JOURNAL OF SUSTAINABLE NATURAL RESOURCES
e-ISSN: 2716-7143

J-SuNR

Vol. 5 No. 1 (2024) 1-8
https://publisher.uthm.edu.my/ojs/index.php/j-sunr

The Application of Factorial Design in Enhancing Soil Fertility Through Compost

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DOI: https://doi.org/10.30880/jsunr.2024.05.01.001

Article Info

Received: 6 April 2023
Accepted: 27 December 2023
Available online: 30 June 2024

Keywords

Design of experiment, soil fertility, factorial design, ANOVA

Abstract

In recent years, agriculture has increasingly relied on chemical fertilizers to achieve higher yields and boost productivity. Unfortunately, excessive use of chemical fertilizers may result in lower crop production and decreased soil fertility. Organic fertilizer and compost may complement chemical fertilizers, providing a low-cost and sustainable plant nutrition supply. This study aims to demonstrate the optimal ratio of composts and water that will maximize soil fertility through the application of a 3^2 factorial design. Using the 3^2 factorial designs with randomized complete blocks, 27 jasmine plants were randomly grouped into three blocks. The treatment or compost used were dried leaves, orange, and banana peels. The height of the plants in each pot was measured for 30 days and the growth rate was calculated. The plant growth rate was analyzed using the analysis of variance (ANOVA). Each factor and combination factors was analyzed according to the main and interaction effect. The result show that soil fertility is maximized with the use of dried leaves with one cup of water, followed by the orange peel with three cups of water, and the banana peel with two cups of water. The results can be improved by taking the measurements for more than 30 days with the addition of other composts and locations for the blockings.

1. Introduction

There are around 400,000 species of terrestrial plants recorded in the world, with around 2,000 new species discovered each year [1,2]. Most of terrestrial ecosystems are occupied by plants [3]. Soil fertility refers to the soil's ability to deliver vital nutrients for plant growth while avoiding damaging amounts of any detrimental element. Fertile soils provide a sufficient and balanced supply of nutrients that are easy to break down and readily available to meet the needs of plants [4]. The important nutrients can be classified as macronutrients and micronutrients. Macronutrients are the nutrients that are needed in high quantities by plants while micronutrients are nutrients that are needed in small amounts by plants but they are as important as macronutrients [5,6]. Fertilizers are substances that have at least one nutrient element in natural and manmade chemical materials that are beneficial to plant growth. There are two kinds of fertilizers, organic fertilizers and inorganic fertilizers [7,8].

Chemical fertilizers such as nitrogen (N), phosphate (P), and potassium (K) are usually formulated and manufactured by fertilizer companies [9]. During the last three decades, this method has significantly increased grain yields in several countries. Nowadays, agriculture is practiced with high amounts of chemical fertilizers. Unfortunately, the overuse of chemical fertilizers lead to a decrease in crop production and soil fertility [9]. Moreover, overuse of chemical fertilizers can cause nutrient deficiency, which can hasten soil acidification [8]. Natural fertilizers come from plants and animals such as green manures, crop wastes, food wastes, and compost

[6,8]. It enhances soil structure by increasing organic matter in the soil [10,11]. One of the key sources of organic matter in the soil is the compost [12]. It contributed a lot to preserving the environment and soil quality [13].

Design of experiments is a crucial technique for analyzing several factors simultaneously and determining their interactions [14]. The experimental design allows each factor to be evaluated individually. This allows a particular study to the most information from the factors in just a few experiments [15]. Randomization, replication, and blocking are three key principles of experimental design [16]. Factorial design is one of the experimental designs that includes all potential combinations of each level of factors [17]. This design can be only used with small numbers of factors and levels [18].

Hopefully, this study can show that factorial design can be applied in various fields including agriculture. The broad aim of this study is to encourage agriculture industry practitioners, to switch from chemical fertilizers to natural fertilizers such as compost. The results of this study will assist in providing their plants with the best compost and water ratio. Consequently, it can minimize greenhouse gas emissions, environmental pollution, the death of aquatic and soil organisms, ozone layer depletion, and human disease. Additionally, this study encourages the usage of compost to resolve the problem of erosion by enhancing the soil's water holding capability, texture, and solid strength [19].

2. Methodology

This section explains all the important methods used in this study. It describes how the data was collected during the experiment, the factorial design, and the analysis of variance (ANOVA). Furthermore, the adequacy of the models is also discussed with the application of the equality variance test, main, and interaction effect.

2.1 Factorial Design

The factorial design used was 3^2 factorial design in a randomized complete block. It included two factors with three levels each that create nine combinations. These combinations were replicated three times at three blocks. The model used in factorial designed is called the effect model. The effect model used in this study is shown in equation (1).

$$y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \delta_k + \epsilon_{ijk} \quad \begin{cases} i = 1, 2, \ldots, a \\ j = 1, 2, \ldots, b \\ k = 1, 2, \ldots, n \end{cases} \tag{1}$$

where

μ = overall mean

τ_i = the effect of the ith level of the row factor A,

β_j = the effect of the jth level of column factor B

$(\tau\beta)_{ij}$ = the effect of the interaction between τ_i and β_j

δ_k = the effect of the kth block

ϵ_{ijk} = random error component

The experimental unit selected for this study is the jasmine plant. Since there are three blocks in this design, 27 pots of jasmine plants were used. There are two factors namely Factor A and Factor B. Factor A is the three different types of compost, which are the banana peel, orange peel, and dried leaves. Only one spoonful of compost had been used. Meanwhile, factor B is the amount of water used in the experiment. The measurement levels are one cup, two cups, and three cups of water, where, each cup is 250ml. Lastly, the blocking factor has three blocks, the outdoor corridor path, garden, and backyard.

2.2 Data Collection

The jasmine plant growth rate is the primary data collected daily for 30 days. The jasmine plant growth is recorded by measuring the height of the plant and its eventual growth rate is calculated by using equation (2) [20].

$$\text{Jasmine plant growth rate} = \frac{S_2 - S_1}{T} \tag{2}$$

where

S_2 = height of the jasmine plant

S_1 = height of the jasmine plant a day before

T = number of days between

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2.3 Analysis of Variance (ANOVA)

The significance of each factor on the response parameter is determined by using the analysis of variance (ANOVA), to test the equality of the row factor effect. The hypothesis is shown in equation (3) [21].

$$\begin{aligned} &H_\theta: \tau_1 = \tau_2 = \cdots = \tau_{\mathrm{a}} = 0 \\ &H_1: \text{At least one } \tau_i \neq 0 \end{aligned} \tag{3}$$

The second hypothesis is used to test the equality of column factor effect. The hypothesis is shown in equation (4) [21].

$$\begin{aligned} &H_\theta: \beta_1 = \beta_2 = \cdots = \beta_{\mathrm{a}} = 0 \\ &H_1: \text{At least one of } \beta_{\mathrm{j}} \neq 0 \end{aligned} \tag{4}$$

The ANOVA test then evaluates whether or not the effect of these factors is equal using the F distribution. It is then compared with $f_{\alpha,a-1,N-a}$ where α is the significance level, N is the number of observations and a is the number of treatments at 0.05 level of significance.

2.4 Model Adequacy Checking

Model adequacy has been simply done by exploring the errors. It was analyzed by graphical analysis of residuals such as normal probability plot, residual plots and test of equality variance. By analyzing the residuals, different model adequacies and ways to deal with several commonly occurring abnormalities have been discovered.

2.4.1 Test for Equality of Variance

Bartlett's test had been used to test the equality of variance. The hypotheses are shown in equation (5) [21].

$$\begin{aligned} &H_\theta:\ \sigma_1^2 = \sigma_2^2 = .\ .\ . = \sigma_a^2 \\ &H_1: \text{Above not true for at least one } \sigma_i^2 \end{aligned} \tag{5}$$

where
a = total number of the factor's levels

When random samples are drawn from independent normal populations, the methods entail calculating a statistic where distribution of the sampling is nearly approximated by the chi-square distribution with $a - 1$ degrees of freedom. The test statistic is showed in equation (6) [21].

$$\chi_0^2 = 2.3026_c^q \tag{6}$$

where
$q = (N-a)log_{10}S_P^2 - \sum_{i=1}^{a}(n_i - 1)log_{10}S_i^2$
$c = 1 + \frac{1}{3(a-1)}\left(\sum_{i=1}^{a}(n_i-1)^{-1} - (N-a)^{-1}\right)$
$S_P^2 = \frac{\sum_{i=1}^{a}(n_i-1)S_i^2}{N-a}$
α = confidence level
a = number of total treatments
n_i = number of samples in i-th treatment
S_i^2 = the sample variance of the i-th population

When the variances of the sample S_i^2 are greatly differ, the number q is large, and when all the S_i^2 is equal, the number q is zero. Therefore, H_0 must be rejected for values of χ_0^2 that are too high. In other words, only reject H_0 when χ_0^2 is larger than $\chi_{\alpha,a-1}^2$ [21].

2.5 Main Effect and Interaction Plots

A factor's effect defined as the change in response caused by a change in the factor's level. Since it pertains to the principal aspects of interest in the experiment, this is commonly referred to as a main effect. On the other hand, the difference in response between the factor's levels is not similar to the levels of another factor. There must be an interaction between the factors when this happens [21].

3. Results and Discussions

The height of the plants is measured at each pot in centimeters and its plant growth is calculated for 30 days. It is summed and represented in Table 1 according to the arrangement of 3^2 factorial design with randomized complete block.

Table 1 *Data for the jasmine plant growth rate*

Factor	Block								
		1			2			3	
B	1	2	3	1	2	3	1	2	3
A									
1	2.2	2.9	4.5	7.2	6.9	4.0	9.1	14.7	9.0
2	3.7	4.4	3.2	7.2	2.2	7.0	11.5	12.7	14.0
3	7.3	4.4	5.5	8.0	9.3	6.9	10.6	8.6	7.6

The results of ANOVA are shown in Table 2. At 0.05 level of significance, the value of *F* distribution for the main effect of composts is $F_{(0.05,2,16)} = 3.63$. Since the *F* ratio, $F_{0}= 0.34 < 3.63$, the H_0 is not rejected. It can be concluded that there is no different effect between the types of compost. Next, the value of *F* distribution for the main effect of the amount of water is $F_{(0.05,2,16)} = 3.63$. Since the *F* ratio, $F_0 = 0.16 < 3.63$, the H_0 is not rejected. It can be concluded that there is no different effect between the levels of the amount of water. Lastly, the value of *F* distribution for the interaction of composts and the amount of water is $F_{(0.05,4,16)} = 3.01$. Since the *F* ratio, $F_0 = 0.87 < 3.01$, the decision is to accept H_0. It can be concluded that there is no different interaction effect between the nine combinations. It is concluded that there is no significant effect between the type of compost and the amount of water. Furthermore, the interaction effects of composts and the amount of water are also insignificant.

Table 2 *Analysis of variance for plant growth in 30 days*

Source of variation	Sum of Squares	Degrees of Freedom	Mean Square	F_0
Compost	3.472	2	1.736	0.34
Amount of water	1.699	2	0.849	0.16
Compost*Amount of water	17.848	4	4.462	0.87
Blocks	204.343	2	102.171	
Error	82.517	16	5.157	
Total	309.879	26		

Based on the model adequacy checking, Fig. 1 shows that the residuals resemble a straight line which indicate that the error distribution is normal. This satisfies the normality assumption. Meanwhile, in Fig. 2, the residuals are randomly scattered which suggests that the variance is constant. Fig. 3 indicates the residuals are independent since the pattern is also randomly scattered. The results support the validity of the assumptions for normality, constant variance, and independence are satisfied.

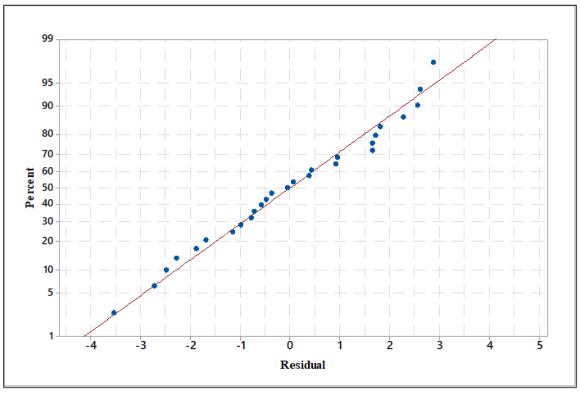

Fig. 1 *Normal probability plot*

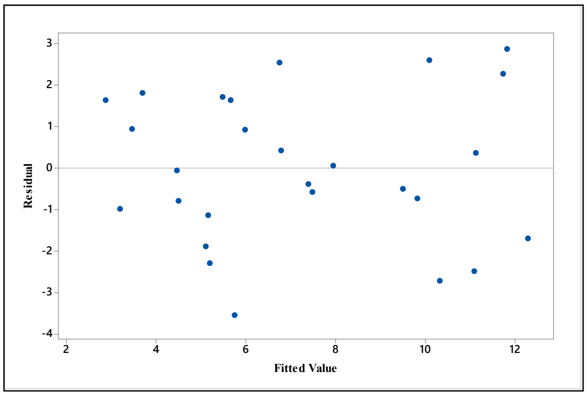

Fig. 2 *Residual versus fits plot*

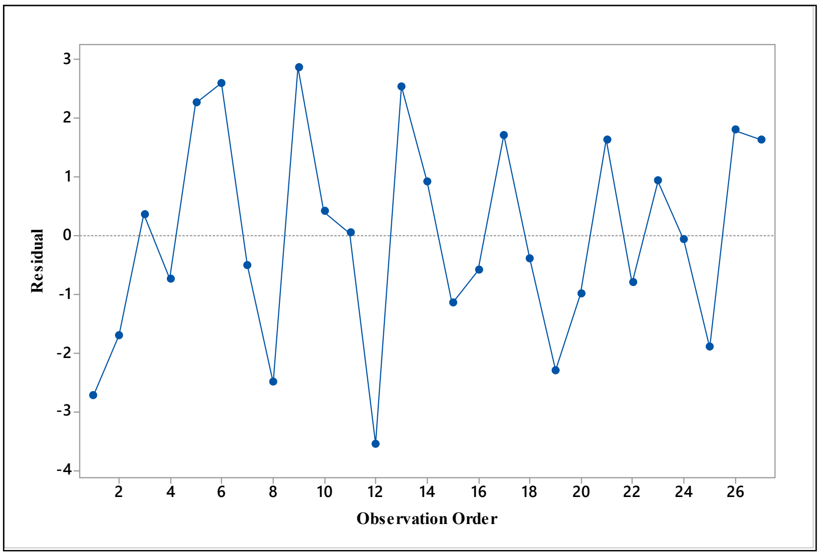

Fig. 3 *Residual versus order plot*

Bartlett's test result for equality of variance for compost can be referred to Table 3. The value of *F* distribution for composts is $F_{(0.05,2)} = 5.99$. Since the *F* ratio, $F_0 = 5.17 < 5.99$, the decision is to accept H_0. It can be concluded that the variances of composts are equal. Fig. 4 shows the confidence intervals are overlap which support that the means the variance of the composts are almost equal.

Table 3 *Result for Bartlett's test for compost*

Test		
Method	Test statistic	*p*-value
Bartlett	5.17	0.075

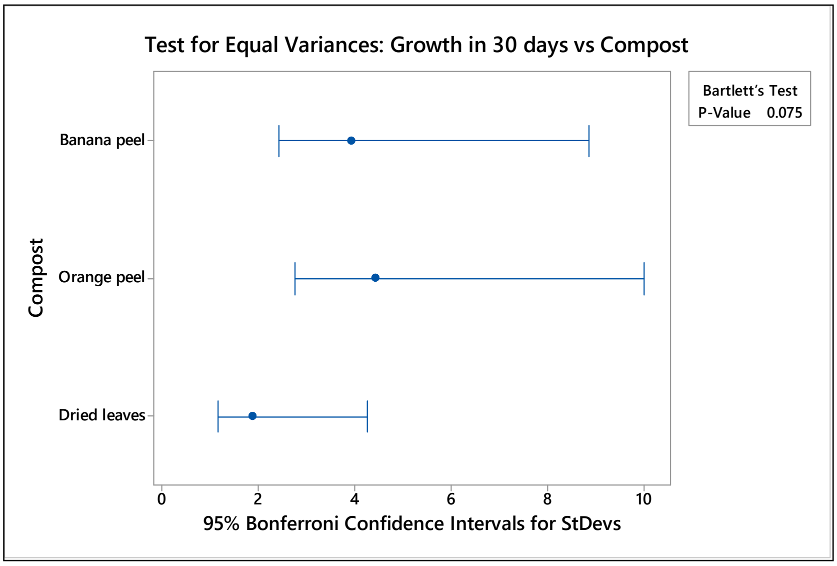

Fig. 4 *Graph for Bartlett's test for compost*

Bartlett's test result for equality of variance for amount of water can be referred to Table 4. The value of *F* distribution for amount of water is $F_{(0.05,2)} = 5.99$. Since the *F* ratio, $F_0 = 1.25 < 5.99$, the decision is to accept the H_0. It can be concluded that the variances of amount of water are equal. Fig. 5 shows the confidence intervals are overlap which means the variance of the amount of water are almost equal.

Table 4 *Result for the Bartlett's test for amount of water*

Test		
Method	Test statistic	*p*-value
Bartlett	1.25	0.536

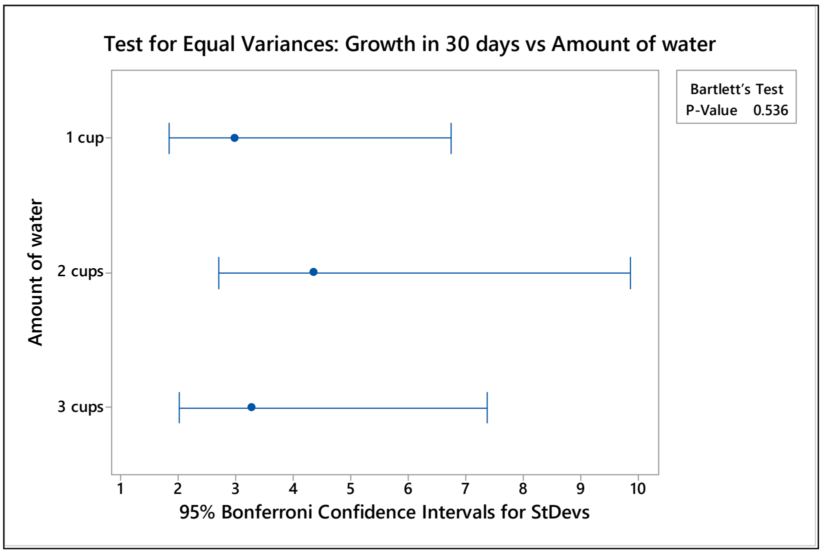

Fig. 5 *Graph for Bartlett's test for the amount of water*

The main effects plot in Fig. 6 shows that the dried leaves and one cup of water produced the highest plant growth in 30 days. Besides, it also shows that the banana peel and three cups of water produced the lowest plant growth in 30 days.

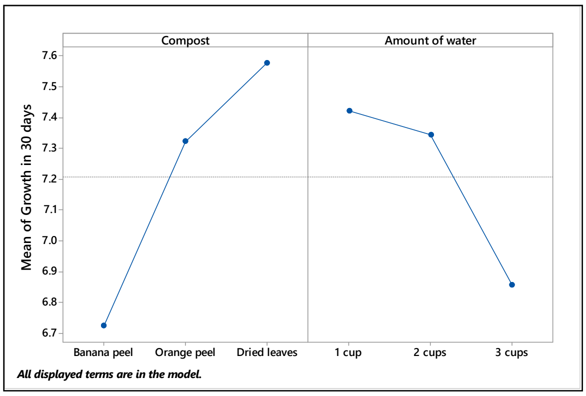

Fig. 6 *Main effects plot for growth in 30 days*

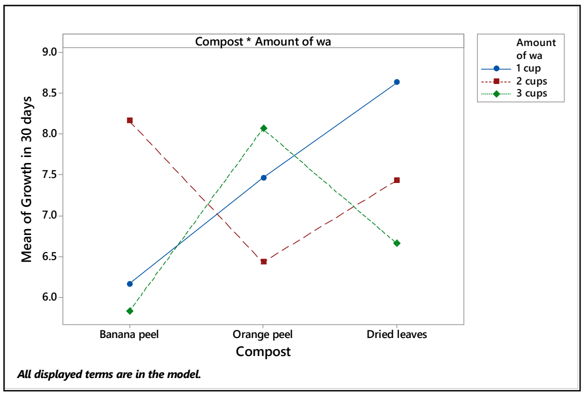

Fig. 7 *Interaction plot for growth in 30 days*

Based on the interaction plot in Fig. 7, a lower plant growth rate was observed from the banana peel with three cups of water, followed by the orange peel with two cups of water, and dried leaves with three cups of water. The greater plant growth rate is attained by the dried leaves with one cup of water, followed by the orange peel with three cups of water, and the banana peel with two cups of water.

4. Conclusion

The mean growth for jasmine plants is studied for 30 days using a 3^2 factorial design. This design was applied with two factors, which are, the type of compost and the amount of water in a randomized complete block. The results found that the mean growth for the jasmine plant was greater when applying the dried leaves with one cup of water. However, the mean growth was lower when the banana peel with three cups of water was applied. Based on the observation during the experiment, it is believed that the outcome of the effects of both factors A and B, which are compost and amount of water respectively, are not significant due to the uncontrol nuisance factor. The inconsistent weather conditions affected the experiment since it was done outside and not in the controlled climate of a greenhouse. Further evaluation of more than 30 days may be required to obtain more significant data.

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Acknowledgement

This research was made possible by funding from the Tier 1 H846 research grant provided by the Ministry of Higher Education, Malaysia. The authors would also like to acknowledge the Faculty of Applied Sciences and Technology (FAST) and Universiti Tun Hussein Onn Malaysia (UTHM) for the opportunity to conduct the study.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Tarschny Tatchnamurthy, Norhaidah Mohd Asrah;* ***data collection:*** *Tarschny Tatchnamurthy;* ***analysis and interpretation of results:*** *Tarschny Tatchnamurthy, Norhaidah Mohd Asrah;* ***draft manuscript preparation:*** *Tarschny Tatchnamurthy, Norhaidah Mohd Asrah. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Cheek, M., Nic Lughadha, E., Kirk, P., Lindon, H., Carretero, J., Looney, B., Douglas, B., Haelewaters, D., Gaya, E., Llewellyn, T. and Ainsworth, A.M. (2020) New scientific discoveries: Plants and fungi, *Plants People Planet, 2(5),* 371–388, 2020. doi: 10.1002/ppp3.10148.

[2] Henkhaus, N., Bartlett, M., Gang, D., Grumet, R., Jordon-Thaden, I., Lorence, A., Lyons, E., Miller, S., Murray, S., Nelson, A. and Specht, C. (2020) Plant science decadal vision 2020–2030: Reimagining the potential of plants for a healthy and sustainable future, *Plant Direct*, 4(8), 1–24. doi: 10.1002/pld3.252.

[3] Borsch, T., Berendsohn, W., Dalcin, E., Delmas, M., Demissew, S., Elliott, A., Fritsch, P., Fuchs, A., Geltman, D., Güner, A. and Haevermans, T. (2020) World Flora Online: Placing taxonomists at the heart of a definitive and comprehensive global resource on the world's plants, *Taxon*, 69(6), 1311–1341. doi: 10.1002/tax.12373.

[4] Foth, H.D. and Ellis, B. G. (2020) *Soil Fertility*, 2nd ed. CRC Press LLC.

[5] Hasanuzzaman, M., Fujita, M., Oku, H., Nahar, K., and Hawrylak-nowak, B. (2018) *Plant Nutrients and Abiotic Stress Tolerance*. Singapore: Springer Singapore.

[6] Itelima, J.U., Bang, W.J., Onyimba, I.A., Sila, M.D, and Egbere, O.J. (2018), Bio-fertilizers as Key Player in Enhancing Soil Fertility and Crop Productivity: A Review, *J. Microbiol.* 2(1), 74–83

[7] Kozai, T. (2018), *Smart Plant Factory*. Singapore: Springer Singapore.

[8] Kumar Bhatt, K., Labanya R., and Joshi, H. C. (2019) Influence of Long-term Chemical fertilizers and Organic Manures on Soil Fertility - A Review, *Univers. J. Agric. Res.*, 7(5), 177–188.

[9] Abebe, T. G., Tamtam, M. R., Abebe, A. A., Abtemariam, K. A., Shigut, T. G., Dejen, Y. A., and Haile, E. G. (2022) Growing Use and Impacts of Chemical Fertilizers and Assessing Alternative Organic Fertilizer Sources in Ethiopia, *Appl. Environ. Soil Sci.*, 2022, 1–14.

[10] Anggraini, W., Fiteriani, I., Prihantini, N. N., Rahmawati, F., Susanti, A., and Septiyani, E. (2021) The effect of organic fertilizers and inorganic fertilizer on mustard growth in Bahway village, Balik Bukit district, West Lampung regency, *IOP Conf. Ser. Earth Environ. Sci.*, 1796(1).

[11] Walsh, J. J., Jones, D. L., Chadwick, D. R., and Williams, A. P. (2018) Repeated application of anaerobic digestate, undigested cattle slurry and inorganic fertilizer N: Impacts on pasture yield and quality, *Grass Forage Sci.*, 73(3), 758–763. doi: 10.1111/gfs.12354.

[12] Manirakiza, N., and Şeker, C. (2020), Effects of compost and biochar amendments on soil fertility and crop growth in a calcareous soil, *J. Plant Nutr.*, 43(20), 3002–3019. doi: 10.1080/01904167.2020.1806307.

[13] Usmani, Z., Kumar, V., Gupta, P., Gupta, G., Rani, R., and Chandra, A., Enhanced soil fertility, plant growth promotion and microbial enzymatic activities of vermicomposted fly ash, *Sci. Rep.*, 9(1), 1- 16. doi: 10.1038/s41598-019-46821-5.

[14] Sandner, V., Pybus, L.P., McCreath, G. and Glassey, J. (2018) Scale-Down Model Development in ambr systems: An Industrial Perspective," 14(4), 1700766, doi: 10.1002/biot.201700766.

[15] Seyedin, S. H., Ardjmand, M., Safekordi, A. A., Raygan, S., Zhalehrajabi, E., and Rahmanian, N. (2018) Using response surface methodology to optimize the operating parameters in a top-spray fluidized bed coating system, *Surf. Coatings Technol.* 334(5) 43–49. doi: 10.1016/j.surfcoat.2017.11.003.

[16] Muslim, E., Tetelepta, Y. W., Asyrof, D. D., and Shabrina, G. (2019) Biomechanics analysis with optimal combination by using foot and distance when the futsal player passing the ball against the accuracy of the target, *AIP Conf. Proc.*, 2092, doi: 10.1063/1.5096703.

[17] Dhasmana, A., Raza, S., Jahan, R., Lohani, M., and Arif, J. M. (2018), High-Throughput Virtual Screening (HTVS) of Natural Compounds and Exploration of Their Biomolecular Mechanisms: An In Silico Approach,

New Look to Phytomedicine Adv. Herb. Prod. as Nov. Drug Leads, 523–548. doi: 10.1016/B978-0-12-814619-4.00020-3.
[18] Souissi, M., Guesmi, A., and Moussa, A. (2018) Valorization of natural dye extracted from date palm pits (*Phoenix dactylifera*) for dyeing of cotton fabric. Part 1: Optimization of extraction process using Taguchi design, *J. Clean. Prod.*, 202, 1045–1055. doi: 10.1016/j.jclepro.2018.08.115.
[19] Ayilara, M. S., Olanrewaju, O. S., Babalola, O. O., and Odeyemi, O. (2020) Waste management through composting: Challenges and potentials, *Sustain.*, 12(11), 1–23 doi: 10.3390/su12114456.
[20] Taiz, L., Zeiger, E., Møller, I. M., and Murphy, A. (2015) The Analysis of Plant Growth, *Plant Physiol. Dev. 6th Ed.*, 2, 1–5
[21] Montgomery, D. C. (2020), *Design and Analysis of Experiments, 9th Edition, EMEA Edition*, Wiley: New Jersey