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RESEARCH ARTICLE

Multivariate analysis in the development of technology packages for corn cultivation by adding fertilizer to compost

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ABSTRACT

The development of cultivation technology is crucial for increasing corn (*Zea mays* L.) production in many parts of the world, including Indonesia. Combination of variety, planting systems, chemical fertilizers, and biofertilizers were developed in a previous study. However, such combinations must be more sustainable by including fertilizer to compost. A practical and systematic approach such as multivariate analysis is needed to increase the effectiveness of the evaluation of cultivation technology. Therefore, the study aimed to identify the best combination of compost rates with previously developed cultivation packages based on multivariate analysis. A split-plot design was used with a randomized complete group design as an environmental design. The main plot consisted of eight Farid cultivation packages (FP); each plot had eight levels (combination of variety, chemical fertilizer, and biofertilizer). Meanwhile, the subplots were four compost (C) rates, namely C0: 0 t ha^{-1}, C1: 2 t ha^{-1}, C2: 4 t ha^{-1}, and C3: 6 t ha^{-1}. Results showed that ear length (coefficient of evaluation index (CEI) = 0.164), number of kernel rows per ear (CEI = 0.067), and 1000-grain weight (CEI = 0.014) can be recommended as supporting characteristics or yield correction factors (CEI = 0.442), in which yield is the main characteristic. This study recommends combining the Farid package consisting of NK variety + fertilizer rate N:P:K = 200:100:50 + 25 kg KNO_3 + Ecofarming 5 cm^3 L^{-1} with 2, 4, and 6 t ha^{-1} compost rates as an alternative technology for corn cultivation.

Key words: Compost, cultivation package, factor analysis, corn, path analysis.

INTRODUCTION

Corn (*Zea mays* L.) is an important cereal crop, along with rice, that affects feed and food stability in Indonesia. The high potential demand for corn must be balanced with its production potential both globally and regionally (Erenstein et al., 2022; Farid et al., 2022). Indonesia imports large quantities of corn because of the imbalance between production and demand. High imports in Indonesia are correlated with a decrease in foreign exchange (Handoyo et al., 2022). Therefore, it is necessary to improve Indonesia's foreign trade, and one way is by optimizing domestic corn production.

Corn production in Indonesia is experiencing an upward annual trend. However, this increase has been based on increasing the planting area. Productivity has experienced a slight increase of approximately 0.27%; optimizing improvements in productivity is the key to supporting domestic production (Farid et al., 2022). There are two approaches for optimizing productivity, which are genetic and environmental engineering (Abduh et al., 2021; Farid et al., 2022). Genetic engineering on corn plants is possible with open pollination and hybrids (Farid et al., 2022).

Generally, the two concepts have very different genetic constitutions (Fromme et al., 2019); however, both have the same direction of genetic combinations to support productivity (Fromme et al., 2019; Farid et al., 2022). However, this optimization concept is dominated by hybrid varieties relying on their heterobeltiosis properties (Hake and Ross-Ibarra, 2015). Open-pollinated varieties in specific environments can show their potential for supporting domestic corn production (Wolde et al., 2018). Therefore, environmental engineering is essential for supporting the genetic potential of a variety.

Environmental engineering can be achieved in several ways by setting spacing and fertilization (Abduh et al., 2021; Farid et al., 2022). The Legowo spacing system for corn has been suggested for optimizing the improvement of the growing environment (Kurt et al., 2017; Alimuddin et al., 2020). This concept can support increased photosynthesis and air circulation so that corn plants can grow and produce well (Kurt et al., 2017). This concept is stable and can be applied as part of environmental engineering. The concept of fertilization has a significant and varied role in environmental engineering, and several types of fertilizers usually play different roles (Hasnain et al., 2020; Abduh et al., 2021). Chemical fertilizers focus on plant nutrition (Kong et al., 2022), while commercial varieties require high nutritional requirements (Baghdadi et al., 2018; Fromme et al., 2019; Kong et al., 2022). This is not easy to accomplish by natural means in some areas, and an easy way to meet plant nutritional needs is using chemical fertilizers (Baghdadi et al., 2018). However, their excessive and intensive use affects the quality of the planting environment, so that chemical fertilization requires supporting fertilization (Baghdadi et al., 2018; Kong et al., 2022). Baghdadi et al. (2018), Abduh et al. (2021), and Farid et al. (2022) have combined chemical fertilization with biological fertilization. Biological fertilizers generally use microorganisms that support plant growth and production. These microorganisms protect plants against the threat of disease-carrying pathogens or accelerate the nutrient mineralization process so that nutrients are available (Nascimento et al., 2020). The results of these studies have recommended several cultivation technology packages by combining varieties, chemical fertilizers, and biological fertilizers. However, one of these packages that combines a compost rate as a soil ameliorant still needs to be developed.

Compost is organic fertilizer occurs when raw organic materials are decomposed (Ho et al., 2022; Omara et al., 2022). This manufacturing process goes through fermentation and putrefaction by using small animals and soil microorganisms (Ho et al., 2022). Besides playing a role in supplying micronutrients, compost also has an essential role in improving soil physical and biological properties (Souza et al., 2016; Murtaza et al., 2019; Pangaribuan et al., 2020; Omara et al., 2022; Ho et al., 2022). It also provides the soil with a stable capacity and structure to support plant productivity; it is suitable material for combining with other technology packages (Murtaza et al., 2019; Pangaribuan et al., 2020; Omara et al., 2022). Farid et al. (2022) investigated one of these technology packages. It is important to study the cultivation technology packages studied by Farid et al. (2022) using a compost rate. However, the valuation of the assessment of the mix requires a systematic concept and is not only based on productivity. Productivity has a polygenic nature, and this characteristic is partly influenced by many minor genes related to environmental influences (Anshori et al., 2022). The concept of multiple characteristic-based evaluation is needed in the present study. The concept of multiple characteristics is enhanced if the evaluation process is combined with multivariate analysis.

Multivariate analysis is recommended for multiparameter decision-making. It can divide and describe this diversity and simplify the dimensions of the overall combination of data parameters so that this potential can be used to determine the main characteristic it supported (Mattjik and Sumertajaya, 2011). The use of this concept in crop evaluation has been reported (Murtaza et al., 2019; Padhi et al., 2022). Multivariate analysis can therefore be applied to evaluate the combination of corn cultivation technology packages on compost rates. The present study aimed to identify the best combination of compost rates with previously developed cultivation packages based on multivariate analysis and evaluate the effectiveness of the multivariate analysis concept.

MATERIALS AND METHODS

The study was conducted in the village of Taroang (5°36'32.2" S, 119°40'31.8" E; 18.3 m a.s.l.), Takalar Regency, South Sulawesi Province, Indonesia. It was conducted from January to April 2022. Soil and climate characteristics at the study location are shown in Tables 1 and 2.

Table 1. Soil properties at the study location.

Parameter	Value
Texture	Dusty clay
Clay, %	40.00
Dust, %	46.00
Sand, %	14.00
Organic C	1.63
pH (H_2O)	6.68
Total nitrogen, %	0.21
C/N, ppm	8.00
P Olsen, ppm	12.27
K, $cmol_{(+)}$ kg^{-1}	0.33
Ca, $cmol_{(+)}$ kg^{-1}	6.88
Mg, $cmol_{(+)}$ kg^{-1}	2.42
Na, $cmol_{(+)}$ kg^{-1}	0.10
Cation exchange capacity, $cmol_{(+)}$ kg^{-1}	23.75

Table 2. Climate parameters at the study location.

Month	Rainfall	Average temperature	Number of rainy days
	mm	°C	d
January	1008	25.5	29
February	618	25.3	22
March	116	26.4	13

The analysis used a split-plot design with a randomized complete group design as an environmental design. The main plot was eight Farid cultivation packages (FP) (Farid et al., 2022). These consisted of different corn (*Zea mays* L.) varieties and fertilizer rates: FP1: 'ADV1', N:P:K = 225:100:75; FP2: 'Pioneer1', N:P:K = 200:100:50 + 25 kg KNO_3 + 5 cm^3 L^{-1} Biotani; FP3: 'NK', N:P:K = 200:100:50 + 25 kg KNO_3 + 5 cm^3 L^{-1} Ecofarming; FP4: 'Bisi 18', N:P:K = 225:100:75; FP5: 'NASA 29', N:P:K = 200:100: 50 + 25 kg KNO_3 + 5 cm^3 L^{-1} Ecofarming; FP6: 'ADV2', N:P:K = 200:100: 50 + 25 kg KNO_3 + 5 cm^3 L^{-1} Biotani; FP7: 'Pioneer2', N:P:K = 200:100:50 + 25 kg KNO_3 + 5 cm^3 L^{-1} Ecofarming; and FP8: 'SINHAS', N:P:K = 200:100:50 + 25 kg KNO_3 + 5 cm^3 L^{-1} Ecofarming.

Ecofarming is a liquid organic fertilizer that contains macronutrients (N, P, K), secondary nutrients (S, Ca, Mg), and micronutrients (Cl, Mn, Fe, Cu, Zn, B, Mo). In addition, this biological fertilizer includes a variety of positive microbes such as soil biodecomposers (Louto et al., 2022). Biota fertilizer is also a liquid organic fertilizer with various nutrients that play a role in plant growth; it also contains microbes that act as decomposers and break down macronutrients in the soil. The sub-plots of were the four compost (C) rates of C0 0 t ha^{-1}, C1 2 t ha^{-1}, C2 4 t ha^{-1}, and C3 6 t ha^{-1}. The compost is described in Table 3 and is compatible with Yassi et al. (2023). Based on these two factors, there were 32 treatment combinations. Each treatment combination was repeated three times for 96 treatment units using double row spacing [(50 + 100) × 20 cm].

Table 3. Description of applied compost.

pH (H_2O)	Walkley & Black C	Kjeldahl N	C/N	HNO_3:$HClO_4$ P	HNO_3:$HClO_4$ K
	%	%		%	%
6.86	15.25	0.55	28	0.15	0.32

Research procedures

Research procedures generally followed those described by Farid et al. (2022). Land was prepared by cultivating perfect soil with a tractor. The prepared soil was then manually made into beds with an 8 m × 8 m hoe and 4 m × 4 m subplots with an inter-bed distance of 1 m and 7 m spacing between replicates. Quality corn seeds were randomly sown according to the treatment. Each planting hole was allocated two sources/planting holes covered with compost and included carbofuran to prevent pest attacks. The planted beds were labeled with a treatment marker to identity them. Fertilization was applied according to the experimental rate and administered in stages. The NPK Phonska (15:15:15) and SP 36 (P_2O_5 = 36%) fertilizers were applied 10 d after planting (DAP) around the plantlets. At 30 and 45 DAP, the corn plants were fertilized with urea according to the needs of the treatment rate. The KNO_3 fertilization in several fertilizer packages was applied once at 20 DAP at 35 g L^{-1}. Ecofarming and Biotani at 5 cm^3 L^{-1}were sprayed three times at 20, 30, and 40 DAP for each fertilization package that included Ecofarming and Biotani.

Other plant maintenance activities included pruning, thinning, weeding, hedging, and watering. Plants that did not grow, died, or grew late in the first and second weeks after the plants were pruned. Thinning was performed in each planting hole in which two plants grew so that one of them was eliminated to optimize corn plant growth in each planting hole. Weeding eliminated weeds around the corn plants, and was regularly intensive in the first month. Piles were raised and the soil was loosened to improve soil aeration. This activity occurred after the second fertilization application. A water pump machine and water hose were used to flood the plots, which were irrigated up to the height of the beds. Watering was also periodically carried out according to the rainfall and humidity of the beds. The last activity was manual harvesting when the corn kernels reached physiological maturity.

Data observation and analysis

Morphological and physiological data were observed. Morphological data included plant height (PH), number of leaves (NL), stem diameter (SD), days to male flowering (DMF), days to female flowering (DFF), ear height (EH), ear weight (EW), ear diameter (ED), ear length (EL), number of kernel rows per ear (NKrE), seed weight per ear (SWE), percentage of seed yield (PSY), 1000-grain weight (W1000G), and yield. Physiological data included chlorophyll *a*, *b*, total chlorophyll, absorbance, transmittance, and reflectance. All data were analyzed for variance (ANOVA) at the 5% level. The correlation path and factor analysis followed the mean trial results. The slices of the results of the three analyses were used as the basis for determining the evaluation criteria. The evaluation index was constructed by a combination of direct influence on path analysis and factor loading on the selected factors representing yield diversity (Anshori et al., 2022).

RESULTS

The ANOVA results showed that most of the characteristics were influenced by all the different sources (cultivation package, compost rates, and their interaction), except for NL, EH, absorbance, reflectance, transmittance, DFF, and yield (Table 4). The different compost rates and the interaction between cultivation packages and compost rates influenced NL and EH. The variety of cultivation packages and compost rates affected DFF. The diversity of the cultivation package only influenced the reflectance, transmittance, and yield aspects. Meanwhile, three different sources did not affect absorbance.

Table 4. Analysis of variance (ANOVA) of morphological and physiological characteristics in the evaluation of corn cultivation technology. *Significant at $\alpha = 5\%$; **significant at $\alpha = 1\%$; ^{ns}: nonsignificant; FP: Farid's cultivation packages; C: compost; Cv: coefficient of variation; PH: plant height; NL: number of leaves; SD: stem diameter; DMF: days to male flowering; DFF: days to female flowering; EH: ear height; EW: ear weight; ED: ear diameter; EL: ear length; NKrE: number of kernel rows per ear; SWE: seed weight per ear; W1000G: weight of 1000 grains; PSY: percentage of seed yield (PSY).

Character	Mean Square					Cva	Cvb
	FP	Errors a	C	FP×C	Error b		
PH	50.69*	7.44	307.28**	94.16**	8.65	1.19	1.28
NL	0.66ns	0.40	10.93**	0.87**	0.33	4.86	4.39
SD	3.69**	0.20	18.48**	6.67**	1.67	2.18	6.26
EH	12.60ns	9.07	356.70**	119.30**	12.76	3.14	3.73
Chl *a*	6372.58**	489.81	3825.50**	1172.04*	658.34	7.38	8.55
Chl *b*	2256.29**	155.71	1192.12**	394.90*	216.61	9.67	11.41
Chl tot	13846.53**	1029.06	8154.59**	2521.40*	1422.15	7.43	8.74
Absorbance	0.00002ns	0.00004	0.00010ns	0.00004ns	0.00006	7.69	9.61
Reflection	0.00068*	0.00009	0.00015ns	0.00031ns	0.00033	8.83	17.17
Transmittance	0.00039*	0.00006	0.00015ns	0.00009ns	0.00009	7.44	9.21
DMF	25.85**	0.21	1.80*	2.13**	0.79	0.86	1.66
DFF	24.70**	0.11	3.28*	1.38ns	1.33	0.61	2.09
EL	0.84*	0.17	3.70**	2.36**	0.09	2.79	2.03
ED	2.53*	0.51	13.73**	4.01**	1.40	1.61	2.66
NKrE	33.67**	0.83	5.95**	1.37*	0.76	5.93	5.66
EW	11430.24**	378.51	18340.59**	5049.00**	609.30	3.29	4.18
SWE	29145.38**	2146.44	71761.29**	98856.29**	30701.42	4.70	5.82
W1000G	990.26*	187.02	1016.38**	658.85**	201.12	4.41	4.57
PSY	0.0047*	0.0008	0.0016ns	0.0015ns	0.0010	4.16	4.67
Yield	9.80**	0.52	8.35**	2.81**	0.52	8.14	8.14

The results of the correlation analysis focused on yield (Figure 1). Based on this correlation, yield was significantly correlated with EL (0.44) and NKrE (0.50). The EL was also significantly associated with W1000G (0.37). The NKrE was also significantly correlated with transmittance (0.46), yield (0.41), SWE (0.47), EW (0.53), DMF (0.57), and DFF (0.62). Yield was significantly correlated with SWE (0.65), EW (0.59), DMF (0.39), and DFF (0.39). Finally, a strong correlation occurred between physiological characteristics and chlorophyll (0.99).

Results of the path analysis focused on the characteristics that were considered to be directly and indirectly correlated with yield. This path analysis had a 25.8% coefficient of determination (Table 5). The NKrE (0.52) was the dominant characteristic that directly affected productivity. Other characteristics that had an immediate positive impact on productivity were DMF (0.30), EL (0.28), PSY (0.27), and W1000G (0.10).

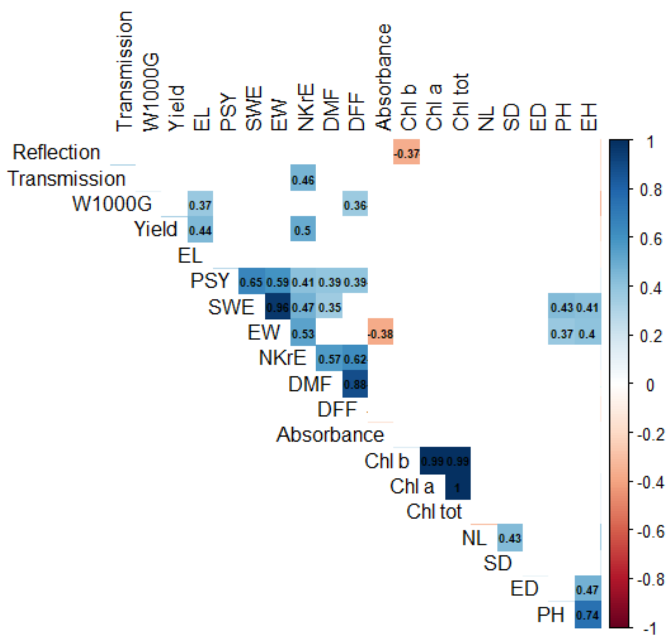

Figure 1. Heat map of significant correlation analysis of growth characteristics in the evaluation of corn cultivation technology with a 5% error rate. PH: Plant height; NL: number of leaves; SD: stem diameter; DMF: days to male flowering; DFF: days to female flowering; EH: ear height; EW: ear weight; ED: ear diameter; EL: ear length; NKrE: number of kernel rows per ear; SWE: seed weight per ear; W1000G: 1000-grain weight; PSY: percentage of seed yield.

Table 5. Path analysis of several growth characteristics on yield in the evaluation of corn cultivation technology. SWE: Seed weight per ear; PSY: percentage of seed yield (PSY); W1000G: weight of 1000 grains; NKrE: number of kernel rows per ear; EL: ear length; DMF: days to male flowering; DFF: days to female flowering; Trans: transmittance; Corr: correlation. Bold values have positive direct effect to the yield.

Characteristic	Direct effect	Indirect effect								Corr
		SWE	PSY	W1000G	NKrE	EL	DMF	DFF	Trans	
SWE	-0.45		0.18	0.02	0.24	0.06	0.11	-0.11	0.00	0.05
PSY	**0.27**	-0.29		0.03	0.21	0.08	0.12	-0.13	0.00	0.29
W1000G	**0.10**	-0.09	0.09		0.14	0.11	0.09	-0.12	0.00	0.32
NKrE	**0.52**	-0.21	0.11	0.03		0.09	0.17	-0.21	0.00	0.50
EL	**0.28**	-0.09	0.07	0.04	0.17		0.06	-0.10	0.00	0.44
DMF	**0.30**	-0.16	0.11	0.03	0.30	0.05		-0.30	0.00	0.33
DFF	-0.34	-0.14	0.11	0.04	0.32	0.08	0.27		0.00	0.33
Trans	-0.01	-0.03	0.08	0.01	0.24	0.00	0.10	-0.09		0.30

The coefficient of determination in the factor analysis showed that there were seven dimensions of optimal factors involved in dividing the diversity of observed data. Factor 7 (Table 6) was the optimal factor that explained the main variation in yield (-0.442). Most of the growth characteristics had the same direction as yield in factor 7, except for SWE, DMF, DFF, PH, and ED. However, the characteristics with optimal diversity in the direction of yield were W1000G (-0.140), WD (-0.174), NKrE (-0.129), EL (-0.584), and NL (-0.192).

Table 6. Factor analysis of growth characteristics in the evaluation of corn cultivation technology. SWE: Seed weight per ear; PSY: percentage of seed yield; W1000G: weight of 1000 grains; EW: ear weight; ED: ear diameter; NKrE: number of kernel rows per ear; EL: ear length; DMF: days to male flowering; DFF: days to female flowering; PH: plant height; EH: ear height; NL: number of leaves; SD: stem diameter. Bold number: Weighting selection criteria based on factor analysis.

Variables	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
SWE	0.001	0.346	0.061	0.029	0.011	0.071	-0.071
PSY	0.047	0.338	0.060	0.233	0.006	0.046	0.083
Yield	0.013	-0.037	0.055	-0.089	-0.248	**-0.442**	0.029
W1000G	-0.010	0.140	0.055	0.263	0.042	**-0.140**	-0.095
EW	-0.009	0.322	0.086	-0.003	0.002	-0.027	-0.106
ED	-0.064	-0.175	-0.098	-0.461	-0.039	-0.174	-0.202
NKrE	-0.046	0.008	-0.198	-0.134	-0.127	**-0.129**	0.083
EL	0.019	-0.043	0.097	-0.092	0.104	**-0.584**	0.081
DMF	0.015	-0.072	-0.401	-0.012	0.133	0.125	-0.018
DFF	0.045	-0.049	-0.392	0.058	0.194	0.140	-0.041
Chl *a*	0.306	0.016	0.017	-0.011	0.026	-0.015	0.037
Chl *b*	0.304	0.010	0.005	0.019	0.037	-0.006	0.024
Chl tot	0.306	0.015	0.015	-0.007	0.027	-0.014	0.035
PH	0.038	0.170	0.002	-0.184	-0.111	0.190	0.215
EH	0.046	0.078	0.035	-0.345	0.000	-0.005	0.047
NL	-0.056	0.008	0.110	-0.151	0.210	-0.192	0.009
SD	-0.001	-0.045	-0.182	0.055	0.530	0.059	0.090
Absorbance	0.134	-0.066	0.007	-0.034	0.270	-0.077	0.477
Reflectance	-0.063	-0.004	-0.046	0.074	-0.053	-0.023	0.531
Transmittance	-0.087	-0.116	-0.249	-0.130	-0.263	-0.026	0.189
Variances	3.313	3,002	2,826	2.144	1,795	1,776	1,507
%var	0.166	0.150	0.141	0.107	0.090	0.089	0.075

The index analysis results for the compost and technology package combination in Table 7 show 14 combinations with a positive index. study The C3 and C2 compost rates were assessed, while the FP3 technology package was the best in the corn planting evaluation. The best combinations of the corn planting assessment were C3FP3, C1FP3, C3FP2, C0FP3, and C2FP3.

Table 7. Evaluation of combined corn cultivation technology (Farid et al., 2022) and several compost rates based on evaluation index values. W1000G: Weight of 1000 grains; NKrE: number of kernel rows per ear; EL: ear length.

Rank	Combination	Real values				Standardized values				Index
		Yield	W1000G	NKrE	EL	Yield	W1000G	NKrE	EL	
1	C3FP3	12.80	324.50	17.44	15.11	3.14	0.72	1.48	0.26	1.54
2	C1FP3	11.69	337.23	16.89	16.17	2.23	1.54	1.05	1.45	1.31
3	C3FP2	11.30	327.70	16.00	14.97	1.90	0.93	0.38	0.10	0.90
4	C3FP8	9.72	325.47	16.78	16.99	0.61	0.79	0.97	2.37	0.74
5	C2FP3	9.61	307.07	17.44	16.09	0.52	-0.40	1.48	1.36	0.54
6	C2FP4	9.49	320.17	17.00	16.10	0.42	0.45	1.14	1.37	0.49
7	C0FP3	9.86	321.57	14.56	15.98	0.73	0.54	-0.72	1.23	0.48
8	C1FP5	9.32	292.47	14.00	16.39	0.28	-1.34	-1.14	1.70	0.31
9	C2FP1	9.26	311.77	16.78	14.94	0.23	-0.09	0.97	0.07	0.18
10	C3FP6	9.04	326.73	15.89	15.42	0.05	0.87	0.29	0.61	0.15
11	C3FP7	9.38	349.13	15.22	14.59	0.33	2.31	-0.21	-0.33	0.11
12	C3FP1	9.50	301.73	15.67	14.38	0.43	-0.74	0.12	-0.57	0.10
13	C0FP4	9.00	313.60	13.89	15.77	0.02	0.02	-1.23	1.00	0.09
14	C2FP5	9.20	312.77	16.00	14.39	0.18	-0.03	0.38	-0.55	0.02
15	C2FP2	8.65	319.70	17.00	14.91	-0.27	0.42	1.14	0.03	-0.03
16	C1FP4	8.63	317.77	15.56	15.32	-0.28	0.29	0.04	0.50	-0.04
17	C2FP7	9.44	301.10	15.22	13.70	0.38	-0.78	-0.21	-1.33	-0.07
18	C3FP4	8.83	318.63	16.78	14.36	-0.12	0.35	0.97	-0.59	-0.08
19	C2FP6	8.45	309.93	17.00	14.84	-0.43	-0.21	1.14	-0.04	-0.12
20	C0FP2	8.55	312.03	15.22	15.13	-0.35	-0.08	-0.21	0.28	-0.12
21	C1FP8	8.81	328.50	13.78	14.66	-0.13	0.98	-1.31	-0.25	-0.17
22	C1FP6	8.81	304.37	15.56	14.03	-0.13	-0.57	0.04	-0.95	-0.22
23	C1FP1	8.38	311.20	15.56	14.62	-0.49	-0.13	0.04	-0.29	-0.26
24	C3FP5	7.60	302.17	16.33	15.32	-1.13	-0.71	0.63	0.50	-0.39
25	C2FP8	8.36	319.37	15.44	13.94	-0.50	0.39	-0.04	-1.06	-0.39
26	C0FP6	8.44	284.90	14.56	13.49	-0.44	-1.82	-0.72	-1.57	-0.52
27	C1FP7	8.37	269.30	15.56	13.17	-0.50	-2.83	0.04	-1.93	-0.57
28	C0FP1	7.81	305.17	13.89	14.52	-0.95	-0.52	-1.23	-0.40	-0.58
29	C0FP7	7.59	318.07	13.89	14.87	-1.14	0.31	-1.23	-0.02	-0.58
30	C0FP5	7.85	284.73	13.22	14.46	-0.93	-1.83	-1.73	-0.48	-0.63
31	C1FP2	6.80	332.17	16.22	14.21	-1.79	1.22	0.55	-0.75	-0.86
32	C0FP8	6.66	312.77	11.78	13.37	-1.90	-0.03	-2.83	-1.71	-1.31

DISCUSSION

The ANOVA results showed that the three different sources influenced almost all the growth characteristics. This indicates that each treatment had an independent and dependent role in affecting growth characteristics, especially corn yield components. The significant effect of the Farid cultivation package reinforced the evidence that the technology package has different features that affect the phenotypes of corn cultivation. This also concurs with the studies by Abduh et al. (2021) and Farid et al. (2022). The significant effect of the compost rate also indicated that composting is essential in supporting the growth of corn plantations, which concurs with research by Ho et al. (2022) and Omara et al. (2022). The interaction of the two treatments indicated that each technology package had a different response to the compost rate; therefore, an in-depth evaluation of combining the two factors could be performed to obtain the best technology package for corn cultivation.

The identification of the effect of the source of variance by ANOVA on corn growth characteristics as an initial stage in concept evaluation has been reported (Abduh et al., 2021; Farid et al., 2022). Evaluating observations with many parameters usually requires a systematic reduction process (Jackson, 2007). If there is no variation in the treatment from the beginning, the evaluation process that includes many characteristics is ineffective (Abduh et al., 2021; Anshori et al., 2022; Farid et al., 2022). The ANOVA is an early indicator to determine a more in-depth analysis process, which can be carried out in this study.

Several studies have reported that the growth characteristic in the evaluation can be reduced by combining several multivariate analyses (Oliveira et al., 2016; Nardino et al.,2020; Yassi et al., 2023). Correlation analysis is essential in some multivariate analyses. Correlation analysis can be used as a starting point to determine the relationship between parameters, especially the main characteristics of productivity (Nardino et al., 2020; Anshori et al., 2022). According to the correlation analysis, the characteristics that significantly correlated with yield were EL and NKrE. This concurs with findings by Mendes-Moreira et al. (2014) and Chethan and Nataraja (2021). However, these results are unlike other studies (Aman et al., 2020; Farid et al., 2022). If the correlation results are examined more thoroughly, NKrE had a significant positive correlation with transmittance, yield, SWE, EW, DMF and DFF. In addition, EL had a significant positive correlation withW1000G. This indicated that the characteristic associated with weight was indirectly related to the production area; the study therefore performed a combination of multivariate analyses.

The multivariate analysis combination that was performed consisted of a path analysis and factor analysis. Based on these two analyses, both NKrE and EL were practical selection criteria. The W1000G was also selected as an additional evaluation criterion; it is consistent with the direction of the variance in this characteristic against yield in both analyses. The W1000G potential is also supported by findings reported by Farid et al. (2022) in which W1000G was recommended in its selection of criteria. Path and factor studies can usually divide the diversity of existing data, although the two have different concepts (Mattjik and Sumertajaya, 2011). Path analysis divides the correlation into direct and indirect effects (Mattjik and Sumertajaya, 2011; Abduh et al., 2021; Anshori et al., 2022). This immediate effect is an indicator of the effectiveness of the secondary characteristic in influencing the diversity of the main characteristics, namely yield (Abduh et al., 2021; Amegbor et al., 2022). Meanwhile, factor analysis can divide the total diversity in a data set into meaningful new dimensions (Rocha et al., 2018). Factor analysis can reduce low covariance and increase high covariance between the size of characteristics; it is effective in looking at the internal relationship between the main characteristic and supporting characteristics (Rocha et al., 2018; Anshori et al., 2022). A combination of the two analyses shows the consistency of a characteristic when determining the diversity of the main characteristics; therefore, characteristics that are consistent with both analyses are feasible for use and recommended as a practical evaluation criterion in a plantation. Anshori et al. (2022) have also reported the effectiveness of this combination. The selection criteria were yield, NKrE, EL, and W100G. The use of these supporting evaluation criteria has also been mentioned by Mendes-Moreira et al. (2014) for NKrE and EL and Farid et al. (2022) for W1000G.

The use of multiple selection criteria for the evaluation can be integrated into a multiple regression equation. The combination in multiple regression analysis produces an index value (Batista et al., 2021). The index concept has been widely reported both in the selection process of lines and technology evaluation (Coutinho et al., 2019; Batista et al., 2021; Farid et al., 2021). The weighting of each evaluation criterion is crucial to construct an index (Batista et al., 2021). This weighting can be a priority value or economic value for a characteristic (Anshori et al., 2022). Weighting can be determined subjectively depending on the researcher's understanding or objectively based on systematic analysis (Coutinho et al., 2019; Batista et al., 2021). The combination of the direct effect value on cross-prints and the factor loading value in factor analysis can be a good indicator in the selection criteria weighting process. This incorporation concept has been reported by Anshori et al. (2022). The index was the loading factor x, which is the direct effect of cross-printing on each selection criterion. This concept has several adjustments. First, negative values in factor analysis only act as the direction. They are not absolute (Jolliffe and Cadima, 2016), and these values can be multiplied by -1 so that the direction of the factor analysis is positively weighted. Second, the direct effect is explained by the cross-pollination focused on yield (Anshori et al., 2022). The evaluation index formula used in this study is:

$$\text{Evaluation index} = (0.442)\ \text{yield} + (0.584\times0.28)\ \text{EL} + (0.129\times0.52)\ \text{NKrE} + (0.14\times0.1)\ \text{W1000G}$$

or

$$\text{Evaluation index} = (0.442)\ \text{yield} + (0.164)\ \text{EL} + (0.067)\ \text{NKrE} + (0.014)\ \text{W1000G}$$

The results of the selection index showed that the FP3 technology package (NK variety, fertilizer rate N:P:K = 200:100:50 + 25 kg KNO_3 + 5 cm^3 L^{-1} Ecofarming) dominated other technology packages. Abduh et al. (2021) indicated that this fertilizer combination was suitable and N:P:K = 200:100:50 + 25 kg KNO_3 + 5 cm^3 L^{-1} Ecofarming was the best cultivation package. The KNO_3 fertilizer is essential for corn flowering and fruiting, and it is often used as the final fertilizer in the cultivation process (Darmanto et al., 2020). Its effectiveness is further supported by Ecofarming organic fertilizers that support nutrient intake (Louto et al., 2022). The combination of Ecofarming chemical and organic fertilizers stimulates the potential for plant growth and production (Abduh et al., 2021), which was reinforced by Farid et al. (2022). However, this fertilizer combination with ‘NK’ was not in the top five of the best technology packages and variety combinations (Farid et al., 2022). One of the excellent varieties recommended in the Takalar Regency was ‘NK’ (Farid et al., 2022); it was therefore suitable for the present study. The different climatic conditions of both studies led to different results. This statement was based on the fact that the fields used in both studies were similar. Cofas (2018) mentioned that climate factors, such as precipitation and temperature, highly contribute to the impact on corn production.

In addition, the compost rate interaction could also be a reason why both studies had different results. This was observed in the FP3, FP2, and FP8 technology packages, which were comparatively responsive to high composting. Compost generally impacts the quality and quantity of plant growth; it is also growth medium for positive microorganisms. Its significant colony can induce more essential nutrients and repair the physical environment for plant growth (Souza et al., 2016; Ho et al., 2022). The corn plant can therefore optimize the genetic potential and pathway metabolism to increase the yield component, such as EL, NL, W1000G, other yield components, and yield (Pangaribuan et al., 2020; Ho et al., 2022; Omara et al., 2022). Conversely, the treatment without compost reduces the genetic potential of a variety. This was observed in the C0FP8 treatment, which had a different response than the C3FP8 combination. However, compost C1 combined with FP3 (C1FP3) was also the phenotype that was better than C2 rate (C2FP3); this could be due to a specific interaction between the C1 compost rate and the FP3 technology. In general, increasing compost can optimize the potential of the technological package of chemical fertilization and natural fertilization.

Using the index concept in the evaluation was adequate because all assessments are cumulative, and the other growth characteristics can correct the yield potential. It is significantly reflected in the C3FP3 index that had a manageable gap with respect to C1FP3 when compared against a case based on only the standardized yield value. Therefore, the effectiveness of the corn index evaluation based on multivariate analysis was further strengthened. In addition, the C3FP3, C1FP3, C3FP2, C3FP8, and C2FP3 combinations were recommended as an alternative technology for corn cultivation.

CONCLUSIONS

Ear length, number of kernel rows per ear, and 1000-grain weight can be recommended as supporting characteristics or yield correction factors for the main yield characteristic. The construction of the evaluation index was 0.442 yield + (0.164) ear length + (0.067) number of kernel rows per ear + (0.014) 1000-grain weight. The results of the evaluation index indicated that the combination of fertilizer rate N:P:K = 200:100:50 + 25 kg KNO_3 + 5 cm^3 L^{-1} Ecofarming with

6 t ha^{-1} compost rate (C3FP3) was the most recommended for corn cultivation. In addition, other alternative combinations were fertilizer rate N:P:K = 200:100:50 + 25 kg KNO_3 + 5 cm^3 L^{-1} Ecofarming with 2 (C1FP3) and 4 t ha^{-1} compost rates (C2FP3). Other combinations included 'Pioneer1' with N:P:K = 200:100:50 + 25 kg KNO_3 + 5 cm^3 L^{-1} Biotani with 6 t ha^{-1} compost rate (C3FP2) and 'SINHAS' with N:P:K = 200:100:50 + 25 kg KNO_3 + 5 cm^3 L^{-1} Ecofarming with 6 t ha^{-1} compost rate (C3FP8). Results also showed the effectiveness of using an index based on multivariate analysis to evaluate corn cultivation. However, the index value might not necessarily be useful in other environments; therefore, recommendations are focused on the concept of index development and not only the index value. The present research suggests that this evaluation concept needs more in-depth study with a more precise approach, such as analyzing vegetation indices with unmanned aerial vehicles (drones) or other precision technologies. This concept also requires a study of the cost-effectiveness of the recommended technology.

Author contributions

Conceptualization: M.Fi., M.Fa., Y.M., M.F.A. Methodology: M.Fi., M.Fa. Software: M.F.A. Validation: M.Fa., Y.M., R.P. Formal analysis: M.F.A., A.N. Investigation: M.Fi. Resources: M.Fi., A.N. Data curation: M.Fa., Y.M., R.P. Writing-original draft: M.Fi. Writing-review & editing: M.F.A., R.P. Visualization: M.F.A. Supervision: M.Fa., Y.M. Project administration: M.F.A. Funding acquisition: M.Fi. All co-authors reviewed the final version and approved the manuscript before submission.

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