Journal of Tropical Crop Science Vol. 12 No. 2, June 2025
www.j-tropical-crops.com

Received 01/03/2024; Revised 10/02/2025; Accepted 23/04/2025
https://doi.org/10.29244/jtcs.12.02.358-364

Alley Cropping System to Increase Corn Crop Production and Agricultural Productivity in Dry Land

Amirudin[A*], Andi Muhibuddin[A], Yunus Musa[B], Indrianto Kadekoh[C] and Hidayati Mas'ud[C]

[A] Agrotechnology Department, Agriculture Faculty, University of Bossowa, Makassar, 90231, Indonesia
[B] Agrotechnology Department, Agriculture Faculty, University of Hasanuddin, Makassar, 90231, Indonesia
[C] Agrotechnology Department, Agriculture Faculty, Tadulako University, Palu, 94118, Indonesia

*Corresponding author; e-mail : amirudin@universitasbosowa.ac.id

Abstract

Alley cropping is an agroforestry system that plants annual crops or food crops between alleys formed by hedges of trees or shrubs. This study aims to determine the effects of the alley cropping system, the provision of Gamal (*Gliricidia sepium)* biomass, and the doses of N, P, and K fertilizers on corn production. The study was conducted in 2022 at the educational plantation area, Integrated Farming System, Faculty of Agriculture, Bosowa University, Bontoramba Village, Pallangga Subdistrict, Gowa Regency, South Sulawesi, Indonesia. The experimental design used was a split plot with and without hedgerow plant treatment as the main plot and doses of N, P, and K as subplots. The subplots consist of the control or without fertilizers, P fertilizer only at 100 kg.ha^{-1} SP-36, K fertilizer only at 100 kg.ha^{-1} KCl, N and K (250 kg.ha^{-1} Urea, 100 kg.ha^{-1} KCl), N and P (250 kg.ha^{-1} Urea, 100 kg.ha^{-1} SP-36), and N, P and K (250 kg.ha^{-1} Urea, 100 kg.ha^{-1} SP-36, 100 kg.ha^{-1} KCl). The research showed that the alley-cropping system increased corn production from 4,690 to 6,089 tons. ha^{-1}, with an average increase of 50% compared to corn production without the alley-cropping system. The N, P, and K fertilization produced the best average corn yields. The alley-cropping system achieved the highest land productivity compared to those without the alley-cropping system.

Keywords: alley cropping system, corn, fertilizers, dry land

Introduction

Indonesia's population continues to increase yearly, so the demand for foods, including corn, increases. Efforts to increase corn production are required, including expanding the production area to the dry lands. Land conversion from agricultural land to non-agricultural land happens everywhere, which resulted in agricultural activities being increasingly pushed toward marginal lands (Saeri et al., 2023)with little irrigation that only depends on rainfall and poor soil fertility. It is possible to grow maize on dry terrain, but first it is important to consider whether socio-economic strategies are effective, affordable, and simple to use. However, dry land farming has some issues, such as water availability, limited plant varieties suited to dry environments, and undeveloped cultivation technology (Ahmed et al., 2022).

Alley cropping is an agroforestry system that cultivates annual crops or food crops between aisles formed by fences of trees or bushes (D'Hervilly et al., 2022, Casanova-Lugo et al., 2023). Hedge plants are pruned periodically to avoid shading the main crop. The prunings can be used as mulch and reduce nutrient competition with food crops. Alley cultivation is suitable for development in Indonesia because it can protect the soil against the destructive power of heavy rainfall and improve soil infiltration and water holding capacity, directly affecting surface flow and controlling erosion.

A wide variety of crops can be used in alley cropping systems, depending on the farmer's goals, local climate, and soil conditions (Wolz and DeLucia, 2018). Alley cropping can affect the microclimate (Cary and Frey, 2020) and soil quality (Guillot et al., 2021) and allow more efficiencies for the crops in using water and fertilizer (Dou et al., 2022). Inorganic fertilizers in the form of N, P, and K are used on corn, as these three elements are required in large quantities (Yahaya et al., 2023). Crops applied with complete fertilizer NPK can produce higher yields than without (Moe et al., 2019; Kasno et al., 2022). However, excessive N or K fertilization causes vegetative growth to be more dominant than generative (Soares et al., 2023), so providing a balanced N, P, and K fertilization is important. In remote areas, N, P, and K fertilizers can be very difficult to get, and the price is very high, and farmers have to spend a lot of money to procure

Received 01/03/2024; Revised 10/02/2025; Accepted 23/04/2025
https://doi.org/10.29244/jtcs.12.02.358-364

these artificial fertilizers. The alley-crop system can be an alternative method to increase corn production. Gamal legume tree (*Gliricidia maculata)* is one of the crops that can be used in an alley cropping system. Gamal requires warm conditions for its growth, around 25–30°C for its optimal growth (Yusmur et al., 2022). Intercropping with Gamal supports soil organic matter stabilization (Maier et al., 2023) which is a common problem in many Southern African regions. Objective of this research was to explore long-term effects of legume-intercropping on SOM pools and soil fertility. We examined a maize-based cropping system with gliricidia (Gliricidia sepium, their leaves can provide green manures and can reduce the use of inorganic fertilizers N, P, and K. Our research aims to study the effects of the alley cropping system and the provision of Gamal biomass and the doses of N, P, and K fertilizers on corn production.

Material and Methods

Data Collection

This research was conducted in 2022 at the educational plantation area, Integrated Farming System, Faculty of Agriculture, Bosowa University, Bontoramba Village, Pallangga Subdistrict, Gowa Regency, South Sulawesi, Indonesia.

The study was arranged in a split-plot design with hedgerow (H1) and without hedgerow (H0) treatment as the main plot and doses of N, P, and K as subplots. The subplots consist of the control (without fertilizers), 100 kg.ha^{-1} SP-36, (P only) and 100 kg.ha^{-1} KCl (P and K only), 250 kg.ha^{-1} Urea (N only) and 100 kg.ha^{-1} KCl (N and K only), 250 kg.ha^{-1} Urea, 100 kg.ha^{-1} SP-36 (N and K only), and 250 kg.ha^{-1} Urea, 100 kg.ha^{-1} SP-36, 100 kg.ha^{-1} KCl (N, P, and K). All treatments had three replications, totaling 30 experimental plots.

Implementation

Soil tillage was carried out twice using hoes, one month before treatment and two weeks before treatment. Raking was performed to clean up the remaining weeds or plant remains and to level the soil surface. Plots of experimental units were created with a size of 24 m x 6 m, with a total of 30 plots. The planting distance was 6 m x 1 m, i.e., 1 m was the distance within the row, and 6 m was between rows of Gamal trees (hedgerows). There were four hedgerows in each research plot. The distance between replications was 1 m, and between plots in each replication was 1 m. Each plot was separated by plastic ropes.

Before planting, corn seeds were soaked for one hour to stimulate seed germination. Planting was performed in rows to a depth of 3 to 4 cm with a spacing of 85 cm x 40 cm, and three corn seeds were planted in each hole. After the plants were two weeks old, thinning was carried out by retaining two plants per hole.

The Gamal hedgerows already grown in the planting area were approximately 15 years old. After the corn was one week old, the gamal trees were pruned to about ± 80 cm in height, and the prunings of the Gamal were separated between the leaves and stems. Gamal leaves were spread evenly in each experimental plot, while the stems were placed between the rows of Gamal trees. The resulting hedgerow prunings were weighed in the field with hanging scales and then distributed over the soil experimental plots as green manures. Composite soil samples from the research were collected in each experimental plot for analysis and determination of the physical and chemical properties of the soil.

Fertilization was performed using organic material in the form of pruned Gamal leaves at 38.82 kg one week after planting. After that, pruning of the Gamal trees was carried out every month during the research to avoid shading the main crop and to reduce nutrient competition with corn. N, P, and K fertilizers at the recommended dosage were applied according to the abovementioned treatments. Urea fertilizer was given twice during corn planting, i.e., one week after planting by applying the 1/3 of the recommended fertilizer combination, and the 2/3 was given thirty-five days after planting. TSP and KCl fertilizers were given once one week after planting, and they were given simultaneously with urea fertilizer according to the recommended fertilizer combination.

Corns were harvested 90 to 100 days after planting. The characteristics of corn crops that were ready to be harvested were the mature corn, in which the dry weight of the corn grains had reached the optimum water content, the hairs were brownish red, and the cobs were whole. Harvesting was done by cutting all plant parts above the ground and 5 cm above the roots.

Observation and Measurements

The corn production components consist of dry-shelled corn per hectare (tons) and plant biomass production (tons) from the alley cropping system. Corn production was measured by counting the number of cobs in each plot of plants harvested from eight plant samples per plot. Thus, the number of samples in this study was 240 from 30 plots. After obtaining the results per plot in kg.ha^{-1}, it was converted to tons.ha^{-1}.

Soil analysis was conducted before and after the experiment to determine the soil organic material (C-Organic), cation exchange capacity (CEC), total N, potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), phosphorus (P_2O_5) and the water content at field capacity. The analyses were conducted in the Soil Chemistry and Physics laboratory, Soil Science Department, Faculty of Agriculture and Forestry, Hasanuddin University, Makassar. Soil samples were analyzed in the laboratory by taking soil samples using a ring sample. The ring sample used had a length of 4 cm, an inner diameter of 7.63 cm, and an outer diameter of 7.93 cm, and the tube was closed with plastic at both ends. Soil samples were taken compositely from a depth of 30 cm in the study area.

Data Analysis

Statistical analysis of soil analysis results used the t-student, where hypothesis testing was calculated using the following formula:

$t_{score} = (x_1 - x_2)/S_{x1-x2}$, with df. = (n_1+n_2-2)
$S_{x1-x2} = \sqrt{S^2}\,[(n_1+n_2)/(n_1.n_2)]$
$S^2 = [(\Sigma x_i^2 - (\Sigma x_i)^2/n_1 + (\Sigma x_2^2 - (\Sigma x_2)^2/n_2] / (n_1 + n_2 - 2)$
If $t_{score} \leq t_{tab}$ accept H0 and if $t_{score} > t_{tab}$ reject H_0

where x = sample mean, S = sample standard deviation and S = represents sample size

Results and Discussion

Corn Yields

Dry-shelled corn with hedgerows was higher than without hedgerows (Table 1). This is likely due to the Gamal biomass increasing the availability of nutrients, increasing the average production of corn. Gamal trees are high biomass producers, so when their leaves are returned to the soil, they function as mulch and green manures. Organic matter improves soil structure and chemical properties, increases the available nutrients, improves soil porosity and the activities of microorganisms, and moderates the soil temperature (Zheng et al., 2022).

Our study showed that even without applying N, P, and K fertilizers (control), the corn productivity with hedgerows produced 5.42 tons.ha^{-1} of dry-shelled corn compared to 2.98 tons.ha^{-1} without hedgerows and N, P, and K fertilizers. This is further strengthened by the absence of N deficiency symptoms found in corn. Another research in oil palm showed similar results, i.e., Gamal leaves could increase fresh fruit bunches and improve the quality of crude palm oil (Giyanto et al., 2024).

The tissue analysis results showed that the nutritional contents of the Gamal leaves at the research location were quite high, i.e., 2.85% N, 0.14% P, 2.21% K, 1.82% Ca, and 0.49% Mg. Gamal leaves have a relatively high N content and increase soil nitrogen availability when used as green or organic fertilizer. Leguminous species have symbiosis with *Rhizobium bacteria*, which can fix nitrogen (De La Peña et al., 2018).

Gamal Leaf Biomass Production

Table 2 shows that the use of N, P, K (250 kg.ha^{-1} Urea, 100 kg.ha^{-1} SP-36, 100 kg.ha^{-1} KCl) resulted in the highest Gamal leaf biomass production in the first week (2.71 tons.ha^{-1}), the sixth week (1.90 tons.ha^{-1}), and the seventh week (2.01 tons.ha^{-1}) and was significantly different from other fertilization combinations (Table 2).

Without hedgerows, the corn is exposed to full sunlight; hence, they are more optimal and efficient for producing photosynthate. Treatment with a fertilizer combination of 250 kg.ha^{-1} Urea, 100 kg.ha^{-1} SP-36, and 0 kg.ha^{-1} KCl resulted in fast vegetative growth. Photosynthetic capacity will improve with the increasing number of leaves and the surface area that absorbs sunlight (Tan et al., 2022).

Table 1. Average corn dry shell production (ton.ha^{-1}) with hedgerows and NPK treatments

Hedgerow	Control	P and K	N and K	N and P	N, P, and K	Average	$LSD_{0.05}$
Without hedgerow	2.98	5.03	5.18	5.57	6.16	4.690^b	1.1160
With hedgerow	5.42	6.20	6.16	6.58	6.53	6.089^a	
Average	4.20^b	5.61^a	5.67^a	6.07^a	6.35^a		
$LSD_{0.05}$	0.9414						

Notes: Values followed by the same letter within the same column are not significantly different according to the least significant difference (LSD) test level at α=0.05.

Received 01/03/2024; Revised 10/02/2025; Accepted 23/04/2025
https://doi.org/10.29244/jtcs.12.02.358-364

In contrast, the average value of solar radiation intensity in treatments with hedgerows was generally lower. This was because hedgerows shaded the corn plants. As a result, the interception of sunlight was reduced. Reduced light interception in shaded plants indicated that the leaves were covered, and the leaves in the lower layers might have received light below the saturation point, hence causing a lower photosynthesis rate.

Gamal Stem Biomass Production

Table 3 presents the average biomass production of Gamal leaf and stem with various fertilizer treatments. Increasing biomass production from Gamal prunings can significantly contribute to corn yields. It was revealed that providing Gamal prunings, apart from increasing the production of dry-shelled corn, improved the chemical properties of the soil and increased the level of N uptake in the corn plant tissues in the alley cropping system.

Tables 2 and 3 show that each increase in cutting age from the sixth week to the seventh week is accompanied by an increase in leaf and stem production. The increase in fresh production occurs because Gamal plants have increased in size. Harjadi (1989) explained that plants will continue to experience cell division and cell differentiation during the vegetative phase, resulting in an increase in biomass and stems. A study on lettuce demonstrated an increase in its productivity with Gamal leaves application (Indarto et al., 2020).

Soil Analysis

All soil chemical properties parameters in the research location showed that the treatment using hedgerows achieved higher and significantly different average C, N, P_2O_5, CEC, Ca, Mg, K, and Na contents compared to the treatment without hedgerows, except for the field capacity water content (Table 4).

This study shows that applying Gamal biomass in alley cropping systems improves soil chemical properties significantly compared to the treatment without hedgerows (Table 4). This demonstrates that the return of pruning biomass and leaf litter as a mulch or green fertilizer contributed to the soil's nutrient content, particularly in the topsoil. These nutrients are available, so they can be used for the main crop (Wolz and DeLucia, 2018).

The corn plant tissue analysis results show high values with hedgerows: leaf N = 2.68%, P = 0.52%, and K = 2.68% compared to 1.75%, 0.18%, and 0.89%

Table 2. Average Gamal leaf biomass production (ton.ha^{-1}) with different NPK treatments

Treatments	Average weekly Gamal leaf biomass production (ton.ha^{-1})		
	1	6	7
Control	2.48^{d}	1.57^{c}	1.71^{c}
P and K	2.52^{cd}	1.67^{bc}	1.78^{bc}
N and K	2.59^{ab}	1.69^{bc}	1.83^{bc}
N and P	2.64^{bc}	1.71^{b}	1.88^{b}
N, P, K	2.71^{a}	1.90^{a}	2.01^{a}
LSD	0.0999	0.1229	0.1229

Notes: Values followed by the same letter within the same column are not significantly different according to the least significant difference (LSD) test level =0.05.

Table 3. Average Gamal stem biomass production (ton.ha^{-1}) with different NPK treatments

Treatments	Average weekly cutting production of Gamal stem biomass (ton.ha^{-1})		
	1	6	7
Control	1.74^{c}	0.97^{c}	1.37^{c}
P and K	1.83^{c}	1.04^{c}	1.46^{bc}
N and K	2.01^{b}	1.09^{bc}	1.53^{b}
N and P	2.06a^{b}	1.20^{ab}	1.55^{ab}
N, P, K	2.18^{a}	1.25^{a}	1.67^{a}
CV LSD0.05	0.1481	0.1442	0.1286

Notes: Values followed by the same letter within the same column are not significantly different according to the least significant difference (LSD) test at α =0.05.

Received 01/03/2024; Revised 10/02/2025; Accepted 23/04/2025
https://doi.org/10.29244/jtcs.12.02.358-364

for N, P, and K, respectively, without hedgerows. This shows that the biomass of Gamal pruning provided a relatively high contribution of N and K to corn crops. Organic matter and total N in the soil can increase the level of N uptake in the tissue of corn crops (Singh et al., 2023)and a few researchers have focused on this issue in this modern period with modern hybrids and improved corn cultivation practices. While almost all the studies were conducted in northern states of the US, information for the Southern Great Plains is still limited. To bridge this knowledge gap, a 2-year field study was conducted in a rain-fed corn production system. The study aimed to evaluate the impact of nitrogen (N). The increase in organic matter and soil N-total aligns with the increase in pruning biomass production as a source of organic matter and soil N-total.

Gamal trees can adapt to slightly acidic soil (Kusumah et al., 2019). The increase in soil organic matter content after using Gamal hedgerow leaves increased the soil’s ability to absorb cations as expressed by the CEC value of the soil in the hedgerow treatment, which increased due to Gamal prunings. The increase in the CEC value of soil in various cultivation systems is in line with the increase in biomass of prunes as a source of soil organic matter (Bastida et al., 2021) unlike plant communities, little is known about how the diversity and biomass of soil microbial communities are interlinked across globally distributed biomes, and how variations in this relationship influence ecosystem function. To fill this knowledge gap, we conducted a field survey across global biomes, with contrasting vegetation and climate types. We show that soil carbon (C).

The soil C, N, P_2O_5, CEC, Ca, Mg, K, Na, and water content at field capacity were not significantly different in fertilization treatments. The combination of 250 kg.ha^{-1} Urea, 100 kg.ha^{-1} SP-36, and 100 kg.ha^{-1} KCl produced higher average contents of C, N, P_2O_5, CEC, Ca, Mg, K, and Na, but it was not significantly different compared to the other fertilization treatments. This treatment also produced a higher water content at field capacity water, even though it was not significantly different from the other fertilization treatments.

Applying Gamal leaves as green manures increases the height and leaf area index of lettuce plants (Nisa et al., 2024). However, it is important to note that according to Ferdush et. al (2019) alley cropping system on acidic soil cannot provide satisfactory results without the addition of chemical fertilizers.

Conclusions

This research revealed that the alley cropping system increased corn production by an average of 50%, or 6.089 tons.ha^{-1} compared to those without alley cropping, which was 4.690 tons.ha^{-1}. Fertilization with nitrogen, phosphorus, and potassium produced the highest corn production. Using Gamal hedgerow in corn increased soil carbon, nitrogen, phosphorus, calcium, magnesium, potassium, and soil cation exchange capacity.

Table 4. Soil chemical properties and corn plant tissue analysis with and without hedgerows

Parameter	Without hedgerows	With hedgerows
C (%)	1.81	2.38 **
N (%)	0.23	0.49 **
P2O5 (ppm)	12.84	18.92 **
CEC (cmol(+).kg^{-1})	21.39	24.61 **
Ca (cmol(+).kg^{-1})	3.18	4.82 **
Mg (cmol(+).kg^{-1})	1.82	2.56 **
K (cmol(+).kg^{-1})	0.15	0.46 **
Na (cmol(+).kg^{-1})	0.15	0.39 **
Field capacity water content (%)	43.51	36.61 **
Corn plant tissue (%)		
N	1.75	2.68
P	0.18	0.52
K	0.89	2.68

Notes: ** = highly significantly different according to the LSD test at α =0.05

Received 01/03/2024; Revised 10/02/2025; Accepted 23/04/2025
https://doi.org/10.29244/jtcs.12.02.358-364

References

Ahmed, M., Hayat, R., Ahmad, M., Ul-Hassan, M., Kheir, A.M.S., Ul-Hassan, F., Ur-Rehman, M.H., Shaheen, F.A., Raza, M.A., and Ahmad, S. (2022). Impact of climate change on dryland agricultural systems: a review of current status, potentials, and further work need. *International Journal of Plant Production* **16**, 341–363. DOI: https://doi.org/10.1007/s42106-022-00197-1.

Bastida, F., Eldridge, D.J., García, C., Kenny Png, G., Bardgett, R.D., and Delgado-Baquerizo, M. (2021). Soil microbial diversity–biomass relationships are driven by soil carbon content across global biomes. *The ISME Journal* **15**, 2081–2091. DOI: https://doi.org/10.1038/s41396-021-00906-0.

Cary, M.A., and Frey, G.E. (2020). Alley cropping as an alternative under changing climate and risk scenarios: A Monte-Carlo simulation approach. *Agricultural Systems* **185**, 102938. DOI: https://doi.org/10.1016/j.agsy.2020.102938.

Casanova-Lugo, F., Lara-Pérez, L.A., Dzib-Castillo, B., Caamal-Maldonado, J.A., Ramírez-Barajas, P.J., Cetzal-Ix, W.R., and Estrada-Medina, H. (2023). Alley cropping agroforestry systems change weed community composition and reduce dominant weed species associated with corn in southern Mexico. *Agriculture, Ecosystems and Environment* 3**50**, 108471. DOI: https://doi.org/10.1016/j.agee.2023.108471.

D'Hervilly, C., Bertrand, I., Berlioz, L., Hedde, M., Capowiez, Y., Dufour, L., and Marsden, C. (2022). Tracking earthworm fluxes at the interface between tree rows and crop habitats in a Mediterranean alley cropping field. *European Journal of Soil Biology* **120**, 103572. DOI: https://doi.org/10.2139/ssrn.4089152.

De La Peña, T.C., Fedorova, E., Pueyo, J.J., and Lucas, M.M. (2018). The symbiosome: legume and rhizobia co-evolution toward a nitrogen-fixing organelle? *Frontiers in Plant Science* **8**, 1–26. DOI: https://doi.org/10.3389/fpls.2017.02229.

Dou, X., Wang, R., Zhou, X., Gao, F., Yu, Y., Li, C., and Zheng, C. (2022). Soil water, nutrient distribution and use efficiencies under different water and fertilizer coupling in an apple–maize alley cropping system in the Loess Plateau, China. *Soil and Tillage Research* **218**, 105308. DOI: https://doi.org/10.1016/j.still.2021.105308.

Ferdush, J., Karim, M.M., Noor, I.J., Ju, S.A.S.A., Ahamed, T., and Saha, D.S.R. (2019). Impact of alley cropping system on soil fertility. *International Journal of Advanced Geosciences* **7**, 173. DOI: https://doi.org/10.14419/ijag.v7i2.29942.

Guillot, E., Bertrand, I., Rumpel, C., Gomez, C., Arnal, D., Abadie, J., and Hinsinger, P. (2021). Spatial heterogeneity of soil quality within a Mediterranean alley cropping agroforestry system: Comparison with a monocropping system. *European Journal of Soil Biology* **105**, 103330. DOI: https://doi.org/10.1016/j.ejsobi.2021.103330.

Indarto, Qoniah, U., Ulmillah, A., Fatimatuzzahra, Maretta, G., and Sugiharta, I. (2020). Gamal leaves (*Gliricidia sepium*) as hydroponic nutrition for lettuce (*Lactucasativa* L.). *Journal of Physics: Conference Series* **1467**. DOI: https://doi.org/10.1088/1742-6596/1467/1/012019.

Kasno, A., Zakiah, K., and Suastika, I.W. (2022). Application of NPK 15-10-12 fertilizer to increase the yield of paddy field, fertilization efficiency, and effectivity of fertilizing in inceptisol. *AGRIC* **34**, 211-224. DOI: https://doi.org/10.24246/agric.2022.v34.i2.p211-224.

Kusumah. (2019). Utilization of Gamal biomass (Gliricidia sepium) as organic mulch on corn (Zea mays L.) plants on dry land. *IOP Conference Series: Earth and Environmental Science* **343**, 012182. DOI: https://doi.org/10.1088/1755-1315/343/1/012182.

Li, G.X., Xu, B.C., Yin, L.N., Wang, S.W., Zhang, S.Q., Shan, L., Kwak, S.S., Ke, Q., and Deng, X.P. (2020). Dryland agricultural environment and sustainable productivity. *Plant Biotechnology Reports* **14**, 169–176. DOI: https://doi.org/10.1007/s11816-020-00613-w.

Mirzabaev, A., Strokov, A., and Krasilnikov, P. (2023). The impact of land degradation on agricultural profits and implications for poverty reduction in Central Asia. *Land Use Policy* **126**, 106530. DOI: https://doi.org/10.1016/j.landusepol.2022.106530.

Maier, R., Schack-Kirchner, H., Nyoka, B.I., and Lang, F. (2023). *Gliricidia* intercropping supports soil organic matter stabilization at Makoka

Received 01/03/2024; Revised 10/02/2025; Accepted 23/04/2025
https://doi.org/10.29244/jtcs.12.02.358-364

Research Station, Malawi. *Geoderma Regional* **35**, e00730. DOI: https://doi.org/10.1016/j.geodrs.2023.e00730.

Moe, K., Htwe, A.Z., Thu, T.T.P., Kajihara, Y., and Yamakawa, T. (2019). Effects on NPK Status, growth, dry matter and yield of rice (*Oryza sativa*) by organic fertilizers applied in field condition. *Agriculture* **9**, 109. DOI: https://doi.org/10.3390/agriculture9050109.

Nisa, C., Idris, M., and Rahmadina. (2024). The effect of gamal leaf (*Gliricidia sepium* (Jacq.) Kunth ex Walp)-based liquid organic fertilizer on the vegetative growth of Lettuce (*Lactuca sativa* L.). *Sciscitatio* **5**, 20–27. DOI: https://doi.org/10.21460/sciscitatio.2024.51.164.

Saeri, M., Tafakresnanto, C., Rejekiningrum, P., Hanif, Z., and Putri, R.L. (2023). Development of corn crops in dry land, dry climate using panca management technology in Situbondo, East Java. *IOP Conference Series: Earth and Environmental Science* **1253**, 012080. DOI: https://doi.org/10.1088/1755-1315/1253/1/012080.

Singh, R., Sawatzky, S.K., Thomas, M., Akin, S., Zhang, H., Raun, W., and Arnall, D.B. (2023). Nitrogen, phosphorus, and potassium uptake in rain-fed corn as affected by NPK fertilization. *Agronomy* **13**, 1913. DOI: https://doi.org/10.3390/agronomy13071913.

Soares, A.B., Assmann, T.S., Missio, R.L., Severo, I.K., Zanella, J.B., Kagimura, L.T., and Arenhardt, M. (2023). Nitrogen and potassium fertilization strategies in integrated systems in different black oat management on corn crop. *Scientia Plena* **18**, 1–10. DOI: https://doi.org/10.14808/sci.plena.2023.050201.

Tan, T., Li, S., Fan, Y., Wang, Z., Raza, M.A., Shafiq, I., Wang, B., Wu, X., Yong, T., Wang, X., Wu, Y., Yang, F., and Yang, W. (2022). Far-red light: A regulator of plant morphology and photosynthetic capacity. *Crop Journal* **10**, 300–309. DOI: https://doi.org/10.1016/j.cj.2021.06.007.

Williams, S.E., van Noordwijk, M., Penot, E., Healey, J.R., Sinclair, F.L., and Wibawa, G. (2001). On-farm evaluation of the establishment of clonal rubber in multistrata agroforests in Jambi, Indonesia. *Agroforestry Systems* **53**, 227–237. DOI: https://doi.org/10.1023/A:1013336822923.

Wolz, K.J., and DeLucia, E.H. (2018). Alley cropping: Global patterns of species composition and function. *Agriculture, Ecosystems and Environment* **252**, 61–68. DOI: https://doi.org/10.1016/j.agee.2017.10.005.

Yahaya, S.M., Mahmud, A.A., Abdullaahi, M., and Haruna, A. (2023). Recent advances in the chemistry of nitrogen, phosphorus, and potassium as fertilizers in soil: A review. *Pedosphere* **33**, 385–406. DOI: https://doi.org/10.1016/j.pedsph.2022.07.012.

Zheng, E., Hu, J., Zhu, Y., and Xu, T. (2022). Effects of different water management and fertilizer methods on soil temperature, radiation and rice growth. *Scientific Reports* **12**, 1–10. DOI: https://doi.org/10.1038/s41598-022-20764-w.

Yusmur, A., Ardiansyah, R., and Marlinda, S. (2022). Biomass Sources for Sustainable Bioenergy Production in Indonesia. *Biodiverse Science Magazine* **1**, 21–26. DOI: https://doi.org/10.56060/bdv.2022.1.2.1977.