dosage forms and has not used sachet and tablet dosage forms. Until now, evaluation of the phenomenon of the roots and leaves of C3 plants infected with VAM in different dosage forms at the screen house scale has not been carried out. In this regard, it is necessary to conduct a more in-depth study of the phenomena of the roots and leaves of C3 plants infected with VAM in different dosage forms under tropical conditions. The research aimed to examine the phenomenon of roots and leaves of C3 plants infected with VAM in different dosage forms at the screen house scale.

Materials and Methods

The research was conducted at the Agrotechnology Laboratory and Screen House, Faculty of Agriculture, Animal Husbandry and Fisheries, Muhammadiyah University of Parepare. This research uses a factorial design. Factor 1 was the dosage form of VAM, namely powder dosage form (D1)/control, sachet dosage form (D2), and tablet dosage form (D3), While other factors were C3 plant species, namely puero (Pueraria javanica) (P1)/control, mung bean (*Vigna radiata*) (P2), and red spinach (*Amaranthus tricolor*) (P3).

The powder dosage form is a standard propagule that consists of zeolite, sand, biochar, root pieces of a host plant, and VAM spores. Standard propagule is required for the manufacture of sachet dosage forms using the sachet packaging, and for the manufacture of tablet dosage forms by adding organic or inorganic adhesives. The planting medium used consisted of soil, biochar, and compost with a ratio of 1:1:1.

The percentage of roots infected is calculated based on the formula from Phillips and Hayman (1970), and root morphology includes root length, secondary root number per 1 cm of primary roots, secondary root diameter, and root volume. Observational data were analyzed using Factorial Variance Analysis followed by Duncan's Test (Akib, 2014).

Calculating the percentage level of infected roots begins with making semi-permanent root preparations. Calculate the percent infection from the roots infected number from 10 observed root sections. Characterized by infected roots are the presence of hyphae and arbuscules in root tissue.

The infections percentage of VAM was calculated using the formula from Phillips and Hayman (1970), which can be seen in equation 1:

$$IP\ VAM = \frac{JAT}{JSP} \times 100 \quad \text{.....(1)}$$

Note: JAT: $\Sigma infectionroots$, JSP : $\Sigma totalobservation$

The percentage of infected roots was determined based on the criteria of Rajapakse and Miller (1992) as follows:

<5% = very low (grade 1)

6 – 25% = low (grade 2)

26 – 50% = moderate (grade 3)

51 – 75% = high (grade 4)

>75% = very high (grade 5)

The root volume (RV) was determined by cutting the cleaned of plant roots. Plant roots were insert to a 1000 ml measuring glass containing 250 ml of water (V1) to obtain an additional volume (V2) (Sattelmacher, 1987). The formula for root volume can be seen in equation 2:

RV = V2 – V1 ……..(2)

Leaf area (LA) is determined using the Gravimetric method. For the implementation of the gravimetric method, as follows: use leaf patterns (leaf replicas) drawn on plain paper. The leaf replicas were weighed using an analytical balance (Chaudhary *et al.*, 2012). Calculate leaf area using the formulain equation 3:

$$\text{LA} = \frac{\text{Leaf replica weight}}{\text{Total paper weight}} \times \text{total paper area} \quad \text{....(3)}$$

Stomata density was measured using the replica method. The steps for the replicated method are as follows: Coat the leaf surface with a thin layer of nail polish and let it dry for about 5-10 minutes. After the nail polish has dried, the scotch tape is applied, and immediately unsealed, and the nail polish is removed immediately as a pore impression.

Place the mold on the glass object and observe the preparation under a microscope with 400x magnification (Brown and Rosenberg, 1970; Paul *et al.*, 2017; Wolf *et al.*, 1979).

Results and Discussion

The variance analysis showed that the VAM application in different dosage forms affects the root phenomenon of C3 plants, especially at infected root percentage, nodules number, and root volume. Furthermore, Duncan's analysis showed that infected roots percentage of VAM and root volume of C3 plants at the application of VAM in sachet dosage forms had significantly different effects from other dosage forms on the three C3 plants. Whereas variable nodule number is shown at the application of VAM in powder dosage form (Table 1).

Dosage forms that increase VAM activity in infecting C3 plant roots are carried out on hyphae organs with moderate infection rates and other organs, namely arbuscules with infection rates low to moderate (Table 1 and Figure 1). Even though the infection class was not optimal, the infection percentage increased from 46.02% to 63.51% compared to powder and tablet dosage forms. Eldina *et al.*, (2021) stated that efficiency of VAM infection in host plants depends on the host plant characteristicsand abiotic factors (Morkunas *et al.*, 2018; Sabrina *et al.*, 2021) such as temperature, pH, humidity, and soil microorganisms.

In addition to these factors, the presence of VAM propagule in sachet dosage forms causes VAM spores to always be around the roots so that they can infect the roots properly as a form of maximum effectiveness.

The number of root nodules formed on C3 plants differs between VAM dosage forms. VAM in a powder dosage form can increase the number of root

nodules by 15.02% to 56.22% compared to other dosage forms. Possibly caused by application of VAM in powder form cannot optimally induce plant root infection, because the number of spores lost by water and wind, provides an opportunity for rhizobium bacteria in the planting medium to initiate infection which eventually forms root nodules.

According to Goyal and Habtewold (2023); Damanhuri *et al.,* (2020), plant roots that symbiosis with Rhizobium sp bacteria can fix nitrogen (N2) from the air.

The free nitrogen is fixation and then stored in the form of nodules that contain nitrogen which is very important because it increases soil fertility (Cheng *et al.,* 2023; Santi *et al.,* 2013)

Vesiclar AM in sachet dosage form, besides increasing infection, can also increase the root volume of C3 plants. The increase in root volume as a performance of root growth is inseparable from the role of VAM in absorbing water and nutrients through hyphae which in turn increases the production of assimilate which is translocated to roots for root growth and fulfills VAM energy needs through the role of arbuscules.

According to Carstensen *et al.,* (2018) and Kayoumu *et al.,* (2023) that VAM plays a significant role in the absorption of nutrients, especially the element P for the formation of assimilates through the process of photosynthesis that occurs in plant leaves.

The construction of ATP and NADPH using the help of sunlight which is absorbed by plant leaves and then converted into chemical energy in the light reaction. Furthermore, in the dark reaction, ATP and NADPH are used to reduce CO2 to produce assimilates in the stroma (Li *et al.,* 2023; Wasilewska-d, 2022)

The results of variance analysis showed that the dosage form of VAM had a significant effect on the number of leaves, leaf area, and number of stomata of C3 plants. While the Duncan test showed a different phenomenon in C3 plants due to the treatment of VAM dosage forms (Figure 2).

Table.1 Phenomenon of C3 plant roots infected with vesiclararbuscular mycorrhizal

No	Treatment	VAM infected roots (%)		Number of Nodules (unit)	Root volume (cm^3)
		Hyphae	Arbuscular		
1	D1P1	$3,33^{i}$	$0,00^{e}$	$79,00^{a}$	$4,36^{b}$
2	D1P2	$21,67^{f}$	$10,00^{b}$	$48,33^{ab}$	$3,60^{b}$
3	D1P3	$41,67^{a}$	$3,33^{d}$	$79,00^{a}$	$4,57^{b}$
4	D2P1	$33,33^{c}$	$7,41^{c}$	$46,00^{ab}$	$15,05^{a}$
5	D2P2	$31,67^{d}$	$11,67^{a}$	$11,00^{b}$	$13,10^{a}$
6	D2P3	$40,00^{b}$	$10,00^{b}$	$59,00^{ab}$	$11,01^{a}$
7	D3P1	$6,67^{h}$	$0,00^{e}$	$0,00^{b}$	$2,77^{b}$
8	D3P2	$15,00^{g}$	$0,00^{e}$	$24,67^{ab}$	$2,82^{b}$
9	D3P3	$26,67^{e}$	$0,00^{e}$	$6,33^{b}$	$2,74^{b}$

Note: Percentage of root colonization by VAM in the combination of VAM dosage forms and C3 plant species (D1, powder dosage forms; D2 sached dosage forms; D3 tablet dosage forms; P1, *Puraria javanica*; P2, *Vigna radiata*; P3, *Amarantus gangeticus*)

Fig.1 Infection of vesiclararbuscular mycorrhizal (VAM) on the C3 plants roots (Magnification 10x 40)

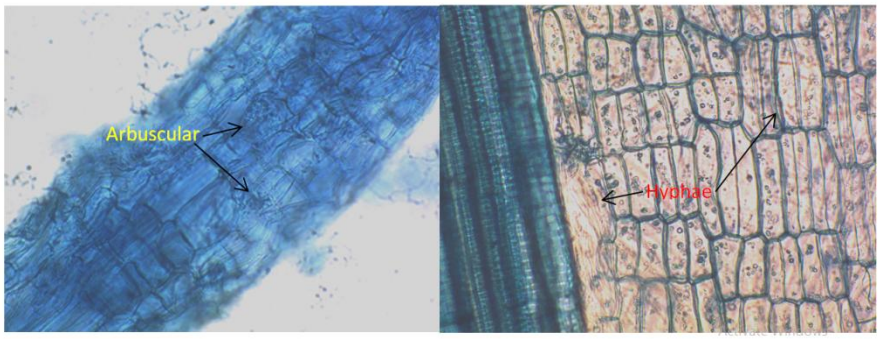
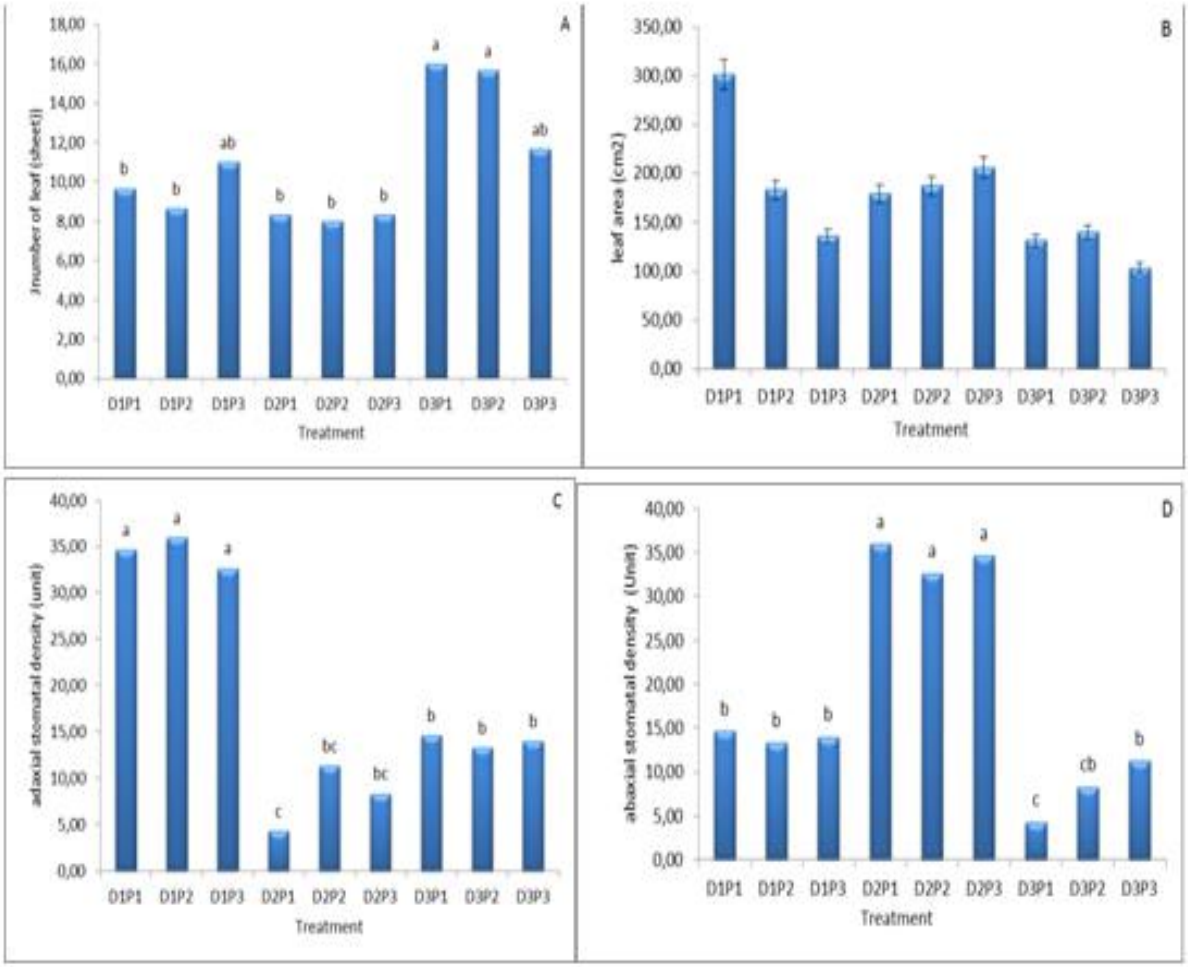


Fig.2 Phenomenon of C3 plant leaf infected with vesicular arbuscular mycorrhiza



Vesiclar AM in tablet dosage forms promotes C3 plants to form more leaves than other dosage forms, although not followed by wide leaf size. Organic materials that function as binders in tablet dosage forms can be a hypothesis for the occurrence of this phenomenon. According to Albano *et al.*, (2023) and Gerke (2022) that the organic matter can increase the availability of nutrients in the soil.

This phenomenon also shows that leaf numbers of more can cause smaller leaf sizes because of internal competition between leaves in a plant in the assimilate use. The different phenomena in C3 plants that received VAM in the sachet dosage form show the leaf number and leaf area were relatively balanced.

The stomatal density phenomenon on the adaxial and abaxial of the C3 plant's leaf was also unique. The C3 plants that received VAM in powder dosage form generally had more congested stomata density on the leaf adaxial parts compared to other VAM dosage form treatments. Meanwhile, the stomata density on the leaf abaxial tended to be higher in C3 plants that received VAM in the sachet dosage form.

Whether this phenomenon is caused by the effects of the VAM dosage form or the genetic factors of the three C3 plants is not yet well clarified. Cui *et al.*, (2023) explain that stomata cells have formed by two cells, namely guard cells and subsidiary cells.

The movement and function of guard cells are supported by subsidiary cells that provide mechanical support or act as reservoirs for ions and water.

Vesicular AM dosage form has a significant effect on root infection, number of nodules, root volume, number of leaves, leaf area, and stomata density with various phenomena. VAM in the dosage form of sachets and tablets can be a new dosage form for VAM applications in the field.

Acknowledgement

Authors thanks to Ministry of Education, Culture, Research, and Technology which has provided support through the competition of Penelitian Dasar Unggulan Perguruan Tinggi (PDUPT) in 2023-2024.

References

Abdelrahman, M. A. E. (2023). An overview of land degradation, desertification and sustainable land management using GIS and remote sensing applications. In *Rendiconti Lincei. Scienze Fisiche e Naturali* (Issue 0123456789). Springer International Publishing. https://doi.org/10.1007/s12210-023-01155-3

Akib, M. A. (2014). *Prosedur Rancangan Percobaan: Aplication Of The Model In Different Environmental Conditions* (1st ed.). Lampena Intimedia.

Albano, X., Whitmore, A. P., Sakrabani, R., Thomas, C. L., Sizmur, T., Ritz, K., Harris, J., Pawlett, M., Watts, C., Haefele, S. M., & Thomas, C. L. (2023). Effect of Different Organic Amendments on Actual and Achievable Yields in a Cereal ‐ Based Cropping System. *Journal of Soil Science and Plant Nutrition*, *23*(2), 2122–2137. https://doi.org/10.1007/s42729-023-01167-w

Anand, K., Pandey, G. K., Kaur, T., Pericak, O., Olson, C., Mohan, R., Yadav, A., Devi, R., Kour, D., Rai, A. K., Kumar, M., & Yadav, A. N. (2022). Arbuscular mycorrhizal fungi as a potential biofertilizers for agricultural sustainability. *Journal of Applied Biology & Biotechnology*, *10*(Suppl 1), 90–107. https://doi.org/10.7324/JABB.2022.10s111

Anwar, P., Islam, A. K. M. M., Yeasmin, S., & Rashid, H. (2021). Weeds and Their Responses to Management Efforts in A Changing Climate. *Agronomy*, *11*(1921), 1–21. https://doi.org/10.3390/agronomy11101921

Begum, N., Qin, C., Ahanger, M. A., Raza, S., Khan, M. I., Ashraf, M., Ahmed, N., & Zhang, L. (2019). Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance. *Frontiers in Plant Science*, *10:1068*, 1–15. https://doi.org/10.3389/fpls.2019.01068

Bhargava, S., & Mitra, S. (2021). Elevated atmospheric CO 2 and the future of crop plants. *Plant Breeding*, *140*(2021), 1–11. https://doi.org/10.1111/pbr.12871

Brown, K. W., & Rosenberg, N. J. (1970). Influence

of Leaf Age, Illumination, and Upper and Lower Surface Differences on Stomatal Resistance of Sugar Beet (Beta vulgaris) Leaves 1. *Agronomy Journal*, *62*(1), 20–24. https://doi.org/10.2134/agronj1970.00021962006200010007x

Carstensen, A., Herdean, A., Schmidt, B., Sharma, A., & Spetea, C. (2018). The Impacts of Phosphorus De fi ciency on the Photosynthetic Electron Transport Chain 1 [OPEN]. *Plant Physiology*, *177*, 271–284. https://doi.org/10.1104/pp.17.01624

Chaudhary, P., Godara, S., N. Cheeran, A., & K. Chaudhari, A. (2012). Fast and Accurate Method for Leaf Area Measurement. *International Journal of Computer Applications*, *49*(9), 22–25. https://doi.org/10.5120/7655-0757

Cheng, Z., Meng, L., Yin, T., Li, Y., Zhang, Y., & Li, S. (2023). Changes in Soil Rhizobia Diversity and Their Effects on the Symbiotic Efficiency of Soybean Intercropped with Maize. *Agronomy*, *13*(997), 1–17. https://doi.org/10.3390/agronomy13040997

Cousins, A. B., Mullendore, D. L., & Sonawane, B. V. (2020). Recent developments in mesophyll conductance in C3, C4, and crassulacean acid metabolism plants. *The Plant Journal*, *101*, 816–830. https://doi.org/10.1111/tpj.14664

Cui, Y., He, M., Liu, D., Liu, J., Liu, J., & Yan, D. (2023). Intercellular Communication during Stomatal Development with a Focus on the Role of Symplastic Connection. *International Jurnal of Molecular Sciences*, *24*, 2593. https://doi.org/10.3390/ijms24032593

Damanhuri, D., Erdiansyah, I., Eliyatiningsih, E., Sari, V. K., Pratama, A. W., & Wiharto, K. S. (2020). Utilization of Rhizobium spp as substitution agent of nitrogen chemical fertilizer on soybean cultivation. *IOP Conference Series: Earth and Environmental Science*, *411*(1). https://doi.org/10.1088/1755-1315/411/1/012065

Eldina, G., Wirawan, I. G. P., & Sritamin, M. (2021). Microscopic Identification Of Vesicular Arbuscular Mycorrhizae (Vam) Associated With Orchid*Cymbidium* sp. *International Journal Of Biosciences And Biotechnology*, *9*(1), 15–23. https://doi.org/10.24843/IJBB.2021.v09.i01.p02

Feeney, C. J., Robinson, D. A., Thomas, A. R. C., Borrelli, P., Cooper, D. M., & May, L. (2023). Science of the Total Environment Agricultural practices drive elevated rates of topsoil decline across Kenya, but terracing and reduced tillage can reverse this. *Science of the Total Environment*, *870*(October 2022), 161925. https://doi.org/10.1016/j.scitotenv.2023.161925

Gerke, J. (2022). The Central Role of Soil Organic Matter in Soil Fertility and Carbon Storage. *Soil System*, *6*(33), 1–14. https://doi.org/10.3390/soilsystems6020033

Goyal, R. K., & Habtewold, J. Z. (2023). Evaluation of Legume – Rhizobial Symbiotic Interactions Beyond Nitrogen Fixation That Help the Host Survival and Diversification in Hostile Environments. *Microorganisms*, *11*(1454), 1–18. https://doi.org/10.3390/microorganisms11061454

Halecki, W., Kruk, E., & Ryczek, M. (2018). Land Use Policy Loss of topsoil and soil erosion by water in agricultural areas : A multi-criteria approach for various land use scenarios in the Western Carpathians using a SWAT model. *Land Use Policy*, *73*(January), 363–372. https://doi.org/10.1016/j.landusepol.2018.01.041

Hoffland, E., Kuyper, T. W., Comans, R. N. J., & Creamer, R. E. (2020). Eco-functionality of organic matter in soils. *Plant Soil*, *455*, 1–22. https://doi.org/10.1007/s11104-020-04651-9

Hristozkova, M., & Orfanoudakis, M. (2023). Arbuscular Mycorrhiza and Its Influence on Crop Production. *Agriculture (Switzerland)*,

13(5), 2–4. https://doi.org/10.3390/agriculture13050925

Huey, C. J., Gopinath, S. C. B., Uda, M. N. A., Zulhaimi, H. I., Jaafar, M. N., Kasim, F. H., & Yaakub, A. R. W. (2020). Mycorrhiza : a natural resource assists plant growth under varied soil conditions. *3 Biotech*, *10*(204), 1–9. https://doi.org/10.1007/s13205-020-02188-3

Kayoumu, M., Iqbal, A., Muhammad, N., Li, X., Li, L., Wang, X., Gui, H., Qi, Q., Ruan, S., Guo, R., Zhang, X., Song, M., & Dong, Q. (2023). Phosphorus Availability Affects the Photosynthesis and Antioxidant System of Contrasting Low-P-Tolerant Cotton Genotypes. *Antioxidants*, *12*(2). https://doi.org/10.3390/antiox12020466

Khangura, R., Ferris, D., & Wagg, C. (2023). Regenerative Agriculture — A Literature Review on the Practices and Mechanisms Used to Improve Soil Health. *Sustainability*, *15*, 1–41. https://doi.org/10.3390/su15032338

Krauss, M, Wiesmeier, M., Don, A., Cuperus, F., Gattinger, A., Gruber, S., Haagsma, W. K., Peigné, J., Palazzoli, M. C., Schulz, F., Krauss, M., Wiesmeier, M., Don, A., Cuperus, F., & Gattinger, A. (2022). Reduced tillage in organic farming affects soil organic carbon stocks in temperate Europe. *Soil and Tillage Research*, *216*, 105262. https://doi.org/10.1016/j.still.2021.105262

Krauss, Maike, Berner, A., Perrochet, F., Frei, R., Niggli, U., & Mäder, P. (2020). Enhanced soil quality with reduced tillage and solid manures in organic farming – a synthesis of 15 years. *Scientific Reports*, *10*(1), 1–12. https://doi.org/10.1038/s41598-020-61320-8

Kumar, V., Sharma, A., Soni, J. K., & Pawar, N. (2017). Physiological response of C3, C4 and CAM plants in changeable climate. *The Pharma Innovation Journal*, *6*(9), 70–79.

Li, R., He, Y., Chen, J., Zheng, S., & Zhuang, C. (2023). Research Progress in Improving Photosynthetic Efficiency. *International Journal of Molecular Sciences*, *24*, 1–13. https://doi.org/10.3390/ijms24119286

Marpaung, D. S. S., Anika, N., & Bindar, Y. (2021). Effect of Land Clearing Activity on Environmental and Arthropods Diversity (Case Study: Jati Agung, Lampung). *Jurnal Ilmu Lingkungan*, *19*(2), 444–449. https://doi.org/10.14710/jil.19.2.444-449

Morkunas, I., Wozniak, A., Mai, V. C., Rucinska-Sobkowiak, R., & Jeandet, P. (2018). The role of heavy metals in plant response to biotic stress. *Molecules*, *23*(9), 1–30. https://doi.org/10.3390/molecules23092320

Muhie, S. H. (2022). Optimization of photosynthesis for sustainable crop production. *CABI Agriculture and Bioscience*, *3*(5), 1–8. https://doi.org/10.1186/s43170-022-00117-3

Paul, V., Sharma, L., Pandey, R., & Meena, R. C. (2017). Measurement of stomatal density and stomatal index on leaf / plant surfaces. In *Manual of ICAR Sponsored Training Programme on "Physiological Techniques to Analyze the Impact of Climate Change on Crop Plants* (Issue January). https://doi.org/10.13140/RG.2.2.13426.40646

Phillips, J. M., & Hayman, D. S. (1970). Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. *Transactions of the British Mycological Society*, *55*(1), 158-IN18. https://doi.org/10.1016/s0007-1536(70)80110-3

Sabrina, N., Abdul, N., Wahida, N., Hamid, A., & Nadarajah, K. (2021). Effects of Abiotic Stress on Soil Microbiome. *International Journal of Molecular Sciences*, *22*, 9036. https://doi.org/10.3390/ijms22169036

Santi, C., Bogusz, D., Franche, C., Perpignan, D., Domitia, V., Alduy, A. P., & Rhizogene, E. (2013). Biological nitrogen fixation in non-legume plants. *Annals of Botany*, *111*, 743–767. https://doi.org/10.1093/aob/mct048

Sattelmacher, B. (1987). Kurzmitteilung - Short communication Methods for measuring root

volume and for studying root morphology. *Z Pflanzenemähr Bodenk*, *150*, 54–55. https://doi.org/10.1002/jpln.19871500112

Sivaram, A. K., Logeshwaran, P., Lockington, R., Naidu, R., & Megharaj, M. (2020). The impact of low molecular weight organic acids from plants with C3 and C4 photosystems on the rhizoremediation of polycyclic aromatic hydrocarbons contaminated soil. *Environmental Technology and Innovation*, *19*, 100957. https://doi.org/10.1016/j.eti.2020.100957

Skendži, S., Zovko, M., & Pajaˇ, I. (2021). The Impact of Climate Change on Agricultural Insect Pests. *Insects*, *12*, 1–31. https://doi.org/10.3390/insects12050440

Theint Theint Win, Thu, M., Swe, T. M., Ko, T. K., Aung, T. T., Ei, K. H., Win, N. N., Swe, K. K., Hlaing, A. A., Winnandar, & Khaing, A. A. (2020). Degradation of Soil Quality in Mandalay Region of Myanmar Due to Overuse of Pesticides in Agriculture. *Asia-Pacific Journal of Rural Development*, *30*(1–2), 113–138. https://doi.org/10.1177/1018529120977247

Upadhyay, P., Agrawal, N., Yadav, P. K., & Patel, R. (2020). The Evolutionary Path from C 3 to C 4 Photosynthesis : A Review. *International Journal of Current Microbiology and Applied Sciences*, *9*(1), 748–762. https://doi.org/10.20546/ijcmas.2020.901.08

2

Wang, F., Gao, J., Yong, J. W. H., Wang, Q., Ma, J., & He, X. (2020). Higher Atmospheric CO 2 Levels Favor C 3 Plants Over C 4 Plants in Utilizing Ammonium as a Nitrogen Source. *Frontiers in Plant Science*, *11*, 1–16. https://doi.org/10.3389/fpls.2020.537443

Wasilewska-d, W. (2022). How Light Reactions of Photosynthesis in C4 Plants Are Optimized and Protected under High Light Conditions. *International Jounal of Molecular Sciences*, *23*, 1–15. https://doi.org/10.3390/ijms23073626

Weng, W., Yan, J., Zhou, M., Yao, X., Gao, A., Ma, C., Cheng, J., & Ruan, J. (2022). Roles of Arbuscular mycorrhizal Fungi as a Biocontrol Agent in the Control of Plant Diseases. *Microorganisms*, *10*(7), 1266. https://doi.org/10.3390/microorganisms10071266

Wolf, D. D., Carson, E. W., & Parrish, D. J. (1979). A replica method of determining stomatal and epidermal cell density. *Journal of Agronomic Education*, *8*(1), 52–54. https://doi.org/10.2134/jae.1979.0052

Wu, S., Shi, Z., Chen, X., Gao, J., & Wang, X. (2022). Arbuscular mycorrhizal fungi increase crop yields by improving biomass under rainfed condition: A meta-analysis. *PeerJ*, *10*, 1–25. https://doi.org/10.7717/peerj.12861

How to cite this article:

Muh. Akhsan Akib, Syatrawati and Retno Prayudyaningsih. 2023. Root and Leaf Phenomenons of C3 Plants Infected with Vesicular Arbuscula Mycorrhizal. *Int.J.Curr.Microbiol.App.Sci.* 12(07): 172-180.
doi: https://doi.org/10.20546/ijcmas.2023.1207.019