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Application of an alternative technique of physical management of the soil in the intercropping cultivation of *Zea mays* L. (Poaceae) and *Phaseolus vulgaris* L. (Fabaceae), Southern Brazil

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ABSTRACT

In Southern Brazil, agriculture and livestock have been the main activities that cause environmental degradation of the soils. However, few works were developed with the purpose of testing different techniques of the physical management of the soil to reduce the impact and to increase agricultural production. In this way, the goal of this work was to evaluate an alternative template of the physical management of the soil in the intercropping cultivation of *Zea mays* and *Phaseolus vulgaris*, with the purpose of improving the environmental conditions (soil conservation) and to increase the production in small properties. For data collection, it was delimited two experimental sample plots of 100 m² each, which one was submitted to the traditional template of soil preparation in the agriculture (minimum cultivation) and the other was applied the roughness techniques (microtopographyin the soil). It wasverified significant differences between abiotic and biotic variables in the two templates of soil preparation. For the irregular sample plot (with roughness) was observed less intense solar irradiation levels(350.6 W/m²), greater relative humidity of the air (86.5%) and smaller thermal amplitudes of the soil (21.6ºC), during the study period. The roughness sample plot also presented significant rise in the growth and production of *Zea mays* and *Phaseolus vulgaris*. For the regular sample plot (without roughness) was observed different abiotic and biotic conditions of the ones described to the irregular sample plot, being less favorable to the development of the culture. This research results indicated that roughnessbrought higher heterogeneity in the microclimate, besides internalizing the water, soil and nutrients in the system, measuring better environmental conditions to the growth and development of *Zea mays* and *Phaseolus vulgaris.*

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INTRODUCTION

Since it began, agriculture has gone through many technological advances in order to supply the needs of an expanding population. However, recently the environmental improvements costs have been questioned (Balsan, 2006; Triches and Schneider, 2015). Soil degradation is associated to the agriculture production decline and can be considered an important factor in today's environmental problems. Associated to the agricultural frontier advance, soil degradation has already reached big areas of Brazilian territory (Guerra *et al*., 1999; Silva *et al*., 2015). In places where agricultural activities are practiced for many years, soil degradation is associated to the drop of productivity and fertility(Guadagnin*et al*., 2005; Thomazini*et al*., 2012). This happens not only because of the loss of nutrient and organic matter, caused mainly by water erosion, but also because of the loss of soil itself, which is an irreversible degrading process (Bertol*et al*., 2004; Sorratto*et al*., 2006; Kitamura *et al*., 2007; Oliveira *et al*., 2015).

In Brazil, the problems with soil erosion occur in function of the fast economic development, withdrawal of vegetal coverage and high rainfall rates. The challenge is on understanding which processes are responsible for the soil erosion, recognizing that these processes are not merely physical and chemical, but also social and economical (Bertol*et al*., 2007). Besides rain effects, soils are eroded because of the withdrawal of vegetal

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coverage and because of the soil preparation method (Guerra *et al*., 1999). The inadequate soil management can affect its chemical, physical and biological attributes, being important, above all, a greater care with the superficial horizons (Kitamura *et al*., 2007; Santos *et al*., 2013).

In areas unprotected by native vegetation, the rain kinetic energy is applied directly to the soil surface, triggering various aggravating. With the impact caused by the raindrop, for example, occurs the destabilization of small aggregates of the soil, causing an effect known as splashed, where the dropped particles finish covering small pores, sealing the surface of the soil and diminishing its infiltration rate (Guadagnin*et al*., 2005).As a result, there is an increase in the superficial flow and consequent worsening in the erosive process, causing losses of soil nutrients and decrease in the agricultural production (Guerra *et al*., 1999; Leite*et al*., 2004; Sorattо*et al*., 2006; Dechen*et al*., 2015; Oliveira *et al*., 2015).

According to Aumond (2007), Aumond*et al*. (2012) toAumondandMaçaneiro (2014), the roughness (microtopography) are variation of the relief, alternating concave and convex surfaces, which influence in the internalization of water, sediments, organic matter and nutrients, and trigger emergent properties that accelerate the vegetation growth. In agricultural areas, the regular surfaces behave as sink of matter and energy and the rains generate superficial flows out of the system, resulting in losses of water, soil and nutrients (Bertol*et al*., 2004; Volk *et al*., 2004; Aumond, 2007). In these areas, the flow of matter and energy presents negative effect, becoming a source of irreversible losses (Aumond, 2007; Aumond*et al*., 2012). Thereby, the knowledge of the soil physical attributes which directly influence in the surface flow of water in the soil is fundamental for the proper handling (Kitamura *et al*., 2007). Also, the knowledge of the water dynamics during the development of a culture provides key elements for the establishment and improvement of agricultural management practices which aim to increase productivity (Cruz *et al*., 2005).

Because it is considered a surface phenomenon, the erosion caused by the superficial flow can be avoided just with the management of the superficial soil layers (Volk *et al*., 2004; Bertol*et al*., 2007).In this way, is necessary the development of soil physical management techniques to reduce the erosive processes, and is important improving the soil physical and chemical conditions and increasing the agricultural production.Thereby, the objective of this work was to evaluate the effect of the soil roughness in the intercropping cultivation of *Zea mays* L. (Poaceae) and *Phaseolus vulgaris* L. (Fabaceae).

MATERIALS AND METHODS

The study area is inserted in the river basin ofItajaí-Açu river, city of Blumenau, Santa Catarina, Brazil (26º53’28.85” S and 49º07’01.82” W). It has a total area of 1,075 m² and altitude of 33m at sea level. According to Köppen classification, the climate in the region is the type Cfa - subtropical humid climate without dry season and with hot summer. The average annual temperature is of 20ºC and the total average annual rainfall is of 1,980 mm, well distributed throughout the year (Aumond*et al*., 2008). In the study area, predominates the Alic Yellow-Red Ultisolof clayey medium texture, in mild hilly relief (Santos *et al*., 2013).

The experiment total area is of 1,075 m², where two smaller sample plots with 100 m² sample area were drawn. After delimiting the areas, it was built the roughness and the land morphology of one of the sample plots (irregular sample plot) was modified. In the other sample plot (regular sample plot), the minimum cultivation was adopted, where the soil preparation was restricted to the planting lines or planting holes, keeping the cultural wastes over the land according to the conventional method. The roughness were built manually, parallels to the contour lines and equidistant of each other at around 0.3 to 0.5 m. Each roughness presented dimensions of 0.6 m x 0.7 m x 0.3 m (0.13 m³). After the roughness preparation, was conducted the intercropping sowing of 320 seeds of *Zea mays* (corn) and *Phaseolus vulgaris* (bean) in the two sample plots of the experiment, presenting an average of five seeds of each specie per planting hole.

For the measurement of the solar radiation, relative humidity of the air and soil temperature, was installed a system of signal acquisition attached to a microcomputer in both sample plots of the experiment.The sensors were managed by the program *Climus*, developed in the Laboratório de MeiosPorosos e PropriedadesTermofísicas dos Materiais (LMPT), of Universidade Federal de Santa Catarina (UFSC) and adapted for this research (Maçaneiro*et al*., 2014). During the growing period, throughout 24 hours a day, the system of signal acquisition attached to the microcomputer did the continuous record of the abiotic variables in each sample plot of the experiment, automatically calculating the averages, every hour, and sending all of them to a file. The solar radiation (W/m²) and relative humidity of the air (%) measures were registered with two sensors of the type thermocouples and of humidity capacitive, respectively. These sensor were installed in 1.3 m high of the soil in both sample plots. All sensors has 5% of degree of uncertainty.

For the measurement of the biotic variables from the plants, two months after the sowing of *Zea mays* (corn) was measured the total height and diameter of the base of each individual. The corncobs that were in stage of ripeness had its length and diameter measured with the aid of digital pachymeter. About the corn production,it was made the counting of the total number of cobs per each plant in the sample plots. After the harvest of *Phaseolus vulgaris* (bean), it was made the counting of the total number of the viable pods (it was considered viable pods those which had at least one seed) per each hole of the sample plots of the experiment.

The sample plots of the experiment were compared by the measured abiotic and biotic variables: solar radiation, relative humidity of the air, soil temperature, number of sprouted seeds, number of pods per planting holes, total height, base diameter, number of cobs per individual, cobs length and diameter. The comparison of the abiotic and biotic variables was made by the test *F* and subsequent test *t* for two sample plots, both using a significance level $\alpha = 0.05$ (Zar, 2010). In order to examine similarities and differences between the frequency distribution of graphics of the solar radiation, relative humidity of the air and soil temperature, was used Kolmogorov-Smirnov test to the significance level of $\alpha = 0.05$ (Siegel and Castellan, 2006).

RESULTS AND DISCUSSION

In relation to the effect of the solar radiation in the sample plots of the experiment, in the first months of evaluationany significant differences have been noted between the templates of soil preparation tested (Table 1). However, in the last month of evaluation the irregular sample plot (with roughness) presented inferior solar radiation ($t = 2.912$; $P< 0.01$) when compared with the regular sample plot (without roughness). The solar radiation frequency between the irregular and regular sample plots showed highly significant differences among each other (Kolmogorov-Smirnov, $D = 0.452$; $P< 0.0001$). This result evinces the difference of the plants effect in the incidence of the solar radiation in the two sample plots. Between the months of September to November the plants did not presented marked differences in the total height, what explains the similarities in the incidence of solar radiation in the soil.However, from the month of Novemberonwards it was observed an increase in the growth of *Zea mays*in in the two sample plots of the experiment. In the irregular sample plot, for example, the plants presented further development, resulting in increase of soil shadowing (Figure 1a).

It was noted highly significant differences ($t = 10.105$; $P< 0.001$) between the relative humidity of the air in the two sample plots of the experiment (Table 1). Besides that, the relative humidity of the air frequency between the regular and irregular sample plots presented highly significant differences among each other (Kolmogorov-Smirnov, $D = 0.165$; $P< 0.0001$). The highest levels of relative humidity of the air occurred during the nighttime, normally getting to 100%, gradually decreasing after the dawn and reaching its minimum values around 15h. From that time onward, the humidity concentration rises again and reaches its maximum values around midnight. With the decrease of the solar radiation intensity in the soil, there is a progressive increase of the relative humidity of the air and climatic conditions more mitigated to the plants, what is evident in the irregular sample plot (Figure 1b).

During the months where were verified significant differences between the relative humidity of the air in the sample plots of the experiment, the best development of *Zea mays* and *Phaseolus vulgaris* can be assigned to the soil roughness. In the month of September, for example, when there was not difference between the size of the plants, the soil roughness ensured the internalization of the water in the soil, creating variations in the microclimate of the area of the experiment (Maçaneiro*et al*., 2013). In the periods with solar radiation higher incidence, the irregular sample plot presented superior levels of humidity (Figure 1b), what guarantee better environmental conditions for the development of the plants (Aumond*et al*., 2012). This fact evinces the effect of higher shading of the *Zea mays* plants on the sample plot of the experiment, what generated greater protection to the soil by the humidity increase. The opposite was observed for the regular sample plot, where the plants did not grant the same protection to the soil.

The soil temperature presented highly significant differences between the sample plots of the experiment, overall in the months of November ($t = 10.706$; $P< 0.001$) and December ($t = 7.566$; $P< 0.001$), being lower in the irregular sample plot and higher in the regular sample plot (Table 1). Besides that, the soil temperature frequency between the irregular and regular sample plots showed highly significant differences among each other (Kolmogorov-Smirnov, $D = 0.207$; $P< 0.0001$). This result indicates that in the area with roughness, due presenting lower incidence of solar radiation and higher relative humidity of the air, the soil temperature also tends to be lower (Figure 1c), similar to the verified by Aumond (2007) and Aumond*et al*. (2012) in recovery of degraded areas because of mining and Maçaneiro*et al*. (2013), in *Eucalyptus grandis* plantings. Both the authors used the same technique of physical management of the soil. Alterations in the soil temperature can considerably affect the seed germination in the field and, still, influence in the growth of *Zea mays* and *Phaseolus vulgaris* (Siqueira*et al*., 1987; Iapar, 1991; Silva *et al*., 2006; Conus *et al*., 2009; Coelho *et al*., 2010).

In the irregular sample plot was verified a gradual decrease in the soil temperature according to the months of evaluation of the experiment, and the tendency was of mitigating the microclimate conditions of the soil according to the cultivation

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months. This result envies the effect of the vegetal coverage of the cultures over the soil microclimate. The sensor installed in the regular sample plot, for example, presented superior average temperature (22.0ºC) when compared to the irregular sample plot (21.6ºC), in function of the lower development of *Zea mays* and *Phaseolus vulgaris*.

Table 1: Measurements of abiotic variables in the irregular sample plots (with roughness) and regular (without roughness) in the study area, in the cultivation period of *Zea mays* (corn) e *Phaseolus vulgaris* (bean).

Abiotic variables / Evaluation period (month)		Irregular	Regular	*t*	*P*
Solar radiation (W/m²)					
	September	360.2	345.0	0.777	0.44
	October	314.2	304.6	0.542	0.59
	November	347.2	350.3	0.173	0.86
	December	388.5	460.2	2.912	< 0.01
	Overall average	350.6	359.2	0.869	0.38
Relativehumidity (%)					
	September	84.7	82.1	2.619	< 0.01
	October	89.8	80.7	9.567	< 0.001
	November	90.4	90.2	0.175	0.86
	December	80.6	83.5	2.386	0.02
	Overall average	86.5	81.3	10.105	< 0.001
Soiltemperature (ºC)					
	September	20.1	19.9	1.478	0.14
	October	22.3	22.1	1.824	0.07
	November	22.3	23.8	10.706	< 0.001
	December	23.5	25.9	7.566	< 0.001
	Overall average	21.6	22.0	4.326	< 0.001

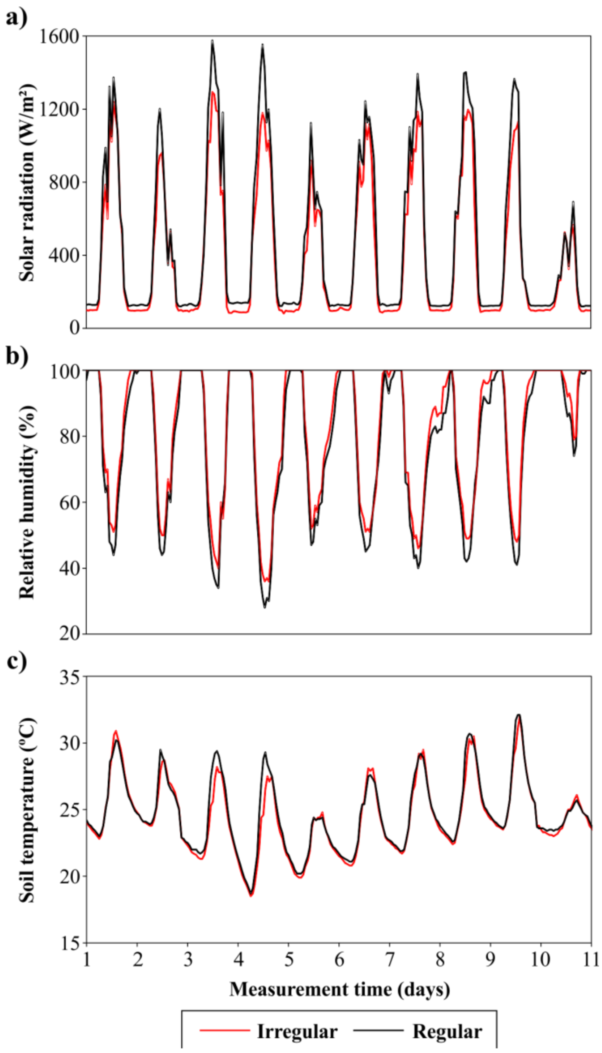

Fig. 1: Measurements of the abiotic variables in the irregular sample plots (with roughness) and regular (without roughness) in the period of 10 days of December in the study area.

In the irregular sample plot, the *Zea mays* and *Phaseolus vulgaris* cultivation presented production statistically superior when compared to the regular sample plot (Table 2), indicating that the soil roughness technique used in this research works for this culture, because when modifying and minimizing the abiotic variables (solar radiation, relative humidity of the air and soil temperature), there is the creation of favorable environmental conditions for the development of *Zea mays* and *Phaseolus vulgaris* in the field.

The *Zea mays* plants presented visible growth differences in the very first weeks after the seed germination in the field, represented mainly by divergences in its height and in the colouring of the leaves. The plants of the irregular sample plot were bigger and theirleavespresented dark green coloration, whereas the plants of the regular sample plot were smaller and had leaves with light green coloration. The *Zea mays* specie is quite demanding in nutrients, especially nitrogen and climatic conditions can significantly influence in its absorption capacity (Iapar, 1991; Cabezas*et al*., 2005; Conus *et al*., 2009; Calderón*et al*., 2015; Carvalho*et al*., 2015). However, the differences observed between both templates of soil preparation tested point to a probable efficiency of the roughness in the nitrogen conservation and in the conservation of the necessary microclimate conditions for its better fixation.

Other important factors in the cycle of *Zea mays* cultivation are the temperature and the soil humidity. To obtain success in the seedlings emergence of this specie, it is essential the existence of good natural conditions of water and soil humidity (Carvalho*et al*., 2015), also the temperature in the root zone must be, preferably, between 25ºC and 35ºC, because over that temperature occurs the decrease in the seedlings development (Silva *et al*., 2006). In mild winter climates, as is the case of Southern Brazil, variations of only 1ºC in the soil temperature can significantly affect the growth rate of *Zea mays*.

The number of viable pods was not the only difference observed in *Phaseolus vulgaris* planting. In observations conducted in the field, was perceptible the difference in the vitality of the plants, reflected by the size of the individuals and in their leaves coloration. In the regular sample plot, for example, *Phaseolus vulgaris* presented smaller height growth, the individuals were more fragile and their leaves presented light green coloration. On the other hand, in the irregular sample plot the individuals were bigger, more robust and had dark green coloration. The *Phaseolus vulgaris* specie is quite demanding in soil nutrition support, besides being sensible to extreme climatic factors, as high and low temperature, soil humidity and strong winds, also being very susceptible to pests and diseases(Silva *et al*., 2006; Silveira*et al*., 2011). This specie root system is essentially superficial, rarely reaching depths over 20 cm, therefore, is important that the nutrients and the soil organic matter concentrate in the surface layer (Soratto*et al*., 2006; Carvalho*et al*., 2014).

The nitrogen, for example, is a nutrient especially important in the phases of flowering and fruiting, because there are many pods and grains growing in the same time, what leads to a considerable demanding for nitrogen (Soratto*et al*., 2006; Silveira*et al*., 2011; Carvalho*et al*., 2014). It is important to point out that in case the weather conditions during the nodulation are not adequate, the nitrogen availability for the plant will became disabled, reducing the production of grains (Santos *et al*., 2005). In the current study, the great vitality of *Phaseolus vulgaris* observed in the irregular sample plot is an indicative of the roughness efficiency in the growth of the plants. Dickson and Boettger (1984) tested different combinations of temperature in the cultivation of *Phaseolus vulgaris* and conclude that the combination 30ºC/8ºC resulted in low production.

Table 2: Measurements of biotic variables in the irregular sample plots (with roughness) and regular (without roughness) in the study area, in the cultivation period of *Zea mays* (corn) e *Phaseolus vulgaris* (bean).

Species / Bioticvariables		Irregular	Regular	*t*	*P*
Zeamays					
	Nº of sprouted seeds (seeds.hole^{-1})	3.85	3.90	0.270	0.79
	Totalheight (m)	0.78	0.47	11.413	< 0.0001
	Base diameter (mm)	21.50	14.91	10.697	< 0.0001
	Nº of cobs (cobs.ind^{-1})	1.14	0.97	5.070	< 0.001
	Cobslength (cm)	25.1	20.1	10.196	< 0.0001
	Cobsdiameter (mm)	6.55	4.28	13.109	< 0.0001
Phaseolusvulgaris					
	Nº of sprouted seeds (seeds.hole^{-1})	4.06	3.96	0.612	0.54
	Nº of viable pods (pods.hole^{-1})	18.5	12.5	4.366	< 0.001

Conclusion:

The roughness technique provided significant microclimate variations between solar radiation, relative humidity of the air and soil temperature in the sample plots of the experiment, and those environmental variables possibly influenced in the development of de *Zea mays* and *Phaseolus vulgaris*.

The greatest growth and production of *Zea mays* e *Phaseolus vulgaris* were observed in the irregular sample plot, what indicates the roughness effect in the soil protection over the erosive process and leaching, also the effect in the internalization of water, soil and nutrients in the system.

The differences observed between the two sample plots, irregular and regular, also indicates the beneficial effect of the microclimates variation arising from roughness. The success of a culture is not guaranteed only with good soil conditions, but also being necessary to relate favorable environmental conditions with the system. The lowest temperature variations and the highest levels of relative humidity of the air observed in the irregular sample plot are indicative of the roughness influence in the microclimate and in the fast growth of the plants.

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