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Potential of legum cover crop in increasing soil organic carbon in sustainable drylands

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Soil organic carbon (soil C-organic) is one of the important constituent components of soil ecosystems, namely as a source (*source*) and binding / absorbent (*sink*) and as a substrate for soil microbes. For this reason, innovation in sustainable dryland management is needed, through a *fallow system* with annual crop cover legumes (CCL). This study aims to: (1) Know the characteristics and potential of several types of CCL - as fallow plants on farms on dry land; (2) examine the role of CCL after exposure to changes in soil organic carbon deposits in dryland farming systems; This study used a field experimental method designed in a randomized block design with five types of CCL treatments which were repeated three times. The potential for CCL is observed by measuring quality, biomass production and carbon uptake, and N which is anchored from CCL. Soil C-technical deposits were estimated by observing bulk density (BD), thickness of soil solum and carbon content (C) of post-grazing soil. The results showed that the type of CCL used as fallow in farms significantly increased soil C-organic deposits, averaging 71.80 t ha⁻¹ or an increase of 20.45% from treatment without ground cover legumes (59 , 60%).

Keywords: Potential cover crop legumes, soil organic carbon deposits.

INTRODUCTION

Soil is a representation of *anorganic carbon pool (organic carbon reservoir)* that is very important in land ecosystems, because land accumulates carbon (C) greater than the amount of C in plant biomass and atmosphere (Tarnocai et al., 2009; Schimel , 1995). However, the ability of land as a *pool* or warehouse to accumulate and release carbon (C) in the soil is not static but is the result of a difference in 'dynamic balance' between incoming organic and inorganic materials (C-input) and outgoing (C-output) from time to time. In general, the sequestration of carbon in *soil carbon stock*, especially in farming lands, is influenced by the types of crops cultivated, soil type, climate, and farming land management practices (Nsabimana et al., 2008).

Dryland farming is an agricultural practice that is susceptible to sequestration of organic carbon

deposits in the soil (Matheus, 2014). The results of the study by Matheus et al., (2016) showed that soil C-organic levels in dryland farming systems measured in three units of farming land use in the Kupang regency region were in the low to moderate category, which was 1.47% C on average Inorganic matter was found on seasonal food crops and 2.24% organic C was found on annual crop farming. This indicates that farming patterns carried out by dryland farmers tend to be a trigger for declining levels of organic C in the soil.

Sequestration and reduction in soil organic carbon in dryland farming ecosystems are predominantly caused by natural factors (erosion) and human factors in managing their farming systems. One of them is the *shifting cultivation system* which is still dominantly practiced by dry land farmers with a main base on seasonal food

crops. This system is detrimental if carried out continuously, because it results in a decrease in the storage of soil organic carbon and in the long run has an impact on the destruction of natural resources in a sustainable manner (Reijntjes et al., 1999). In addition, the intensity of land use and land management patterns, is also another cause of declining soil organic carbon deposits. Therefore, it is necessary to carry out conservation efforts. Vegetative soil conservation can improve (restore) and improve the condition of the damaged soil to function optimally, both as an element of production, water management media and as an element of environmental protection (Arsyad, 2010).

In connection with these constraints, this effort can be made through a *fallow* system on intensive farming land with annual crop cover crop management in aquaculture systems either as intercropping plants or filling plants during fallow periods (Acosta, 2009; Wang et al., 2010; Olson et al., 2010).

Enrichment system innovations with annual crop cover legumes allow it to be introduced by dryland farmers, because it has the potential to restore soil quality and land productivity in a short period of time through increasing soil organic carbon stocks. The introduction of cover crop legume plants in farming systems also does not sacrifice farmer land, because it is introduced during fallow periods, which is between 5-7 months (post-harvest annual seasonal crops), compared to natural yields of 5-7 years (Matheus, 2014). This article is intended to: (1) Discuss the characteristics and potential of several types of covert legumes in the soil as soil fertility plants on farms on dry land; (2) identifying carbon stocks stored in farming land after the introduction of several types of cover crop legumes.

MATERIALS AND METHODS

Site description

This research was carried out at the Agricultural Polytechnic trial garden in Kupang-East Nusa Tenggara-Indonesia for 7 months, from April to October 2017. The area is located at 9°19' - 10°57' Lat. and 121°30' - 124°11' Longt. under a subtropical climate with a total rainfall of 1,400 mm.yr⁻¹ and an annual average temperature of 27°C. The land used in this experiment is continuously cultivated upland fields (> 5 years) of planting. In addition, the soil used in this experiment is included in the Grumusol soil type which has characteristics: clay (72.74% clay), C-

org 1.56% (low); pH 7.35 (neutral), N-tot 0.16% (low) and C: N ratio of land is 9.75.

Design

Experimental research designed in Randomized Block Design (RBD) with five treatments of cover crop legume types (CCL), which were introduced into farms, namely: Land left open (without CCL), farmer practice (L₀); Land is planted with *Centrosema pubescens* (Cp); land with *Phaseolus lunatus* (Cl); The land is planted with *Mucuna pruriens* (Mp); The land is planted with *Crotalaria usaramoensis* (Cu).

Planting of cover crop legumes (CCL) is carried out before the harvest of annual crops, then maintained during the resting period (fallow), for 6 months until the next planting season. After the fallow period, it was followed by observation of biomass production and soil properties (soil density, soil c-organic content and soil C-organic deposits), which was carried out at the end of the experiment.

To find out the potential of CCL as fallow plants, it was observed:

1. CCL biomass production (calculated in dry weight, t ha ha⁻¹), total biomass dry weight calculated by the formula:

$$BKB = (100 - \% Ka) / 100 \times BBs \quad (1)$$

Where: BKB: total biomass dry weight (t ha⁻¹)

% Ka: biomass water content (%)

BBs: total weight of fresh biomass (t ha⁻¹)

2. Carbon stock (t ha⁻¹), calculated using the plant biomass approach, assuming 50% of biomass is stored carbon (Brown, 1997; Hairiah and Murdiyarso, 2007), as follows:

$$Carbon\ stock\ (t\ ha^{-1}) = 0.5 \times \text{biomass dry weight}\ (t\ ha^{-1}) \quad (2)$$

3. Total N tethered by a legume cover crop, calculated by multiplying the N content by weight biomass plant tissue in an oven dried legumes (tonnes)

As for knowing the amount of soil organic carbon storage after vallo system, be measured against :

a. Land (*densitybulk density*); Mass density / level of density (BD) of land is expressed as mass per unit volume of land (g / cm³ or ton / m³). calculated by Equations:

$$\dots\dots\dots (3)$$

where: pb: *bulk density* in g cm⁻³,

Bp: the weight of absolute dry land,

vt: soil volume in ring

b. Soil C-organic content was analyzed by the method (Walkley & Balck Method)

c. Soil Carbon Deposits (*soil carbon organic storage*); Calculation of the amount of soil carbon deposits measured at the end of fallow at a depth of 0-30 cm. The amount of soil carbon organic deposits is calculated similar to the calculation of soil organic carbon deposits in general, which is based on the method of fixed depth approach shown by Komatsuzaki and Syaib, (2010) with the following equation:

$$\text{SCOS (t ha}^{-1}\text{)} = \text{BD} \times \text{SOC} \times \text{DP} \times 100 \quad (4)$$

where: SCOS: *soil carbon organic storage* (t ha⁻¹)

BD: *bulk density* (g cm⁻³)

SOC: *soil organic carbon* (%)

DP: *depth of soil solum* (m)

The Statistical analysis

observed data were analyzed using analysis of variance (ANOVA) according to the complete randomized group design with a 95% confidence interval. To see differences in the effect of variables Duncan's multiple distance test was carried out at a 5% significance level (Gomez and Gomez, 2007). To determine the relationship between post-fallow C-organic deposits with CCL (Y) with five X variables tested, namely: Bulk density (X1), C-organic (X2), absorption C (X3), biomass products (X4), and tethered N (X5); done by regression analysis. Data processing is carried out by statistical programs using COSTAT and MSTATC.

RESULTS AND DISCUSSION

Table 1: Average chemical quality of four seasonal CCL types tried on dry land

Composition of chemical properties of biomass CCL *)	Type of CCL			
	Cp: <i>C. pubescens</i>	Mp: <i>Mucuna pruriens</i>	Cu: <i>Crotolaria usaramoensis</i>	Pl: <i>Phaseolus lunatus</i>
a. N total (%)	2.14	2.47	3.21	2.87
b. P total (%)	0.12	0.15	0.25	0.37
c. C total (%)	32.21	34.30	36.28	38.73
d. C / N	15.05	13.89	8.99	13.49
e. C / P	360.67	307.94	156.88	115.46
f. K (%)	0.96	0.98	0.39	1.37
g. Ca (%)	2.67	2.46	3.58	3.56
h. Mg (%)	0.11	0.14	0.03	0.42
i. Lignin (%)	17.64	11.52	9.64	11.36
j. Polyphenols (%)	10.32	7.86	3.76	4.01

*) Laboratory analysis result

1. Potential Crops Cover Legum (CCL) in Dryland Farming

To determine the potential of annual crop cover legumes as fallow plants in dryland farming systems, field experiments have been carried out on intensive farming land. Experiments are carried out after harvesting annual food crops or during the fall period (rest) of the land to utilize the remaining soil moisture. Legume plants are allowed to grow and the residue is returned before the planting season (early rainy season). The results of the study are as follows:

1.1. CCL biomass quality

The results of the analysis of the quality of CCL biomass showed differences in the value of chemical properties between CCL types (Table 1). The highest total C levels are shown respectively in the type of *Mucuna pruriens* (MP) followed by *Centrosema pubescens* (CP), *Phaseolus lunatus* and *Crotolaria usaramoensis* (CU). Likewise with N levels, it shows *Phaseolus lunatus* (PL) and *Crotolaria usaramoensis* types that have higher N levels, followed by *Mucuna pruriens* and *Centrosema pubescens*. While the highest P level was shown in types *Phaseolus lunatus* followed by *lower usaramoensis Crotolaria* and *Centrosema pubescens*.

In addition to the levels of C, N and P CCL tissue, biomass CCL quality was also determined by the C / N ratio, C / P ratio, lignin and polyphenols which are quality indicators that determine the speed of biomass decomposition and nutrient mineralization (Table 1).

The C / N and C / P ratios measured in this study show that types *Cu* and *PI* have lower C / N and C / P ratios compared to types *Mp* and *Cp* (Table 1).

The lowest lignin content is shown in the type of *Cu* followed by the content of lignin in the type of *PI*; *Mp* and *Cp*. While the content of polyphenols analyzed in this study, showed that the type of CCL *Cu* and *PI* showed a lower polyphenol content compared to the content of polyphenols in the types *Mp* and *Cp*. Furthermore, the levels of K, Ca and Mg also show differences in the content between types of CCL. The highest K, Ca and Mg levels are shown in type *PI* and followed by other types (Table 1). The chemical quality of CCL described above is an important indicator and determinant of the rate of decomposition and release of nutrients from CCL biomass.

1.2. Biomass production, plant C uptake and CCL-bound N

The use of CCL as fallow plants in cultivated land has a significantly different effect on biomass production, plant C uptake and the amount of N anchored (Table 2). Table 2 shows biomass production (in dry weight) at the end of the highest grazing period indicated by legumes *Cu* of 11.99 t ha⁻¹ or an increase in biomass production of 3.52 times that of control (without CCL).

Biomass production achieved by *Cu* also tends not to be significantly different from legumes *Mp*, with biomass production of 11.99 t ha⁻¹ or an

increase of 3.09 times, followed by type *PI* (10.22 t ha⁻¹) with an increase of 2.85 times greater than treatment without CCL (2.65 t ha⁻¹). The lowest biomass production was shown by *Cp* (5.73 t ha⁻¹) or only an increase in biomass production was 1.16 times the treatment without CCL (Table 2).

Types of CCL planted during fallow can significantly increase plant C uptake (Table 5.2). This is indicated by the legumes *Cu* which during the fallow period can absorb C by 5.99 t ha⁻¹ and are not significantly different from *Mp* (5.42 t ha⁻¹), followed by *PI* (5.11 t ha⁻¹). The lowest uptake of C plants is indicated by the type of legume *Cp* which can absorb C by 2.86 t ha⁻¹ (Table 2).

Likewise with N tethering capability, the results of the analysis show that the type of CCL *Cu* can hold N at 384.87 kg N ha⁻¹ higher, followed by *PI* (293.31 kg N ha⁻¹), *Mp* (267.75 kg N ha⁻¹) and the lowest is obtained at *Cp* (122.62 kg N ha⁻¹) (Table 2).

2. Soil Mass Density, Organic Carbon Levels and Soil Organic Carbon Deposits Post Fallowing with CCL

The results of the variance analysis showed that the treatment of landfill with annual crop cover legumes (CCL) had a very significant effect ($P < 0.01$) on soil density, grade organic carbon and organic carbon deposits in the soil after six months of giving.

Table 2: Pengaruh types of CCL as fallow crops to the production of biomass, plant C and N uptake were tied after six months vallo system

CCL type	of biomass production (bk t ha ⁻¹)	Uptake of C plants (t ha ⁻¹)	N tethered (kg ha ⁻¹)
Control (without CCL)	2.65 ^d	1.32 ^d	-
Cp: <i>Cantroseme pubescens</i>	5.73 ^c	2.86 ^c	122.62 ^c
Mp: <i>Mucuna pruriens</i>	10.84 ^{ab}	5.42 ^{ab}	267.75 ^b
Cu: <i>Crotolaria usaramoensis</i>	11.99 ^a	5.99 ^a	384.87 ^a
PI: <i>Phaseolus lunatus</i>	10.22 ^b	5.11 ^b	293.31 ^b

Description: the numbers followed by the same supercript letters in the same column are not significantly different in Duncan's multiple distance test level 5%.

Table 3: Effect of CCL types as fallow plants on soil mass density (g cm^{-3}), soil C-organic content (%) and soil C-organic deposits (t ha^{-1})

Type CCL	Soil Period Density (g cm^{-3})	Soil C-Organic Content Soil C-Organic (%)	Deposits (t ha^{-1})
Control (without CCL)	1.25 ^a	1.59 ^c	59.60 ^b
<i>Cp: Cantroseme pubescens</i>	1.06 ^b	2.16 ^b	68.44 ^a
<i>Mp: Mucuna pruriens</i>	1.02 ^b	2.42 ^a	74.29 ^a
<i>Cu: Crotolaria usaramoensis</i>	1.10 ^b	2.17 ^b	71.31 ^a
<i>Pl: Phaseolus lunatus</i>	1.00 ^b	2.45 ^a	73.15 ^a

Description: the number followed by the same supercriptst letter in the same column is not significantly different from Duncan's multiple distance test at 5%

Data from the results of further testing of the effect of CCL types as fallow plants on changes in soil mass density (g cm^{-3}), soil C-organic content (%) and soil organic carbon deposits (t ha^{-1}) after 6 months of feeding are presented in Table 3.

2.1: Soil mass density (bulk density)

The average mass density of the soil at a depth of 0-30 cm on the effect of the feed on land with different types of CCL (Table 3). In general, the CCL field load shows that soil mass is not significantly different and has decreased, which is between 1.00-1.06 g / cm^{-3} compared to the control treatment (without CCL), which has a soil density of 1.25 g cm^{-3} . Future density(*bulkdensity*)soil decreased very significantly ($p < 0.01$) of 1.25 g cm^{-3} to 1.00 to 1.06 g / cm^{-3} after six months vallo system. While in the control plot treatment (without CCL), the density of soil mass was higher by 1.25 g cm^{-3} and significantly different from other treatments (Table 3).

Statistically, among the four types of CCL tested during the six months of the grazing period there was no significant difference in bulk density, and even decreased. The decrease in soil density in the topsoil (0-30 cm) obtained in the four types of CCL treatment (*Cp*, *Mp*, *Cu* and *Pl*), is closely related to the increase in the amount of litter (CCL biomass products), CCL root activity, moisture content soil and soil carbon content. The supply of organic material sourced from CCL in the upper layer and decomposition rate of organic matter from deciduous CCL plant leaves and dead plant roots, is also thought to contribute greatly to the decrease in soil mass density in the soil layer.

While the control treatment (without CCL) shows the value of high soil density, due to the low litter (plant biomass) that exists on the land,

and the low level of land cover so that direct exposure to sunlight hits the ground. differences in soil bulk density between land functions can be caused by compaction due to grazing of livestock and heavy equipment, differences in volume and turnover of root materials, land processing, and biological activities (Mendham et al. 2003)

2.2: The content of soil organic carbon (organic soil carbon)

In Table 3, the carbon content (C) of land were measured after six months vallo system showed significant differences among treatment types CCL. The use of CCL as a fallow plant during the feeding period significantly increases soil C-organic levels. Land that is fed by *Mp* and *Pl* is significantly able to increase soil C-organic levels by 2.45% and 2.42% after six months of incursion, or there is an increase in C-organic by an average of 53.14% of control (1.59%). The increase in soil organic-C was also followed by the treatment of *Cu* and *Cp* of 2.17 and 2.16% of organic C-soil, or an increase of 36.16% from control (1.59). This is different from the control treatment which did not experience changes in soil C-organic content, which was only 1.59%. C-organic levels after six months of administration with CCL increased significantly from the control treatment ($p < 0.01$). Among the four types of CCL, soil C-organic levels were significantly different after six months of giving.

Increased levels of soil organic carbon (*Organic Soil Carbon*) in the topsoil (0-30 cm) in the four types of CCL treatment (*Cp*, *Mp*, *Cu* and *Pl*) occur due to a supply / input of C organic soil sourced from litter (biomass) plants that are above the ground. so that soil organic matter tends to be concentrated in the topsoil. While the carbon content in the control treatment (without CCL) tends to be lower (1.59%) and statistically

different from the other four treatments due to the low supply of plant litter that is above the ground.

Giving with type CCL *Mp* and *PI* significantly increased organic C levels in the topsoil (0-30 cm) after six months of giving, and significantly different from other CCL types. Differences in levels of C-organic among CCL types are thought to be closely related to CCL biomass products and CCL plant growth. *Mp* and *PI* are types of CCL whose growth types propagate with high biomass production (4.89 and 4.24 t ha⁻¹) thus can cover the land surface (land), so that the micro climate (soil moisture) is always guaranteed. This microclimate condition helps increase the activity of organisms in the *risosphere* in decomposing plant litter (deciduous plant leaves and dead plant roots) thereby increasing the supply of organic C to the soil. It is different from the treatment of CCL *Cu* which shows the organic C-virgin is 2.17% in terms of its higher biomass production reaches (6.09 t ha⁻¹), but because the type of growth is upright so it does not fully cover the surface of the soil. This condition affects the relative humidity of the soil is fluctuating, thus affecting the activity of organisms in the soil in carrying out its role to decompose litter (leaves) of plants that fall on the ground. While the type of *Cp* after six months of giving showed levels of organic C that were not different from the type of CCL *Cus* (2.16%) because it was influenced by lower biomass production which was equal to 2, 73 t ha⁻¹.

While the control treatment (without CCL) showed lower soil C-organic levels, which was only 1.59%. The decrease in soil organic C levels is thought to be because the biomass of plants on land is very small, which is dominated by grass weeds as well as low levels of soil surface cover (land), so it does not support the activity of organisms in the soil to decompose.

Increasing the biomass supply of plants by increasing the density of plant roots in the soil layer contributes to higher levels of soil C-organic compared to the low biomass supply. The main source of soil C-organic in sub soil is the supply of carbon from the roots of dead plants or surviving roots releasing organic compounds to the surrounding environment), like mushrooms

2.3. Soil carbon organic deposits

The results of the study (Table 3) showed that cumulative deposits of organic carbon at a depth of 0-30 cm increased very significantly ($p < 0.01$) after six months of land acquisition with CCL. *PI* statistically planting CCL types *Cp*, *Mp*, *Cu* and *PI* significantly increased soil C-organic storage

compared to controls. The results of the analysis (Table 3), showed that the CCL type *Mp* significantly increased soil C-organic deposits by 74.29 t ha⁻¹, followed by *PI* at 73.15 t ha⁻¹, and the type of legume *Cu* at 71.31 t ha⁻¹ and the legume *Cp* of 68.44 t ha⁻¹. Or the average increase in soil C-organic deposits is 20.45% from control (without CCL). While cumulative soil carbon deposits at a depth of 0-30 on land not planted with CCL (plot control), soil carbon deposits are lower at 59.60 t ha⁻¹ and significantly different from the other four treatments (Table 3).

Increased storage of soil organic C, caused by land cover during fallow (6 months) by CCL plant phytomasa which has high quality and higher biomass (BK) production and higher C uptake by CCL compared to control treatment (Table 3). In addition, these four types of CCL are able to adapt well to dry conditions and have rapid growth as indicated by a high percentage of land cover. Increased organic C deposits in the soil reflect the amount of C absorbed by CCL plants from the air that has entered and decomposed. in the soil through the biomass *in situ* returned, plant roots and biota in the soil. According to Collins *et al.* (1992) stated that half of the amount of carbon dioxide (CO₂) absorbed by plants from free air enters the soil through returning plant residues (litter), dead plant roots, and other soil organisms and decomposes so that it accumulates in the soil layer .

Furthermore, Stevenson (1994), high C-organic deposits in the soil also affect soil quality. C-organic plays an important role as a source (*source*) and (*sink* nutrient) and as a substrate) for soil microbes, also as soil enhancers (Kimble *et al.* 2002; Rachman *et al.* 2006; Tornquist *et al.* 2009) . The benefits of organic material (soil organic C), besides being a source of nutrients can also be useful as soil enhancers have been proven. The summary results from various studies can be concluded that soil enhancers in the form of organic polymers have better ability to improve soil properties, both physical, chemical and biological properties of the soil (Rachman *et al.* 2006). Research Hairiah and Murdiyarso (2007) stated that the role of C-organic deposits in improving soil physical properties is to create soil aggregation so as to provide nest conditions on the soil and can reduce soil weight.

The results showed that cumulative soil organic carbon deposits at a depth of 0-30 cm increased significantly ($p < 0, 01$) after six months of land tenure. The regression analysis results show that, of the five variables X tested, Bulk

density (X1), C-organic (X2), absorption C (X3) and biomass products (X4), N are tethered (X5); there are only two variables, namely Bulk Density (X1) and organic C content (X2) which gives a very significant effect on the C-bank deposit in the soil, with the regression equation model is $Y_{\text{Deposits C}} = -72.90 + 62.89 \text{Bulk Density} + 34.32 \text{C-Organic}$, with a coefficient of determination of 0.98

The regression equation above proves that 99% of post-grazing soil organic deposits with CCL are significantly affected by bulk density (X1) and C-organic content (X2) in the ground. The results of this study are in line with the Siringoringo (2013) study which states that the level of soil carbon storage (ton / ha) is determined by not three main variables, namely the concentration of soil organic carbon (SOC) (C%), soil density (BD) (g / cm³) and soil depth (cm). The higher the content of organic C in the soil, the lower the weight of the soil content, so that it will increase soil C-organic deposits. Increasing soil C-organic deposits will improve soil quality. According to Collins *et al.* (1992) one of the indicators of the success of agricultural land management efforts is the continued maintenance of soil organic carbon deposits resulting in a balance in soil, environment and diversity of biological resources in the soil. The results of this experiment prove that CCL as a fallow in the cultivation system on dry land is able to maintain and increase C-organic deposits and soil quality.

CONCLUSION

Based on the description of the results of the research and discussion, it can be concluded as follows:

1. CCL types have the potential as green manure in improving soil quality naturally in dryland farming
2. CCL types used as fallow plants significantly increase soil C-organic deposits amounting to 20.45% (from 59.60% increased to, on average, 71.80 t ha⁻¹ of C-organic deposits).
3. There is a close relationship between deposits of soil organic C (*soil storage organic carbon*) and *bulk density and the content of C-organic soil*
4. Innovation system with CCL is economically *profitable*, technically and socially acceptable and implemented by farmers (*acceptable and applicable*), and ecologically able to sustain dryland productivity sustainably (*sustainable productivity*)

CONFLICT OF INTEREST

The authors declared that present study was

performed in absence of any conflict of interest.

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