International Journal of Agricultural Technology 2026 Vol. 22(4):1859-1870
DOI: https://doi.org/10.63369/ijat.2026.22.4.1859-1870
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Comparative study of different cultivation systems of black soybean on ultisol land

Pujiwati, H.[1 *], Susilo, E.[2], Prameswari, W.[1], Fitri, M. A.[3], Sari, S. R.[4], Widodo, W.[1] and Arraudah, R.[1]

[1]Department of Crop Production, Faculty of Agriculture, University of Bengkulu, Bengkulu 38121, Indonesia; [2]Department of Agrotechnology, Faculty of Agriculture, University of Ratu Samban, Arga Makmur, Bengkulu 38618, Indonesia; [3]Department of Agribusiness, Faculty of Agriculture, University of Bengkulu, Bengkulu 38121, Indonesia; [4]Departement of Agricultural Industrial Technology, Faculty of Agriculture, University of Bengkulu, Bengkulu 38121, Indonesia.

Pujiwati, H., Susilo, E., Prameswari, W., Fitria, M. A., Sari, S. R., Widodo, W. and Arraudah, R. (2026). Comparative study of different cultivation systems of black soybean on ultisol land. International Journal of Agricultural Technology 22(4):1859-1870.

Abstract The study demonstrated that soybean growth and yield under water-saturated conditions differed significantly from those under conventional cultivation systems. In addition, the root physiology and anatomy of soybeans grown under water-saturated conditions also showed significant differences compared to those under conventional systems. The average plant height of soybeans under water-saturated conditions was 47.67 cm, compared to 40.13 cm under conventional conditions. Similarly, the number of soybean pods was higher under water-saturated conditions (121.40 g) than under conventional systems (84.13 g). The dry shoot weight and dry root weight were also significantly greater under water-saturated conditions (24.07 g and 5.07 g, respectively) than under conventional conditions (16.93 g and 1.70 g, respectively). These findings highlighted the importance of water-saturated cultivation systems in enhancing soybean growth and yield on Ultisol.

Keywords: Agro-physiological, Black soybean, Ultisol land, Water-saturated systems, Conventional systems

Introduction

Soybean (*Glycine max* (L.) is a food crop commodity from the Leguminosae family, recognised as a significant source of vegetable protein and as having high economic value. It is widely used as a raw material for processed products such as tofu, tempeh, and soy sauce. The primary product of soybeans is their seeds, which are rich in protein, B vitamins, and amino acids, providing important health benefits (Aulia *et al.*, 2014). According to the Central Statistics Agency (2022), Indonesia's population increased by 2.4–3 million annually

*Corresponding Author: Pujiwati, H.; Email: hesti_pujiwati@unib.ac.id

between 2020 and 2022, driving greater national demand for soybeans. Furthermore, the Indonesian Ministry of Agriculture, through the Secretary General (2020), reported that only 21.61% of soybean demand is supplied by domestic production, whereas 78.44% is met through imports. The low level of national soybean production, along with its limited concentration, is due primarily to the cultivation area being dominated by rice fields under a rice–soybean cropping pattern. Meanwhile, soybean consumption in Indonesia continues to rise with annual population growth and increasing public awareness of nutrition. Therefore, efforts are urgently needed to boost soybean production through expanding cultivation areas and improving productivity.

To mitigate this challenge, it is necessary to expand soybean cultivation by utilizing suboptimal land, such as dry and acidic Ultisol soils (Septiadi *et al.,* 2024). Ultisol land is one strategy to increase production and broaden soybean planting areas in Indonesia. The potential area of Ultisol land in Indonesia is estimated at 45,794,000 hectares. However, Ultisols face constraints related to soil fertility and topography (Maryani *et al.,* 2024). These soils are characterised by low organic matter content, acidic pH, and high rates of base leaching. Therefore, improving Ultisol productivity requires soil management practices such as fertilisation and the application of organic matter (Sujana, 2015). Soybean cultivation on dry land is also strongly influenced by climate, with many farmers still relying on rainfall as the primary water source for crop production. However, weather conditions have become increasingly difficult to predict and changing climate patterns pose risks of flooding and drought, significantly affecting soybean productivity (Ruminta *et al*., 2020).

Water-Saturated Cultivation (WS) is a potential approach to address the challenges of soybean cultivation on dry land that depends heavily on rainfall. In this method, crops are planted on raised beds, while and water is continuously supplied around the planting plots, ensuring that the soil layer beneath the roots remains saturated, while the water table maintained below the soil surface (Purwaningrahayu *et al*., 2004). This system also facilitates soil leaching, thereby reducing the harmful effects of toxic substances on plant growth. At a water table depth of approximately 20 cm below the ground surface, field capacity in the root zone can be sustained (Prasetya *et al*., 2021). The application of water-saturated cultivation technology on tidal land has been shown to increase soybean productivity by up to 4.5 tons per hectare (Pujiwati, 2016).

Saturated water cultivation has been shown to enhance the growth and productivity of soybean plants. Susilo *et al.* (2019) reported that this method can increase soybean yields by up to 4 tons per hectare. Various strategies can be employed to improve soybean productivity, including comparative studies between saturated water cultivation systems and conventional cultivation systems. The choice of cultivation system plays a crucial role in determining soybean growth, yield, and productivity, particularly on Ultisol soils. Therefore, further research is required to compare different black soybean cultivation systems on Ultisol land.

Materials and methods

Research design

This experiment used a completely randomized design with two factors. The first factor was the water-saturated cultivation system (Figure 1). The second factor was the conventional cultivation system.

Population and samples

The combination of the two treatments produced two treatment groups, each replicated four times, resulting in a total of eight experimental units. Each unit consisted of 25 plants, giving a total of 200 plants, with six sample plants taken from each experimental unit.

Research stage

Preparation of planting media

The research site was prepared by clearing debris and tilling the soil to a depth of 30 cm. Seven days later, a second tillage was conducted to ensure the soil was loose, levelled, and weed-free. Each experimental plot measured 100 cm × 150 cm, with 50 cm spacing between plots. The beds were maintained at a height of 30 cm, while the water level was regulated at 15 cm per the water-saturated cultivation method. Soybean seeds were planted in rows perpendicular to the east–west direction or parallel to the north.

Planting

Soybean planting was done by making holes 3–4 cm deep at 30 × 20 cm spacing. Before sowing, each hole was treated with Furadan insecticide to protect against soil pests. Two Detam-2 soybean seeds, pre-inoculated with *Rhizobium* to enhance nitrogen fixation, were placed in each hole and then covered with soil. Planting rows were oriented either perpendicular to sunrise or parallel to the north to optimise light exposure.

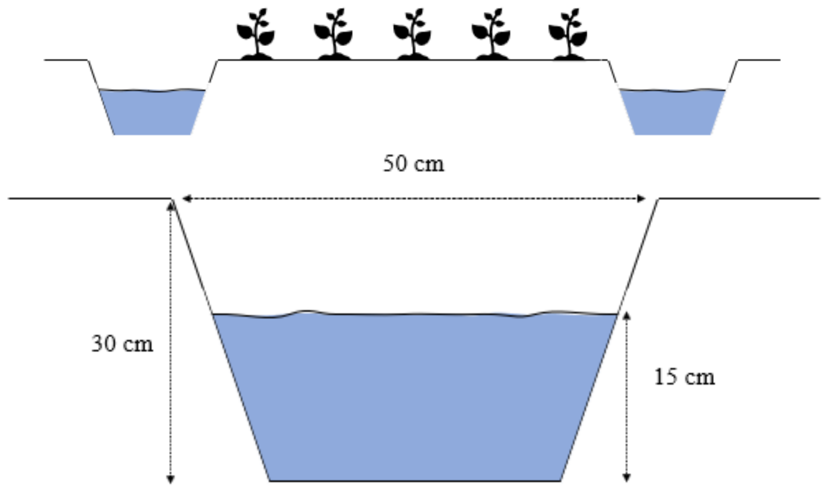

Figure 1. Illustration of a water-saturated cultivation to used

Data collection and analysis

Data were collected in terms of plant height (PH), number of leaves (NL), number of branches (NB), number of pods (NP), seed weight of 100 (SW 100), seed weight per plant (SWP), shoot dry weight (SDW), and root dry weight (RDW). Data were analyzed using analysis of variance (ANOVA) using the F test at a 5% of probability level. Data with a significant effect were further tested using Orthogonal Polynomials (PO) and Least Significant Differences (LSD) 5%.

Results

Results revealed significant differences between the conventional (CS) and water-saturated cultivation systems (WSS) for all observed variables, including plant height, number of leaves, number of branches, number of pods, seed weight per plant, shoot dry weight, root dry weight, and all anatomical variables (stem and stomata). However, the seed weight of 100, all variable anatomy root, and the diameter of stomata-c was did not differ significantly between the two systems (Table 1).

Table 1. Analysis of variance for each observed variable

No	Variable	Treatments	Coefficient of diversity
1	Plant height	37.78**	3.42
2	Number of leaves	37.27**	6.65
3	Number of branches	9.85*	5.95
4	Number of pods	499.97**	1.99
5	Seed weight 100	5.47 ns	8.48
6	Seed weight per plant	380.87**	10.04
7	Shoot dry weight	8.15*	14.93
8	Root dry weight	75.01*	14.07
9	Stem-a	0.000**	2.17
10	Stem-b	0.000**	1.89
11	Stem-c	0.008**	24.82
12	Stem-d	0.033*	28.94
13	Stem-e	0.007**	33.95
14	Stem-f	0.002**	20.1
15	Root-a	0.583ns	13.6
16	Root-b	0.238ns	13.79
17	Root-c	0.154ns	28.16
18	Root-d	0.531ns	22.42
19	Stomata-a	0.04*	6.71
20	Stomata-b	0.039*	11.24
21	Stomata-c	0.28ns	12.03
22	Stomata-d	0.001**	16.28

* = significant difference at 5 % significance level according to Least Significant Different. Stem a = overall stem diameter; Stem b = endodermis diameter; Stem c = epidermis + collenchyma + parenchyma; Stem d = parenchyma; Stem e = collenchyma; Stem f = epidermis; Stomata a = outer/vertical diameter; Stomata b = inner/vertical diameter; Stomata c = outer/horizontal diameter; Stomata d = inner/horizontal diameter; Root a = overall root diameter; Root b = stele diameter; Root c = cortex; Root d = epidermis.

Comparative growth and yield of black soybeans in conventional cultivation and water-saturated cultivation systems

Significant differences in black soybean growth were observed between the conventional and saturated cultivation systems. On Ultisol soils, the saturated cultivation system produced notable improvements across all measured growth parameters, including plant height, number of leaves, branches, and pods. The average plant height under saturated cultivation reached 47.67 cm, compared to 40.13 cm under the conventional system. Likewise, the number of pods was higher in the saturated system (121.40 pods) than in the conventional system (84.13 pods). The number of black soybean plants in the conventional cultivation system shows fewer branches, only around 6.47. In comparison, the number of black soybean branches in the water-saturated cultivation system produces 7.53 branches (Table 2).

Table 2. Effect of cultivation systems on black soybean growth traits

Treatment	PH (cm)	NL	NB	NP
CS	40.13 b	19.47 b	6.47 b	84.13 b
WSS	47.67 a	27.20 a	7.53 a	121.40 a

Notes: Numbers followed by the same letter in the same column are not significantly different in the BNT test at the 5% level. CS = Conventional cultivation systems; WSS = Water-satured cultivation systems; PH = Plant height, NL = number of leaves; NB = number of branches; NP = number of pods.

The seed weight per plant of black soybean differed significantly between the conventional and water-saturated cultivation systems. On Ultisol land, plants grown under the water-saturated system produced an average seed weight of 192.67 g per plant, nearly ten times greater than that under the conventional system (21.40 g). In contrast, the seed weight 100 showed no significant difference between the two cultivation systems. Furthermore, the dry shoot and root weights were higher in the water-saturated system (24.07 g and 5.07 g, respectively) compared with the conventional system (16.93 g and 1.70 g, respectively) (Table 3).

Table 3. Effect of cultivation systems on black soybean yield traits

Treatment	SW 100	SWP	SDW	RDW
CS	10.40	21.40 b	16.93 b	1.70 b
WSS	12.23	192.67 a	24.07 a	5.07 a

Notes: Numbers followed by the same letter in the same column are not significantly different in the BNT test at the 5% level. CS = Conventional cultivation systems; WSS = Water-satured cultivation systems; SW100 = seed weight of 100, SWP = seed weight per plant; SDW = shoot dry weight; RDW = root dry weight.

Comparative anatomy stem and stomata of black soybeans in conventional cultivation and water-saturated cultivation systems

Cross-sectional anatomical analysis of black soybean stems revealed significant differences between plants grown under water-saturated and conventional cultivation systems. The endodermis diameter was larger in the water-saturated system (3419.06 µm) compared to the conventional system (2431.18 µm). Similarly, the parenchyma and collenchyma diameters were greater under the water-saturated system (592.65 µm and 173.44 µm, respectively) than under the conventional system (331.44 µm and 59.79 µm, respectively) (Table 4).

The stem-C diameter (epidermis + collenchyma + parenchyma) showed a very significant difference between the two black soybean cultivation systems, where the stem-C diameter in the water-saturated cultivation system showed a diameter size 2 times larger than the stem-C diameter in the conventional cultivation system, namely 1004.38 mm (WSS) and 496.2 mm (CS). Similarly, the stem epidermis diameter in the water-saturated cultivation system was almost 3 times that in the conventional cultivation system, 125.88 mm and 56.99 mm, respectively.

Table 4. Effect of cultivation systems on black soybean anatomy stem

Treatment	Anatomy Cross Section of Stem					
	a	b	c	d	e	f
CS	2431.18^{b}	1421.02^{b}	496.2^{b}	331.44^{b}	59.79^{b}	56.99^{b}
WSS	3419.06^{a}	1746.22^{a}	1004.38^{a}	592.65^{a}	173.44^{a}	125.88a

Notes: Numbers followed by the same letter in the same column are not significantly different in the BNT test at the 5% level. CS = Conventional cultivation systems; WSS = Water-satured cultivation systems; Stem a = overall stem diameter; Stem b = endodermis diameter; Stem c = epidermis + collenchyma + parenchyma; Stem d = parenchyma; Stem e = collenchyma; Stem f = epidermis.

Table 5. Effect of cultivation systems on black soybean stomata

Treatment	Anatomy Cross Section of Stomata			
	a	b	c	d
CS	17.72^{b}	9.74^{b}	12.08	1.74^{b}
WSS	20.89^{a}	12.85^{a}	13.65	6.06^{a}

Notes: Numbers followed by the same letter in the same column are not significantly different in the BNT test at the 5% level. CS = Conventional cultivation systems; WSS = Water-satured cultivation systems; Stomata a = outer/vertical diameter; Stomata b = inner/vertical diameter; Stomata c = outer/horizontal diameter; Stomata d = inner/horizontal diameter.

The cross-sectional dimensions of black soybean stomata showed significant differences between the conventional and saturated cultivation systems. The outer vertical diameter of the stomata was greater under the saturated system (20.89 µm) than the conventional system (17.72 µm). Likewise, the inner vertical diameter was larger in the saturated system (12.85 µm) than in the conventional system (9.74 µm). In addition, the horizontal stomatal diameter in the saturated system (6.06 µm) was substantially larger—over three times that observed in the conventional system (1.74 µm) (Table 5).

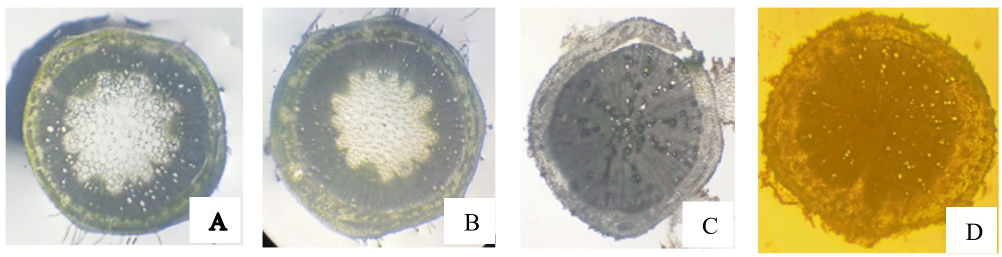

Figure 2. Anatomy cross section of stem and root of black soybean: A= Conventional system (stem anatomy); B = Water-satured system (stem anatomy); C = Conventional system (root anatomy); D = Water-satured system (root anatomy)

Anatomical observations of black soybean stems and roots under conventional and water-saturated cultivation systems on Ultisol land showed contrasting outcomes. While stem anatomy exhibited significant differences between the two systems, root anatomy did not. Specifically, no significant differences were observed in root diameter, stele diameter, cortex thickness, or epidermis structure across the two cultivation systems (Figure 2).

Discussion

Analysis of variance from destructive sampling showed that the conventional and water-saturated cultivation systems significantly affected nearly all observed variables. The coefficients of variation (CV) for vegetative growth, yield, and stem, root, and stomatal anatomical parameters ranged from 1.89% to 33.95%. The data can be considered reliable since all CV values were below 35%. According to Gomes and Gomez (1995), the variation coefficient reflects the accuracy level in the measured parameters, where higher CV values indicate lower experimental precision.

Ongoing land-use changes constrain efforts to expand soybean planting areas to boost production. One alternative strategy is optimising marginal land, supported by appropriate cultivation technologies, as a potential approach for future soybean production. Indonesia has an estimated 20 million hectares of tidal swamps (Wandasari and Pramita, 2019), of which about 9 million hectares are considered suitable for agricultural development (Suriadikarta and Sutriadi, 2007). Ultisols, however, pose challenges due to their low organic matter content, acidic pH, and high rates of base leaching. To improve the productivity of Ultisols, soil management practices such as fertilisation and the incorporation of organic matter are required (Sujana, 2015). Soybean cultivation on dry land is also highly influenced by climatic factors, with many farmers still dependent on rainfall as the primary water source. However, increasingly unpredictable weather and shifting climate patterns heighten the risks of flooding and drought, both of which substantially reduce soybean productivity (Ruminta *et al*., 2020).

The water-saturated cultivation system is a technological approach in which water is supplied continuously, to maintain a constant depth of approximately 5 cm below the soil surface. This practice ensures that the soil remains saturated throughout the growth cycle, from planting until maturity. By regulating the groundwater level, soybeans are protected from the adverse effects of waterlogging, as the plants can acclimate and enhance their growth under these conditions (Suntari *et al.,* 2023). Water-saturated cultivation a form of groundwater management tested in highland areas, has proven effective in improving soybean yields (Ghulamahdi *et al*., 2016).

The results of this study indicate that the black soybean water-saturated cultivation system on ultisol land shows better growth, yield, stem anatomy, and stomata compared with the conventional cultivation system. These findings demonstrate that the water-saturated cultivation system is among the most adaptable technologies for black soybean cultivation on Ultisol soils. This adaptability is evidenced by higher pod production and greater seed weight per plant compared with the conventional cultivation system. These results are consistent with the findings of Lestari *et al.* (2024), who reported that several soybean varieties, including Tanggamus, Wilis, and Slamet, perform well under water-saturated conditions. Notably, black soybeans exhibited greater responsiveness to the water-saturated system in this study, as reflected in enhanced growth, yield, and stem and stomatal anatomical characteristics on Ultisol soils compared with the conventional system.

Acknowledgements

This research was funded by the DRTPM of Ministry of Higher Education, Science, and Technologi (Kemdiktisaintek) 2025 No. 2915/UN30.15/PM/2025.

Conflict of interest

The authors declare no conflict of interest.

References

Suntari, S., Ghulamahdi, M. and Melati, M. (2023). Relay-cropping soybean–maize in saturated soil culture increases efficiency of land use and nitrogen fertilizer. Jurnal Agronomi Indonesia, 51:91-100. https://doi.org/10.24831/ija.v51i1.44905

Aulia, R., Rosmayati and Bayu, E. S. (2014). Growth and production response of several black soybean (*Glycine max* L.) varieties based on seed size. Jurnal Online Agroekoteknologi, 2:1324-1331. https://doi.org/10.32734/jaet.v2i4.8422

Central Statistics Agency (2022). Soybean imports by country of origin, 2017–2022. https://www.bps.go.id/statictable/2019/02/14/2015/impor-kedelai-menurut-negara-asal-utama-2010-2019.html

Ghulamahdi, M., Melati, M. and Sagala, E. (2016). Response of soybean varieties under saturated soil culture and temporary flooding on tidal swamp. Procedia Environmental Sciences, 33:87-93. https://doi.org/10.1016/j.proenv.2016.03.060

Gomez, K. A. and Gomez, A. A. (1995). Statistical procedures for agricultural research (2nd ed.). John Wiley & Sons.

Lestari, A. P., Adriaani, Nusifera, S., Zulkarnaien, Mapegau and Martino, D. (2024). Optimizing an Ultisol of marginal land for soybean cultivation through inorganic fertilizer substitution with compost and biochar ameliorant. Journal of Degraded and Mining Lands Management, 12:6685-6693. https://doi.org/10.15243/jdmlm.2024.121.6685

Maryani, S., Sari, N. M., Niken, P. N. R. and Yulistia, E. (2024). Physical characteristics of Ultisol soil on horticultural agricultural land in Sriwijaya Science Techno Park, South Sumatra. UEEJ–Unbara Environmental Engineering Journal, 4(2).

Ministry of Agriculture, Republic of Indonesia (2020). Soybean outlook 2020. Center for Agricultural Data and Information Systems. https://www.pertanian.go.id/

Prasetya, R., Idwar, I. and Armaini, A. (2021). The effect of groundwater level on growth, production, and physiological quality of soybean (*Glycine max* (L.) Merr.) seeds produced. Jurnal Dinamika Pertanian, 37:157-166.

Pujiwati, H. (2016). Water-saturated cultivation technology to increase soybean productivity in tidal swamp land. In Proceedings of the National Seminar on Suboptimal Land (Palembang, Indonesia, 20–21 October 2016).

Purwaningrahayu, R. D., Taufiq, A. and Adie, M. M. (2004). Soybean cultivation technology in tidal swamp land with a water-saturated system. Buletin Palawija, 8:45-54. https://repository.pertanian.go.id/server/api/core/bitstreams/e1cd25af-5ba7-4447-a239-11af90b13344/content

Ruminta, R., Irwan, A. W., Nurmala, T. and Ramadayanty, G. (2020). Analysis of the impact of climate change on soybean production and strategic adaptation options on rainfed land in Garut Regency. Jurnal Kultivasi, 19:1089-1097. https://doi.org/10.24198/kultivasi.v19i2.27998

Septiaji, E. D., Bimasri, J. and Amin, Z. (2024). Characteristics of the physical properties of Ultisol soil based on the slope gradient. Agroradix, 7:41-49. https://e-jurnal.unisda.ac.id/index.php/agro/article/download/6462/3187/16089

Sujana, I. P. (2015). Ultisol soil management by providing organic biochar amendment towards sustainable agriculture. Agrimeta Journal, 5(9). https://www.neliti.com/publications/89640/pengelolaan-tanah-ultisol-dengan-pemberian-pembenah-organik-biochar-menuju-perta

Suriadikarta, D. A. and Sutriadi, M. T. (2007). Land types with potential for agricultural development on suboptimal land. Journal of Agricultural Research and Development, 26:115-122.

Susilo, E., Novitasari, H. and Hamron, N. (2019). Application of water-saturated cultivation technology to four soybean varieties in swampy areas with the addition of ameliorants containing natural calcium. AGRITEPA: Journal of Agricultural Science and Technology, 6:55-63. https://doi.org/10.37676/agritepa.v6i2.881

Wandansari, N. R. and Pramita, Y. (2019). Potential for the utilization of swamp lands to support agricultural development in border areas. Jurnal Agriekstensia, 18:66-73. https://pdfs.semanticscholar.org/1896/ac4c339eb09af1cff1193eb697083eb52a14.pdf

(Received: 26 September 2025, Revised: 25 December 2025, Accepted: 7 January 2026)