Practices for the improvement of the agricultural resilience of the forage production in semiarid environment: a review

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Abstract

Water scarcity, climatic conditions and low availability of fodder produced in Caatinga are some of the main problems faced by farmers in the Brazilian semiarid region. Therefore, the objective of this paper is to review some agricultural resilience practices that aim to increase forage production in the Brazilian semiarid. Several studies have shown that the use of fodder plants tolerant to this type of environment is essential to improve the production of ruminant feed. Among these, we highlight the forage cactus, which is rich in water, energy and minerals and highly tolerant to water deficit. Millet, in turn, is another plant that adapts to this environment, presenting better nutritional characteristics, besides being a more fibrous vegetable, and can be associated with cactus in the diet of the herds. This association can be done through the intercropping, which allows the simultaneous cultivation of two or more species in the same area, aiming at the most efficient use of available natural resources. The use of irrigation events with minimal and regular water use in cactus crops has been shown to be a very promising practice. However, the scarcity of this resource in semiarid regions, adding to this increasing salt concentrations in the springs, requires proper management. Additionally, other agricultural resilience practices, such as mulching, can directly contribute to reducing the need for irrigation, conserving soil moisture, decreasing soil thermal amplitude, improving its chemical, physical and biological properties, contributing to improved agricultural yields.

Key-words: Forage Cactus, Millet, Intercropping, Mulching

Introduction

The Brazilian semiarid region, located predominantly in the Northeast, has the agriculture and cattle raising as one of the most important activities, in which is based on the provision of native and cultivated forage plants (Ferreira et al., 2009). However, this activity has been hugely affected by extreme heat and drought events in the last few years, causing great economic and social damage. In 2012/2013 alone, nearly 1,300 municipalities and 10 million people all over Brazil were touched by the drought; in economic terms, there was a loss of approximately US$ 1.5 bi due to the mortality rate of the cattle herds (Cunha et al., 2015). Such environmental conditions tend to intensify mainly due to the climate changes (Gutiérrez et al., 2014).

In this scenario and the inherent features of the Brazilian semiarid, as the space-time irregularity in the rainfall distribution, its natural vegetation (Caatinga), it becomes inadequate for the feeding supply of the herds during the long periods of drought (Ferreira et al., 2009). For this reason, it is crucial the adoption of forage cultures that present good tolerance to the adverse conditions, and that ensure the food safety of the animals in the critical period.
The forage cactus (*Opuntia* and *Nopalea*) presents itself as a great alternative for the animal feeding in arid and semiarid environments, due to its high adjustability morphophysiological features. It is a plant that possesses the Crassulacean Acid Metabolism (CAM), with high water storage capacity and high efficiency in its utilization, besides being rich in energy and minerals (Scalisi et al., 2016). Despite the forage cactus present several qualities, it is a culture poor in fiber (Ben Salem and Smith, 2008), this characteristic is observed among other cultures as in the millet (*Pennisetum glaucum*) which, in turn, also appears as a good alternative to boost the production of forage, since it is a species of metabolism C4, averagely tolerable to salinity, as well as the hydric stress and to the high temperatures (Nelson et al., 2018), common features in the arid and semiarid regions. It also possesses good biomass production and nutritive value (Santos et al., 2017a). Thus, the practice of intercropping between these cultures show great potential of exploitation.

On the other hand, the utilization of irrigation events, with the minimum and regular use of water in forage cactus cultivation, has demonstrated for this species to be a very promising practice, for this species, spite of presenting high tolerance to the hydric deficit, has brought good answers to the water application (Queiroz et al., 2015). However, besides the water shortage, the salinization of the springs (superficial and subterranean) is a constant problem in the Semiarid, in virtue of the high evaporation rates of the reservoirs and of the irregular rainfall, bringing more limitations for the irrigation management.

Another practice that can be adopted in the semiarid region is the usage of mulch in productive systems, which has diminished the necessity of water application through irrigation, because of the decrease of the evapotranspiration of the cultures, reduction of the temperature and of the temperature span of the soil, offering the increase in the performance of the agricultural production (Murga-Orrillo et al., 2016; Yin et al., 2017). Nevertheless, there is a lack of studies that relate the utilization and the benefits of the mulch and the intercropping in the cultivation of forage cactus under hydric complementation (Carvalho et al., 2017). So, the purpose of this study is to present a review about some practices of the agricultural resilience that aim to increase the production of forage in the Brazilian semiarid.

**Literature review: Characterization of the Brazilian semiarid (BSA) and forage availability**

The Brazilian semiarid region takes an area superior to 1.03 million km², in which live more than 27 million people, covering nowadays 1,262 municipalities, mainly in the Northeast region of the country (Ministério da Integração, 2017; Sudene, 2017). This region is featured for presenting high air temperatures, low relative humidity of the air, high insolation and – mainly – irregular space-time rainfall distribution, in which there is a shorter period of rainfall than the dry period, concentrated in the summer period, in general, with the rainfall regimen between 250 and 600 mm, reaching up to 800 mm per year depending on the location (Ferreira et al., 2009; Alvares et al., 2013). Furthermore, the Brazilian semiarid has been facing, in the last few years, great rainfall variations linked to the elevated atmospheric demand (Silva et al., 2017). These factors in association with the recurring changes all over the globe are responsible for the advancement of extreme events of drought and heat.

The drought that occurred in the last few years (2011 to 2016) was considered the most severe of the last decades in the Brazilian Northeast, in addition, the projection is that in this region, the extreme events of drought tend to increase not only in frequency but also in intensity (Gutiérrez et al., 2014). Accordingly to Cirilo (2008) it is estimated that will be a reduction of 10 to 20% of rainfall, and a raise of 2 to 4 °C in the air temperature, provoking the aridization of the region and the replacement of the vegetation for typical vegetation of arid regions.

The drought that was intensified in 2012 in the Brazilian northeast was directly related to the abnormal warming at the north of the tropical Atlantic that was responsible for the displacement to the north of the Intertropical Convergence Zone (ITCZ), contributing for the reduction of rainfall in the region (Marengo et al., 2017). Though, the event La Niña, in 2013, was not enough to compensate the drought of the previous years; moreover, in 2015, the drought increased because of the El Niño (Marengo et al., 2017). In studies made by Alvalá et al. (2017), it was observed that in the period between 2015 and 2016, around 50% of the area of 923 municipalities was affected by the drought, especially in the states of...
Bahia and Ceará; escalating to 53 million acres the total area hit by the drought in the Northeast.

These extreme drought events have caused major social and economic losses, for the water shortage has enhanced the vulnerability of the poorer population to the climate changes that can cause serious consequences to the welfare at short and long terms. The hydric scarcity has not only reduced the agricultural production but also the consuming of nutrients, which presents direct reflexes on human health (Rocha and Soares, 2015). Some other consequences entailed by the drought are hunger, malnutrition, misery and rural exodus, for the food safety and the means of subsistence of several farmers are found to be exposed to the climate storms (Cunha et al., 2015).

In face of this reality, the livestock activity of the Brazilian semiarid has been strongly affected, being characterized by its low productive performance, in function, especially, of the great seasonality of the forage production, once it concentrates in the rainy period in non-irrigated conditions (Dubeux Júnior et al., 2010; Silva et al., 2014). The diet of the herds whether they are bovine, goats, or sheep, is based, primarily on the use of cultivated forage plants, as well as in the use of forage available in the Caatinga, which possesses several species of forage in its herbaceous, shrub and arboreal strata. Still, 70% of the known vegetal species of the Caatinga has direct participation in the diet composition of the herds; the herbaceous dicots and the grass represent more than 80% of the ruminants diet in the rainy period, however, these plants became insufficient to attend the food demand of these animals in the dry period (Ferreira et al., 2009).

The mass of the forage from the Caatinga can vary considerably, especially due to the kind of predominant vegetation, rainfall and method of grazing. Furthermore, in qualitative terms, several vegetal species from the Caatinga can even display high level of crude protein, however, their digestibility is very low, and once the N can be strongly linked to the fibers (Santos et al., 2010). Santos et al. (2017b), studying the nutritional potential of six forage plants found in the Caatinga, verified that the species Bauhinia cheilantha, Mimosa caesalpinifolia, Leucaena leucocephala and Gliricidia sepium displayed high level of protein linked to the neutral detergent fiber (NDF), where the first two had their high levels of protein linked to the acid detergent fiber (ADF), which represents unavailability of the crude protein present in the forage. In other study, Nunes et al. (2016) studying antinutritional factors in 30 forage species found in the Brazilian semiarid, verified that 90% of the plants presented low levels of tannins and lignin, what made them suitable for the utilization in the diet of the ruminants.

The decrease in the production of ruminants during the dry season in tropical and subtropical regions is due to, besides the problems of quantitative order, the availability of low quality forage, which holds high lignification, low level of nitrogen and low digestibility, also resulting in the enhancement of the emissions of methane by the ruminants (Santos et al., 2017b). Other factors that are directly linked to the vulnerability of cattle raising in semiarid regions is the fact that the small rural producers have their own productive systems under conditions that depend on nature, besides having low technological resources, and using cultivars with low productivity that do not present any tolerance to plagues and diseases, as well as the hydric deficit; and many of the low income producers still face credit restrictions (Martins et al., 2018).

Agricultural resilience

The original concept of resilience comes from the Physics, which was firstly used by the engineering, and it refers to the ability of determined material to suffer tension and return to its original state, discontinuing the “state of risk” (Sentelhas and Monteiro, 2009).

Under the agro-meteorological scope, agricultural resilience is directly related to the adoption of strategies that aim to mitigate the adverse effects of the climate over the cultures, for example, droughts, frosts, high temperatures, strong winds, etc. The knowledge about the effects of the weather and the climate over the agricultural species is indispensable for the definition of the technical improvements of action (Sentelhas and Monteiro, 2009).

On the agricultural and cattle raising, it indicates the capacity of agricultural systems to resist to the unexpected and severe adversities in the form of climatic extremes (extended drought), plagues and diseases, market fluctuation and external input costs
once this resilience will depend on the intensity of the production (Mavi and Tupper, 2004).

At that, among the several most used strategies can be cited: the diversification of the cultures; species choice, cultivars or adaptable varieties; adequate population density; correction of nutritional densities, as well as the integrated management of plagues and diseases; utilization of the irrigation (reduction of the hydric stress) and; the use of soil coverage (Sentelhas and Monteiro, 2009).

Adapted species to the Brazilian semiarid (BSA): Forage cactus and millet

The low water availability in arid and semiarid environments, and especially in dry seasons, compromising forage supply, has been the main barrier for the increasing of animal productivity (Gusha et al., 2015). In view of this, it is necessary to use adapted forage species to these conditions in order to ensure the food safety of the herds. Among these species, the forage cactus (Opuntia e Nopalea), which due to its energetic value, high digestibility coefficient and great adaptability to climatic conditions, became the food base of herds in the Brazilian semiarid region (Vilela et al., 2010). In long periods of drought, besides providing nutrients, it is used as source of water for animals (Costa et al., 2012; Falcão et al., 2013).

The forage cactus is originally from Mexico; it belongs to the Cactaceae family and was introduced in Brazil in the 19th century, and presents a great adaptability to the ecological conditions of semiarid regions (Falcão et al., 2013). It is also found in the Mediterranean basin and semiarid regions of North America, South America and the African continent (Consoli et al., 2013). The plant has high water use efficiency due to its photosynthetic metabolism CAM (Crassulacean Acid Metabolism), producing up to four to five times more dry matter for each millimeter of precipitation, when compared to other species (Gusha et al., 2015), besides having a high water storage capacity (Scalisi et al., 2016).

The CAM mechanism allows the plants to open their stomata at night and close them during the day. This behavior is responsible for minimizing water loss through transpiration and capturing atmospheric CO₂ at night. At night, the malate is transported to the chloroplasts and decarboxylated by the NADP-malic enzyme, and the released CO₂ is fixed by the Calvin-Benson cycle, while C3 acid resulting from decarboxylation is converted to phosphate trioses and subsequently to starch or sucrose (Scalisi et al., 2016; Buchanan and Wolosiuk, 2017).

Regarding its composition, the forage cactus contains low dry matter, crude protein and fibrous carbohydrate (neutral detergent fiber (NDF) and acid detergent fiber (ADF)). However, it has a high content of mineral matter as well as non-fibrous carbohydrates, standing out as an energetic food (Ben Salem and Smith, 2008). Despite having a high acceptability and a high digestible energy content, the forage cactus is sometimes not readily accepted by ruminants due to the presence of thorns, and its exclusive supply can cause diarrhea due to its low fiber content (Gusha et al., 2015), decreased fat content in milk, low dry matter intake and consequent weight loss (Ben Salem and Smith, 2008). However, many studies have shown that the addition of forage cactus to the ruminant diet, replacing grass silage and hay (e.g. maize, Tifton grass), has increased mineral, dry matter and carbohydrate intake and coefficients. NDF and dry matter digestibility, as well as reduced voluntary water consumption due to its low fiber content, high acceptability and high passage rate (Costa et al., 2012; Siqueira et al., 2017; Moraes et al., 2019).

The millet crop (Pennisetum glaucum) was introduced in Brazil in 1929, but it was not until the 1960s that research programs began to work on the genetic improvement of P. glaucum species in order to use the crop for various purposes: land cover plant in no-tillage systems, especially in the Cerrado, use of grains for feed production and use as fodder, either in the form of pasture, silage or hay (Dias-Martins et al., 2018). Among the most common cultivars are: BRS 1501, which was developed in 1999 by Embrapa Maize and Sorghum, presenting good potential for grain production and; IPA Bulk 1, developed by the Instituto Agronômico de Pernambuco (IPA) in 1973, adapted for forage production in Pernambuco Semiárid (Dantas and Negrão, 2010).

Millet is an annual grass (cycle between 75 and 120 days, depending on the cultivar and atmospheric CO₂, which is reduced to malate and stored in vacuoles (malic acid). At dawn, when the stomata close to prevent water loss and CO₂ entry, the malate is transported to the chloroplasts and decarboxylated by the NADP-malic enzyme, and the released CO₂ is fixed by the Calvin-Benson cycle, while C3 acid resulting from decarboxylation is converted to phosphate trioses and subsequently to starch or sucrose (Scalisi et al., 2016; Buchanan and Wolosiuk, 2017).
environmental conditions) widely grown in arid and semiarid regions of India, Latin America and the Sahelian zone (Africa). It is a species with type C4 metabolism, presenting itself as a plant highly tolerant to abiotic stresses, adapting well to unfavorable environmental conditions such as water deficit, heat, high salinity and reduced soil fertility (Singh et al., 2015). However, it satisfactorily responds to balanced nutrition, even in warmer and drier seasons, through increased water use efficiency (Uppal et al., 2015). In addition, it has a high nutritional value with about 12% protein in the grain, as well as iron, zinc and other nutrients (Ghatak et al., 2016; Marmouzi et al., 2018). The high nutritional value of millet stands out in relation to other important crops such as sorghum, rice, wheat and maize, in terms of crude protein (11.8%), fat (4.8%), ash (2.2%), energy (363 kcal), calcium and iron, being also higher than sorghum in the crude fiber content (2.3%) (Ullah et al., 2017).

Regarding its morphological characteristics, the millet has a height that varies, depending on the cultivar, from 1.5 to 3 m (Figure 1); the stalks are smooth and have a diameter of 1 to 2 cm, reaching secondary and tertiary branches from lateral buds; Its panicles are similar in shape and size and can be cylindrical, conical or spiral, with a diameter ranging from 2 to 3 cm, and 15 to 60 cm in length, with the ability to produce 500 to 2000 seeds per panicle. In addition, the seeds, white or yellow in color varying from brown to purple (depending on the variety), are 3-4 mm long and weigh approximately 8 g per 1000 seeds. Leaf blades are long and sharp (Dias-Martins et al., 2018; Yadav et al., 2019).

One of the biggest advantages of growing millet in the Brazilian semiarid region is that it is a crop with low water demand, requiring an average of 350 mm of water per cycle (Figure 2), while sorghum, wheat, maize, cotton, rice and sugarcane require 14, 28, 42, 71, 257 and 500% more water compared to millet, respectively (Ullah et al., 2017).

Irrigation in forage plants

In regions of hot and dry climate, as in the case of the semiarid region of Brazil, irrigation can be considered as the main or only way to ensure safe agricultural production, since during most of the year rainfall levels are low, lower than atmospheric demand, causing a water deficit for vegetables (Holanda et al., 2016). Due to this water stress,
protein yield once that the low water content in the soil makes it difficult for plants to absorb essential nutrients. Similar results were found by Vitor et al. (2009), where irrigation, both in the dry season and in the rainy season, influenced positively on elephant grass dry matter production; however, forage quality parameters were not affected by different water depths, but by nitrogen fertilizer treatments he had used.

Although forage cactus crop has a low water requirement due to its CAM metabolism, modern studies involving irrigation management as well as agrometeorological parameters for this forage have been developed in the Brazilian semiarid region (Silva et al., 2017). Queiroz et al. (2015) found that different irrigation depths did not increase the production of green matter and forage cactus dry matter, however, these variables presented values higher than those reported under non-irrigated conditions, 131.16 and 8.18 t ha\(^{-1}\), respectively.

Despite its CAM metabolism, the accumulated water consumption of the forage cactus is directly related to the environmental conditions (meteorological) at different times of the year and the morphological characteristics of the plant and cladodes of its different species (Barbosa et al., 2017). Scalisi et al. (2016) concluded that water deficit reduces cladode both thickness, as well as stomatal conductance and growth dynamics. Under dry conditions, cladodes are less thick due to lower soil water content. Already the thickness changes of the cladodes submitted to irrigation are more related to the air temperature (Scalisi et al., 2016).

Due mainly to the climatic instability of the region, non-irrigated agriculture becomes a high economic risk activity. However, it is necessary to consider that only 2 to 3% of the Brazilian semiarid region has potential for irrigation, taking into account the low availability and quality of water, as well as limitations related to the edaphic environment (Dubeux Júnior et al., 2010). For this reason, some practices must be observed in order for irrigation management to be successful, following sustainable principles, such as irrigation method, species or cultivar choice, crop rotation, intercropping systems, among others (Lacerda et al., 2016).

Irrigation with saline water

The salinization process is due to two processes, the natural and the induced. The first occurs due to the weathering of the rocks; the latter occurs due to anthropic action, through irrational management of irrigation, indiscriminate use of chemical fertilizers and drainage deficiency in semiarid regions (Medeiros et al., 2016). This induced salinization process is even more evident and aggravated in places with high rainfall deficit and high atmospheric demand, added to the intense use of irrigation in irrigated agriculture projects.

The waters used in irrigation can be classified according to their salinity as well as their sodicity, being that the electrical conductivity (EC) is the most used parameter to quantify the concentration of soluble salts in the water, being classified as C1 (<0.25 dS m\(^{-1}\), low salinity), C2 (0.25 - 0.75 dS m\(^{-1}\), medium salinity), C3 (0.75 - 2.25 dS m\(^{-1}\), high salinity) and C4 (> 2.25 dS m\(^{-1}\), very high salinity). As for the risk of sodicity, the most commonly used parameter is the sodium adsorption ratio (SAR), which correlates very well with the percentage of exchangeable soil sodium (ESP) (Richards, 1954).

The excess of salts and sodium cause distinct effects on the soil. While the high concentration of salts such as calcium, magnesium, among others, cause the flocculation of clays and, consequently, the increase of soil permeability, the excess of sodium ions causes the dispersion of the clays, resulting in serious consequences such as obstruction of the clays soil micropores and increased resistance to penetration by plant roots (Ribeiro et al., 2016). The excess of salts present in the root zone of the crops, caused mainly by the inadequate irrigation management, can cause great damages to the vegetables. There are at least three harmful effects to plants. 1) Osmotic effect, where the plant cannot absorb water from the soil; 2) Toxicity of specific ions, where excessive accumulation of ions in tissues causes damage to the cytoplasm, reflecting on yield; 3) Plant nutritional imbalance, where absorption of potentially toxic ions reduces absorption of other nutrients, affecting plant physiological functions (Dias et al., 2016).

Freire (2012), evaluating the effect of salinity and frequency of water application on the development of forage cactus Miúda (Nopalea cochenillifera), observed that water with higher salinity (3.6 dS m\(^{-1}\)) applied more frequently (seven days) caused a higher percentage of damage, as well
as lower yield, showing the low tolerance of forage cactus Miúda to salinity. In a second experiment, this author found that of the twenty genotypes evaluated, the Orelha de Elefante Mexicana clones (Opuntia sp.) had the highest yields, being irrigated with saline water (3.6 dS m⁻¹) every 14 days.

**Intercropping**

Intercropping consists of the simultaneous production of two or more agricultural crops in the same area. It is an extremely important agricultural practice that aims to improve the land use rate, especially in places where there is limited farmland (Du et al., 2018). Although research related to this practice is often restricted to intercropping systems of legume grasses, there are several benefits from the intercropping to the ecosystem such as reduced demand for chemicals to control pests, diseases and weeds (Martin-Guay et al., 2018), as well as stabilization of agricultural production, since intercropping systems are considered more resilient than exclusive cropping systems when subjected to environmental disturbances and biotic and abiotic stresses (Raseduzzaman and Jensen, 2017).

However, it must be taken into consideration that competition between plants for natural resources such as water, light and nutrients in an intercropped system is inevitable, and this leads to distinct yields between monocultures and intercropping (Sadeghpour et al., 2013). Nelson et al. (2018) found that intercropping with cowpea significantly decreased millet yield in a semi-arid region of India; however, millet was tolerant to the region's high temperatures and water restriction in treatments with poor irrigation.

Despite the competition, generated by the practice of intercropping, caused reductions in yield of component crops, when taking into account the sum of them, yields tend to be higher when compared to their monocultures. As an example, Temesgen et al. (2015) realized that the intercropping did not affect maize yield when compared to their exclusive system, and beans had significantly reduced yield when mated with maize, however the total yield of maize intercropped bean was higher than the yield of single beans. Already in the study by Masvaya et al. (2017), the total yield (maize + cowpea) was higher in the intercropping than in the exclusive crops of the two crops, showing that the intercropping brought benefits to biomass production due to higher soil cover, reducing its evaporation and increasing the water use efficiency.

Among the main natural resources used by plants, solar radiation stands out, which is responsible for providing light for the photosynthetic processes of plants (Buchanan and Wolosiuk, 2017). Regarding this very important resource, the crops that make up a intercropped system compete with each other, seeking better use and utilization of sunlight.

Therefore, aiming to evaluate the efficiency of resource use in monocultures and maize intercrops with legumes (cowpea, soybean and peanuts), Kermah et al. (2017) observed that single legume cultivation intercepted more radiation than intercropping; however, they intercepted higher radiation than exclusive maize cultivation; However, the same authors observed that the conversion of intercepted radiation to grain yield was more efficient in intercropping than in exclusive crops. Wang et al. (2015), using wheat and maize crops, observed that in the exclusive crops the radiation interception rates were higher than the intercropping, however, the total interception was lower due to the shorter cycles. These authors also found that the radiation use efficiency (RUE) values were higher for maize compared to wheat in all treatments, thus showing the differences between plants C3 and C4. Although RUE values were higher for exclusive maize compared to intercropped maize (13.2 and 9.9%), nonetheless, grain yields of both crops were higher in intercropping systems (Wang et al., 2015).

In locations where water availability is a limiting factor in agricultural production, it is necessary to understand how crops respond to the intercropping with respect to water use. Recent studies concerning the intercropping of forage cactus culture with other forage species are advancing in the Brazilian semiarid region. In this perspective, Lima et al. (2018) observed that while forage cactus monoculture obtained a water use efficiency (WUE) of 8.4 kg dry matter (DM) ha⁻¹ mm⁻¹, the forage cactus-sorghum intercropping obtained a value of 18.9 kg DM ha⁻¹ mm⁻¹. The WUE values of the intercropped were higher than the monoculture with irrigation depths from 1096 mm. In terms of income, Diniz et al. (2017) found that increasing irrigation depths increased forage production in the forage cactus-sorghum intercropping, due to the benefits of forage sorghum cultivation.

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Nevertheless, one of the main ways of assessing whether a syndicated system is more viable than a monoculture is to use competitive indices, which show how the components of a intercropping utilize the resources available in the agroecosystem. Among the main competitive indices we can mention: land use efficiency (LUE), relative density coefficient (RDC), competitiveness ratio (CR), aggressiveness (A) and system productivity index (SPI) (Sadeghpour et al., 2013; Yilmaz et al., 2015; Diniz et al., 2017).

Diniz et al. (2017) concluded that the forage cactus-sorghum intercropping obtained higher biological efficiency and competitive ability than the exclusive systems of both crops. The same authors observed that the intercropping LUE obtained a value of 1.51, indicating that the exclusive system would need 51% more land to have similar yield. However, the forage cactus was dominant over sorghum culture. Similar behavior was observed by Sadeghpour et al. (2013), where the intercropping of forage barley with the legume *Medicago scutellata* presented an LUE of 1.07, being the dominant barley over the secondary crop.

**Mulch**

Mulch is the agricultural practice of placing crop residues, or any other materials, on the soil for specific soil and water conservation purposes, and may bring better yields to agricultural crops (El-Mageed et al., 2016; El-Mageed et al., 2018); In turn, plant residues contribute to the increase of soil organic matter (SOM) content, improving its physical quality and fertility level (Jordán et al., 2011). However, in order that the organic cover, inserted in an area, can supply nutrients, it is necessary to take into consideration its carbon:nitrogen ratio (C:N), which is responsible for determining its decomposition speed, as well as interfering with the mineralization or immobilization of N by soil microorganisms.

Troeh and Thompson (2007) explained that when microbial activity acts on SOM decomposition, the release of inorganic forms of elements occurs, a process known as mineralization. However, when inorganic ions are converted into organic forms, it is called immobilization (Troeh and Thompson, 2007). These authors also stated that a large part of N immobilization occurs due to the fact that soil microorganisms require N to synthesize proteins, concluding that the introduction of decomposable materials in the soil with low concentrations of this nutrient will result in greater immobilization of the soil itself.

According to Silva et al. (2009), plants that present high levels of N in their biomass, such as vegetables, provide residues with low C:N ratio, which means faster decomposition and consequently, higher N mineralization rate for plants. However, according to Carneiro et al. (2013), other factors besides the C:N ratio should be considered in the determination of N mineralization rates, such as N, lignin, polyphenols content and N forms present in the residues. Results obtained by Maluf et al. (2015) showed that the decomposition of the plant residues was significantly influenced by the concentrations of N, and the release rates of macronutrients, by their contents in the residues, being K the nutrient released faster because it is not a constituent of plant structures. However, when it is desired to use plant residues as mulch in arid and semiarid environments, it is ideal that it has a high C:N ratio in order to prolong its permanence in the field.

The surface soil coverage has been a widely studied alternative in areas where evaporation rates are high and rainfall is low and irregular, especially in semiarid regions of China for water saving (Ding et al., 2018; Li et al. 2018; Wang et al., 2018). This technique promotes several benefits to the edaphic environment (Figure 3), among which stand out the conservation of soil moisture, less fluctuations in soil temperature, improved microbial activity and soil physicochemical properties (once organic cover also serves as a source of nutrients through decomposition) and suppression of weed germination depending on the type of soil cover (Kader et al., 2017).
Fig. 3. Principles and benefits of soil coverage. Adapted from Kader et al. (2017).

The physical quality of the soil is an attribute strongly influenced by mulching, since its use prevents the direct impact of raindrops, reducing soil erosion losses and runoff. Consequently, there is an increase in infiltration capacity and water storage in the soil, because the added organic matter (organic mulch) acts on the improvement of soil structure (Prosdocimi et al., 2016).

It is important to highlight that the weather conditions, as well as the available water content in the soil (evaporation stage) and the type of mulch, are determinant factors for its efficiency in reducing soil evaporation. Zribi et al. (2015), testing different types of organic and inorganic mulch to control soil evaporation, observed a decrease in their evaporation rate as a function of the decreasing surface water content, revealing the probable ineffectiveness of mulch in low frequency irrigated soil systems. However, the same authors pointed out that in the initial phase of the drying cycle, all mulch materials reduced soil evaporation compared to bare soil.

The crop growth response to mulch depends on broad interactions between mulch and other factors such as irrigation method, irrigation frequency, evaporative potential and soil texture (Wang et al., 2018), directly affecting irrigation management. In an experiment conducted for three consecutive years (2013 - 2016) trying to evaluate the effects of mulch with three drip irrigation blades on wheat crop evapotranspiration, grain yield and water use efficiency, Wang et al. (2018) found that the mulch reduced from 9 to 11% the total amount of water applied via irrigation (65 to 85% of field capacity) in relation to treatments without coverage. The mulch also decreased the cumulative total soil evaporation (19 to 34 mm), as well as its daily average (25 to 41%). Moreover, they observed that mulching, besides reducing significantly crop evapotranspiration, it increased wheat yield, noting high water use efficiency. The results obtained by Li et al. (2018) also showed that the seven mulching treatments used in summer maize crop reduced soil water evaporation in the early stages of growth, leading to water savings and boosting maize growth in subsequent phases, improving their yields and water use efficiency.

On the other hand, Ding et al. (2018), studying the effect of soil coverage on the evapotranspiration of maize (rainy season) and wheat (dry season) crops in a rotation system on the Loess Plateau of China, found that in the dry season evapotranspiration tended to be greater in treatments with coverage; in the rainy season, evapotranspiration tended to be higher in treatment without coverage. This is because mulching reduced soil evaporation, but promoted productive plant transpiration. These same authors pointed out that, although covering did not cause significant difference in evapotranspiration compared to treatment without covering, treatments with covering obtained better results in grain yield. Regarding the use of mulch in the forage cactus crop, the studies still are incipient.

Carvalho et al. (2017) observed that the adoption of mulch in the forage cactus crop did not influence in the soil moisture when compared to the exclusive cactus plantation system, however, there was a
reduction in the soil evaporation rate, promoting the decreasing of the variability of the soil humidity (15.7%). The temporal variability of soil humidity was most affected by rainfall conditions, and the physical attributes of the soil were differentiated by their variation in depth (Carvalho et al., 2017).

**Final considerations**

In this review the primary characteristics of the Brazilian semiarid were discussed, in association with the climate changes, and how they have been drastically affecting the agriculture and cattle raising activity, bearing in mind the risks that these factors have caused in the reduction of the food safety of the herds. However, several studies have demonstrated that the utilization of forage cultures with high adaptability to arid and semiarid environment, as the forage cactus and the millet can be considered an excellent alternative for the resilience to the drought.

Associated with these plants, some agricultural practices can be employed, aiming the improvement of the environment of vegetal growth, as for example, the mixing of cultivations and the use of mulching over the soil. The first allows the exploitation of the biophysical resources in a more efficient way. Based upon the indexes of competition presented in the literature it becomes possible to infer about the viability of the intercropping, as well as about the level of dominance of the composing cultures. The second helps, primarily, in the conservation of the soil humidity, providing a more favorable edaphic environment for the growing and development of vegetables. Therefore, such practices and cultures present a high potential as tool for the confrontation of the more problems of the semiarid.

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