



Bioferdom Farmer Field School: Enhancing Agricultural Productivity Through SOP Adoption and Bioferdom Fertilizer Implementation in Banggai Regency

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Keywords:	Abstract
Farmer field school; SOP adoption; Bioferdom; agricultural productivity; SDGs	This study aimed to assess the impact of a needs-based farmer field school integrated with Bioferdom fertilizer application on farmers' knowledge, adoption of standard operating procedures (SOPs), corn productivity, and the economic feasibility of corn farming. The study employed a descriptive qualitative approach incorporating active community participation and a single-group pretest–posttest design. Data were collected through focus group discussions (FGDs), in-depth interviews, field observations, and demonstration plot monitoring involving 24 members of the Mosa'angu Farmers Group. The effects of biosulfur fertilizer were evaluated separately in an experimental plot using a 5×5 factorial randomized complete block design (RCBD), with nitrogen, phosphorus, and potassium (NPK) fertilizer rates and biosulfur application rates as treatment factors, each replicated three times. The findings revealed that the average knowledge score increased from 40.0 to 77.8 (normalized gain [N-gain] = 0.63; $p < 0.001$), while SOP adoption increased from 19.9% to 85.1% ($p < 0.001$). Corn productivity increased from 0.99 to 1.87 metric tons per hectare, representing an 89.4% improvement, while the revenue-to-cost (R/C) ratio increased from 1.26 to 2.10. In the experimental plot, the combination of 75% of the recommended NPK fertilizer rate with 75–100% of the designated biosulfur application rate produced plant growth comparable to that achieved with 100% NPK fertilizer without biosulfur supplementation. This finding suggested the potential to reduce NPK fertilizer requirements, although the reported 9–19% cost savings would require further economic validation. Overall, the integration of needs-based farmer field schools with fertilizer innovations derived from gas industry by-products demonstrated potential as a community empowerment model consistent with circular economy principles. The program also supported progress toward the Sustainable Development Goals (SDGs), particularly No Poverty (SDG 1), Decent Work and Economic Growth (SDG 8), Climate Action (SDG 13), and Life on Land (SDG 15).

INTRODUCTION

Corn farming in Banggai Regency, Central Sulawesi, plays a crucial role in sustaining rural livelihoods and strengthening the economic resilience of farming households. However, corn productivity among smallholder farmers remains substantially below the yield potential of cultivated varieties and the national average of 5.9 metric tons per hectare recorded in 2024 (Ternate, 2025). At the national level, the technical efficiency of corn farming has been estimated at only 68.3% (Haryanto et al., 2023). Similar challenges were observed in Kayowa Village, where the average corn yield before the program intervention was approximately 1 metric ton per hectare, resulting in financial losses for 10 of the 24 participating farmers during each planting season (“Combined Application of Amino Acid Compound Fertilizer and Sulfur Enhances Yield, Nutrient Use Efficiency, and Starch Accumulation in Waxy Maize,” 2025; “Nutrient Circularity from Waste to Fertilizer: A Perspective from LCA Studies,” 2025; “The Circular Phosphorus Economy: Agronomic Performance of Recycled Fertilizers and Target Crops,” 2025).

These productivity constraints were attributable not only to limited agricultural inputs but also to cultivation practices that deviated from recommended agronomic standards. Conventional farming practices, including inconsistent planting distances, imprecise fertilizer application, and inadequate implementation of integrated pest management (IPM), indicated insufficient adoption of recommended cultivation techniques. Furthermore, exclusive reliance on nitrogen, phosphorus, and potassium (NPK) fertilizers may result in inadequate supplementation of other essential nutrients, particularly sulfur (S), which plays a critical role in protein synthesis and chlorophyll formation (Zenda et al., 2021). Adequate sulfur availability also supports nitrogen uptake and utilization efficiency in corn plants, thereby contributing to improved crop growth and productivity (Agyin-Birikorang et al., 2024; Barłóg & Łukowiak, 2022).

Conventional, one-way agricultural extension approaches that inadequately account for local farming conditions have demonstrated limitations in promoting sustainable changes in farmers' cultivation practices, particularly when instructional materials are overly generalized (Bachtiar et al., 2025; Martina et al., 2024). In contrast, Farmer Field Schools (FFS) provide participatory, experiential learning opportunities that enable farmers to observe, experiment, and develop practical agricultural knowledge through direct field engagement (Jabbar et al., 2022; Nuzuliyah, 2022). Nevertheless, many farmer field school programs continue to rely on standardized curricula that may not adequately address location-specific agricultural challenges. To overcome this limitation, the present program developed instructional materials based on preliminary field assessments and mentoring activities, focusing on the most frequently identified deficiencies in local corn cultivation practices (Ghorbani, 2025; Habanyati & Paramasivam, 2025; Kubo et al., 2025; Thobane et al., 2025).

Meanwhile, natural gas processing operations in the region generate recovered sulfur as a by-product of hydrogen sulfide (H_2S) removal from natural gas streams. This recovered sulfur was incorporated into Bioferdom fertilizer, which was developed to supply sulfur and organic matter for agricultural applications. Converting recovered industrial sulfur into agricultural inputs represents a resource recovery strategy consistent with circular economy principles (Cordeiro,

2024). Previous studies have also investigated the agricultural application of sulfur recovered from gas purification processes, including its potential use as a fertilizer for corn cultivation in Europe (Fontaine & Eriksen, 2021; Škarpa et al., 2021). However, the adoption of innovative fertilizer technologies may remain limited when farmers lack sufficient knowledge of their functions, benefits, and appropriate application methods. Therefore, integrating fertilizer innovation with structured agricultural extension and technical assistance is essential to facilitate effective adoption and sustainable agricultural practices (Cordeiro, 2024; Kurniawati et al., 2023).

This study offers three primary contributions to the existing literature. First, it examines the integration of a needs-based farmer field school with Bioferdom fertilizer application as a comprehensive agricultural intervention combining capacity building and fertilizer innovation. Second, it incorporates a participatory learning approach in which instructional materials were tailored to locally identified cultivation challenges, addressing the limitations of conventional, standardized agricultural extension programs. Third, it evaluates the effects of combining biosulfur and NPK fertilizers on corn growth through a 5×5 factorial randomized complete block design (RCBD), providing experimental evidence regarding the potential of biosulfur-based fertilizer as a complementary nutrient source. By integrating participatory agricultural education with resource recovery-based fertilizer innovation, this study seeks to advance the understanding of sustainable agricultural extension practices while providing empirical insights into strategies for improving corn farming performance in Indonesia.

Based on these considerations, this study aimed to (1) assess changes in farmers' agricultural knowledge following participation in the farmer field school; (2) evaluate changes in the adoption of standard operating procedures (SOPs) for corn cultivation; (3) examine the effects of combined biosulfur and NPK fertilizer applications on corn growth under experimental field conditions; and (4) analyze changes in corn productivity and the economic feasibility of farming activities among participating farmers.

This study contributes to both theoretical knowledge and practical agricultural development. Theoretically, it expands the literature on participatory agricultural extension and circular economy applications by examining the integration of a needs-based farmer field school with Bioferdom fertilizer innovation. Practically, the findings provide a potentially replicable framework for strengthening farmer capacity, improving adherence to recommended cultivation practices, and promoting the responsible utilization of recovered industrial resources in agriculture. The results may also inform agricultural extension workers, policymakers, and farmer organizations in developing context-specific training programs and evaluating alternative fertilizer strategies. Furthermore, the study provides a foundation for future investigations into the agronomic effectiveness, economic feasibility, and long-term environmental implications of Bioferdom fertilizer and similar resource recovery-based agricultural innovations.

METHOD

This study employed a descriptive qualitative approach incorporating active community participation. The research was conducted in Kayowa Village, Batui District, Banggai Regency,

Central Sulawesi, Indonesia. Primary data were collected through interviews and pretest–posttest questionnaires administered to 24 active members of the Mosa'angu Farmers Group, who collectively managed 44 hectares of agricultural land. Secondary data were obtained from program documentation and activity reports.

Data collection included focus group discussions (FGDs) involving farmer group members, village government officials, company representatives, and regency government officials to identify cultivation challenges and develop the farmer field school curriculum. The program comprised five modules: alternative fertilizer utilization, farm economic analysis, integrated pest and disease management, adoption of standard operating procedures (SOPs) for corn cultivation, and plant nutrition and fertilization techniques. Experimental field trials and demonstration plot monitoring were also conducted to evaluate the effects of Bioferdom biosulfur fertilizer on corn growth and productivity.

Data were analyzed using qualitative descriptive analysis, source triangulation, and quantitative statistical methods. Changes in farmers' knowledge were assessed using the Wilcoxon signed-rank test and normalized gain (N-gain) scores, while SOP adoption was evaluated based on compliance percentages across 14 cultivation stages. The effects of NPK and biosulfur fertilizer application rates were examined using a 5×5 factorial randomized complete block design (RCBD) with three replications, resulting in 75 experimental units. Experimental data were analyzed using two-way analysis of variance (ANOVA), multivariate analysis of variance (MANOVA), and polynomial regression. Changes in agricultural productivity were assessed using corn yields (metric tons per hectare), while the economic feasibility of corn farming was evaluated using the revenue-to-cost (R/C) ratio.

RESULTS AND DISCUSSION

Corn cultivation is carried out in stages, from land preparation to harvest. Land preparation involves plowing and weed control, followed by the application of 1–2 metric tons per hectare of Bioferdoman base fertilizer. Planting uses hybrid corn seeds at a rate of 15–18 kg per hectare, with planting spacing adjusted according to the planting pattern used. Crop maintenance includes thinning, soil and foliar fertilization, weed control, and periodic pest and disease control. Soil fertilization using NPK Phonska and urea is carried out during several growth stages, while foliar fertilizer is applied periodically to support plant development. Pest and disease control is carried out based on the growth stage and severity of infestation, including control of shoot caterpillars as well as stem rot and ear rot. During the grain-filling stage, soil moisture levels and pest infestations are monitored. Crops are harvested approximately 112 days after planting (DAP) based on physical characteristics indicating harvest readiness. The following is an SOP guide for farmers:

Table 1. Standard Operating Procedures for Corn Cultivation Using Bioferdom Fertilizer

Planting Age (HST)	Stages	Summary of Activities
-10 HST	Land Management/Sanitation	Tilling and weed control using systemic herbicides when soil conditions permit.
-7 HST	Basal Fertilization	Apply 1–2 metric tons of Bioferdoman per hectare by spreading it over the soil, mixing it in, and then letting it sit for approximately one week.
0 HST	Planting	Use hybrid corn seeds at a rate of 15–18 kg/ha and various planting-distance options depending on growing conditions.
7 HST	Embroidery	Replace plants that are not growing or developing properly within 7 days of planting
8 HST	Foliar Fertilization	Application of foliar fertilizer by spraying.
14 HST	First Fertilization	Application of NPK Phonska and urea to support early plant growth.
16 HST	Pest Control I	Control of shoot caterpillars to prevent plant damage.
20 HST	Weed Control & Bioferdoman	Apply a selective herbicide and spray Bioferdoman in a band if it has not already been applied as a base fertilizer.
25 HST	Second Fertilization	Application of NPK Phonska and urea to support growth as the plant enters the generative phase.
32 HST	Foliar Fertilization	Application of foliar fertilizer by spraying.
35 HST	Pest Control II	Control leaf-feeding caterpillars as needed.
49 HST	Third Fertilization	Application of NPK Phonska and urea to support plant growth as it enters the generative phase.
55 HST	Foliar Fertilization	Application of MKP, magnesium sulfate, or liquid organic fertilizer containing potassium.
65 HST	Pest Control III	Control of caterpillars and diseases such as stem rot and ear rot, depending on the severity of the infestation.
70 HST	Booster	The use of a growth booster to promote seed weight gain is conditional.
70-80 HST	Monitoring	Monitoring of groundwater conditions and pest infestations during the seed-filling period.
112 HST	Harvest	Harvesting is carried out when the plants/corn have exhibited the physical characteristics appropriate for harvesting.

In addition, the implementation of the Farmer Field School (FFS) based on location-specific needs significantly reconstructed the cognitive knowledge landscape of farmers in Kayowa Village. Prior to the program intervention, farmers' technical understanding of cultivation principles was low, as indicated by a mean pre-test score of 40.0. However, following participatory learning via the FFS, a significant cognitive acceleration occurred, with the mean post-test score surging to 77.8 (Wilcoxon signed-rank test, $p < 0.001$). The learning effectiveness was further reinforced by a Normalized Gain (N-gain) score of 0.63, falling into the moderate improvement category. This cognitive growth was consistent across all participants; no farmers fell into the low N-gain category, with 18 farmers (75%) achieving a moderate increase and 6 farmers (25%) achieving a high increase.

The dynamics of cognitive enhancement showed interesting variations when broken down by training module. The detailed structure of changes in farmers' cognitive knowledge across the five modules is presented in Table 2 below.

Table 2. Farmers' knowledge scores before and after the farmer field school

Module	Pre-test (Mean $\pm$ SD)	Post-test (Mean $\pm$ SD)	Increase (Points)	N-gain
Plant nutrition and fertilization	36,2 $\pm$ 14,4	79,6 $\pm$ 11,2	43,3	0,69
Farm economic analysis	41,7 $\pm$ 5,6	82,1 $\pm$ 10,2	40,4	0,70
Integrated pest and disease management	38,8 $\pm$ 11,9	78,3 $\pm$ 12,7	39,6	0,66
Natural resource utilization for alternative fertilizers	31,7 $\pm$ 8,2	65,4 $\pm$ 12,5	33,8	0,50
Corn SOP adoption	51,7 $\pm$ 11,7	83,3 $\pm$ 7,0	31,7	0,65
Average across five modules	40,0 $\pm$ 6,5	77,8 $\pm$ 7,9	37,8	0,63

Based on data in Table 2, the highest cognitive gains were observed in the Plant Nutrition and Fertilization module (N-gain = 0.69) and the Farm Economic Analysis module (N-gain = 0.70). The substantial increase in these two modules indicates that aligning instructional material directly with practical field problems and daily financial outcomes served as the primary driver of learning motivation among farmers. Conversely, the Natural Resource Utilization and Biosulfur Innovation module recorded the lowest post-test score (65.4) and an N-gain of 0.50. This reflects cognitive abstraction barriers, as converting industrial gas waste into agricultural inputs was a novel concept for local farmers. Meanwhile, the SOP Adoption module had the highest baseline score (51.7),

indicating that reference cultivation knowledge was already passively known by farmers, but required external momentum to be converted into concrete action.

This cognitive transformation achieved through a needs-based curriculum confirms that the FFS approach successfully moves beyond rigid, conventional extension methods. When curriculum content is derived from diagnosing real field vulnerabilities, farmers feel valued and absorb information more readily due to its high relevance. These findings align with studies by (Jabbar et al., 2022; Nuzuliyah, 2022), which emphasize that field-based experiential learning significantly accelerates the assimilation of new knowledge.

This expansion in cognitive capacity directly translated into the institutionalization of field technical behaviors. Aggregate adoption across all 14 standard corn cultivation SOP stages increased sharply from 19.9% prior to the program to 85.1% post-program (Wilcoxon signed-rank test, $p < 0.001$). This behavioral shift demonstrates that farmers progressed beyond the "knowing" phase to the "doing" and internalizing phases of precision farming principles.

The most transformative changes occurred in steps that were almost entirely ignored during the pre-intervention period. Precision planting using a 70×20 cm spacing, IPM based on "6 right" principles, second-stage follow-up fertilization, and foliar fertilizer application surged from sub-15% adoption rates to 100% full compliance. While initial fertilization was already practiced by all farmers (100%) from the beginning, dosage precision and procedural accuracy met standard SOP criteria only after completing the training.

Nevertheless, the adoption of these innovations was not uniform across all SOP components. Three technical steps require ongoing evaluation: replanting (*penyulaman*) was practiced by only 21% of farmers due to labor allocation trade-offs; third follow-up fertilization was not recommended and thus not applied (0%); and precision harvesting procedures did not fully reach quality benchmarks. Furthermore, a significant portion of recorded changes remained at the "applied" level rather than fully achieving the "SOP compliant" benchmark.

These dynamics highlight that farmers act as rational decision-makers who adopt innovations selectively while weighing capital constraints, labor availability, and financial risks. Consequently, this adoption phase requires ongoing institutional support to solidify these new habits into a permanent farming culture.

In addition to social learning via the FFS, the success of the cultivation intervention was supported by technical-agronomic validation of the biosulfur fertilizer (Bioferdom) on experimental plots. Field trials confirmed that inorganic NPK availability remained the primary determinant governing vegetative corn growth dynamics across all observation periods. A summary of biosulfur effects on vegetative growth variables is shown in Table 2.

Table 3. Summary of ANOVA results for the biosulfur factor in research plots

Variable	2 WAP	4 WAP	6 WAP	8 WAP
Plant height	Not significant	Not significant	Significant (p = 0,0002)	Significant (p = 0,0015)

Stem diameter	Not significant	Not significant	Not significant	Not significant
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(Note: WAP = Weeks After Planting)

As shown in Table 3, the biosulfur factor yielded a statistically significant response for plant height during the critical phases of 6 WAP ($p = 0.0002$; partial $\eta^2 = 35.9\%$) and 8 WAP ($p = 0.0015$; partial $\eta^2 = 30.1\%$). In contrast, biosulfur effects on stem diameter were not statistically significant throughout the observation period. Furthermore, statistical analysis revealed no significant interaction between NPK and biosulfur (NPK $\times$ Biosulfur), indicating that biosulfur operates additively (complementary) with NPK rather than synergistically during early vegetative stages.

At 8 WAP, combining a 75% NPK substitution with biosulfur doses of 50–100% produced plant heights reaching 151.7–156.9 cm. This growth performance surpassed the control treatment (100% NPK without biosulfur), which reached only 130.0 cm, while maintaining comparable stem diameters (25.5–25.9 mm vs. 25.4 mm in control). Polynomial regression modeling indicated that the optimal NPK dose when combined with 1 ton/ha of biosulfur ranged between 81–91%, implying a potential reduction in NPK fertilizer usage of 9–19% (45–95 kg/ha).

However, biosulfur does not serve as a complete substitute for NPK. Under low NPK conditions (25% and 0%), plant growth remained stunted despite high biosulfur applications. Microbiological laboratory testing revealed a *Penicillium* sp. abundance of 1.25×10^3 cfu/g, which is relatively low for an active bio-fertilizer. Consequently, Bioferdom's main benefits lie in improving soil chemical and physical properties via sulfur supplementation and organic matter addition. Bioferdom is best positioned as a complementary fertilizer that enhances NPK nutrient uptake efficiency (Kurniawati et al., 2023).

The synergy between knowledge accumulation, improved SOP compliance, and efficient biosulfur application translated directly into enhanced production capacity and financial resilience. Total corn yield across the 24 participating farmers rose from 43.4 tons to 82.2 tons over the same aggregate land area (44 ha). Mean productivity surged from 0.99 tons/ha to 1.87 tons/ha, representing an increase of +89.4% (Wilcoxon signed-rank test, $p < 0.001$).

This productivity boost generated positive economic impacts across cost structures, gross revenue, and net profit. Overall changes in financial indicators are summarized in Table 3.

Table 4. Changes in productivity and farm economics

Indicator	Before	After	Change
Productivity (tons/ha)	0,99	1,87	+89,4%
Total production cost (IDR million)	174,8	198,6	+13,6%
Total revenue (IDR million)	220,6	417,6	+89,3%

Total net profit (IDR million)	45,8	219,0	+378,6%
R/C ratio	1,26	2,10	+0,84
Unprofitable farmers (R/C < 1)	10 orang	1 orang	−9 orang

Data in Table 4 indicate that total production costs increased by only a marginal 13.6% (allocated primarily to follow-up and foliar fertilizers), yet triggered an 89.3% surge in gross revenue under stable selling prices. This drove an aggregate net profit gain of +378.6%, as reflected in the improved financial efficiency index (R/C ratio) from 1.26 to 2.10. Most critically, the number of farmers operating at a financial loss ($R/C < 1.0$) dropped from 10 individuals before the intervention to just 1 individual post-intervention.

Overall, these outcomes demonstrate the success of a holistic intervention package merging social-cognitive transformation via field schools with agronomic innovations via biosulfur fertilizer. Knowledge gains drove disciplined SOP adoption in the field, which was subsequently optimized by corn crops through biosulfur nutrient support. Ultimately, this process transformed subsistence corn farming in Kayowa Village into a more profitable, efficient, and competitive enterprise.

CONCLUSION

The implementation of a needs-based Farmer Field School (FFS) effectively promoted experiential learning and capacity building among corn farmers in Kayowa Village, Banggai Regency. This improvement was demonstrated by a significant increase in average knowledge scores from 40.0 to 77.8, with a normalized gain (N-gain) of 0.63. The greatest improvements were observed in the plant nutrition and fertilization modules. These gains in agricultural knowledge were accompanied by increased farmer engagement and greater adherence to standard operating procedures (SOPs) for corn cultivation, with adoption rates rising from 19.9% to 85.1%. The most substantial improvements in cultivation practices were observed in planting distance management, supplemental fertilizer application, foliar fertilization, and integrated pest management.

From an agronomic perspective, the application of Bioferdom biosulfur fertilizer demonstrated potential as a complementary nutrient source when combined with nitrogen, phosphorus, and potassium (NPK) fertilizers. Experimental findings indicated that applying 75% of the recommended NPK fertilizer rate in combination with 75–100% of the designated biosulfur application rate resulted in vegetative growth comparable to that achieved with 100% NPK fertilizer without biosulfur supplementation. These findings suggested potential NPK fertilizer cost savings of 9–19%, although further economic assessment would be required to confirm these estimates. Nevertheless, Bioferdom functioned as a supplementary sulfur source and soil amendment rather than a complete replacement for conventional NPK fertilizers.

The integration of the needs-based Farmer Field School with Bioferdom fertilizer application generated economic, social, and environmental benefits, contributing to agricultural productivity and the economic resilience of participating farmers. Corn productivity increased from 0.99 to 1.87 metric tons per hectare, representing an 89.4% improvement, while the revenue-to-cost (R/C) ratio increased from 1.26 to 2.10. Additionally, the number of farmers experiencing financial losses decreased from 10 to 1, indicating improved economic outcomes among program participants. Beyond these productivity and financial improvements, the program integrated adult learning principles and community empowerment with circular economy practices by promoting the conversion of industrial by-products into agricultural inputs. These findings highlighted the potential of combining participatory agricultural education with resource recovery-based fertilizer innovations to support more sustainable corn farming practices.

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