The effect of fertilization and variety on maize productivity in two tillage systems in North Sumatra

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Abstract. Maize is the second crucial food crop commodity that has great potential to develop in North Sumatra. The study's objective is to determine maize production is influenced by fertilization and varieties under two tillage systems. The experiment is conducted in Batu Mamak Village, Juhar Sub-District, Karo District period March-August 2019. The three factorial experiments are tillage systems (non-tillage and conventional), fertilization (soil test kid (STK), site-specific nutrient management (PuJS), and farmers practice (FFP), and variety (Bima 2, Bima 20, JH-27, Nasa-29, NK 22, P23). Each treatment is replicated four times using a randomized complete block design with a plot size is 25 m². The result showed that a non-tillage system with the PuJS increased grain yield by 1.1% and 21.3% compared to PuJS and FFP on the tillage system, respectively. The existing variety was still dominant compared to the newly introduced types supported by total dry matter, harvest index, and 100 grains. Bulk density was inversely related to all components was inversely associated with Ksat (infiltration). The application of organic fertilizers with a non-tillage system can increase Ksat and grain yield and provide benefits to farmers of IDR22,778,591 with a B/C ratio of 1.36.

1. Introduction
Maize is the second important source of carbohydrate and protein used for food, feed, and industrial in Indonesia. As the 4th maize producer in Indonesia, North Sumatra experienced an increase in harvested area and production by 23.7% and 22.5% in 2019, respectively, compared to 2015 [1]. Karo District is one of the center maize production that can contribute 31.9% in 2019. Cultivation components such as variety, fertilization, plant population, tillage system, and pest and disease control significantly contribute to increasing maize production in North Sumatra.

Further, the use of new, improved varieties is one way to increase maize production [2]. The characteristics of high-yielding varieties are high yield and quality. Based on [3], around 80% of farmers in the maize center in North Sumatra used hybrid maize such as NK, Pioneer, Bisi, Bioseed, and Pertiwi, while the rest is a local variety and sweet maize. According to [4], hybrid maize varieties have higher production than local or composite varieties. Since 2005 seed aid has been in the form of a hybrid like Bisi 816, P27, DK 7722, NK 6325 Pertiwi-3, SHS-4, etc. [5] stated that hybrid varieties are 27.4% and 33.1% higher than local varieties and composites.

As the second important component, the fertilizer application at the maize center in North Sumatra is relatively high, around 800-1,000 kg ha⁻¹. It is incomparable with the mean production of only 7-8 t ha⁻¹ [3]. They need fertilizer to produce 1-ton grains is 16.7 kg N; 3.8 kg P; and 11.4 kg K; thus, the
need to produce 7-8 ton ha\(^{-1}\) grains are 9-133.6 kg N; 26.6-30.4 kg P; and 79.8-91.2 kg K \([6]\) or equivalent to 461.0-526.9 kg.

In general, farmers in maize centers cultivate the land with heavy equipment such as four-wheeled tractors right after harvest, aiming to loosen the soil, reduce weeds, and prepare for planting. Based on \([7]\), soil cultivation systems can cause plants to experience drought due to evaporation. Furthermore, the loss of soil organic carbon was more significant with complete soil cultivation than stubble burning \([8]\). Because of the problems faced at the maize center in North Sumatra, it is necessary to conduct research to obtain the best production of several varieties and fertilize the two types of tillage at the maize center in North Sumatra.

2. Methods

2.1. Research site
The research was conducted in the period 23 March-25 July 2019 (± 125 days after planting/DAP) at maize centers in Batu Mamak Village, Juhar Sub-District, Karo District, North Sumatra (30° 2’ 16” South Latitude and 98° 25’ 18” East Longitude, altitude 700 masl). Soil types in the study location were included in the Andic Eutrudept family level \([9]\). The soil analysis results using STK and laboratory analysis showed that the soil pH was slightly acidic (pH 5-6), with high P\(_2\)O content, low organic matter, and clay loam texture.

2.2. Research design
The study used a randomized complete block design in which tillage and fertilization were used as blocks and varieties to obtain a combination of 36 treatments with four replications. Tillage consists of two, namely without tillage and conventional fertilization, consisting of the soil test kit (STK), site-specific maize fertilization (PuJS), and farmer methods. The varieties used were hybrid products of the Agricultural Research and Development Agency and the private sector consisting of Bima-2, Bima-20, JH-27, Nasa-29, NK-22, and P-23. Generally, the experience of farmers farming maize in this location is more than ten years with a cropping index of 2-2.5 (maize-maize-maize).

2.3. Plant management
The plant management and other agricultural inputs were the same, except for fertilizers, varieties, and tillage based on the treatment. Tillage systems are two types, namely 1) non-tillage, only used herbicides before planting and plant maintenance; 2) conventional using a four-wheeled tractor twice, then flattened until ready for planting. The varieties used were Bima-2 (± 100 days after seedling = DAS), Bima-20 (± 102 DAS), JH-27 (± 98 DAS), Nasa-29 (± 103 DAS), NK-22 (± 98 DAS), and P-23 (± 95 DAS) which has been mixed with a fungicide with active metalaxy ingredients which aims to protect the seeds from ant attack and downy mildew at the beginning of plant growth. The spacing used is 70 x 40 cm with two plants per hill. Fertilization application three times, namely 7, 30 and 45 DAS for STK and PuJS, while the FFP treatment was twice at 15 and 40 DAS. Fertilization consists of 161 kg ha\(^{-1}\) N; 36 kg ha\(^{-1}\) P\(_2\)O\(_5\), 60 kg ha\(^{-1}\) K\(_2\)O; 2-ton ha\(^{-1}\) organic fertilizer for STK; 195.5 kg ha\(^{-1}\) N; 9 kg ha\(^{-1}\) P\(_2\)O\(_5\), 30 kg ha\(^{-1}\) K\(_2\)O; and 2-ton ha\(^{-1}\) of organic fertilizer for PuJS; while the farmer treatment was applied twice, consisting of 191.5 kg ha\(^{-1}\) N; 151.5 kg ha\(^{-1}\) P\(_2\)O\(_5\), 37.5 kg ha\(^{-1}\) K\(_2\)O, and 1,000 kg dolomite.

2.4. Soil analysis
Analysis of the chemical and physical properties of the soil was carried out on-site using a soil test kit. In contrast, the soil permeability (Ksat = cm hour\(^{-1}\)) was measured using a double ring in each direct treatment at the research location until it reached a stable condition \([10]\). Soil texture (%) using the hydrometer method, bulk density (g cm\(^{-3}\)) with soil sampling using the ring sample method. Soil texture analysis was carried out at the North Sumatra AIAT laboratory.
2.5. Observations
Observations include plant growth and production, which consist of yield and production components. Growth observations had chlorophyll, plant height, and biomass at two rows x 0.8 m (1.4 m x 0.8 m), yield components such as plant height (cm), biomass (kg), the weight of 100 seeds (g), and harvest index on two rows x 0.8 m (1.4 m x 0.8 m), while for production measuring 5.88 m² (2.1 m x 2.8 m). Plant observations and processing were carried out in the field and the Pasar Miring Experimental Station.

2.6. Data analysis
Data for each and the combination of treatment observed were analyzed using the Statistical Tool for Agricultural Research (STAR). The Tukey-Kramer test (Honest Significant Difference or HSD) was used to compare treatment means based on a 5% probability level. Pearson's correlation coefficient for parameters measured using STAR. Significance at the 0.05 probability level; 0.01; and 0.001 are indicated by *, **, and ***, respectively. Agronomic costs are analyzed by comparing net income to costs (B/C ratio). Secondary data is in the form of climate data produced by [11].

3. Results and discussion
3.1. Climate
Maize centers in North Sumatra are in the lowland to highlands with a varied climate. Based on [12], the highly suitable climate category for maize is a mean temperature of 21-26°C, annual rainfall 1,200-1,500 mm, wet months (> 200 mm/month) 3-5. Table 1 shows the climatic data at each stage of growth of the maize plant that has met the growing requirements above. Based on the daily climate during the planting season (figure 1), the plants begin to experience drought at 36 to 53 days after planting (V10-VT) even though several rainy days are averaging 1 mm except on May 5, 2019 at 19 mm. The farmers' habit of full-tillage, stubble burning, and no application of organic matter cause the leaves to roll in this phase. Water stress during tasseling has an impact on decreasing the leaf area index, which affects the photosynthesis process [13], inhibition of the emergence of silking, and delays in the maturation period [14] and decreased yields [15]. The presence of high rainfall on days 54-56 at 18, 40 and 41 mm respectively and the optimum rainfall per ha during the planting period of 82 mm resulted in surface runoff (erosion), especially at full-tillage. [16] stated that minimum tillage could increase soil organic matter and wet aggregate stability. Furthermore, 60% decreased sediment delivery with organic farming using minimum tillage [17].

| Table 1. The number of days, mean temperature, maximum and minimum temperature, total rainfall, and humidity based on growth stages in DS 2019. |
|---------------------------------|--------|--------|--------|--------|--------|
| Parameter                      | Sowing-V6 | V6-V10 | V10-VT | VT-Maturity | Total   |
| Number of days                 | 18.8    | 19.3   | 19.3   | 19.2   | 19.2   |
| Mean temperature (°C)          | 18.8    | 19.3   | 19.3   | 19.2   | 19.2   |
| Maximum temperature (°C)       | 23.9    | 23.9   | 24.2   | 24.2   | 24.1   |
| Minimum temperature (°C)       | 15.7    | 16.0   | 16.6   | 16.3   | 16.1   |
| Total rainfall (mm)            | 332.0   | 520.0  | 208.0  | 258.0  | 1,318.0|
| Humidity (%)                   | 91.7    | 89.3   | 90.3   | 87.9   | 89.8   |

Note: The source of data from Meteorology, climatology, and geophysical agency.
3.2. Yield components and grain yield

The effect of tillage system and varieties on plant height, total dry matter (TDM), and SPAD readings are shown in table 2 while effecting of fertilizer in table 3. Both tables show that there are three dominant varieties in all phases, namely P23 (at V6 and Maturity in non-tillage), NK-22 (at V10 in non-tillage), and Nasa-29 (at Maturity in conventional), and showed significant differences from other varieties. Variety plays a significant role in growth and production [18] and the third important component after labor and fertilizer in maize farming [19]. Furthermore, STK and PuJS fertilization recommendations showed the highest values in the V10 phase and physiological maturity and were significantly different from FFP treatment (table 3).

At the beginning of plant growth (phase V6), the variable total dry matter (TDM) has not shown superior varieties even though statistically shows a significant difference where the lowest is Bima-2 and JH-27 varieties, but in the V10 and maturity phase is dominated by Nasa-29, NK-22, and P-23 (table 2). It is supported by other yield components such as 100 grains, grain yield, HI, and HI cobs. On the other hand, fertilization with PuJS and STK on growth and yield parameters (table 3) shows how important organic matter to increase maize productivity in North Sumatra. The addition of 2-ton ha\(^{-1}\) of organic fertilizer on both recommendations has had a positive impact starting from phase V10 to maturity. Inorganic fertilizers without being balanced with organic fertilizers on the area that is continuously burning stubble impacts decreasing land quality and production. [20] stated that the combination of organic and inorganic fertilizers significantly increases biomass, carbon fixation, and grain yield.

The habit of farmers in the research location is to add inorganic fertilizers every year without applying organic fertilizers. After harvesting, the stubble is burned and processed to be ready for planting. Short fallow time (1-2 weeks) to produce a cropping index of 2-2.5 results in decreased soil organic content and maize production. [21] stated that the burning of crop residues reduces carbon stocks in the soil. Furthermore, the loss of soil organic content reached 1.73 ton C ha\(^{-1}\) during 19 years of stubble burning at a depth of 0-10 cm [22].

Another factor during the research period was the increase in pests and diseases at the research site due to climate change. Preventive action has been taken from the start so that attacks are only on a low scale at the research location. Based on [23] and [24] that the peak of FAW attacks in North Sumatra in April 2019 (DS) was to flowering plants, which resulted in a decrease in production by 26.6%. Other studies suggest that the spread of FAW is speedy and causes a loss of one-third of annual maize production or 1 million tons [25].
Table 2. Effect of tillage system and varieties on yield components, grain yield, and soil physical properties.

| Treatment | Plant Height (cm) | TDM (kg ha⁻¹) | 100 grains (gr) | Grain yield (t ha⁻¹) | HI (kg kg⁻¹) | Cobs HI (kg kg⁻¹) |
|-----------|------------------|---------------|----------------|----------------------|-------------|-------------------|
|           | V10 Maturity     |               | V6 V10 Maturity |                      |             |                   |
| NT C      | NT C             |               |                |                      |             |                   |
| Bima-2    | 140.2 bc         | 143.6 a       | 228.4 b        | 236.8 b              | 1.0 c       | 3.4 b             | 11.6 c           | 32.8 bc         | 6.3 b           | 0.399 c         | 0.809 abc       | 0.748 a         |
| Bima-20   | 128.3 c          | 147.7 a       | 230.6 b        | 212.5 c              | 1.2 abc     | 3.4 b             | 11.4 c           | 33.1 abc        | 6.4 b           | 0.402 c         | 0.785 bc        | 0.733 a         |
| JH-27     | 140.9 abc        | 154.7 a       | 226.7 b        | 229.8 bc             | 1.1 bc      | 3.4 b             | 12.2 bc          | 32.5 c          | 5.9 b           | 0.424 bc        | 0.753 c         | 0.729 a         |
| Nasa-29   | 148.0 abc        | 151.3 a       | 247.6 ab       | 263.6 a              | 1.2 ab      | 4.2 a             | 15.7 abc         | 34.3 abc        | 7.7 a           | 0.455 ab        | 0.828 ab        | 0.743 a         |
| NK-22     | 168.6 a          | 136.5 a       | 250.8 ab       | 233.8 bc             | 1.3 a       | 4.3 a             | 15.0 a           | 34.7 ab         | 8.2 a           | 0.485 a         | 0.864 a         | 0.770 a         |
| P-23      | 165.8 ab         | 134.7 a       | 266.7 a        | 248.8 ab             | 1.2 abc     | 4.5 a             | 14.8 ab          | 34.9 a          | 7.9 a           | 0.463 a         | 0.827 ab        | 0.749 a         |

Within rows for a given parameter, means followed by the same upper-case letter are not significantly different according to Tukey–Kramer (0.05).

Table 3. Effect of fertilizer application on yield components, grain yield, and soil physical properties.

| Treatment | Plant height (cm) | TDM (t ha⁻¹) | SPAD Reading | 100 grains (g) | Grain yield (t ha⁻¹) | HI (kg kg⁻¹) | Cobs HI (kg kg⁻¹) |
|-----------|------------------|---------------|--------------|----------------|----------------------|-------------|-------------------|
|           | V10 Maturity     |               | V6 V10 Maturity | V6 V10 VT      |                      |             |                   |
| NT FT     | NT FT            |               | NT FT        |                |                      |             |                   |
| STK       | 152.0 a          | 243.3 a       | 241.0 b      | 1.2 a          | 4.0 a                | 13.2 b      | 35.1 ab           | 32.3 b          | 40.8 b          | 47.1 ab         | 33.8 b          | 7.0 b           | 0.433 b         | 0.779 b         |
| PuJS      | 155.0 a          | 250.7 a       | 256.2 a      | 1.3 a          | 4.3 a                | 14.6 a      | 36.9 a           | 35.7 a          | 42.0 a          | 48.8 a          | 35.5 a          | 7.6 a           | 0.465 a         | 0.815 a         |
| Farmers   | 133.1 b          | 231.4 b       | 215.5 c      | 1.0 b          | 3.3 b                | 11.5 c      | 32.7 b           | 32.0 b          | 37.5 c          | 45.8 b          | 31.9 c          | 6.1 c           | 0.417 b         | 0.741 c         |

Within rows for a given parameter, means followed by the same upper-case letter are not significantly different according to Tukey–Kramer (0.05).
A further positive thing is the non-tillage system with the addition of organic matter is very helpful in reducing BD and increasing Ksat at harvest time. Table 4 shows the first non-tillage on DS with the addition of organic matter increased the mean production by 0.2 t ha\(^{-1}\) with the HI and cobs HI of 0.479 and 0.809, respectively, which were statistically significantly different from conventional. The combination of organic matter and inorganic fertilizers is beneficial in improving the physical and chemical properties of the soil. The clay loam texture and uneven rainfall can store water at non-tillage, where it becomes a reserve when the dry season comes. [26] state that treatment without tillage conserves soil and water, reduces machine use, and increases production. [27] stated that an increase in production occurred from the second season and showed a very strong correlation \((r = 0.83, p < 0.01)\) was found between the yield and tillage systems.

| Treatment          | Grain yield (t ha\(^{-1}\)) | HI (kg kg\(^{-1}\)) | Cobs HI (kg kg\(^{-1}\)) |
|-------------------|----------------------------|---------------------|--------------------------|
| Non-tillage (NT)  | 7.0 a                      | 0.479 a             | 0.809 a                  |
| Conventional (C)  | 6.8 b                      | 0.397 b             | 0.748 b                  |

Within rows for a given parameter, means followed by the same upper case letter are not significantly different according to Tukey–Kramer (0.05).

3.3. The relationship between soil and plant

Table 5 shows the relationship between yield components, grain yield, and soil physical properties. The negative correlation shown by BD to all features is inversely related to Ksat that has a positive correlation to yield components and grain yield. The decrease BD due to the addition of organic matter [28] was inversely related to grain yield \((P < 0.001)\) [29] and was a significant increase \((p < 0.05)\) in all growth and yield parameters [30]. A positive correlation is shown among yield components, where grain yield increases with increasing TDM, HI, cobs HI, and 100 grains. The strongest correlation grain yield with 1000-kernels weight \((P < 0.01)\) [31] can be used as a determining factor for high production, namely ears plant\(^{-1}\), grains ear\(^{-1}\), and 1000 grain weigh [32].

| Relationship            | TDM  | HI  | Cob HI | 100 grains | BD   | Ksat* |
|-------------------------|------|-----|--------|------------|------|-------|
| Grain yield (t ha\(^{-1}\)) | 0.66*** | 0.48* | 0.54** | 0.38* | -0.54** | 0.37*  |
| TDM (t ha\(^{-1}\))     | 0.51** | 0.65*** | 0.47* | -0.51** | 0.52** |
| HI (kg kg\(^{-1}\))     | 0.60*** | 0.41* | -0.65*** | 0.40* |
| Cob HI (kg kg\(^{-1}\)) | 0.55** | -0.67*** | 0.59*** |
| 100 grains (g)          | -0.48* | 0.60*** |
| BD (g cm\(^{-1}\))      | -0.50** |

*, **, and *** denote significance at the probability level of 0.05, 0.01, and 0.001, respectively, data from 144 samples.

3.4. Farming analysis

Analysis of maize farming in two tillage systems and three fertilizer recommendations (table 6) shows the labor costs are the highest, followed by land rent costs. The third highest price is fertilizer for the farmer’s treatment, while the other treatment is seeds, followed by loan interest costs and land tax. Table 6 shows that the highest production is non-tillage with PuJS treatment at 7,612 t ha\(^{-1}\), which is 1.1% higher (non-significant difference) than PuJS with tillage. It could be an excellent opportunity to reduce the production gap between yield potential and actual yields of maize in North Sumatra. [33] stated that the maize production gap in Indonesia is 5 t ha\(^{-1}\). Furthermore, [34] stated that profitability increased by 15% \((\geq \text{US$100 ha}^{-1} \text{per season})\) in rainfed land and reduced the yield gap in Southeast Asia.
On the other hand, non-tillage costs are lower than tillage because there is a reduction in land cultivation costs, but there are additional pesticide costs. These two methods still provide advantages based on the tillage system because the lowest R/C ratio is 1.86. The cost-efficiency of the non-tillage method balanced with applying organic fertilizers in the STK and PuJS treatments is an important aspect of this research. According to [35] stated, farmers' profit with zero tillage compared to conventional is USD 97.5 ha\(^{-1}\) with a B/C ratio of 1.43.

### Table 6. Analysis of maize farming for two tillage systems and three fertilizer recommendations.

| Component        | Conventional | Non-Tillage |
|------------------|--------------|-------------|
|                  | STK          | PuJS        | FFP          | STK          | PuJS        | FFP          |
| Seeds            | 1,720,000    | 1,720,000   | 1,720,000    | 1,720,000    | 1,720,000   |
| Inorganic Fertilizer | 1,346,667   | 1,202,500   | 2,091,359    | 1,346,667    | 1,202,500   | 2,091,359    |
| Organic Fertilizer | 1,250,000   | 1,250,000   | 1,250,000    | 1,250,000    | 1,250,000   |
| Dolomite         |              | 710,000     |              | 710,000      |
| Pesticide        | 920,000      | 920,000     | 920,000      | 1,070,000    | 1,070,000   |
| Labor            | 5,930,130    | 6,199,945   | 5,202,292    | 5,260,040    | 5,426,332   |
| Land tax         | 150,000      | 150,000     | 150,000      | 150,000      | 150,000     |
| Land rent        | 5,000,000    | 5,000,000   | 5,000,000    | 5,000,000    | 5,000,000   |
| Loan interest    | 987,000      | 987,000     | 987,000      | 987,000      |
| Total cost       | 17,303,797   | 17,429,445  | 16,780,650   | 16,783,707   | 16,805,832  |
| Yield (kg)       | 6,834        | 7,526       | 5,993        | 7,186        | 7,612       |
| Selling price (IDR/kg) | 5,200     | 7,526       | 5,993        | 7,186        |
| Gross income     | 35,535,067   | 39,132,600  | 31,163,889   | 37,367,200   | 39,584,422  |
| Net income       | 18,231,270   | 21,703,155  | 14,383,239   | 20,583,493   | 22,778,591  |
| R/C ratio        | 2.05         | 2.25        | 1.86         | 2.23         | 2.36        |
| B/C ratio        | 1.05         | 1.25        | 0.86         | 1.23         | 1.36        |

Note: *) The values used are rounded. **) The average cost is calculated for 144 samples.

### 4. Conclusions

Increasing maize production is an effort to minimize the gap between potential and actual results. For varieties, farmers in maize centers in North Sumatra are hybrid-minded and dominated by Pioneer and NK varieties compared to national products. Farmers carried out the increase in production by increasing fertilizers with conventional tillage, which resulted in a stagnant production even a decline. The results show that the Pioneer and NK hybrid varieties could be balanced with Nasa-29 with the recommendation for PuJS and STK fertilization to apply 2 t ha\(^{-1}\) of organic fertilizer. This condition can reduce soil BD and is inverse to Ksat and grain yield and yield components.

Furthermore, non-tillage is the right choice in reducing erosion due to surface runoff, resulting in reduced production. Although the increase in yield with non-tillage using the PuJS recommendation was only 1.1%, it gave farmers a profit of IDR22,778,591 with a B/C ratio of 1.36 due to the efficiency of land processing and fertilization costs compared to farmers' methods.

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