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Article

Effect of soil cover on the growth and productivity of buffel grass (*Cenchrus ciliaris* L.) in degraded soils of arid zones

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Abstract:

The objective of this study was to evaluate the use of corn crop residues as mulch and its impact on soil moisture content and the establishment, development and productivity of buffel grass (*Cenchrus ciliaris* L). A randomized block design with three replications was used. The treatments were: sowing of 10 kg ha-[1] of buffel grass seed (Bs); vegetation cover on soil with 10 t ha-[1] of corn crop residues (Vc); Bs + Vc combination; and control (no grass sowing and no vegetation cover). The Bs + Vc treatment maintained a higher soil moisture content ($P\leq0.05$), with 13.8 % *vs* 10.6 % of the control. Consequently, the number of grass plants m-[2], buffel grass cover, plant height, chlorophyll index and dry biomass production had a tendency to respond better, with values of 518.5 plants m^{-2}, 51.23 %, 31.8 cm, 162 and 167.8 g m^{-2}, respectively, and they exhibited a tendency toward a statistically similar response as to this treatment when applied separately (Vc and Bs). Photosynthesis (µmol $s^{-2}s^{-1}$), stomatal conductance, transpiration (mmol H_2O m^{-2} s^{-1}), and water use efficiency were not affected by any of the treatments in this study, their response being equivalent to that of the control.

Key words: Plant stress, Soil moisture, Pasture, Extensive livestock farming.

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Introduction

Every year, the productive capacity of 10 million hectares of agricultural land is lost due to soil degradation caused by a series of natural and anthropogenic factors[1,2]. Water erosion is one of the main causes of soil degradation in arid areas, where rainfall is erratic and torrential, producing high volumes of water runoff in a short period with a strong erosive impact[3]. Among the soil properties that determine water erosion are those related to infiltration and sediment stability, such as texture, organic matter content, and type of particle aggregates[4].

The vegetation cover over the soil reduces particle shedding by intercepting raindrops and reducing their erosive energy. Vegetation and surface plant debris reduce the velocity of water flow over the soil and promote sediment settling[5]. The impact is greater in these regions due to the lack of adequate vegetation cover, low organic matter content, and low soil moisture retention capacity, among other factors[6]. In order to mitigate soil degradation, agronomic practices are carried out according to the type of agricultural production system and the specific conditions of each region[7,8].

The construction of curbs on contour lines, the construction of masonry to reduce the velocity of rainwater, on-site rainwater harvesting systems based on micro-watersheds, the replanting of native grasses with conventional tillage methods, the establishment of different species of native or introduced plants with forage potential, and the use of different types of soil moisture retainers(9) are some of the technologies applied to mitigate the problem of erosion. Most of these techniques are aimed at retaining soil moisture in the face of high potential evaporation rates, which can be up to ten times higher than precipitation in semi-arid areas.

Livestock production systems in semi-arid zones are vulnerable due to recurrent droughts, the presence of soils with low vegetation cover, and low organic matter content, which generate a process of natural resource degradation that results in low productive potential(10). In addition, overgrazing is one of the most recurrent problems that reduce the productivity of pasture areas with deficient precipitation(11). All this makes it necessary to strengthen the lines of research and generate strategies to improve the use and management of water, soil, plant and animal resources in livestock areas based on native grazing vegetation and the regular presence of pastureland, so as to greater sustainability from the productive, economic, social and environmental points of view(12).

One factor that improves physical soil conditions to increase and conserve moisture after rainfall is the use of soil cover(13). If the use of vegetation cover is complemented with the replanting of native grasses of the region, there is a greater possibility of mitigating the degradation of pasture land.

Buffel grass (*Cenchrus ciliaris* L.) is an introduced species in Mexico that has shown adaptation to critical environmental conditions in semi-arid zones, which to a large extent sustain their economy through extensive cattle raising on pastureland(13,14). Even though this grass species has a high potential for adaptation and development in degraded soils of semi-arid areas(9,15), the establishment of this forage species in marginal environmental conditions requires an adequate management of natural resources to guarantee its germination, growth and productivity according to its development potential(16,17). From this perspective, vegetative soil covers and other soil moisture retainers, among other practices, are proving to be an effective strategy in the sustainable development of pasture-based livestock areas in degraded soils of arid zones(6,18,19).

The objective of this study was to evaluate the use of corn crop residues as soil cover, and its impact on soil moisture content and the establishment, development and productivity of buffel grass in degraded soils of arid zones in northern Mexico.

Material and methods

Geographic location

The study was carried out in an area with microphyllous and rosette scrub vegetation and small areas of grassland in the municipality of Mapimí in the north of the State of Durango, Mexico. The area is located at 25° 52' 23.65" N and 103° 43' 41.74" W and at an altitude of 1,176 m, with an average annual rainfall of 304 mm, a maximum temperature of 44 °C and a minimum of 10.2 °C[20].

Description of the experimental site

According to physical-chemical soil analysis, the experimental site presents a sandy loam soil with 56, 28, and 16 % sand, silt and clay respectively; a permanent wilting point (PWP) of 9.6 %, and a field capacity (FC) of 19.7 %. These soils are low in macro and microelements, although they have good levels of potassium (68.4 mg·kg^{-1}) and calcium (33.7 meq·L^{-1}), the latter making them alkaline soils with a pH of 8.3 and a slope of 1 % (Figure 1)[21].

Figure 1: Geographic location of the study area in the Municipality of Mapimí, State of Durango, Mexico

Experimental and treatment design

A randomized block experimental design was used with three replications and four treatments: sowing of 10 kg ha^{-1} with buffel grass seed (Bs); no sowing of grass and only application of 10 t ha^{-1} of corn stubble as mulch on the soil (Vc); the combination of the treatments Bs + Vc, plus the control (no sowing of grass or application of vegetative cover). Each experimental unit had a dimension of 5x5 m.

The study was carried out in the summer-autumn of 2017, for which soil preparation of the experimental area was performed by using a rake to a depth of 5 cm. In the grass sowing treatments, the seeds were scattered, ensuring their even distribution on the ground, and then covered with a light layer of the same soil by a second pass of the rake, in order to prevent the seeds from being exposed to the wind and dragged by it. The treatments using dry corn stubble as soil cover were applied immediately after planting. The experiment was established on dry soil, and the treatments were exposed to the first rain, which occurred in July with a rainfall volume of 64.8 mm, whereby the grass seed was allowed to germinate. Rainfall in the area of experimental influence during the study period was measured using a La Crosse Technology™ Heavy Weather Pro WS 2800 microclimatic station (USA).

Variables measured

The soil moisture content (%) was quantified using a Soil Tester™ Model HB-2 digital tensiometer (Ontario, Canada); while plant variables such as the number of grass plants m^{-2} were measured with a 20x20 cm quadrant, counting the number of plants within the quadrant; grass height (cm); grass cover (%) estimated in one m^2 using a 20x20 cm quadrant and using a scale of 0 to 100 to estimate the % of ground cover by grass per unit area. All these variables were measured at six different dates: 36, 52, 67, 87, 107, and 127 d after sowing (DAS), and three measurements were taken as sampling unit per treatment at each evaluation date.

The physiological variables of the grass were: chlorophyll index, measured using a Spectrum Technologies Inc . Fieldscout CM 1000 chlorophyll meter; photosynthesis (µmol CO_2 m^{-2} s^{-1}); stomatal conductance; transpiration (mmol H_2O m^{-2} s^{-1}) —these last three measurements were made with a model LI-6400XT infrared gas flow analyzer, (LI-COR®, Inc. Lincoln, Nebraska, USA)—; water use efficiency, product of the quotient of the amount of CO_2 assimilated and the amount of water transpired by the plant. These variables were measured only once at 107 DAS, for which three plants were taken per experimental unit. At the end of the experiment (127 DAS), the dry biomass produced from the grass (g m^{-2}) was obtained by cutting and drying the whole plant, except the root, at constant weight.

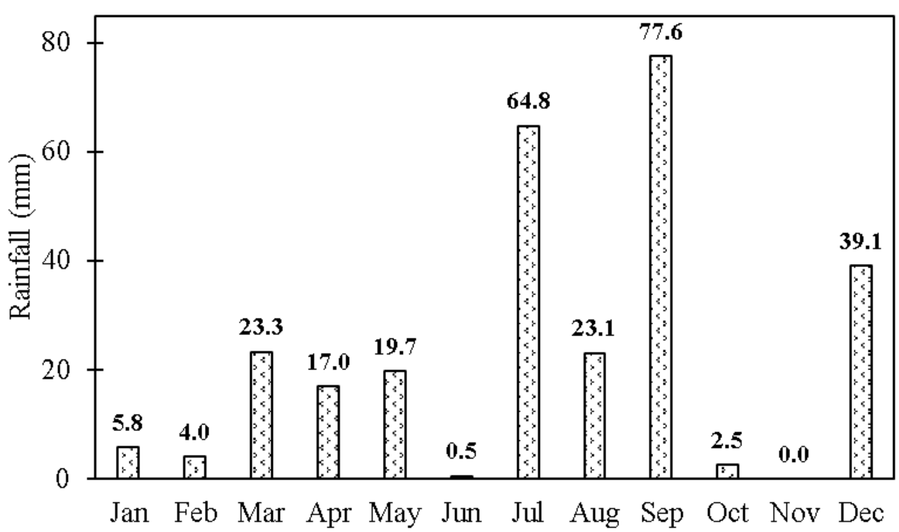
Data analysis

An analysis of variance and a Tukey multiple range test of means (P≤0.05) were performed using the SAS package (Version 9.0) to identify the effect of the treatment.

Results and discussion

According to precipitation records in the study area, the precipitation in year 2017 was 277.4 mm, slightly lower than the annual average, which 304 mm. The July-September period had the highest rainfall, with a total of 165.5 mm, representing 59.6 % of the total for the year (Figure 2). Buffel grass thrived adequately under these rainfall conditions, since the optimal range of summer rainfall reported a growth of 150 to 550 mm(22), which coincides with that recorded at the study site. Martin *et al*(23) reported that, for a period of 3 yr, the growth activity of this species was observed 15 d after a rainfall of 20 mm or more, a condition that occurred in the months of July and September in the present study. In arid grasslands of southern New Mexico, it was found that rainfall of < 20 mm in one day does not contribute to adequately wet the topsoil by 0.1 m(24).

Figure 2: Behavior of pluvial precipitation in the study area during the year 2017. Mapimí, Durango, Mexico



Soil moisture content, grass growth and development

The average soil moisture content was significantly higher ($P \leq 0.05$) in the treatment with buffel grass sowing + soil cover of corn crop residues (Bs + Vc) than that of the control, exhibiting values of 13.8 *vs* 10.6 %, respectively; the former (Bs + Vc) showed no statistical difference with respect to the other two treatments (Bs and Vc) applied separately (Table 1).

Table 1: Effect on soil growth and development of buffel grass (*Cenchrus ciliaris* L) with and without the use of a vegetative soil cover consisting of corn crop residues

Treatments	**Soil moisture (%)**	**Number of plants m^{-2}**	**Grass cover (%)**	**Plant height (cm)**
Control*	10.6^{b}	172.8^{b}	12.65^{c}	17.1^{bc}
Bs	12.2^{a}	358.0^{ab}	7.11^{c}	6.5^{c}
Vc	13.0^{ab}	481.5^{ab}	25.68^{b}	22.3^{ab}
Bs + Vc	13.8^{a}	518.5^{a}	51.23^{a}	31.8^{a}

* No grass sowing or soil cover was applied, only natural-born grass. Bs= Sowing of 10 Kg ha^{-1} of Buffel grass seeds without the application of corn crop residues on the soil. Vc= Application of 10 t ha^{-1} of corn crop residues on the soil as soil cover. Bs + Vc= Combination of the last two treatments mentioned above.

^{ab} Figures with the same letters within the same column are statistically equal ($P \leq 0.05$).

As a result of this water availability condition in the Bs + Vc treatment, the number of grass plants m^{-2}, grass cover, chlorophyll index, and grass plant height were significantly higher than in the Bs + Vc treatment ($P \leq 0.05$), with values of 518.5 plants m^{-2}, 51.23 %, 162 and 31.8 cm, respectively; the control registered the lowest values for these variables, with no statistical difference between the control and the Bs treatment. There was no consistent response to the Bs and Vc treatments when applied separately, since they fluctuated between statistically similar values to those of the Bs + Vc treatment and the control (Table 1).

The above results are consistent with those reported by Cruz-Martínez *et al*(9), who found that buffel grass improved growth, chlorophyll content, and grass cover in the soil when hydrogel was applied at different doses as soil moisture retainers. Alcalá(25), indicates that the development of buffel grass depends largely on the amount of water retained in the soil. On the other hand, soil moisture conservation practices in pasture sites have been reported to increase water infiltration and, therefore, plant productivity(26). In contrast, physical soil degradation negatively affects the growth and yield of agricultural crops, as a consequence of limited root depth, low soil moisture reserves, and low availability of nutrient content, which negatively affects soil organic carbon, nitrogen, phosphorus and potassium contents, and soil pH[27].

Physiological indicators and grass biomass productivity

The Bs + Vc treatment stood out for its higher chlorophyll index with respect to the control, which would be reflected in an adequate photosynthetic activity[28]. Pezeshki[29] and Carter and Knap[30] identified that a degradation of chlorophyll by any stress factor has repercussions in the reduction of the photosynthetic capacity of the leaves, as it limits the photochemical process in the absorption of radiation.

With the treatment that combined the sowing of 10 kg ha^{-1} of pasture and the application of 10 t ha^{-1} of corn crop residues as soil cover (Bs + Vc), the chlorophyll content and biomass production were significantly higher ($P \leq 0.05$) than with the rest of the treatments —with values of 162.0 and 167.8 g m^{-2}, respectively—, compared to the control, which registered values of 18.9 µmol $m^{-2}s^{-1}$, 105.7 and 54.4 g m^{-2}. This represents an increase of 12.1, 53.2 and 208.4 % between these variables, respectively, which suggests that the sowing of grass needs to be complemented with the incorporation of a soil cover (in this study, corn crop residues) or some other type of soil moisture retainer, as reported by various authors[12,17,28]. Stomatic conductance, transpiration, and water use efficiency were not affected by the treatments applied in this study (Table 2).

Table 2: Physiological indicators and biomass productivity of buffel grass (*Cenchrus ciliaris* L) in different grass seeding treatments and use of corn crop residues as soil cover

Treatm.	Photosynthesis (μmol $m^{-2}s^{-1}$)	Stomatic conductance	Transpiration (mmol H_2O_2 $m^{-2}s^{-1}$)	WUE	Chlorophyll index	Dry matter (g m^{-2})
Control*	18.9^{ab}	0.156^{a}	2.75^{a}	6.9^{a}	105.7^{b}	54.4^{c}
Bs	14.1^{b}	0.111^{a}	2.16^{a}	7.1^{a}	75.1^{c}	53.3^{c}
Vc	20.1^{ab}	0.176^{a}	2.95^{a}	7.0^{a}	146.4^{a}	102.7^{b}
Bs + Vc	21.2^{a}	0.138^{a}	2.53^{a}	8.4^{a}	162.0^{a}	167.8^{a}

Treatm.= Treatments. WUE= water use efficiency. * No grass sowing or soil cover application: only natural-born grass. Bs= Sowing of 10 Kg ha^{-1} of buffel grass seeds; no application of corn crop residues to the soil. Vc= application of 10 t ha^{-1} of corn crop residues as soil cover. Bs + Vc= combination of the last two treatments mentioned above.

^{abc} Figures with the same letters in the same column are equal ($P \leq 0.05$).

In a projection of dry biomass production measured in g m^{-2}, the best treatment (Bs + Vc) yielded 1.6 t ha^{-1}, while the control produced 0.54 t ha^{-1}, 208.4 % more of the former with respect to the latter, and an overall average of 0.89 t ha^{-1} among all the treatments. Therefore, in terms of productivity, this technology also opens up a prospect, given the low bioproductivity of these areas.

The results in Tables 1 and 2 show that lower soil moisture corresponded to a significant ($P \leq 0.05$) decrease in photosynthetic activity, at least in the Bs + Vc treatment, with respect to the control. This is consistent with the findings of Tezara *et al*(31), who report that the presence of moisture in the soil favors plant photosynthesis, while water deficit decreases it. The positive result of the chlorophyll index as a function of higher soil moisture content is contrary to that reported by Meléndez *et al*(32) and Trujillo *et al*(33), who observed that the chlorophyll content increases in soils with low moisture gradients and decreases in soils with high soil moisture gradients. In contrast, in a study on *Opuntia ficus-indica*, Aguilar and Peña(34) reported that the chlorophyll concentration decreased significantly in plants under drought, consistently with the findings of this study. The above contrasting results regarding the response to water stress in terms of chlorophyll content may be related to the genetic nature of the plant materials used, such as cactus, and to the ecological conditions in which the different studies were conducted(35). Additionally, Cabrera(36) points out that the physiological activity, such as photosynthesis, conductance, and transpiration of buffel grass, depends on the fluctuations of the weather conditions of each year.

Conclusions and implications

The use of soil cover with corn crop residues in combination with the sowing of buffel grass (*Cenchrus ciliaris* L.) was the treatment with the best effect on the soil moisture content, which favored the growth and development of the grass plant, with a better number of plants per unit area, a higher plant cover, a higher chlorophyll index, and a higher dry matter production. However, these same treatments applied separately showed inconsistent behavior, with a response similar to that of the combination of both practices, but differentiated from the response of the control. Grass plant physiology in terms of photosynthesis, stomatal conductance, transpiration, and water use efficiency showed no effect of the soil cover practices tested in this study.

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