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Mini Review

The application of agrometeorological techniques contributes to the agricultural resilience of forage cactus: A review

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Abstract

The Brazilian semi-arid is an area that has a strong influence on climatic factors and agricultural vulnerability, which govern the availability and supply of fodder. The understanding of the limitations and the alternatives to be adopted, aid in the improvement of the systems of production of fodder and an increase in the benefits of the system. In this review, we sought to address agrometeorological aspects and agronomic techniques aimed at improving resilience in forage cactus production systems under different cropping systems in arid and semi-arid environments through information on the stability of the plant population contributing to reducing the risk environmental degradation and production losses.

Key-words: *Opuntia*, *Nopalea*, Agriculture in Semiarid, Forage Production

Introduction

In the last few years, one of the most studied and discussed environmental theme, all over the world, has been the climate changes, which predict impacts in several regions of the planet, especially in the susceptible areas of the developing countries (*i.e.*, arid and semiarid regions). These areas, in most cases, have higher vulnerability due to the reduced capacity in adaptation of the human communities to the impacts caused by these changes to the ecosystems (Mesquita and Bursztyn, 2017).

In Brazil, studies have indicated that the Northeast Region and chiefly the semiarid areas holders of the Caatinga biome are the most susceptible areas to the impacts of the climate changes and elevation of the global temperatures, in which, associated with the anthropic actions can contribute to the acceleration of the process of desertification of this region (Lima et al., 2011). Corroborating with these studies, Morais et al. (2015) have offered evidence of the impacts resulting from climate changes to the state of Pernambuco, particularly in the Vale do Pajeú, Sertão of the state, where there was an increase of the daily maximum temperature of the air in 4 ºC, for the period corresponding from 1961 to 2009 and average reduction of 57% of the rainfall events.

In addition to presenting meagre conditions derived from climate elements, extended periods of drought and irregularity in the rainfall events, Brazilian Semiarid has shown vulnerability to the climate changes, thus, the meteorological conditions are aggravated by this phenomenon (Cunha et al., 2015; Queiroz et al., 2016). These factors pose a challenge to the agricultural production, once the socioeconomic relations of the rural population of this region depend closely on these activities, which, in the region are affected by the water shortage and, consequently, reflect in the food production for the livestock (Souza et al., 2014; Marengo et al., 2017).

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Hence, it is very important the use of management farming techniques, especially regarding the use of tolerant species to the water deficit, as it happens with the forage cactus (*Opuntia* spp. e *Nopalea* spp.) and of supplementary irrigation to the cultivation in the periods of water scarcity (Amorim et al., 2017). Another practice that presents relevant importance in this scenario is the usage of mulch, where it shows potential for the modification of the microclimate, having effect in the conservation of the soil humidity, in the temperature, weed suppression, aside from reduce the evaporation, mitigate the effects of the accumulation of salts in the soil by irrigation water, and provide nutrients to the plants (Abd El-Mageed et al., 2016; Saglam et al., 2017).

Forage cactus is a xerophyte species that due to its morphological and physiological characteristics it presents significant tolerance to environments with extended periods of drought. Even with these characteristics, studies have shown the successful performance of this cactus in response to the use of irrigation, with which it is possible to improve the development and productivity of this cultivation (Almeida et al., 2011; Pereira et al., 2015; Queiroz et al., 2016; Silva et al., 2017a).

Still, in the usage of irrigation it is of major importance to know the water needs of the cultivation, as for the actual evapotranspiration and the crop coefficient, for a better planning of the water use, seeking economy and increasing in the productivity (Silva et al., 2017b). The water balance in the soil is one of the low cost resource which can contribute with information to determine these parameters for a sensible use of irrigation water, and so, a better understanding of the water dynamics in the system soil-plant-atmosphere (Rodrigues Cruz et al., 2005; Lima et al., 2006; Byrne et al., 2017; Mota et al., 2018).

This method of water balance in the soil is of importance in studies of the hydric relationships between environment and plant, however, it is known that there are few studies with this kind of method for semiarid regions (Consoli et al., 2013; Silva et al., 2015a; Pereira et al., 2017a), particularly, under irrigated conditions including cultivations of forage cactus, which is of importance for the realization of studies in this area (Silva et al., 2015a).

In view of this question, it is believed that the usage of mulch in the cultivation system of forage cactus will bring a reduction in the consumption of water by the cultivation, as well as, improvement in its quantitative performance, presenting differences among the values of the cultivation evapotranspiration, crop coefficient, and in the productive earnings throughout its cycle, bringing renovation to the cultivation system in semiarid environment.

Literature review

Characterization of the environment

Terrestrial area of the planet, approximately one-third is represented by arid and semiarid regions, where live, approximately, 400 million people, while in Brazil, especially in the Northeast region, the semiarid corresponds to about 1.03 million km^2 of the national territory, covering the states of Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Sergipe, Alagoas, Bahia and part of the North of the State of Minas Gerais (Southeastern Region), being formed by 1,189 municipalities with approximately 25 million of inhabitants, whose great part of the population, seeks their sustenance in agricultural activities (Silva et al., 2014; Ministério da Integração, 2017).

The Northeastern region of Brazil presents a large space-time variation in the climate and in the weather, in intra and interannual scale, being 56.46% of its territory represented by the semiarid region (Medeiros et al., 2012). The Brazilian semiarid region (BSA) is characterized by large periods of water scarcity, mainly due to irregularity and poor rainfall distribution (*i.e.*, 350 to 800 mm year^{-1}), with potential evapotranspiration (ETp) values of up to 2,000 mm year^{-1}, with a wide variation in the air temperature (20.1 to 32.9 ºC) and relative humidity of 60% (Silva et al., 2014; Pereira et al., 2015). According to Alves et al. (2014a) and Carneiro et al. (2014), these conditions are related to the high incidence of solar radiation in this region, also affecting soil temperature and evapotranspiration, affecting plant growth and development.

According to the Köppen classification, in BSA prevails three types of climate: BShw - semiarid, with a short rainy season in the summer and precipitations concentrated in the months of December and January; the BShw’ - semiarid, with a short rainy season in summer-autumn and greater rainfall in the months of March and April, and the BShs' - semiarid, with a short rainy season in autumn and winter and rainfall concentrated in the months of May and June (Coutinho et al., 2007). In the present study, it was observed that the dry season was characterized by two distinct periods: rainy and dry, ranging from four to six months and six to eight months, respectively (Pereira Filho et al., 2013; Nascimento et al., 2013).

Besides the poor spatial and temporal distribution of rainfall, which is concentrated in a small period of time, usually no more than four months (Souza et al., 2015a), there is also the phenomenon of droughts caused by the water deficit in an extended period of months or years. Thus, the drought can be classified into four distinct types (*e.g.*, meteorological, hydrological, agricultural and socioeconomic) (Yang et al., 2018a). The meteorological drought is caused by long periods of drought in subsequent months or years, with below-average rainfall for the region. However, the hydrological drought is due to the insufficiency of the surface and underground reservoirs (Cunha et al., 2015) (Figure 1).

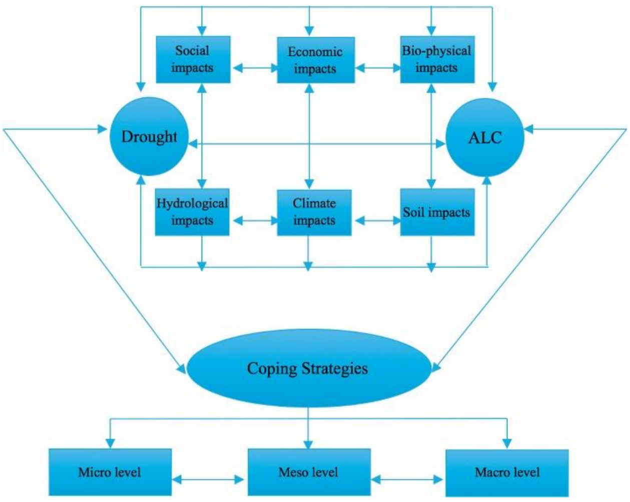

Fig. 1. Flowchart of interactions between droughts and their impacts on production and socioeconomic systems. Adapted from Azadi et al. (2018).

Thus, when allied to meteorological drought with anthropogenic action, such as deforestation, the introduction of not adapted agricultural species to Brazil's semiarid conditions and the misuse of land, they can cause another type of drought, called agricultural drought, which is affected by the hydric availability to levels that do not satisfy the development of the plants (Cunha et al., 2015), and consequently affecting the production and productivity of small farms, where they are mostly classified as subsistence agriculture and depend strictly from nonirrigated agriculture (Aylanlade et al., 2018).

This way, the drought (*i.e.*, meteorological, hydrological and agricultural) phenomena, when they overlap, they culminate in the so-called socioeconomic drought, which is related to the low performance of agricultural systems and water availability for the development of activities, resulting in low agricultural productivity, and subsequently, generating alimentary insecurity and income instability for the farmers, causing the displacement of a large part of the rural community to large urban centers, thus destabilizing the poorest groups (Gutiérrez et al., 2014; Djebou, 2017).

In addition to these climatic factors that drastically affect the Brazilian semiarid, impacting directly on the socioeconomic conditions of the populations of this region, the soils of this area in the majority do not present great agricultural aptitude from the physical point of view, since they are young soils in the pedogenetic perspective , low weathered soils with low effective depth and low moisture retention capacity in the profile, influencing the local floristic composition and making subsistence farming difficult due to the nonirrigated agriculture (Montenegro and Montenegro, 2012; Oliveira et al., 2018).

The caatinga is the dominant vegetation within the BSA, being quite rustic and heterogeneous as to its floristic composition, varying widely according to the meteorological conditions (mainly rainfall) and edaphic for each locality within the BSA, allowing greater or lesser supply of resources to local populations (Tomasella et al., 2018). In addition to this characteristic imposed by the environmental factors, the anthropic actions have contributed to the degradation and advancement in the desertification process of the Caatinga, due to the disorganized exploitation of the resources, reflecting in the socioeconomic follow-up of the region (Mariano et al., 2018).

In addition to the already existing factors that hinder agricultural production and the sustainability of BSA populations, several studies show a strong trend towards impacts in this region due to climate changes, such as the reduction of agricultural and livestock productivity, with an increase in the air temperature and the reduction of rainfall (Silva et al., 2017c; Marengo et al., 2017; Mariano et al., 2018). Due to the susceptibility of the agricultural ecosystems and of the Caatinga to the climate changes, livestock farming emerged as the main mean of financial support of the rural population (Nunes et al., 2016; Silva et al., 2017c).

The crops are more vulnerable to environmental constraints, being considered only as a subcomponent of the prevailing production systems (Souza et al., 2014). In this context, ruminants (*e.g.*, cattle, goats and sheep) comprise the main livestock raising activity, with greater concentration in an extensive way, feeding on the native vegetation (*i.e.*, caatinga), presenting in turn low zootechnical indexes (Almeida et al., 2011).

In BSA, forages are the main source of food for domestic ruminants, where more than 70% of the known species that make up the Caatinga flora expressively take part of the diet of cattle, goats and sheep (Coutinho et al., 2013; Nunes et al., 2016). Even with all this importance in animal feeding, native pastures are strongly influenced by rainfall, being abundant in the rainy season and limited or almost null in the dry periods of the year, resulting in a fall in the production of livestock and socioeconomic losses to the producers of this region (Alves et al., 2014b). Thus livestock also becomes vulnerable to the phenomenon of droughts.

Forage cactus and its usage in the semiarid

Due to the seasonality of the production of the most part of the plants that compos the native pasture, it is of importance the usage of forage species (*e.g.*, exotic or native) that adapt to the edaphoclimatic conditions of the SAB, offering stability to the productive systems, mitigating the dietary deficit and the low yields of the livestock in this region (Santana Neto et al., 2015). Cândido et al. (2009) cited some plants of forage potential adapted to the semiarid conditions, such as: Buffel grass (*Cenchrus ciliaris*), the maniçoba (*Manihot* spp.), the fodder sorghum (*Sorghum* spp.) and the forage cactus (*Opuntia* spp. e *Nopalea* spp.).

Among the cited cultures above, forage cactus stands out due to its elevated potential of green phytomass production, when compared to the other, in arid and semiarid regions under low hydric availability, becoming a viable cultivation for the production system (Ramos et al., 2014).

This xerophytic cactus is native to the Americas, having Mexico as its center of origin and it can be found in almost all localities of the terrestrial globe, persisting in places of climate from arid to temperate (Aruwa et al., 2018), from latitudes 59º N to 52º S, tolerating a great amplitude in the altitude, being able to be found from areas at sea level, to regions that exceed 5,000 m as the regions located in Peru (Silva et al., 2015b).

Even though it is a native plant to the Americas, it is widely found in the African, Asian, European and Oceanic continents, with a wide variety of purposes (Nharingo and Moyo, 2016). Cactus species, cultivated worldwide, were primarily for forage production, but in the last decades it has intensified research on the use of this plant in several areas, such as in the production of pharmaceuticals, cosmetics, food, production of alcoholic beverages, soil conservation and recovery of degraded areas, as raw material in the production of biofuels, in the treatment of residual water (*e.g.*, greywater), among other uses (Andrade-Montemayor et al., 2011; Volpe et al., 2018; Aruwa et al., 2018; Chahdoura et al., 2018).

In Brazil, this cactus was introduced around the second half of the 19th century in the state of Pernambuco, not exposing the finality of the fodder plant. Only in 1902 this cultivation started to be part of the animal diet as an alternative fodder plant in the states of Pernambuco and Alagoas, in order to lessen the low offering of forage in the dry periods of the year (Galvão Júnior et al., 2014).

It is estimated that currently in Brazil there are 600 thousand hectares occupied by cactus cultivation, where approximately 90% of this total is in the Northeast (550 thousand ha). It was used mainly in the form of bulky ruminant diet (Oliveira et al., 2010; Marques et al., 2017). This major utilization in the Northeast and mainly in the semiarid zone is related to the great production of dry matter (DM) of the forage cactus on the hydric shortage, when compared to other fodder plants (Peixoto et al., 2018).

According to Guevara et al. (2011) the forage cactus can reach productivity in the order of 20 t DM ha^{-1} $year^{-1}$ under natural conditions, as average for the whole world. For the Brazilian semiarid conditions, Silva et al. (2014) found productivity of 22.5 t DM ha^{-1} in 12 months of evaluation for the clone Miúda

(*Nopalea cochenillifera* Salm-Dyck) under natural conditions. Silva et al. (2015b), evaluating the Orelha de Elefante Mexicana (*Opuntia stricta* (Haw.) Haw.), under nonirrigated conditions in the semiarid of Pernambuco, found a productivity of 15.6 t DM ha^{-1} in a two-year cycle.

The satisfactory performance of this cactus in the semiarid regions in the whole world, including the BSA, is related to the morphophysiological characteristics. Within the morphological and anatomical mechanisms of adaptation of this cultivation, which make it endure long periods of water deficit, it is highlighted: the modification of the stem in a succulent structure denominated cladodes or article, in order to store water; the transformation of the leaves into spines to reduce the loss of water by transpiration; presence of a thick layer of wax covering the cladodes; reduced amount of stomata; as well as an efficient radicular system, which is presented in four distinct types (*e.g.*, structural, absorbent, spurred and developed from areoles) (Oliveira et al., 2010; Rocha, 2012; Marques et al., 2017).

Physiologically, the forage cactus has CAM metabolism (Crassulacean Acid Metabilism), which consists in the high adaptability to the arid and semiarid zones, allowing the plants to survive extreme heat, low temperatures and intense droughts due to their high efficiency in water use (Melgar et al., 2017). Plants equipped with this mechanism have higher efficiency with fixed CO_2 per unit of water lost, approximately 3 and 6 times, when compared with photosynthetic plants C4 and C3, respectively (Liu et al., 2018).

CAM plants consist of the night opening of the stomata for CO_2 fixation, where air temperatures are milder and the humidity is more elevated when compared to daytime, the fixed CO_2 is converted into malate by means of biochemical processes and stored in the vacuoles in the form of malic acid. During the daytime period occurs the process of decarboxylation of the malic acid to the CO_2 for its use in the photosynthetic processes, remaining with the stomata partially closed, avoiding water loss by transpiration (Souza Filho et al., 2016; Liu et al., 2018).

The main clones of forage cactus used in BSA belong to the genus *Opuntia* and *Nopalea*. The most widespread until the early 2000's were the clones Redonda, Giant (*Opuntia ficus-indica* Mill.) and Miúda (*Nopalea cochenillifera* Salm-Dyck), where the first two clones are susceptible to carmine cochineal (*Dactylopius opuntiae* [Hemiptera: Dactylopiidae]) (Vasconcelos et al., 2009; Silva et al., 2015b).

According to Vasconcelos et al. (2009) several forage cactus plantations in the Northeast were affected by *D. opuntiae*, leading to a large reduction of palms in the BSA. Due to these factors, there was great interest in the research on finding forage cactus clones resistant to this plague. Thereafter it was found that the clones of the Orelha de Elefante Mexicana (*Opuntia stricta* (Haw.) Haw.) were distinguished in relation to the other clones (Vasconcelos et al., 2009; Lopes et al., 2010; Galvão Júnior et al., 2014).

After the selection of carmine cochineal resistant clones, the production systems began to show more productive stability and reduced plant mortality, improving the supply of bulky plants during the year in the dry periods. As forage cactus became the basis for ruminant diet in BSA (Costa et al., 2012).

In addition to the high adaptation to the edaphoclimatic conditions of the BSA, forage cactus presents good palatability and acceptance by the animals, being a food rich in energy and good digestibility, besides, it is composed of about 90% of water and can complement part of the water and nutritional demand of the animals in the periods of low water and food availability (Almeida, 2012).

Costa et al. (2012) reported the use of forage cactus and its benefits in ruminant diet in the Brazilian semiarid region, showing a slight difference in daily weight gain when compared to corn replacement by forage cactus, at lamb termination. It has shown to be viable at the animal performance, when fed with bulky of lower production cost and higher stability, without many risks to the production.

Even with all this importance for the BSA region, forage cactus has not expressed its full potential, presenting low productivity yields (Almeida et al., 2011). On the other hand, according to Rocha (2012), if well managed this cultivation can reach high productivity, bringing stability to the systems of creation.

In this context, by means of practices such as adequate spacing, fertilization (chemical and/or organic), control of spontaneous vegetation, irrigation and conservation practices, such as, mulch with vegetal remains, can improve the productivity of forage cactus (Lopes, 2012). In studies carried out in the Central Sertão region of Cabugi, in the state of Rio Grande do Norte, cited by Almeida et al. (2011), showed yields higher than 600 t ha^{-1} of green mass in the first year of cultivation for the forage cactus with the appropriate use of planting and irrigation techniques.

According to Oliveira et al. (2010), forage cactus, when cultivated in regions of low rainfall and high nocturne air temperature, do not present good productive performances, so a hydric complementation is needed by means of irrigation.

Irrigated forage cactus

The complementary irrigation is a fundamental tool of importance to boost the productive potential of the cultivations and supply the demand for the animal food in the dry periods of the year, chiefly in regions as the SAB that present low rate and pronounced seasonality rainfall (Blanco et al., 2011; Oliveira and Roque, 2016).

As for the forage cactus, although it is a widely studied plant in the SAB, little are the inferences in relation to the usage of complementary irrigation in this cultivation, being more commonly known the studies related to the its management, different clones, planting distance, such as fertilizations (Pereira et al., 2015). However, recently some researchers have turned to this area, using practices previously cited in association with irrigation (Lima et al., 2010; Lima et al., 2018).

Due to the characteristics of the BSA (*i.e.*, rainfall seasonality, high air temperatures) the productivity of cactus in this region vary a lot from year to year when cultivated in a non-irrigated system, affecting directly the offering of forage to the livestock. Nonetheless, the complementary irrigation practice offers a greater stability of these production systems, in order to improve the constancy of the production throughout the year (Rego et al., 2014).

According to Rocha, Voltolini and Gava (2017), in addition to improve the offering of forage throughout the year, the use of complementary irrigation can promote the anticipation of the cactus harvesting in six months, when compared to what is cited in the literature that make reference to two years. Still according to the authors, it is possible to obtain a satisfactory performance of the cultivation in the first four months after planting, being able to supply the livestock necessities in the dry period on the first year of planting.

Thus, it is of great importance the studies of this practice in the cultivation of forage cactus, in order to improve the productive performances and supply the forage need of the livestock in these areas affected by the seasonality in the offering of forage.

Mulch

Aside from the irrigation, another practice that has been used in the last few years is the adoption of mulch over the soil. Mulch consists in the usage of plant remains for the coverage of the soil, being more commonly used the plant remains of hoeing, remains of commercial cultivation, grass products among others (Lourenço et al., 2001; Kader et al., 2017).

So, mulch provides an improvement of the water and thermic conditions in the soil, offering a higher content of water to the plants, aside from diminishing the temperature range of the soil, promoting the development of the radicular system in more superficial layers (Li et al., 2018). These advantages may promote major elevation in the biomass of the radicular system and of the aerial parts of the plant (Luo et al., 2015) (Figure 2).

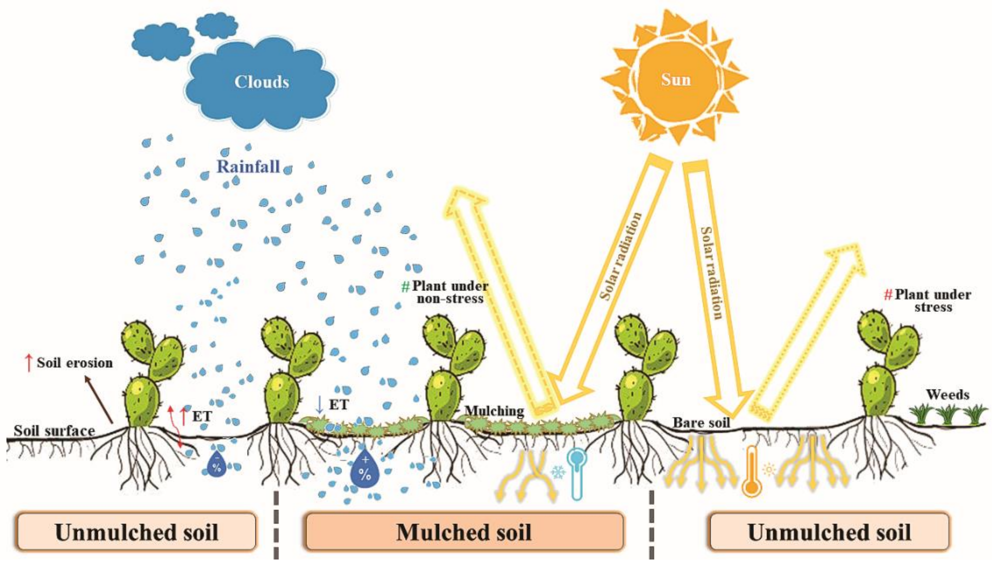

Fig. 2. Effects of mulching on the interaction of soil-plant-atmosphere system and its benefits on agricultural resilience.

In addition to the water conservation of the soil and the modification of the temperature, mulch promote improvements in the physical, chemical and biological aspects of the soil, preventing erosion, diminishing the impacts from the drops of rainfall, improving the structure, porosity and aeration, also providing nutrients to the plants after the mineralization process of the organic matter and stimulating the activity of the beneficial microbial fauna in the soil (Yang et al., 2018b; Namaghi et al., 2018; Chen et al., 2018).

This practice promotes several advantages to the production systems, where it causes changes in the local microclimate, preventing the excessive evaporation of the water retained in the soil, once this process is ruled only for the meteorological conditions (*i.e.*, solar radiation, relative humidity of the air, air temperature and wind velocity). In this situation the coverage promotes a physical barrier, reducing the interaction soil-atmosphere (Zribi et al., 2015; Zhang et al., 2018).

This way, the presence of haystack in the surface of the soil promotes the diminishment in the evapotranspiration rate of the cultivations, increasing the efficiency of the use of water, and consequently higher productivities, when added in adequate quantities (Silva et al., 2012). Li et al. (2018) state that the quantity of haystack by about nine tons per hectare were enough to promote the water conservation in the soil and improve the performance of the cultivation in the semiarid areas of China.

Evapotranspiration and crop coefficient

Evapotranspiration (ET) is one of the main components involved in the comprehension of the systems soil-plant-atmosphere, it can be responsible for about 95% of the water balance in the arid and semiarid regions (Kool et al., 2014). This term refers to the direct water evaporation (E) in the naked soil and the transpiration (T) of the cultivation (Unkovich et al., 2018). Rana and Katerji (2000) state that about 99% of the water used in the agriculture is lost in the form of ET, which depends on the type of the soil, the available water and the resistance of the plant canopy.

Information about ET are fundamental for the understanding and management of the hydric resources, as well as a better exploitation of the water for irrigation in agricultural systems, simulation of the productivity of the cultivation, projects and water balance (Fanaya Júnior et al., 2012; Maček et al., 2018).

In the rational use of the irrigation water is very important the knowledge of the evapotranspiration of the cultivation (ETc), that helps the producers in the decision-making situations, when apply and how much water to use in the irrigation (Payero and Irmak, 2013). So, for the determination of the ETc, the most common method is the multiplication of the crop coefficient (Kc) by the reference evapotranspiration (ETo) accordingly to Allen et al. (1998). The values of the Kc depend on the type of cultivation (*e.g.*, canopy, growth habit, roughness, soil cover, developmental stage for the plant) and edaphoclimatic characteristics of the cultivation spot (Park et al., 2017; Fan and Thomas, 2018).

Having in mind the edaphoclimatic importance combined with the morphophysiological characteristics of the cultivation, influencing directly in the ETc, it is of extreme necessity the measurement of these components for each location, in order to diminish the errors with the values found in the literature, which are not, sometimes, calculated for the same cultivation conditions. ETc can be stipulated by several methods, being the water balance in the soil largely used in the last few years (Souza et al., 2011).

Water balance of the soil

I rrigation is very important for the agricultural sector, for this is responsible of about 80% of fresh water consumption in the world, and facing this scenario of climate changes and an even bigger demand of water for agricultural production, irrigated agriculture must improve the management of this resource (Pizetta, 2015).

At that, for the rational management of irrigation water in a production system, it is necessary the knowledge of the water needs of the cultivation, which suffers great influence of the environment energetic requirement, of the available water in the soil, and the resistance of the plant while losing water for the atmosphere, being of importance the measurement of the evapotranspiration (ET) and the variation of the water soil storage (Δh), where the volumetric content of the water soil (θ) is of great importance for the calculation of these components (Araújo Primo et al., 2015; Queiroz et al., 2016; Carmo et al., 2017).

Therefore, the demand of water for irrigation purposes can be defined through the atmospheric data or by the monitoring of the soil humidity where the estimative for the gathering of atmospheric data, can be acquired through mathematical models, as in the case of the Hargreaves and Samani method (1985) or the Penman Monteith FAO-56 (Allen et al., 1998), these are widely accepted models, these methods are empirical and are amenable to errors, even being properly calibrated (Gava et al., 2016).

As for the methods of soil humidity readings, are real measurements, which can be obtained for direct measures, being the gravimetric method (standard method) very precise and with a relatively low cost, however, it presents some disadvantages that make impractical its use in some studies, such as the time for the determination of a sample (at least 24 hours) and the fact of being a destructive procedure, so, it is more utilized for the calibration of indirect methods (Lyra et al., 2010; Souza et al., 2016; Oliveira and Roque, 2016).

The indirect methods allow the quantification of the water content in the soil, based upon electric pulses emanated in the matrix of the soil by humidity sensors that are based on physical properties of the soil (Souza et al., 2016). The capacitive sensors present great precision, in addition to make possible instantaneous readings, provide continuous readings and do no use gamma radiation (*e.g.*, neutron moisture gauge), facilitating the studies in the management of the irrigation water (Pizetta et al., 2017).

According to Libardi (2005) the water balance of the soil is considered a direct method that allows the study of the water absorption of the plants in different depths of the profile of the soil. To perform the water soil balance (WSB) is necessary the quantification of all entry components of water in the soil (positive flow), such as: precipitation (P); irrigation (I); capillary rise (+Q); surface run-offs and subsurface of entry (R_e e R_e’, in this order). Since the exit components consist in: evapotranspiration (ET), deep drainage (–Q) and surface run-offs and subsurface of exit (R_s e R_s’, in this order), whose sum results in the variation of the water soil storage (Δh) (Moraes et al., 2015).

As for the clones of forage cactus, the information about the necessity and usage of water are scarce, as well as the interaction of this cultivation with the environment, particularly, when it concerns the water soil dynamic and the evapotranspiration (ET), creating controversies about the little water requirement of this cultivation (Queiroz et al., 2015; Silva et al., 2015a).

Final considerations

This review emphasized the importance of understanding the biophysical dynamics at field scale, on the resilience of forage cactus in varied agroecosystems, highlighting their yields and plasticity under differentiated crops, and how climatic conditions can affect forage quality and yield.

The need for research aimed at the use of species adapted to the arid and semi-arid conditions are still quite insipient in the literature, being necessary the deepening of crops such as those of high resilience and productivity that provide ecosystem services, even in an environment harsh environments.

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