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# Use of Vegetable covers as a strategy to reduce soil erosion and increase the yield of corn (*Zea mays* L.)

## *Uso de coberturas vegetales como estrategia para reducir la erosión del suelo e incrementar el rendimiento de maíz amiláceo (*Zea mays *L.)*

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**ABSTRACT**

Soil degradation is a problem facing agriculture, with water being the most important erosive agent, affecting, among others, crop yields. The objective of this study was to know the effect of four plant covers on soil erosion and starchy corn yield, in three locations in the Ayacucho region (Peru) during the 2018 - 2019 agricultural season. Five treatments were assigned: control, clover cover, vetch cover, vetch-oat cover, and *mulch*, in corn plots under a randomized complete block design (RCBD), with four blocks. Combined analysis of variance was used to evaluate the results. It was observed that soil erosion and corn yield were significantly ($P < 0.001$) influenced by plant cover and locations. Vetch-oat and clover cover significantly reduced soil erosion (–53 and –36%, respectively) due to the higher leaf biomass produced by both (6131 and 6052 kg $ha^{-1}$, respectively). Clover cover produced the highest corn yield (3749 kg $ha^{-1}$; +78%); while vetch-oats produced the lowest (1955 kg $ha^{-1}$), without significant differences with the control. The highest production of biomass, N and C of the foliar coverages was produced in the location with the least slope; while the highest performance occurred in steeper areas. Clover cover turned out to be a better option to reduce soil erosion and increase corn yield.

**Keywords**: Conservation agriculture, regenerative agriculture, soil productive capacity, soil erosion rate, resilience system.

***RESUMEN***

*La degradación del suelo es un problema que enfrenta la agricultura, siendo el agua, el agente erosivo más importante, afectando, entre otros, el rendimiento de cultivos. El objetivo de este estudio fue conocer el efecto de cuatro coberturas vegetales sobre la erosión del suelo y el rendimiento de maíz amiláceo, en tres localidades de la Región Ayacucho (Perú) durante la campaña agrícola 2018-2019. Se asignaron cinco tratamientos: testigo, cobertura de trébol, cobertura de vicia, cobertura de vicia-avena, y* mulch*, en parcelas de maíz bajo un diseño de bloques completo al azar (DBCA), con cuatro bloques. Se utilizó el análisis de varianza combinado para evaluar los resultados. Se observó que la erosión del suelo y el rendimiento de maíz fueron significativamente ($P < 0,001$) influenciados por las coberturas vegetales y las localidades. Las coberturas de vicia-avena y de trébol disminuyeron significativamente la erosión de suelo (–53 y –36%, respectivamente), a partir de la mayor biomasa foliar producida por ambas (6131 y 6052 kg ha-1, respectivamente). La cobertura de trébol generó el mayor rendimiento de maíz (3749 kg $ha^{-1}$; +78%); mientras que vicia-avena, generó el menor (1955 kg $ha^{-1}$), sin diferencias significativas con el testigo. En la localidad con menor pendiente se produjo la mayor producción de biomasa, N y C foliar de las coberturas; mientras que el mayor rendimiento se produjo en zonas más empinadas. La cobertura de trébol resultó ser una mejor opción para reducir la erosión del suelo e incrementar el rendimiento de maíz.*

***Palabras clave****: Agricultura de conservación, agricultura regenerativa, capacidad productiva del suelo, tasa de erosión del suelo, sistema de resiliencia.*

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## Introduction

Currently almost 33% of global soils are degraded (FAO, 2019), with water being the most important erosive agent, generating the loss of up to 30 Pg $yr^{-1}$ of soil, compared to soil loss by plowing (~5 Pg $yr^{-1}$) and mobilization by wind (~2 Pg $yr^{-1}$) (FAO & ITPS, 2015). Specifically, in agricultural systems, erosion can reach values of up to 20 Mg $ha^{-1}yr^{-1}$ when crops are grown on slopes, while average erosion rates are below 10 Mg $ha^{-1}yr^{-1}$ (FAO & ITPS, 2015). In Latin America, the situation is not different, as it is one of the three continents (Asia, Africa and LAC) with the highest rate of soil erosion (annual average of 30 to 40 Mg $ha^{-1}$), an event that becomes the main cause of soil degradation in the western Andes (Gardi et al., 2014). In Peru, the level of erosion reaches 127 945 790 hectares, of which 6.4% has a severe level of erosion, and the highlands represent the most affected natural region with severe erosion (INRENA, 1996).

### The role of vegetative covers in erosion reduction and climate change mitigation

The use of vegetative covers to control erosion and, with it, nutrient loss, is a practice that is recommended by the Soil and Water Conservation Society (SWCS) to put resources to sustainable use (SWCS, 2011). Vegetative covers' effects on soil erosion control have been classified as (i) direct, which are related to the morphology, planting density and root depth of the covers, whose role is centered on buffering the energy of raindrops, reducing water runoff and the movement of soil masses; and (ii) indirect, which are related to the incorporation of the foliar and root biomass of the cover crops into the soil, increasing in organic matter content, soil aggregates, carbon content, water retention, among others (Morgan, 2005).

Reports indicate that the use of cover crops can reduce soil erosion in different intensities. In a citrus orchard, erosion was reduced by 66.8% (Duan *et al.*, 2020); while the legume in an olive grove reduced soil loss by 40%. A reduction in nutrient loss due to the use of vegetative covers has also been observed, for example, Liu *et al.* (2021) reported a significant reduction in water runoff (48.5%), in soil loss (70.5%), and in nitrogen (N, 53.4%) and phosphorus (P, 56.9%) losses in water runoff. Additionally, it has been observed that cover crops can provide benefits in terms of climate change mitigation, as they have the capacity to reduce greenhouse gas emissions between 12 and 150 g $CO_{2eq}/m^2$/year, as a result of carbon (C) sequestration, reduction in fertilizer use and in albedo (Kaye and Quemada, 2017).

### Relevance of corn cultivation in Peru

During the last decade, the national production of starchy corn in Peru has increased at a rate of 2% per year, reaching a production of 304463 tons in 2018 (MINAGRI, 2019). The Ayacucho region is the fourth region with the highest production of starchy corn (8.5%) in Peru, with an annual growth rate of 5.7% (MINAGRI, 2019). The benefits of using cover crops, which are considered to improve crop yields, include reducing weed growth, managing soil diseases, enriching the soil by incorporating biomass, enhancing soil structure, and boosting soil organic matter (Lupwayi *et al.*, 2017). In addition, the effect of topography, rainfall (Muñoz, 2014), planting synchronization between crop and cover crops, and type of cover crops are factors that also determine the yield of the main crop (Yeganehpoor *et al.*, 2015). Reports indicated that the use of legumes as vegetative cover crops increases corn yield between 30 and 37% (Muñoz *et al.*, 2014; Marcillo *et al.*, 2017).

Considering the different reports of the positive but variable effect of cover crops in agriculture, the current study aims to determine the plant cover that reduces soil erosion and also increases corn yields, by planting four different cover crops (clover, vetch, vetch-oat and *mulch*) associated with corn cultivation, in three locations of the Ayacucho Region (Peru) in the 2018-2019 agricultural season.

## Materials and Methods

### Study area

The study was conducted during the 2018 - 2019 agricultural season, in Yanapampa (13º 0' 50.44'' S and 74º 11'44.03'' W, at 3033 m.a.s.l.), in the district of Huamanguilla, province of Huanta, Pultunchara (12º 55' 7.24'' S and 74º 13' 52.88'' W, at 3119 m.a.s.l.) and Patasucro (12º 54' 38.62'' S and 74º 14' 5.58'' W, 3335 m.a.s.l.), both in the district of Huanta, province of Huanta, department of Ayacucho, located in the Quechua region, with slopes of 5%, 40% and 21%, respectively. The climate is temperate with an average annual temperature of 15 ºC and rainfall of 400 mm per year.

**Soil sampling**

Before the establishment of the treatments, soil conditions were evaluated. One kg of soil (composite sample) was taken from 15 subsamples taken across the entire area (20 cm depth), through the zig-zag sampling method, for analysis at the Laboratorio de Suelos, Aguas y Foliares (LABSAF) of the Estación Experimental Agraria Canaán - Ayacucho, of the Instituto Nacional de Innovación Agraria (INIA) (Table 1).

**Treatments establishment**

The treatments a. control, b. clover (*Medicago hispida*) cover, c. vetch (*Vicia sativa*) cover, d. vetch-oat (*V. sativa - Avena sativa*) cover, and e. *mulch*, were allocated in corn plots under a randomized complete block design (RCBD) with four blocks. The same experiment was repeated in the three locations. Each plot (experimental unit) had 24 $m^2$, with five furrows of six meters long and a spacing between furrows of 0.8 m. For the sowing of corn (INIA variety 607 - Chécche Andenes), three seeds were used per stroke, with a spacing between strokes of 0.40 m. The cover crop was sown by broadcasting and at the time of the second earthing-up (60 days after sowing corn), between the irrigation furrow. A total of 450 kg $ha^{-1}$ of clover seed, 75 kg $ha^{-1}$ of vetch seed, 25 and 75 kg $ha^{-1}$ of vetch and oat seed, respectively, and 1200 kg $ha^{-1}$ of crop residues (*mulch*) were used. The corn fertilizer rate was 200-200-150 kg of N-$P_2O_5$-$K_2O$ per hectare, and was applied twice ($P_2O_5$ and $K_2O$ 100% at sowing, N 50% at sowing and the other 50% at the first

Table 1. Soil characterization analysis of three locations in the province of Huanta, Ayacucho Region (Peru) before the installation of the treatments (clover, vetch, vetch-oat and *mulch*).

| Parameter | Measure unit | Location | | |
|---|---|---|---|---|
| | | Yanapampa | Pultunchara | Patasucro |
| pH in $H_2O$ | (1:1) | 6,38 | 5,68 | 6,60 |
| CE (1:1) dS $m^{-1}$ | dS $m^{-1}$ | 0,45 | 0,29 | 0,84 |
| MO | (%) | 1,79 | 2,73 | 1,70 |
| Extractable P | (mg $kg^{-1}$) | 7,39 | 4,88 | 7,89 |
| Extractable K | (mg $kg^{-1}$) | 232 | 175 | 159 |
| Textural class | | Clay | Loam | Sandy clay loam |
| CIC | ($cmol_{(+)}$ $kg^{-1}$) | 12,47 | 6,16 | 12,88 |
| $Ca^{2+}$ | ($cmol_{(+)}$ $kg^{-1}$) | 4,97 | 3,65 | 9,16 |
| $Mg^{2+}$ | ($cmol_{(+)}$ $kg^{-1}$) | 4,96 | 1,20 | 1,47 |
| $K^+$ | ($cmol_{(+)}$ $kg^{-1}$) | 0,48 | 0,25 | 0,58 |
| $Na^+$ | ($cmol_{(+)}$ $kg^{-1}$) | 0,36 | 0,36 | 0,47 |
| $Al^{3+}$ + $H^+$ | ($cmol_{(+)}$ $kg^{-1}$) | 0,06 | 0,06 | 0,07 |
| Da* | (g $cm^{-3}$) | 1,40 ± 0,02 | 1,26 ± 0,10 | 1,36 ± 0,14 |
| Moisture* | (%) | 12,94 ± 1,49 | 14,67 ± 0,99 | 11,83 ± 3,67 |
| Fungi* | Ln (UFC $g^{-1}$ dry soil) | 14,38 ± 0,40 | 15,12 ± 0,17 | 14,76 ± 0,22 |
| BFN* | Ln (UFC $g^{-1}$ dry soil) | 15,46 ± 0,11 | 13,64 ± 0,09 | 15,19 ± 0,21 |
| BN* | Ln (UFC $g^{-1}$ dry soil) | 15,13 ± 0,46 | 14,44 ± 0,46 | 15,50 ± 0,23 |

*Values are averages of four replicates ± standard deviation. BFN= nitrogen-fixing bacteria; BN= nitrifying bacteria; Da= bulk density.

hilling), using guano and potassium chloride as fertilizer sources. Two topdressings were made at 45 and 60 days after sowing.

### Post-treatment data collection

Cover crop sampling was carried out at the end of flowering (120 days after planting), where biomass, nitrogen (N) and carbon (C) were determined. Leaf samples were taken inside 1 $m^2$ of each experimental unit. N and C percentages were determined from 250 g of fresh biomass. For the estimation of colony forming units (CFU) of nitrogen fixing bacteria (NFB), nitrifying bacteria (NB) and fungi, soil samples were taken thirty days later from each experimental unit (1 kg composite sample, from 3 subsamples extracted from the central furrows at 0.2 m depth), and were determined through serial dilutions and culture plate. The collected samples were sent to the Laboratorio de Suelos, Aguas y Foliares (LASPAF) of the Universidad Nacional Agraria La Molina for analysis. At the same time, soil erosion was determined through the method of nails or erosion rods. One month later (180 days after the installation of the mulch treatments), gravimetric moisture (gravimetric method) was evaluated at LABSAF of the Estación Experimental Agraria Canaán - Ayacucho.

At 180 days after planting the corn was harvested when the grains had 30% of moisture. Then, they were dried, threshed and weighed.

### Statistical analysis

Using R statistical software version 3.4.3 (R Core Team, 2017), a combined analysis of variance was performed on the data of the response variables. Tukey's test was used at a significance level of 0.05, to compare the means of each variable.

## Results and Discussion

### Soil erosion

Soil water erosion was significantly influenced by cover and location ($P < 0.001$) (Table 2). The four covers protected the soil from erosion between 26 and 53% compared to the control. The vetch-oat and the clover cover reduced soil erosion the most, by 53% (12.7 kg $ha^{-1}$and 36% (8.6 kg $ha^{-1}$), respectively. Vetch cover reduced erosion by 30% (7.13 kg $ha^{-1}$), while mulch was the least effective in reducing erosion (26%; 6.3 kg $ha^{-1}$). A global meta-analysis of 85 publications also found that living cover was more effective than mulch in reducing soil erosion (Liu *et al.*, 2021). The fact that the biomass of cover crops reduces water erosion (Sumiahadi *et al.*, 2019) is confirmed by the results of the current experiment, as the clover and vetch-oat cover crops significantly reduced erosion due to the higher values of leaf biomass produced by both. It was observed that vetch cover mitigated soil erosion to a lesser extent than clover and its leaf biomass production was also lower, both being leguminous species. However, when vetch (legume) was mixed with oats (grass), erosion was significantly reduced. This result may be due to the fact that the mixture of both species (legume and grass) provided greater biomass and a more uniform surface cover than a single species, resulting in greater water erosion control. Overall, the study showed that the cover that produced higher leaf biomass reduced soil erosion more, indicating that biomass has a direct effect on reducing soil erosion by reducing raindrop energy and preventing mass movement (Sumiahadi *et al.*, 2019).

In Pultunchara (40% slope), erosion was 24.96 kg $ha^{-1}$, the highest soil loss; in Patasucro (21% slope), erosion was reduced by 30%; while in Yanapampa (5% slope), soil loss was reduced by 70% of that reported in Pultunchara. The steepest locations were the most eroded and those with the lowest cover crop leaf biomass production, a pattern consistent with Liu *et al.* (2021), who observed that cover crops on slopes between 10 and 15º reduced soil erosion by 68%, with effectiveness decreasing as slope increased. Our results are probably due to the fact that soil organic matter and nutrients, and water distribution were maintained.

### Gravimetric moisture

For the gravimetric soil moisture parameter, the analysis showed significant differences between cover crops ($P < 0.001$) and locations ($P < 0.05$) (Table 2). The average initial soil moisture (13.14%), measured before the installation of the cover crops, was increased by the effect of all treatments, including the control. However, the control showed a smaller increase in moisture (25%) than the cover crops. Clover, vetch, *mulch* and vetch-oat coverings

Table 2 Mean physical and biological soil indicators after the installation of three vegetation cover (vetch, clovers and vetch-oat) and *mulch* in three locations in the highlands of Ayacucho - Peru.

| | | Physical indicators | | Biological indicators | | |
|---|---|---|---|---|---|---|
| | | Hg | Erosion | Fungi | NFB | NB |
| | | % | kg ha$^{-1}$ | Ln (UFC g$^{-1}$ dry soil) | | |
| Coverage | T1 | 16,54 ± 0,92b | 23,75 ± 15,06a | 17,37 ± 0,63a | 16,27 ± 0,88b | 16,27 ± 0,39b |
| | T2 | 22,43 ± 2,58a | 15,12 ± 7,55bc | 17,31 ± 0,12a | 17,84 ± 0,71a | 17,04 ± 0,56a |
| | T3 | 21,47 ± 2,69a | 16,62 ± 9,19b | 16,89 ± 1,03c | 16,19 ± 1,59b | 16,80 ± 0,91a |
| | T4 | 19,76 ± 1,39ab | 11,05 ± 3,48c | 17,04 ± 0,76b | 15,68 ± 1,57c | 15,34 ± 0,68c |
| | T5 | 21,50 ± 1,08a | 17,45 ± 9,41b | | | |
| Location | Yanapampa | 19,07 ± 2,21b | 7,55 ± 0,34c | 17,51 ± 0,33a | 17,21 ± 0,89a | 16,75 ± 1,10a |
| | Pultunchara | 22,22 ± 3,11a | 24,96 ± 9,31a | 17,23 ± 0,32a | 15,48 ± 1,50c | 16,01 ± 1,01b |
| | Patasucro | 19,72 ± 1,95ab | 17,88 ± 4,42b | 16,51 ± 0,59b | 16,79 ± 1,27b | 16,33 ± 0,51a |
| Signif. F | Coverage | ** | *** | *** | *** | *** |
| | Locatuion | * | *** | *** | *** | *** |
| | Cover.*Local. | | *** | *** | *** | *** |

Means of treatments (± standard deviation) within the same column followed by the same letter are not significantly different ($p < 0.05$), by Duncan's test. T1 = Control (no cover); T2 = Clover cover; T3 = Vetch cover; T4 = Vetch cover with oats; T5 = *Mulch* cover. NFB = nitrogen-fixing bacteria; NB = nitrifying bacteria. For the analysis of variance, the s ignificance levels are: not significant ( ), significant (* $p < 0.05$), very significant (** $p < 0.01$) and highly significant (*** $p < 0.001$). Evaluation of the 2018-2019 crop year.

had moisture increases of 70, 63, 63, 63 and 50 %, respectively. There were no significant differences between the four covers, although on average the clover cover accumulated more moisture than the others. Our results may be due to the fact that in all treatments 25% responded to the effect of the root system and biomass of the corn crop, while the three covers (clover, vetch and vetch-oat), beyond the effect of their foliar biomass, provided the soil with their root system at different depths, which helps to absorb more water and retain moisture (Sumiahadi *et al*., 2019). The *mulch* cover, a cover without a root system anchored to the soil, probably incorporated its biomass (in the process of decomposition) into the soil, increasing soil organic carbon, with a consequent increase in moisture retention (Morgan, 2005). It is likely that the biomass of the three living cover crops was not incorporated into the soil, or at least not to the same extent as that of the *mulch*, because while the mulch was decomposing, the other three cover crops were in the process of growing. On the other hand, the carbonated root exudates of the *mulches* could have accumulated in the soil during their growth and development, affecting moisture retention. All of the four cover crops fulfilled the role of covering the soil with biomass, either living or dead, which could increase water retention and reduce evaporation.

According to the statistical analysis, soil moisture was directly proportional to the slope of the locations; the soil with the steeper slope (Pultunchara) accumulated more moisture. The higher content of organic matter (2.73%) in comparison to the other soils may have promoted the retention of more moisture (Morgan, 2005).

## Microbial population

The effects of covers and locations on all microbial populations analyzed were statistically significant ($P < 0.001$), as well as the interaction of both (Table 2). The average initial populations of fungi (14.75 Ln (CFU g$^{-1}$)), N-fixing bacteria (14.76 Ln (CFU g$^{-1}$)) and nitrifying bacteria (15.02 Ln (CFU g$^{-1}$)) increased in all treatments, including the control (no cover). The increase of the microbial communities with respect to the initial population, in decreasing order, was as follows: fungi > nitrogen-fixing bacteria > nitrifying bacteria. Fungi increased between 16 and 18%, with the control and the clover cover (without significant differences between them) standing out above the other treatments. Previous studies demonstrated that mulch plants can significantly inhibit the activity of microorganisms, including pathogens in the soil, through root exudates and biomass decomposition products (Bending and Lincoln, 2000). According to our results, vetch and vetch-oat covers created conditions to decrease, in greater proportion, soil fungal populations; while the soil without cover stimulated the increase of fungi. Similarly, Patkowska and Błażewicz-Woźniak (2014) reported that after using oats and common vetch as cover crop in carrot cultivation, microorganism communities were reduced more than in the control. In both works, it was determined that the fungal population reduced by the covers were pathogenic fungi. Thus, it was also shown that oats and vetch significantly reduced the population of pathogenic fungi in the salsify crop (Patkowska and Konopiński, 2013).

In the case of nitrifying and N-fixing bacteria populations, clover cover produced the largest increases (13 and 20%, respectively), followed by vetch, and finally, the smallest increases were obtained with vetch-oat cover (between 2 and 6%). Conversely, in a study where vetch and oats were tested as cover crops, there was a higher formation of bacterial populations in the soil with oats (Patkowska and Konopiński, 2013). The higher bacterial formations with clover and vetch cover crops, in part, could be due to the influence of the higher soil moisture recorded in these treatments, since it is considered as a main factor in the structure of the bacterial community (Patkowska and Konopiński, 2013), controlling not only the diffusion of oxygen, but also the availability of nutrients, both important for microbiome communities (Schimel, 2018). In turn, Chamberlain *et al.* (2020), found negligible effects of mulches on soil bacterial communities when installing oat and rye mulches. The authors claim that the short period of the cover crops was not enough to impact bacterial communities, as soil microbiota tend to resist change and cycle more slowly than rhizospheric communities.

The population of fungi, NFB and NB increased more in Yanapampa (21, 11 and 10%, respectively), compared to the populations before the installation of the treatments. The results could be due to the topographic condition of Yanapampa, which presented a flatter slope (5%), with higher soil moisture, therefore, greater availability of nutrients for the microbiota (Schimel, 2018), higher biomass production of the covers, allowing greater release of root photosynthates, as a source of carbon for soil microorganisms. It should also be noted that Yanapampa registered the lowest soil loss by erosion, thus reducing nutrient losses by leaching and runoff (Kuo and Sainju, 1998), nutrients that were lost in the other sites and that favored the microorganisms in Yanapampa.

**Biomass, nitrogen (N) and leaf carbon (C) of vegetation covers**

The combined analysis of variance of the data on biomass, N and foliar C of the cover crops showed significant effects by type of cover crops associated with corn and by locations ($P< 0.001$) (Table 3). The interaction of cover crops and planting locations was also significant for these variables. The clover and vetch-oats coverages recorded the highest biomass and leaf C values, but the highest N value was only obtained with clover. The clover and vetch-oat covers produced on average 51% more biomass and leaf C than the vetch cover. Although both covers (clover and vetch) belong to legumes, whose potential to capture N is high (Thilakarathna *et al.*, 2015), Quemada *et al.* (2013), confirmed the existence of leguminous species that assimilate smaller amounts of N. Even non-leguminous species (oats), which, although they do not fix N, can assimilate it quickly from the soil as growth occurs, were reported (Thorup-Kristensen, 2006). Therefore, the higher biomass and C values obtained by the vetch-oat cover could be due to the synergy between the two; vetch tends to capture more N (although not as much as clover) and oats tend to capture more C (Thilakarathna *et al.*, 2015), resulting in increased leaf biomass and reduced soil erosion (Sumiahadi *et al.*, 2019).

Yanapampa, the flatter location produced higher values of biomass, N and foliar C (5% slope; biomass: 5967 kg $ha^{-1}$; N: 259 kg $ha^{-1}$; C: 3581 kg $ha^{-1}$) compared to the steeper slope locations; Pultunchara (40% slope; biomass: 4099 kg $ha^{-1}$; N: 156 kg $ha^{-1}$; C: 1845 kg $ha^{-1}$) and

Table 3 Mean biomass, nitrogen (N) and carbon (C) values of foliar cover crops and grain yield of starchy corn in three locations in the highlands of Ayacucho - Peru.

| | | Leaf biomass | N contribution | C contribution | Corn yield |
|---|---|---|---|---|---|
| | | kg. ha$^{-1}$ | kg. ha$^{-1}$ | kg ha$^{-1}$ | kg ha$^{-1}$ |
| Coverage | T1 | | | | 2103 ± 394c |
| | T2 | 6052 ± 719a | 253 ± 45a | 2723 ± 323a | 3749 ± 688a |
| | T3 | 4028 ± 2 951b | 163 ± 111b | 1813 ± 1328b | 3336 ± 702b |
| | T4 | 6131 ± 3406a | 149 ± 69b | 2759 ± 1533a | 1955 ± 231c |
| | T5 | | | | 3406 ± 532b |
| Location | Yanapampa | 5967 ± 1880a | 259 ± 39a | 3581 ± 846a | 2855 ± 746b |
| | Pultunchara | 4099 ± 1376b | 156 ± 44b | 1845 ± 619b | 3426 ± 1071a |
| | Patasucro | 4154 ± 2234b | 149 ± 117b | 1870 ± 1005b | 2449 ± 667c |
| Signif. F | Coverage | *** | *** | *** | *** |
| | Location | *** | *** | *** | *** |
| | Cover.*Local. | *** | *** | *** | ** |

Means of treatments (± standard deviation) within the same column followed by the same letter are not significantly different ($p < 0.05$), by Duncan's test. T1 = Control (no cover); T2 = Clover cover; T3 = Vetch cover; T4 = Vetch cover with oats; T5 = *Mulch* cover.
For the analysis of variance, the significance levels are: not significant ( ), significant (* $p < 0.05$), very significant (** $p < 0.01$) and highly significant (*** $p < 0.001$).

Patasucro (21% slope; biomass: 4154 kg ha$^{-1}$; N: 149 kg ha$^{-1}$; C: 1870 kg ha$^{-1}$). Similarly, Muñoz *et al.* (2014) reported that red clover covers in flat areas produced the highest amounts of leaf biomass, N and C, due to higher water and nutrient storage than in slope areas. It is also necessary to consider that the soils of Yanapampa, before the installation of the treatments, presented a higher value of nitrogen-fixing bacteria than the other locations, a situation that, added to the properties of the soil due to its flatness, could have influenced the growth of the cover crops and the production of biomass.

## Corn yield

The combined analysis of variance of the corn yield data showed highly significant effects at the level of cover crops associated with corn and locations ($P < 0.001$) (Table 3). The control and the vetch-oat cover produced the lowest corn yields (no significant difference between the two); while the clover cover produced the highest yield, which is 78% more than the control, followed by the vetch and mulch cover (58% more than the control). The trend of higher yield of clover over vetch was also reported by Yeganehpoor *et al.* (2015). The meta-analysis by Marcillo *et al.* (2017), reported that the mixture of grass and legume cover crops produced a yield of 13% more than the control, attributing the benefits to reduced erosion and improved weed control, a product of higher biomass production and greater permanence in the field (Sumiahadi *et al.*, 2019); however, in our study we found that despite the fact that the mixture of cover crops (vetch-oat) generated the highest amounts of leaf biomass, it produced the lowest corn yields. Given this, it is possible to consider that the months of duration of the cover crops in the soil were not sufficient or that the rapid assimilation of N from the soil by the oats could have generated a certain degree of competition with the roots of the corn plant, causing a drop in yield (Thorup-Kristensen, 2006). It has been demonstrated that vegetative covers can positively influence crop yield as a result of increased biomass, increased soil microbial populations (Lupwayi *et al.*, 2017) and reduced nutrient loss through soil erosion (Liu *et al.*, 2021). The results obtained in the present study are consistent with other studies since the clover cover produced the best corn yield, higher microbial population, better biomass production and greater reduction of soil erosion compared to the other covers.

Marcillo *et al.* (2017) obtained 30 to 33% corn yield increases over the control, when nitrogen fertilizer rates were zero or low, conditions similar to our study. On the other hand, corn yields due to the effect of clover were lower than those obtained by Yeganehpoor *et al.* (2015), who indicated that clover influenced better yields, as long as the cover crop was planted at the same time as corn. However, in our study, the cover crops were sown 60 days later than corn, a possible reason why our yields were lower.

At the location level, Pultunchara showed the highest corn yield and Yanapampa the lowest. One of the reasons could be due to the difference in slopes, as noted by Muñoz *et al.* (2014). They reported higher corn yields in areas with steeper slopes than in flatter areas, but in seasons of high rainfall, while the opposite happened in seasons of low rainfall. According to the authors, the reason is due to good drainage, water redistribution and exposure to solar radiation offered by the slope in conditions of higher rainfall, while in flat areas, the accumulation and availability of water is favored in conditions of low rainfall. It is necessary to consider that in Yanapampa, the conditions that allowed greater biomass production from the covers could affect obtaining higher corn yields, due to competition for resources (Marcillo *et al.*, 2017).

## Conclusions

In general, in comparison with the control, the clover and vetch-oat cover significantly reduced soil erosion. The effect was favored by the higher production of their biomasses, which, by covering the soil, decreased the kinetic energy of raindrops. The clover cover crop proved to be a legume with greater potential to assimilate N, compared to vetch. However, the latter, when mixed with oats, produced a biomass similar to that of clover. Although the vetch-oat cover had a positive impact on soil conservation by reducing erosion, the corn crop was affected, generating a yield similar to the control. The clover cover produced a yield 78% higher than that obtained with the control and with the vetch-oat cover. The higher yield of corn with clover could, in part, be influenced by the increase of N-fixing bacteria in the soil, since their population was significantly higher than the control. As for the locations, the study reveals that the higher slope allowed a lower biomass, N and foliar C production of the cover crops, higher erosion, but also the higher corn yield. The results of this study show that cover crops, especially clover, represent a great potential in reducing soil erosion and increasing corn yields, and also show that the response variables are influenced by a set of factors (slope, water availability, microbial population, type of cover, climatic season, drainage, solar exposure, time of cover planting). With this in mind, future studies, as well as management strategies that include the installation of vegetative covers should take these relationships into account.

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