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Assessing soil conservation techniques on sloping lands in the humid tropics area of Indonesia in the context of maize cultivation

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Abstract. *Neswati R, Abdullah S, Musa Y, Nasaruddin. 2023. Assessing soil conservation techniques on sloping lands in the humid tropics area of Indonesia in the context of maize cultivation. Biodiversitas 24: 1686-1692.* Sloping land is prone to severe erosion, particularly in areas with high precipitation, such as in humid tropics. In addition to slope and rain factors, crop management also influences soil erosion. This research aims to identify the most appropriate techniques to mitigate soil erosion by comparing three different techniques of maize (*Zea mays* L.) cultivation planted on sloping land in Indonesia's humid tropics. A field experiment was conducted in Gorontalo Regency, Gorontalo Province, Indonesia, in three maize growing seasons at a location with a slope of 15-30%. We used a split-plot design in a randomized block design, with the main factor being conservation techniques, namely no treatment (control) (K0), contour terrace (K1), strip cropping using *Pennisetum purpureum* Schumach. (K2) and alley cropping using *Gliricidia sepium* (Jacq.) Kunth (K3), and the side factor was *Z. mays* of two varieties: composite variety Arjuna BC (H1) and hybrid variety NK-33 (H2). The effects of each treatment were measured in term of soil erosion, and maize growth and productivity. The results showed that the strip cropping resulted in a lower erosion level compared to the contour terrace and alley cropping. However, erosion still exceeded the tolerable soil loss in all conservation techniques. The effects on the growth and production of maize of the two varieties in growing seasons 1, 2, and 3 were not statistically different ($p<0.05$). Maize production can reach >6 tons ha-1 in the two varieties planted and the value of the revenue to cost (R/C) ratio of all treatments ranged between 1.77 and 2.54. The results imply that the application of appropriate soil conservation methods has the potential to reduce erosion in the sloping land-humid tropics of Indonesia without compromising growth and productivity. However, it will take a longer period to reduce soil erosion significantly in a maize-based cultivation system on sloping land.

Keywords: Alley cropping, humid tropics, strips cropping, terraces, tolerable soil loss

INTRODUCTION

Soil and water serve as the basic resources for living organisms, as well as the main support system for nutrients and water cycle (Teague and Kreuter 2020). In the context of agriculture, crop productivity is closely related to the availability of soil and water as a medium for plant growth and development (Gerland et al. 2014; Karlen et al. 2014; Karlen and Rice 2015). Currently, there is a large extent of degraded lands which most of it has been classified as damaged or critical. Land degradation is considered a global problem due to its occurrence across the world (DeLong et al. 2015; Gomiero 2016). Soil degradation can be in many forms, including erosion, salinization and loss of organic matter (DeLong et al. 2015). The manifestations of soil degradation are as diverse as the causes with erosion being the most common type of land degradation (Troeh et al. 1991; Oldeman 1997).

Erosion is a type of soil degradation that occurs when soil is exposed to water or wind energy (Pimentel and Burgess 2013). In many cases, it is caused by a poor agricultural land management (Gomiero 2016; Sitorus and Pravitasari 2017). According to Montgomery (2007), conventional agricultural practices can cause a higher erosion rate at one to two orders of magnitude compared to natural conditions. Annual erosion rates under natural conditions are 0.0045 $t.ha^{-1}$ for areas of moderate slope and 0.45 $t.ha^{-1}$ for areas of a steep slope. Conversely, erosion rates of agricultural land range from 45 to 450 $t.ha^{-1}$ (Morgan 2005). Erosion can reduce crop yields by 30% to 90%, and in the United States, erosion can cause crop yield reductions of 20% to 40% (Gomiero 2016; Panagos et al. 2018).

Conservation techniques such as strip cropping, alley cropping and contour terracing can help overcome erosion risks of agricultural land located on sloping terrain (Hilger et al. 2013; Baumhardt and Blanco 2014; García-Lara, Serna-Saldívar 2019). According to Safford and Vallejo (2019), contour terraces are built to reduce erosion on steep slopes, enhance soil depth for plant roots, and improve water infiltration. Contour terraces are constructed along contour lines on slopes to increase arable area while conserving water and soil (Cao et al. 2013). As a result, contour terraces improve grain yield and soil moisture content by 44.8% and 12.9%, respectively, and reduce runoff and sediment by over 41.9% and 52%, respectively (Xu et al. 2018; Xu et al. 2011; Deng et al. 2021).

Another measure of erosion control is by implementing grass strips. Grass strip conservation techniques typically use grass that is managed and intentionally planted in strips according to contour lines. According to Zhang et al. (2018) optimal placement of grass strips reduces runoff and sediment by 7.35% and 62.93%, respectively. In addition, for a short period of time, grass could provide better erosion control compared to shrubs and trees (Li et al. 2021; Zhu et al. 2021). Grassroots increase soil organic matter, improve soil shear strength and reduce soil shedding (Liu et al. 2018; Hao et al. 2021; Smith et al. 2021; Liu et al. 2022). The grass cover could also protect the soil from raindrops (De Almeida et al. 2018).

Besides the two methods, alley cropping is also effective in reducing erosion rates. Alley cropping is a technique for growing trees, shrubs, and crops in alternate rows. Alley cropping can also help nutrient retention and erosive decay (Grebner et al. 2013). With good planning and management, alley-cropping agroforestry systems in temperate climates can reduce wind erosion by more than 80% (Van Ramshorst et al. 2022). According to Kang and Gutteridge (2002), planting tree avenues on sloping land will provide a physical barrier to soil and water movement and reduce losses from erosion.

The appropriateness of the selected method of erosion control primarily determines the soil-conserving treatment. Determining how to control soil erosion effectively is important from a scientific and technical aspect. Therefore, the experiment of the soil conservation method is required to determine its effectiveness to be used on slopes, particularly its role in preventing erosion. This research aims to identify the most appropriate techniques to mitigate soil erosion by comparing three different techniques (i.e. contour terracing, strip planting of grass and alley cropping) on maize (*Zea mays* L.) cultivation planted on sloping land in Indonesia's humid tropics. The choice of maize as the object of study is because maize is one of the staple food crops grown and consumed by the community in Gorontalo Province. This research is expected to demonstrate the effect of different conservation methods in reducing erosion on sloping areas in an effort towards sustainable land use.

MATERIALS AND METHODS

Description of the study area

This research was conducted in Limboto Sub-district, Gorontalo District, Gorontalo Province, Indonesia (Figure 1). The soil type in the research location is classified as Inceptisols with medium soil depth (80 cm), moderate soil fertility (soil pH 5.9, C-organic 1.8%, soil cation exchange capacity 23 cmol/kg and soil bulk density 1.27 g/cm^3). The average annual rainfall of the study area is 1956 mm/year and the average temperature is 27.01ºC. The slope of the study site is 30% (slightly sloping) and the dominant land use is mixed gardens planted with maize. Soil analysis was performed at the Chemical Fertility and Soil Physics Laboratory, Department of Soil Science, Faculty of Agriculture, Universitas Hasanuddin, Makassar, Indonesia.

Experimental procedures

This research was conducted in three growing seasons: Growing season 1 began from November 2020 to February 2021; Growing season 2 started from March to June 2021; Growing season 3 from November 2021 to February 2022. This study used a split-plot design in a randomized block design, with the main plot being a conservation technique, namely natural conditions (control) (K0), contour terrace (K1), strip cropping of *Pennisetum purpureum* Schumach grass (K2) and alley cropping using *Gliricidia sepium* (Jacq.) (K3), while the side plots were *Z. mays* of two varieties: composite variety Arjuna BC (H1) and hybrid variety NK-33 (H2). Each treatment had three replicates, resulting in a total of twenty-four experimental units.

Conventional practices in maize cultivation were applied across all experimental units, for example, fertilization which was carried out according to technical instructions or recommendations. The parameters measured in this study were erosion (tonnes ha-^{1}), *Zea mays* growth (height) and *Zea mays* production (1000 grain weight with 14% moisture content, production per hectare). Soil erosion was measured using the erosion plot method in the field, which was regularly monitored to measure the sediment produced.

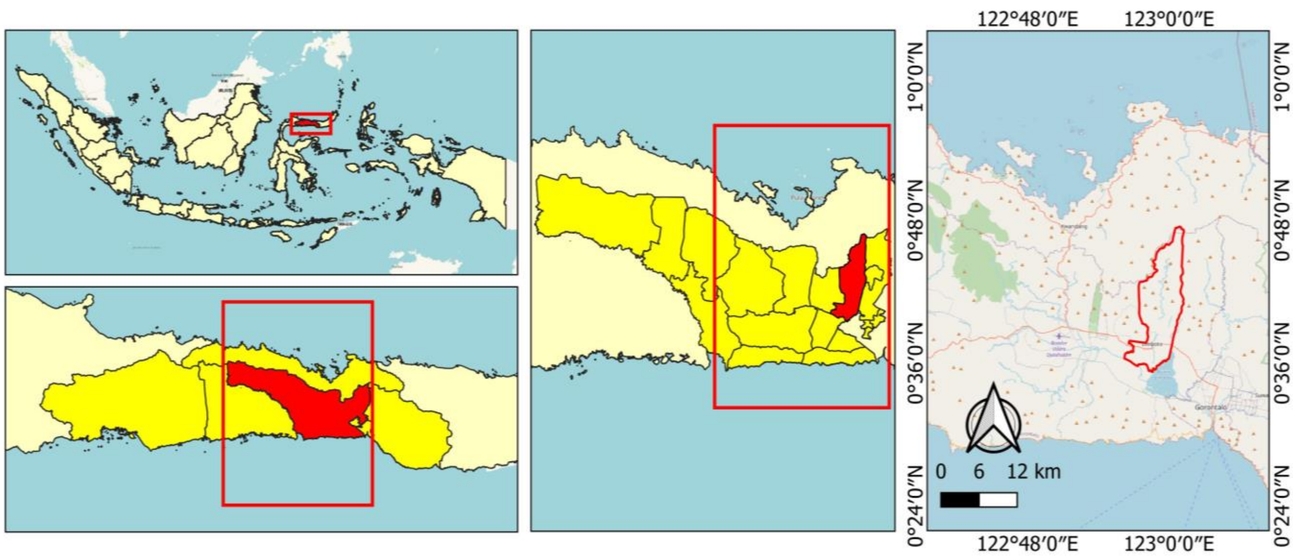

Figure 1. Location of the study area in Limboto Sub-district, Gorontalo Province, Indonesia

Data analysis

Data of soil erosion and growth and productivity parameters were analyzed using SPSS statistical analysis. The economic analysis was calculated at the end of the experiment by calculating the R/C (Revenue Cost) ratio. When the R/C ratio exceeds 1, the cultivation system is considered economically feasible; if it is less than 1, it is not feasible for cultivation.

RESULTS AND DISCUSSION

Effects of soil conservation techniques on soil erosion

The results of research on planting seasons 1, 2, and 3 showed that the three conservation techniques: alley cropping using *G. sepium*, contour terracing, and strip planting of *P. purpureum* had no significant effect on soil erosion. Nonetheless, strip planting of *P. purpureum* can suppress erosion relatively better than alley cropping and contour terracing (Table 1). However, the erosion level of the three methods applied exceeded the tolerable value according to the criteria of Thompson (1957) who stated that the erosion level on slightly permeable subsoil on the slightly consolidated substrate might not exceed 11.21 tons ha^{-1}. For example, erosion of 44.01 tons ha^{-1} was found for the strip planting of *Pennisetum purpureum* grass, 74.73 tons ha^{-1} for the contour terrace and 76.31 tons ha^{-1} for the alley cropping using *G. sepium* technique.

While there was a reduction compared to no treatment (control), soil erosion was still high in all conservation techniques used, presumably due to the ineffectiveness of cultivation practices in growing seasons 1, 2 and 3. This was due to the use of tillage plows on all experimental plots, thereby keeping the land open. In addition, the soil was crushed by the processing equipment, so the soil aggregate had low stability. Therefore, it took a long time for the application of erosion control techniques to become effective. The research by Abdurachman and Sutono (2002) on typical Eutropepts in Ungaran, Central Java, Indonesia, found that bench terraces, contour terraces, grass strips and alley cropping with *Gliricidia* become effective after five years.

It rained in the early phase of plant growth (<30 days after planting) with an average rainfall of >130 mm/day. The canopy of *Z. mays* at the time was not sufficiently able to withstand the energy of rainwater, which could destroy soil aggregates and also transport dispersed soil particles. At that time, the contour terraces were not strong enough to withstand the high volumes of water. Even the roots of the *P. purpureum* planted as strips between the *Z. mays* plants cannot stop the flow of water. The same also occurred in the treatment of alley cropping using *Gliricidia* as a hedge. As a result, the soil was quickly destroyed and transported with surface water (i.e. erosion). Moisa et al. (2022) and Negash et al. (2021) discovered that the relationship between changes in LU/LC, climate, topography and the rate of soil loss clearly indicates that planted steep slopes experience significant soil loss. Furthermore, people's reliance on agriculture contributes to increased erosion (Moisa et al. 2021).

Effects of soil conservation techniques on the growth and production of *Zea mays*

Crop height

Crop height was not statistically significant across different soil conservation techniques applied to both *Zea mays* varieties as shown in Figure 2. This figure shows the average plant height in each growing season. The lack of a significant difference indicates that the conservation methods used had no effect on the plant height of the two maize varieties tested. This is likely due to the fact that preservation techniques had just been started and undergone environmental adaptation, particularly preservation techniques using cover crops. Pratiwi and Narendra (2012) discovered that the effect of conservation on plant height was visible in the second and third years.

Crop leaf area

The crop leaf area of the different conservation techniques used did not show statistically significant results. Similarly, the differences in leaf area between the composite and hybrid varieties in each conservation technique plot were not significant as shown in Figure 3. These results indicate that conservation techniques had no effect on leaf area. According to Ariyanti et al. (2016), growth variables such as leaf area are influenced more by plant genetics than by environmental factors.

Table 1. Average soil erosion for various conservation techniques in each growing season

Treatment	Erosion (ton ha^{-1})		
	GS-1	GS-2	GS-3
K0	77.05	65.43	53.02
K1	74.73	60.12	30.29
K2	44.01	42.30	37.50
K3	76.31	69.32	65.98

Notes: GS: Growing season; K0: control; K1: contour terrace; K2: strip planting of *P. purpureum* grass; K3: alley cropping using *G. sepium*

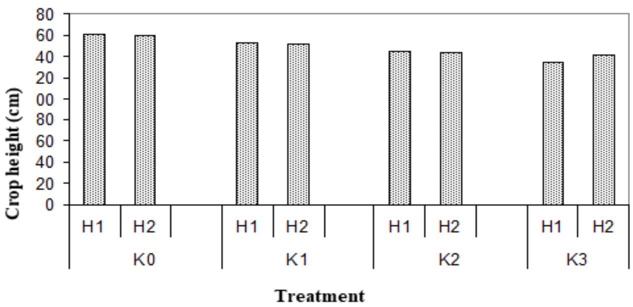

Figure 2. Crop height of composite (H1) and hybrid (H2) varieties of *Zea mays* in natural conditions (control) (K0), contour terrace (K1), strip cropping of *P. purpureum* grass (K2) and alley cropping using *G. sepium* (K3)

Cob height

There were no statistically significant results for the height of the maize cobs among the three preservation methods and types of varieties tested as shown in Figure 4. These results indicate that preservation techniques had no effect on cob height regardless of the maize varieties. This is consistent with the results of Sibonginkosi et al. (2019), who found that neither cultivar nor preservation technique affected maize plant height or maize cob height. They also stated that the height of the plant is directly proportional to the height of the cob.

Cob weight without husks

There were no statistically significant results for the weight of maize cobs without the husk among the three preservation techniques and the types of varieties tested as shown in Figure 5. However, the weight of cobs without the husk was higher in the strip cropping, followed by the alley cropping. According to Datta et al. (2019), the use of cover crops and biochar affects biological yields. In contrast to Datta 2019; Afzalinia and Zabihi (2013) indicated that land management treatments would not affect yield parameters such as cob length.

Maize cob length

The length of the maize cobs in the different preservation methods showed no statistically significant results. This indicates that preservation techniques have no impact on cob length. Afzalinia and Zabihi (2013) reported that all growth parameters, including plant height, dry matter index and leaf area, as well as yield parameters such as cob number and cob weight were not significantly affected by tillage, meaning that these attributes are rather genetically regulated and require other practices such as genetic/breeding approaches, etc. for their manipulation. However, differences can be seen in the interaction of conservation techniques and different varieties as shown in Table 2 and Figure 6. For example, treatment with the *P. purpureum* strip cropping had the longest cob measuring 17.37 cm.

Maize cob diameter

As with the other yield parameters, cob diameter did not show statistically significant results. This indicates that preservation techniques have no effect on cob diameter. However, the cob diameter treated with *Pennisetum purpureum* strips was relatively large compared to other techniques. The composite variety also appears to have relatively larger cobs than the hybrid variety (Figure 7).

Maize weight of 1000 grains

The weight of 1000 grains of shelled maize with a moisture content of 14% was not statistically different among the three preservation techniques. However, the weight of 1000 grains was relatively higher in treatments K2 (strip cropping) and K3 (alley cropping) planted with the H2 variety (hybrid) compared to the contour terrace treatment, as shown in Figure 8.

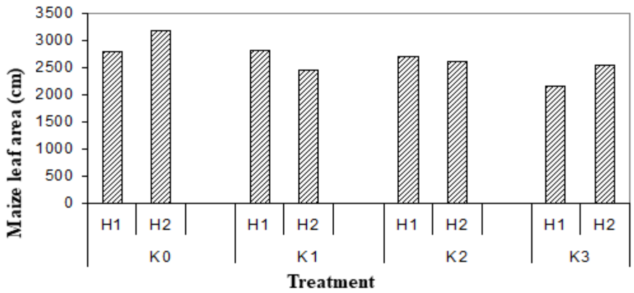

Figure 3. Leaf area of composite (H1) and hybrid (H2) maize varieties in natural conditions (control) (K0), contour terrace (K1), strip cropping of *P. purpureum* grass (K2) and alley cropping using *G. sepium* (K3)

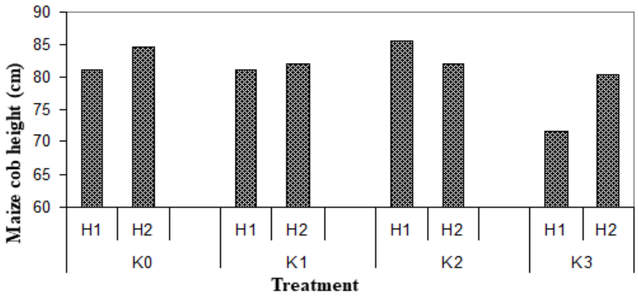

Figure 4. The height of the maize cobs of composite (H1) and hybrid (H2) varieties in natural conditions (control) (K0), contour terrace (K1), strip cropping of *P. purpureum* grass (K2) and alley cropping using *G. sepium* (K3)

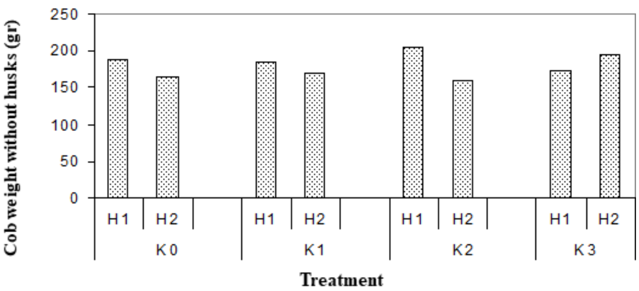

Figure 5. Maize cob weight without husks of composite (H1) and hybrid (H2) varieties in natural conditions (control) (K0), contour terrace (K1), strip cropping of *P. purpureum* grass (K2) and alley cropping using *G. sepium* (K3)

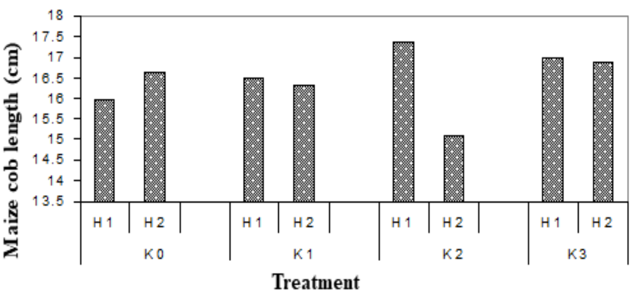

Figure 6. Maize cob length of composite (H1) and hybrid (H2) varieties in natural conditions (control) (K0), contour terrace (K1), strip cropping of *P. purpureum* grass (K2) and alley cropping using *G. sepium* (K3)

Table 2. The length of maize cobs of composite (H1) and hybrid (H2) varieties in natural conditions (control) (K0), contour terrace (K1), strip cropping of *P. purpureum* grass (K2) and alley cropping using *G. sepium* (K3)

Treatment	Length of cob (cm)
K0H1	15.97ab*
K0H2	16.63a
K1H1	16.48a
K1H2	16.32ab
K2H1	17.37a
K2H2	15.08bc
K3H1	17.00a
K3H2	16.87a

Note: *The numbers followed by the same letter are not significantly different at the JBD Test level of 0.05

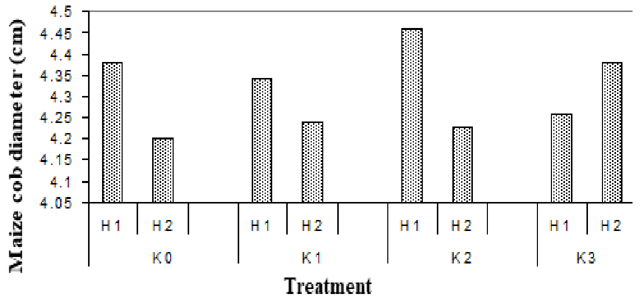

Figure 7. Diameter of maize cobs of composite (H1) and hybrid (H2) varieties in natural conditions (control) (K0), contour terrace (K1), strip cropping of *P. purpureum* grass (K2) and alley cropping using *G. sepium* (K3)

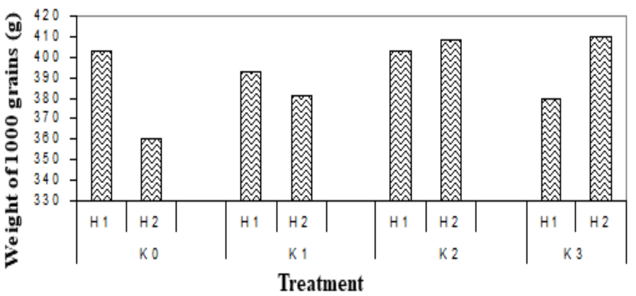

Figure 8. Weight of 1000 shelled maize with 14% water content for composite (H1) and hybrid (H2) varieties in natural conditions (control) (K0), contour terrace (K1), strip cropping of *P. purpureum* grass (K2) and alley cropping using *G. sepium* (K3)

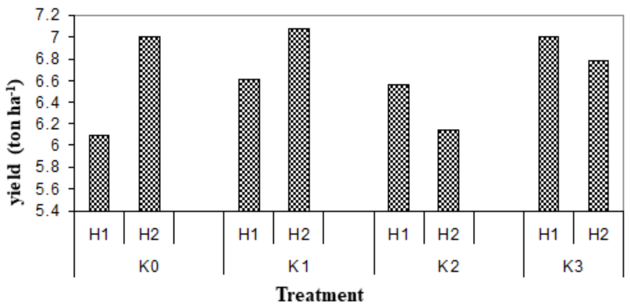

Figure 9. Maize yield per hectare of composite (H1) and hybrid (H2) varieties in natural conditions (control) (K0), contour terrace (K1), strip cropping of *P. purpureum* grass (K2) and alley cropping using *G. sepium* (K3)

Maize yield per hectare

The results of maize yield per hectare for the different preservation techniques used were not statistically significant. Furthermore, several studies have found that land suitability, particularly land surface temperature (LST) and altitude, has a greater influence on maize production. Areas with a low elevation and a high LST are ideal for maize production (Moisa et al. 2022). However, maize production in contour terraces (K1) and alley cropping (K3) had a relatively higher average production per hectare than that of *P. purpureum* strip cropping (Figure 9). Figure 9 also shows that the yield of hybrid maize (H2) without conservation treatment (K0) had a higher yield than with strip cropping and alley cropping treatments.

The lower yield in strip cropping is likely due to the shrinkage of cultivated fields caused by part of it being used to plant strips of *P. purpureum.* According to Yusuf (2020), there was a 5-13% shrinkage if the strip width was 0.5 meters and a 9-27% shrinkage if the strip width was 1 meter. The same also occurred with the alley cropping technique using gliricidia and contour terraces. The components of the contour terraces that cause cultivated land area reduction are hills, ditches, and drains (SPA). However, this does not mean that the technique used does not affect cultivation efforts, since the main purpose of applying conservation techniques on slopes is for erosion control, which affects the conservation of soil and water resources, even if the land is used more intensively.

In this study, alley cropping using gliricidia hedges was not effective in increasing soil productivity over three growing seasons, despite the potential use of *Gliricidia* as cover manure to enrich nitrogen elements. This is likely because no green manure was applied, since the cultivated *Gliricidia* were just beginning to grow. The results showed that the impact of preservation techniques on growth parameters and maize yield was not statistically significant. This happened due to the ineffective effect of treatment in the first planting season on crop growth. For all plant growth parameters observed, it appears that the parameter value, including crop height, leaf area, leaf length and cob height, was relatively better in the strip cropping preservation technique treatment than in the alley cropping and contour terrace treatments. However, when compared to the potency of Arjuna (composite) and NK-33 (hybrid) varieties, the observed parameter values exceeded the mean value of the varieties in all treatments.

Likewise, the potential yield (production) per hectare for all treatments reached >6 tons, namely an average of 6.57 tons ha^{-1} (H1) and 6.76 tons ha^{-1} (H2). The yield potential of the Arjuna variety is 5-6 tons ha^{-1} (FAO 2023) and the NK-33 hybrid variety is 8.1-10.2 tons ha^{-1} (Syngenta Indonesia 2023). This shows that the effect of preservation technique treatment on maize production is not statistically significant. However, the production yield achieved was quite good and could be even better if the effect of the treatment compared to the erosion control became effective and reached an erosion value of >44 tons ha^{-1} per planting season.

Table 3. Economic analysis of the application of soil conservation techniques in two maize varieties

Treatment		R/C
KO	H1	2.21
	H2	2.52
K1	H1	1.99
	H2	1.97
K2	H1	2.07
	H2	1.78
K3	H1	2.22
	H2	1.97
Average		2.09
Maximum		2.52
Minimum		1.78

Note: K0: control; K1: contour terrace; K2: strip planting of *P. purpureum* grass; K3: alley cropping using *G. sepium*

Economic analysis

The results of the economic analysis in Table 3 show that each treatment combination produced different R/C ratio values. The highest costs were in the hybrid variety with the contour terrace technique and the lowest were in the hybrid variety without any preservation treatment (control). The R/C calculations show that using the hybrid variety without the preservation method (control) had the highest R/C value with 2.52, while the lowest was the hybrid variety treated with *P.purpureum* strip cropping with an R/C value of 1.78. The R/C value indicates that cultivation is feasible when the value is greater than or equal to one. The results of the profitability calculations in three different soil conservation systems still showed higher results compared to the control (no conservation treatment). We assumed that the treatment had not affected maize yields because of the short test duration of the treatment. Nevertheless, the overall treatment is classified as feasible.

In conclusion, soil erosion in the strip cropping using *P. purpureum* grass was relatively lower compared to alley cropping and contour terrace techniques. Nonetheless, it still exceeded the tolerable soil loss (>44 tons ha^{-1}). In the three growing seasons, the three conservation techniques had no significant impact on the growth and production of the composite and hybrid varieties, but the maize yield can reach >6 tons ha^{-1} for the two varieties planted. The value of the R/C ratio of all treatments ranged between 1.78-2.52. The results of this study suggest the possibility of applying appropriate soil conservation methods on sloping land for the development of food crops such as maize, integrated with terrace-strengthening plants and other soil-conserving plants. However, validation of this research needs to be applied over a longer period of time to obtain a significant result to reduce soil erosion.

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