Article

A rainfed agroforestry system for the semi-arid Altiplano of Mexico

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Abstract

In the semi-arid Altiplano of North-Central Mexico, soil erosion is one of the main problems affecting the sustainability of agricultural lands. As a result, yields and incomes are low and soil quality continues to decline. With the objective of developing an agroforestry exploitation system for the sustainable management of soils, a rainfed agroforestry system (SAF) was designed that included sorghum (*Sorghum bicolor* L. Moench) of brown rib (*bmr*) and beans (*Phaseolus vulgaris* L.) in rotation, nopal (*Opuntia* sp.) and leucaena (*Leucocephala glauca*) as an alternative to improved management of the agricultural production units, and not as another variant of the productive reconversion. The SAF was evaluated in the Experimental Site 'Sandovales', Aguascalientes, during 2014 and 2015, under restrictive environmental conditions, with 344 and 320 mm of precipitation in the cultivation cycles to prove that it is sustainable, since it favors the conservation and fertility of the soil and the use of rainwater. The average yield of sorghum planted in bed with six rows was 6.33 t ha^{-1} of MS, that of the bean of the varieties Flor de Junio Dalia, Pinto Saltillo, Pinto Centenario, Flor de Mayo Dolores and Azufrado 2, in four rows was 2.03, 1.80, 1.74, 1.34 and 0.60 t ha^{-1} grain. It is concluded that it is possible to implement a SAF of sustainable productivity, where sorghum and rainfed beans are included in a crop rotation. The proposed SAF offers technically efficient options for erosion control in rainfed agriculture, with low productivity.

Keywords: *Opuntia* sp., *Leucocephala glauca*, agroecosystem, aqueel, live barriers, pooling.

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Introduction

Rainfed agriculture in the temperate semi-arid Altiplano of North-Central Mexico is characterized by low production of grain and forage with high spatial and temporal variability.

Each year 1.25 million hectares are planted in the states of Aguascalientes, Chihuahua, Durango, San Luis Potosi and Zacatecas, Mexico. In years with severe intermittent drought, the losses have affected 80% of the sown area (SIAP-SAGARPA, 2011). Therefore, priority must be given to water harvesting and soil conservation in order to maintain agricultural productivity in the region (Osuna-Ceja *et al*., 2013; Arellano-Arciniega *et al*., 2015).

The National Institute for Forestry, Agriculture and Livestock Research (INIFAP) has generated complete technological packages and testimonies of new solution alternatives that help solve the challenges facing modern agriculture and contribute to improving the competitiveness of national agriculture.

The establishment of barriers of living walls and terraces are effective practices in the conservation of soil and water, such is the case of the system of crops in alleys (Lal, 1991; Ramírez-Cruz and Oropeza-Mota, 2001; Uribe-Gómez *et al*., 2002; Perez-Nieto *et al*., 2005; Camas *et al*., 2012), defined by Nair *et al*. (1994) as an arrangement of annual weeding crops growing between living wall barriers of shrubs or trees preferably legumes, whose residues from their continuous pruning, increase the mulch and the organic matter content of the soil and trap the runoff, sediments and the nutrients.

Crop rotation is an agricultural practice that, in particular under rainfed conditions, cannot guarantee obtaining high yields, which is why it must be accompanied by adequate soil conservation practices that allow maximum use of rainwater and improvement of the physical, chemical and biological quality of the soil, to maintain production levels within a sustainable agriculture (Osuna-Ceja *et al*., 2006; Aguilar-Benítez *et al*., 2012; Osuna-Ceja *et al*., 2015a; Arellano-Arciniega *et al*., 2015).

The bean (*Phaseolus vulgaris* L.) are part of the crops that are traditionally sown under rainfed conditions in the semiarid region; however, their unit yields are very low (SIAP-SAGARPA, 2015). For this reason, new improved bean varieties have been developed with proven or probable adaptation in local bean areas. The sowing of sorghum (*Sorghum bicolor* L. Moench) with the *bmr* (*brown midrib*) or brown vein gene is a novelty in the region.

Given the current demand for grain and fodder in the semiarid region under study, it is interesting to know if the agroecological conditions of the same are favorable, to the cultivation of sorghum and allow attractive yields to the producer, for what in the medium term, incorporate it into its production unit (Ríos-Saucedo *et al*., 2010; Osuna-Ceja *et al*., 2015a). Given the scarcity of water, sorghum shows greater adaptation than corn (*Zea mays* L.) (Borrell and Hammer, 2000).

In general, corn exceeds in sorghum dry matter yield under adequate soil moisture conditions; however, with moderate or severe water deficiencies, the efficiency in the use of sorghum water is greater than that of corn (Reta *et al*., 2010), due to its deep root system, precocity and osmotic adjustment capacity in the face of water stress (Reta *et al*., 2006; Bolaños-Aguilar and Emile, 2013).

Conservation agriculture is considered a sustainable soil management system, which allows the conservation of soil and water in rainfed lands, through innovative agronomic practices that control erosion, reduce surface runoff and mitigate the effects of drought. (Ventura *et al*., 2003; Figueroa-Sandoval *et al*., 2011; Bolaños-Aguilar *et al*., 2012; Osuna-Ceja *et al*., 2015b; Arrellano-Arciniega *et al*., 2015).

The objective of this study was to develop a rainfed agroforestry system for the crop pattern of brown rib bean in rotation with beans and live barriers to the outline of nopal (*Opuntia* sp.) and leucaena (*Leucocephala glauca*), maintaining the characteristic of use low inputs. The hypothesis proposed was that the establishment of several coverage strata with different annual and perennial species combined with soil conservation and water harvesting practices minimizes soil erosion, maximizes yield and diversifies the rainforest agroecosystem with alternative systems that improve productivity.

Materials and methods

The study was conducted during 2014-2015, at the Sandovales Experimental Site, Aguascalientes, Mexico (21° 53’ 09” North latitude, 102° 04’ 14” West longitude and 2 049 altitude) with 350 mm of average rainfall in the crop cycle, average temperature of 16.3 °C and crop cycle of 110 days (end from June to mid-October) (Medina *et al*., 2006). The soil is ≤0.45 m deep, with less than 1% organic matter, sandy loam texture in the topsoil, 2% slope and pH 6.6 (Osuna-Ceja *et al*., 2013).

In 2014, a variety of brown rib sorghum (Triunfo x LT BMR-6) was evaluated and in 2015, five different bean varieties with different growth and precocity habits: Pinto Centenario, Pinto Saltillo, early varieties of modest development and small area foliar per plant; Flor de Mayo Dolores, Flor de Junio Dalia and Azufrado 2, intermediate varieties with a good development and greater leaf area per plant, all of habit of indeterminate growth type III. With the exception of sorghum, all bean materials come from the genetic improvement program of INIFAP.

The evaluated SAF integrated the following crop rotation: in 2014: strips of 15 m wide were established with plantings of brown ribbed sorghum (*bmr*) in beds of 1.6 m (width of tractor gauge) with six rows, the separation between these were 20 cm and 10 seeds per linear meter, in 2015 followed the rotation with beans in beds to four rows, the separation between them was 30 cm and 14 cm between plants. Every 15 m three lines of nopal (*Opuntia* sp.) of the staggered region and one row of leucaena (*Leucocephala glauca*) planted at high densities (between 1 800 and 3 000 plants ha^{-1}) and counter-pending, were established for the purpose that they serve as living barriers that support the control of laminar erosion and promote the maintenance of organic matter and soil fertility.

These lines were established in the month of May of the year 2014 in the whole study area. The experimental unit consisted of five strips, each measuring 15 m wide and 160 m long, where the sowing of the sorghum was done in 8 beds per stripe and the bean was planted in a strip with 8 beds per variety. The established population density was 252 and 180 000 plants ha^{-1} for sorghum and beans respectively.

The land was fallowed and tracked in the first year and in the second year only one step of multi plow and one crawl before the sowing was applied. The sowing of sorghum was carried out on June 28, 2014 and that of bean on July 8, 2015 in humid soil. The first was made with a mechanical seeder for forage crops designed for sowing in beds of 1.6 m wide with six rows coupled to a system of water collection *in situ* (Aqueel roller). Bean planting was carried out with a versatile precision mechanical seed drill designed for sowing in beds with four rows coupled to an on-site water collection system. Both equipment was designed by the Pabellon Experimental Field Mechanization Program of INIFAP (Rojas *et al*., 2014). In addition, sowing was implemented on the sides of the bed in both cases (Arellano-Arciniega *et al*., 2015; Osuna-Ceja *et al*., 2015b).

The seeds of the sorghum and bean materials were inoculated with mycorrhiza at the time of sowing with the INIFAP strain (*Glomus intraradices*). Also, an application of foliar fertilization was made: in sorghum it was done at the beginning of flowering, and for beans it was applied during grain filling, with urea and phosphoric acid at 2 and 1%, respectively; said practices are described by Osuna-Ceja *et al*. (2012). The control of pests in both crops was done with an insecticide application; at 30 dds, CE 38 Dimetoate was applied in a dose of 1 L ha^{-1} to prevent the attack of the soldier worm (*Pseudaletia unipuncta*) and the aphid of the head (*Rhopalosiphum maidis*) and to control the leafhopper (*Empoasca kraemeri*) and mosquito white (*Trialeurodes* sp.).

The observations that were made to determine the response of the system were:

For the climate: in the two years of study, the daily climatic data were recorded in an automated meteorological station, located 300 m from the experimental site. A classification of rainfall events according to their magnitude was also conducted to determine the amount of total annual precipitation that causes erosion. Using the regional application model generated by Cortés (1991), the erosivity (R) of rainfall was estimated as a function of annual precipitation.

$$R= 2.8959P + 0.002983P^2$$

Where: R= represents the annual rainfall erosivity index (Mj mm ha^{-1} h^{-1} year^{-1}) and P= represents the average annual precipitation (mm).

For the soil: In each crop cycle, before sowing, soil samples were taken in the root zone of the plants (0-10, 10-20 and 20-30 cm deep) and sent to the laboratory to determine texture, organic matter (MO), pH and electrical conductivity (CE) of the experimental area. Texture (Bouyoucos hydrometer), CE in extract, MO (Walkley and Black, Page *et al*., 1982) and pH in a water: soil ratio 2.5:1 (Page *et al*., 1982). The apparent density (ρ_a) of the soil was calculated as the quotient between the mass of dry soil at 105 °C (M_{ss}) and the total volume (V_t) that occupies this unaltered soil mass and was determined in five points distributed at random and in each one the root zone of the plants was sampled using the double-cylinder auger method (Jury *et al*., 1991). This allowed to determine the percentage of pores (f_t) with the following equation, where ρ_a is the average value.

$$\rho_a = \frac{Mss}{V_t} \qquad f_t = 1 - \frac{\rho_a}{2.65}$$

For the plant: during the cycle of cultivation of sorghum and beans the phenological characteristics were quantified: number of days at emergence, at flowering and at physiological maturity. The dynamics of plant cover in the different phenological stages of both crops was also determined according to the leaf area index (IAF). For the measurements, a linear ceptometer (Decagon Devices Inc. Accupar Ver. 4.1) was used, which directly provides the IAF data of the crops (Padilla *et al*., 2005). The sorghum crop was carried out at 97 dds, when the grains showed a milky- doughy state. For the determination of the yield of dry matter (MS), within each experimental unit ten samples of 1.2 m wide by 5 m long were taken at random.

The cutting height was 5 cm from the ground level. The cut forage was weighed, obtaining a subsample of 0.5 kg per harvested plot, which was taken to the laboratory to be dried in a forced air oven at 60 °C until reaching constant weight, to have the MS percentage and transform the results on a dry basis (Reta *et al*., 2007). The forage quality was also determined in terms of concentration of crude protein (PC), neutral detergent fiber (FDN) and acid detergent fiber (FDA). In bean, the yield of grain and straw and the number of pods per plant (NV plant^{-1}), number of grains per pod (G V^{-1}), the weight of 100 seeds and the Harvest Index (IC) were quantified. For the determination of said parameters, within each experimental unit, five repetitions of 1.2 m wide by 5 m long were taken at random.

The experimental design was completely random blocks, the treatments in 2015 were: the bean varieties, the experimental unit was 15 m wide by 100 m long by treatment. With the data an analysis of variance was performed, and the means of the treatments were compared with the Tukey test ($p \leq 0.05$). SAS version 8 was used for these analyzes (SAS, 1999).

Results and discussion

In rainfed crops, rainfall is a determining factor in productivity, even more so if it is a semi-arid region, as is most of the Altiplano. Figure 1 (a and b) shows the maximum temperature (Tmax) and minimum (Tmin) data for the two years of study; in this it is observed that the daily distribution during the development of the sorghum fluctuated between 23 and 26 °C, for Tmax and between 11 and 14 °C, for Tmin, in 2014, while for 2015 during the development of the bean, the temperature fluctuated between 24 and 26 °C, for Tmax and between 6 and 11 °C, for Tmin, respectively.

It should be noted that both Tmax and Tmin remained practically constant throughout the development of the crop in both years. The seasonal rainfall was 573.5 mm in the first year and 531.6 mm in the second, 60% (344.1 and 320.6 mm) of this occurred during the development of the crop. Of the 344.1 and 320.6 mm, 63% (216.8 and 202.6 mm) occurred during the stage of vegetative development and 37% (127.3 and 118. mm) during the flowering and reproductive stages of the sorghum and bean materials; this indicates an erratic distribution for the needs of the agrosystem.

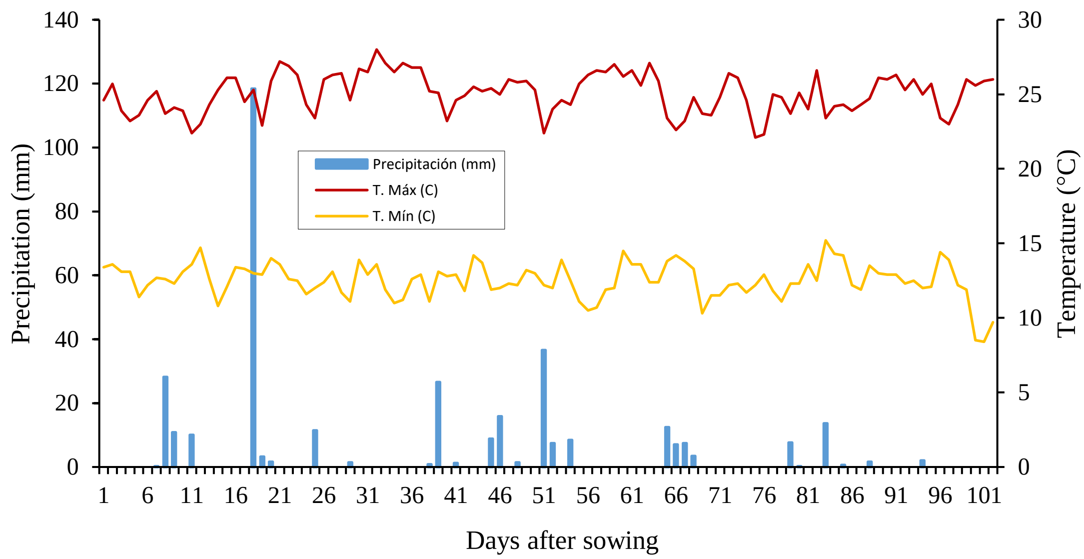

Figure 1a. Maximum and minimum temperature and daily precipitation, during the crop cycle of sorghum and dry beans. Sandovales, Aguascalientes, 2014.

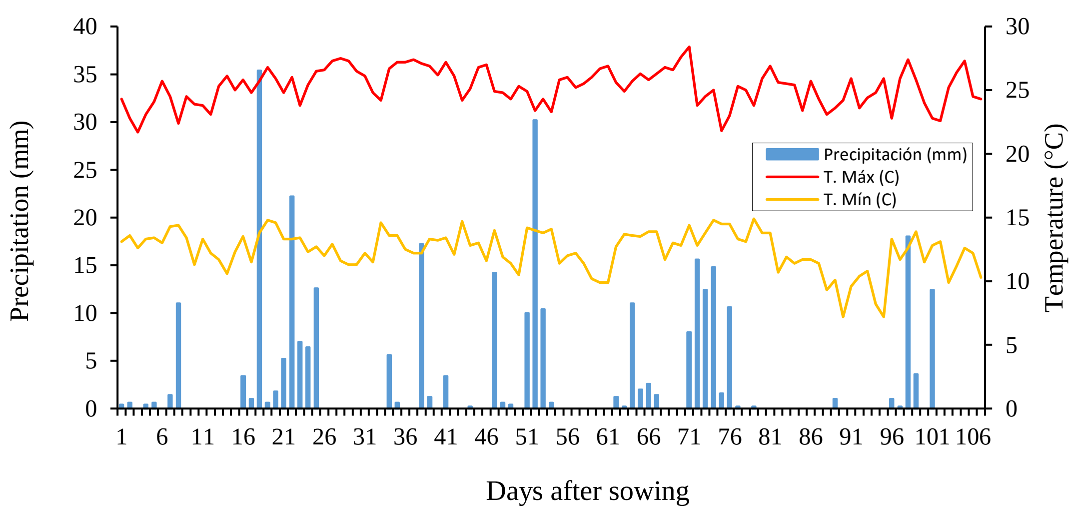

Figure 1b. Maximum and minimum temperature and daily precipitation, during the crop cycle of sorghum and dry beans. Sandovales, Aguascalientes, 2015.

Frequency of the amount of rain

In 2014 and 2015, for the Sandovales Experimental Site, Aguascalientes, Mexico, the daily rains occurred indicate that only 52 and 76% corresponded to 5 to 10 mm daily, in this interval rains ≤5 mm are included (Figure 2); for rains between 15 to 20 mm, the frequencies are between 6 and

17%, for rains from 25 to 30 mm, they are between 5 and 1% and from 35 to 40 mm, they are between 1 and 5%, for two years, respectively. The occurrence of rainfall with values above 100 mm was 1% and only occurred in 2014. The erosivity of the annual rainfall (R) described by the Cortes equation (1991) for this region was 2 653.9 Mj mm ha^{-1} h^{-1} $year^{-1}$ in 2014 and 2 900 for 2015, respectively. The distribution of erosivity was concentrated with 60 and 53% during the two years of study, in three months, from July to September, which coincides with the cultivation period (Figure 3).

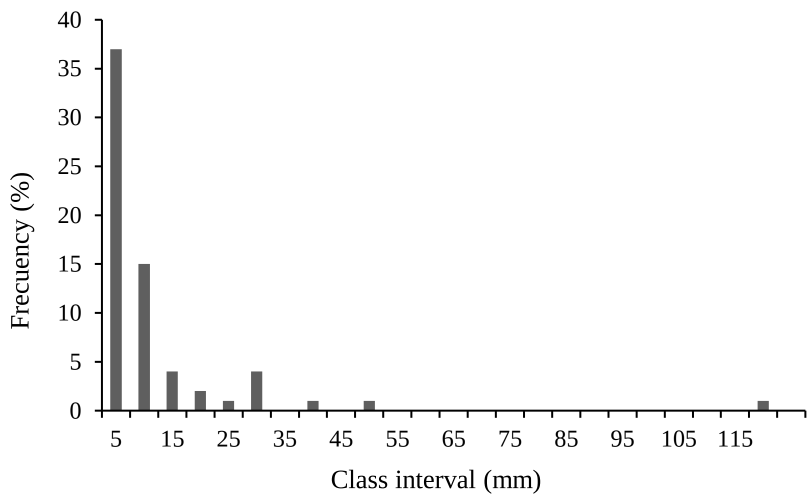

Figure 2a. Frequency of daily rains at the Sandovales Experimental Site, during 2014.

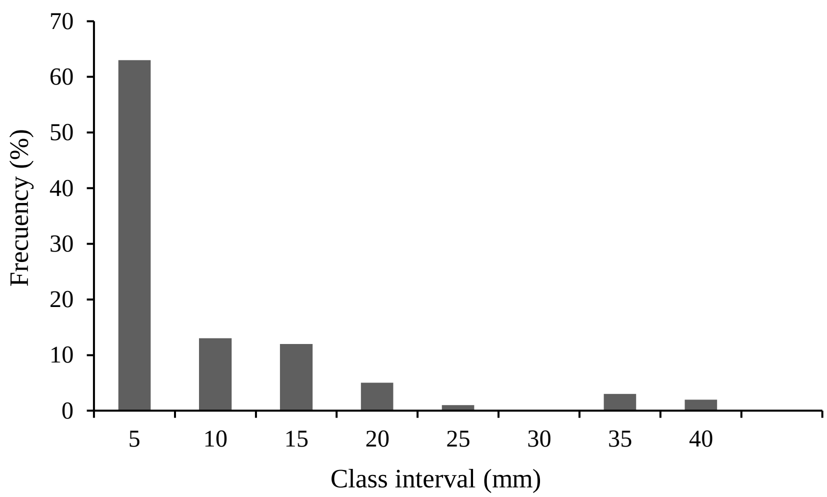

Figure 2b. Frequency of daily rains at the Sandovales Experimental Site, during 2015.

When comparing the cumulative distribution of the annual 'EI' for the two years of study and the vegetable cover of sorghum and dry beans with different sowing method (SAF and traditional system 'ST'), differences in plant cover (CV) were observed of the crops (Figure 3). When comparing the systems, a soil cover is observed through the CV of 30% 10 days after sowing in the case of beans and sorghum under the SAF, while the traditional system took 20 days after sowing achieve this CV value.

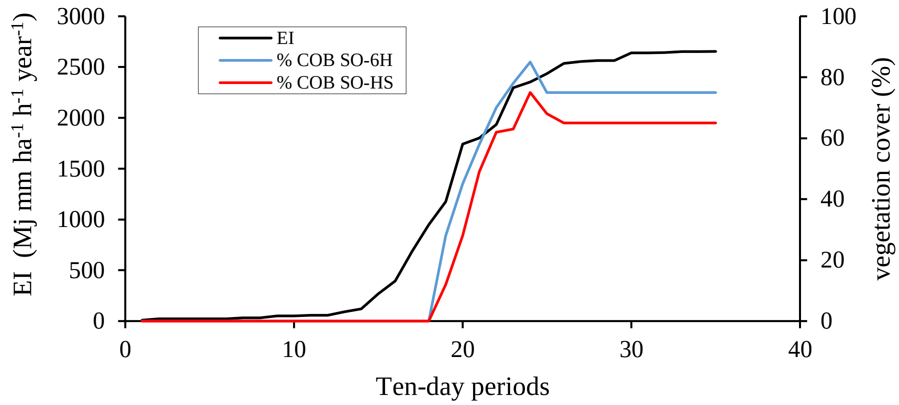

Figure 3a. Rain erosion (EI) and percentage of vegetation cover for rain sorghum, 2014. Sandovales, Aguascalientes.

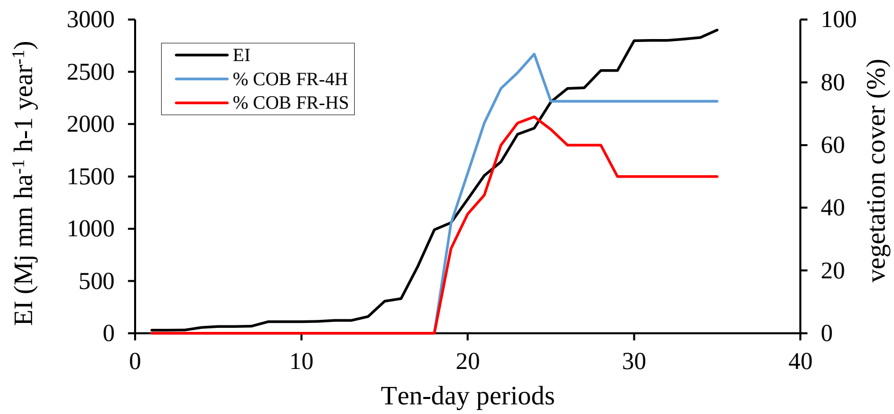

Figure 3b. Rain erosion (EI) and percentage of plant cover for rainfed beans, 2015. Sandovales, Aguascalientes.

The above is attributed, on the one hand, to the sowing to the contour in beds of six and four rows for sorghum and beans, respectively. Which, due to its early vegetative closure, provides a greater coverage protecting the soil from its detachment due to the impact of raindrops, as well as the strengthening of the runoff filter with live wall barriers (of nopal and leucaena). In systems considered as conservation tillage it is indicated that 30% of the soil cover causes a 50% decrease in erosion (Galeana *et al*., 1999; Velázquez *et al*., 2002).

Behavior of live barriers of nopal-leucaena

The living barriers of nopal and leucaena established at the beginning of summer 2014, after two years of development, have an optimal growth dynamic that guarantee the improvement and stability of the sustainable productivity of the SAF (Figueroa-Sandoval *et al*., 2011). The establishment of the barriers is accompanied by drainage boards that reduce runoff, soften the speed of runoff and intercept sediments mobilized by runoff, which are effective filters that retain soil and promote the slow passage of water (Figueroa-Sandoval *et al*., 2011).

Behavior of the sorghum-bean rotation

As a complement to the living barriers, planting in beds with multiple lines managed in the rotation system sorghum-bean with six and four rows respectively was used as plant cover. The decision to validate these two species as promising in the rotation system, is due to the results obtained with them in the research carried out in the triennium, 2012-2014, in the experimental site Sandovales, Aguascalientes (Osuna-Ceja *et al*., 2013; Osuna-Ceja *et al*., 2015b).

The behavior of these coverages (Table 1), shows that the coverage speed of both crops, in the case of SAF, reaches more than 60% from 30 days of germination, producing an almost total reduction at the end of the 50 days of weeds and empty spaces without plants. In this period (end of August) the crop reaches its maximum development, providing maximum protection to the soil against the impact of raindrops; in addition, there is less moisture in the soil due to the transpiration of the crop and consequently the runoff decreases and with it the soil losses. In addition, the high roughness produced by the pooling established on the sides of the sowing bed guarantees a retention of runoff from the furrow area.

Table 1. Dynamics of foliage coverage estimated for sorghum-bean crops. Sandovales, Aguascalientes. 2014-2015.

Cultivation system	Phenological stages of sorghum-bean							
	V_2(10)	V_3(20)	V_4(30)	R_5(40)	R_6(50)	R_7(60)	R_8(70)	R_9(80)
	(%) of coverage							
Sorghum with six rows	28	48	65	75	84	92	75	73
Traditional sorghum	12	28	36	55	62	69	56	52
Bean with four rows	35.1	51.4	66.7	77.5	85	92.6	83.7	73
Traditional bean	20	35	44	55	62	69	56	50

Sorghum= V_2-R_5- vegetative stage 10-55 DDS; R_6-R_9-reproductive stage 55-95 DDS, beans= V_2-V_4 - vegetative stage 10-30 DDS; R_5-R_8- reproductive stage 30-75 DDS; R_9-maturation 75-95 DDS. The value in parentheses is the number of days elapsed after planting.

These results indicate the positive effect of CV of sorghum and beans in SAF by covering the soil more quickly through the management and topological arrangement of the crop. SAF is more efficient to reduce erosion and surface runoff, compared to ST of both crops because in this last CV does not cover the entire area of the furrow leaving a significant percentage of unprotected soil and exposed to direct impact of rain (Table 1).

Modifications of soil properties under conservation practices

The soil texture is sandy loam in the topsoil (0-10 and 10-20 cm) and sandy-clayey in the underlying layer (20-30 cm), with a pH of 6.6 to 7.6, the lowest value corresponding to the first 10 centimeters of the profile. The CIC varied from 2.2 to 4.6 cmol $(^{+})$ kg^{-1}, the MO from 0.4 to 1.3% and the total N from 0.1 to 0.2% (Table 2). Therefore, soil fertility in this ecosystem is low. In general, the studied soil presented strong problems of compaction throughout the root zone of the plants. The apparent density variation (ρ_a) ranged between 1.36-1.45 Mg m^{-3} with a general average of 1.42 (±0.044) Mg m^{-3} (Table 2). The lowest values are associated with the surface layer plowed (0-10 cm deep).

The highest values can be related to the low MO contents and the greater degree of compaction that exists in the lower layers due to the sedimentation process of the materials. However, in the literature it is reported that the critical value of ρ_a for the penetrability of the soil by the roots, for different crops varies between 1.47 and 1.9 Mg m^{-3} (Alvarado and Forsythe, 2005). Therefore, the values of ρ_a in this study, being lower than those reported, allow us to assert that there were no restrictions for radical growth.

Table 2. Physical and chemical characteristics of the soil in the SAF where the bean varieties were evaluated. Sandovales, Aguascalientes, 2015.

Characteristic	Depth soil values (cm)		
	0-10	10-20	20-30
Texture	Franco-sandy	Franco-sandy	Clay-sandy loam
Sand (%)	53.44	56.88	51.44
Clay (%)	18.2	17.12	20.2
Silt (%)	28.36	26	28.36
ρ_a † (Mg m^{-3})	1.36 a	1.42b	1.45b
f_t ¶ (%)	48.68 a	46.4b	45.28b
pH (1:2.5)	6.6	6.7	7.6
CIC ($cmol^{(+)}$ kg^{-1})	4.6	2.3	2.2
MO (%)	1.3	0.5	0.4
N total (%)	0.2	0.1	0.1

†= apparent density; ¶= total pore. Means with different letters are statistically different (Tukey, $p \leq 0.05$).

In relation to the depth of the soil, a slightly lower value of ρ_a can be noticed in the first depth strata, probably due to a greater influence of the tillage operations and a greater biological activity near the surface, which results in a high percentage of roots, an important number of wildlife of the soil and an addition of residues greater than that which occurs in the deepest intervals. The ρ_a increases with the depth of the soil due to the reduction of MO and the compaction of the coarse materials (sands and gravel) (Figure 4).

The soil structural quality indicators such as ρ_a and total porosity (f_t) were different ($p \leq 05$) in the first 10 cm of depth, in relation to the other compacted horizons of the underlying layers. These differences should be interpreted as favorable, since lower values of ρ_a and f_t in the surface layer indicate a lower degree of compaction and a more favorable structure. The values of f_t show that the upper stratum presents more porous spaces within the soil matrix.

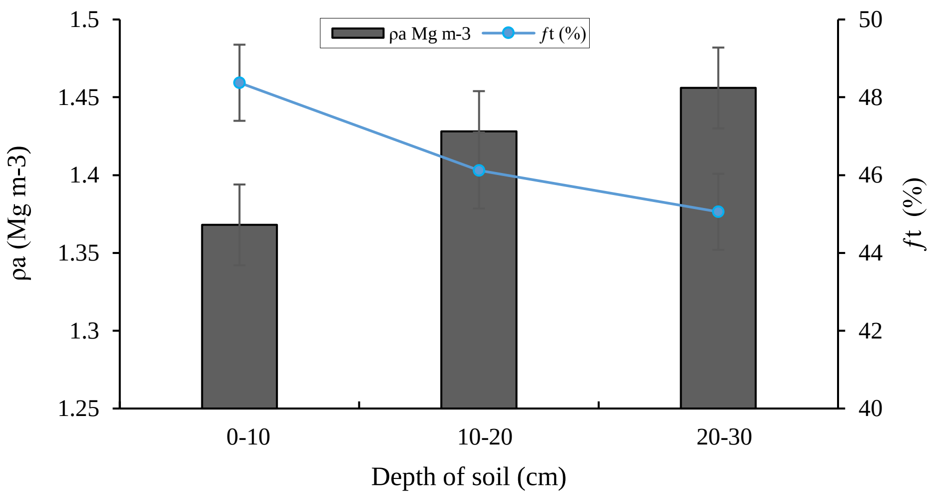

Figure 4. The apparent density (ρ_a) and total porosity (ft) in relation to the depth for the horizons studied. Sandovales, Aguascalientes, 2015.

This is explained because it coincides with the highest level of MO achieved (Table 2), since C is important for porosity (Osuna-Ceja *et al*., 2006; Sandoval-Estrada *et al*., 2008). Vertical and horizontal tillage in soils with physical degradation, produces a decrease in ρa and an increase in f_t (López-Santos *et al*., 2011) that favor water retention and protect MO from microbial attack (Bronick and Lal, 1992). This coincides with Salazar-Sosa *et al*. (2010), who indicate that MO promotes the retention of water in the soil due to its colloidal nature, favoring its porosity.

The data for 2014 showed no change in fertility, as the values of MO, N, P and K were similar to those of 2015 and corroborate that this soil is of low fertility. In relation to physical properties, in 2015 there was a slight increase in porosity and a decrease in compaction in the surface layer of the soil under study.

Culture phenology

The phonological stages in the evaluated sorghum and bean materials showed a variable behavior: in brown rib sorghum, the emergence (E) was presented at 9 DDS, the beginning of flowering (IF) at 85 DDS and the physiological maturity (MF) to 100 DDS. For Pinto Centenario beans, the E occurred at 7 DDS, the IF at 33 DDS and the MF at 80 DDS, for Pinto Saltillo, the E occurred at 8 DDS, the F at 42 DDS and the MF at 90 DDS, for FM Dolores, FJ Dalia and Azufrado 2, the E oscillated between 7 and 8 DDS, the flowering period from 46 to 49 DDS. A similar behavior occurred, although with greater variation, in the case of the number of days at physiological maturity, in the varieties FM Dolores and FJ Dalia since the number of days ranged between 95 to 98 DDS and in the Azufrado 2 reached 100 DDS.

Impact of established practices on the performance of sorghum, beans and their yield components

In 2014 the average yield of dry matter (MS) of brown rib sorghum planted in beds to six rows under dry land was 6.33 t ha^{-1} (± 0.923), which is considered a good yield (Table 3). The quality of sorghum forage (*bmr*) evaluated with this method of sowing is considered superior to traditional corn forage, mainly due to its crude protein (PC) content, at low values of acid detergent fiber (FDA), fiber neutral detergent (FDN) and lignin content (Table 3). This response is in line with the improvement of the efficiency in the use of rainwater and the increase in population density to 252 thousand plants per hectare (Reta *et al*., 2006). The proposed management system allows the brown rib sorghum under rainfed conditions to present adaptation characteristics and forage quality of important potential for the ecosystem of the semi-arid altiplano (Osuna *et al*., 2015a).

Table 3. Dry matter yield, quality characteristics of corn and sorghum forage and efficiency in the use of water under different sowing systems. Sandovales, Aguascalientes, 2014.

Treatments	Dry material (t ha^{-1})	PC¶ (%)	FDN§ (%)	FDA¤ (%)	Lignin (%)
Sorghum in beds with 6 rows	6.33 a	14.54 a	42.44 b	23.38	1.2
Traditional corn†	3.49 b	12.93 b	51.44 a	25.68	2.7

†= sowing of corn at 76 cm between rows; ¶= crude protein; §= neutral detergent fiber; ¤= acid detergent fiber. Means with different letters are statistically different (Tukey, $p\leq 0.05$).

In 2015, bean planting in four-row beds after sorghum showed significant difference (Tukey, $p\leq$ 05) for the yield variables and their components (Table 4). However, the yield obtained with the variety Azufrado 2 was below the average of the varieties tested. This could be due to the excess of relative humidity and humidity of the soil, which caused a strong attack of common blight (*Xanthomonas campestris* pv *phaseoli*), which affected the growth and foliage of the plants. In relation to straw production (t ha^{-1}), the general average obtained was 0.92 t ha^{-1}, the varieties that exceeded this average were: Pinto Saltillo and FJ Dalia. The rest of the varieties had lower than average yields, these materials are: FM Dolores, Pinto Centenario and Azufrado 2 (Table 4). With the exception of the number of pods per plant, the yield components, grains per pod and the weight of one hundred seeds, showed a response similar to that of yield. The results obtained (Table 4) exceed 257% of the regional average of beans (0.44 t ha^{-1}), reported for the traditional system (SIAP-SAGARPA, 2015).

Table 4. Average yield values of grain and straw (t ha^{-1}), number of pods $plant^{-1}$, number of beans pod^{-1}, weight of one hundred seeds (g) and harvest index (%) of five varieties of beans planted in four-row beds in Sandovales, Aguascalientes, 2015.

Variety	RG†	RP¶	NV Pl^{-1}§	G V^{-1}¤	P 100 S Þ	IC††
P. Saltillo	1.8 a	1.03 ab	9.8	3.81 ab	27.2 c	0.636 b
P. Centenario	1.74 ab	0.77 c	9	2.81 c	33.74 a	0.69 a
FM. Dolores	1.34 b	0.87 bc	9.4	3.52 abc	29 bc	0.608 b
FJ. Dalia	2.03 a	1.18 a	8.8	3.99 a	29.22 b	0.632 b
Azufrado-2	0.6 c	0.76 c	7.6	3.03 bc	28.72 bc	0.438 c

†= grain yield; ¶= straw yield; §= number of pods per plant; ¤= grains per pod; Þ= weight of one hundred seeds; ††= harvest index. Means with different letters are statistically different (Tukey, $p\leq 0.05$).

In relation to the harvest index, it showed differences ($p\leq$ 05) between varieties. The IC of the Pinto Centenario variety was superior to Pinto Saltillo, FJ Dalia, FM Dolores and Azufrado 2. The average value varied 0.43 to 0.69 with a general average of 0.6 (± 0.096). The low index presented by the variety Azufrado 2, probably related to a low allocation of photoassimilates to the reproductive structures due to the strong attack of common blight (*Xanthomonas campestris* pv *phaseoli*) suffered by this variety during the stage of pod formation and filling of grain. The above shows that the Pinto Centenario, Pinto Saltillo, FM Dolores and FJ Dalia bean varieties have a high degree of adaptation to this altiplano region.

The adaptation and the productive potential were partly conferred by the biological cycle and the level of resistance to diseases, especially the diseases that cause root rot (*Fusarium* spp. and *Rhizoctonia solani*) and common blight (*Xanthomonas campestris* pv. *phaseoli*), pathogens that were present in this locality (Acosta-Gallegos *et al*., 2011; Acosta-Gallegos *et al*., 2014; Rosales-Serna *et al*., 2012).

The proposed SAF that includes the rotation of dry-land sorghum-bean crop, in six- and four-row beds in contour strips with live wall barriers (nopal and leucaena), are technically efficient options for the control of soil erosion in Semi-arid conditions and high-intensity, short-duration rainfall.

Conclusions

A SAF of sustainable productivity was designed and tested in the semiarid temperate Altiplano of North-Central Mexico, integrating conservation tillage practices, in situ rainwater harvesting, crop rotation, high plant densities, use of improved varieties and barriers of living wall of nopal and leucaena, proving that the SAF offers technically efficient options for the control of erosion in rainfed agriculture by preventing erosive processes through the interception of rain energy with vegetation, increasing yields and diversify forage sources.

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