UNIVERSIDADE FEDERAL RURAL DO SEMI-ÁRIDO
PRÓ-REITORIA DE PESQUISA E PÓS-GRADUAÇÃO
PROGRAMA DE PÓS-GRADUAÇÃO EM FITOTECNIA
DOUTORADO EM FITOTECNIA

MATHEUS DE FREITAS SOUZA

EFFECT OF WATER MANAGEMENT IN SOIL ON WEED INTERFERENCE IN THE ONION CULTIVATION SYSTEM

MOSSORÓ
2019

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Tese apresentada ao Programa de Pós-Graduação em Fitotecnia da Universidade Federal Rural do Semi-Árido como requisito para obtenção do título de Doutor em Fitotecnia.

Linha de Pesquisa: Plantas daninhas

Orientador: Prof. D.Sc. Daniel Valadão Silva

Co-orientador: Prof. D.Sc. Leilson Costa Grangeiro

MOSSORÓ

2019

Dados Internacionais de Catalogação na Publicação (CIP)
Biblioteca Central Orlando Teixeira (BCOT)
Setor de Informação e Referência (SIR)

F729e Freitas Souza, Matheus.
Effect of water management in soil on weed interference in the onion cultivation system / Matheus Freitas Souza. - 2019.
89 f. : il.

Orientador: Daniel Valadão Silva.
Coorientador: Leilson Costa Grangeiro.
Tese (Doutorado) - Universidade Federal Rural do Semi-árido, Programa de Pós-graduação em , 2019.

1. Dominance. 2. Drip . 3. Interference. 4. Micro-sprinkler. 5. Richness. I. Valadão Silva, Daniel, orient. II. Costa Grangeiro, Leilson, co-orient. III. Título.

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Defendida em: 09/04/2019.

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SUMMARY

Dedico

Aos meus pais Roberto Albino de Souza e Dalva Maria de Freitas Souza; ao me irmão Lucas de Freitas Souza; e ao professor Daniel Valadão pela confiança, apoio e paciência em todas as minhas derrotas e conquistas.

AGRADECIMENTOS

Ao SENHOR JESUS CRISTO, que colocou em minha vida pessoas maravilhosas que fizeram tudo em minha vida ser possível, me mostrando o caminho da bondade e honestidade;

Aos meus pais, Roberto Albino de Souza e Dalva Maria de Freitas Souza que são fundamentais na minha vida, pelo aconselhamento, ajuda e incentivo nas horas difíceis, essências na minha formação como pessoa e profissional;

Ao meu irmão, Lucas de Freitas Souza (Tizil), pelo apoio, amizade e companheirismo;

À Universidade Federal Rural do Semi-Árido (UFERSA), pela oportunidade de participar do Programa de Pós-Graduação em Fitotecnia;

À Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), pela concessão da bolsa;

Ao professor orientador, doutor Daniel Valadão Silva, por me dar um propósito na minha vida profissional. Muito obrigado mesmo, por tudo;

Aos meus amigos de longa data, Antônio Neto (Tony), Marcio Moreira (Marcim), Sergio Alves (Tete), Rafael Freitas (Bujão), Marco Moreira (Timão), Manoel e Sônia, Charuntinho.

A minha namorada Laís Tereza pelo companheirismo durante essa grande jornada.

Ao Núcleo de Estudos em Matologia no Semiárido (NOMATO), por todo apoio na condução dos experimentos. A Daniel Valadão, Ana Beatriz, Hamurábi Lins, Tatiane Silva, Taliane Teófilo, Hélida Campos, Maria Alice, Alex Monteiro, Bruno Caio, Darlan Borges, Paulo Chagas, Cássia Araújo, Cydianne Pinheiro, Fernando Sarmento, Gisellya Cruz, Karoline Viana, Raíres Silva, Lidiane Martins, Jesley Bandeira, Quésia Pavão, Gabriela Daier, Mateus Pará, Beatriz Menezes, Odonil, Márcio Abraão, Márcio Freitas, Cláudia Daianny, Juliana Pamplona;

Aos funcionários da Horta, Sr. Antônio, Alderí, Nanan e Josimar, e os da Fazenda, Flabênio, pelas ajudas na condução do trabalho em campo;

Aos professores do Programa de Pós-graduação em Fitotecnia PPGF/UFERSA – Mossoró-RN, pelos conhecimentos transmitidos;

Aos professores doutores membros da banca examinadora;

Por fim, a todos que, de forma direta ou indireta contribuíram para a realização deste trabalho.

Construir conhecimento significa sujar as mãos, saltar no meio de tudo, cair de cara no chão; é ir além de si mesmo [...].

(Leo Buscaglia)

ABSTRACT

SOUZA, Matheus de Freitas. **Effect of water management in soil on weed interference in the onion cultivation system.** 2019. 89f. Thesis (Doctorate in Plant Science) - Universidade Federal Rural do Semi-Árido (UFERSA), Mossoró-RN, 2019.

Agricultural practices function as an ecological filter of weeds, selecting those more adapted to the agro-system. The characteristics of the weed species and the disturbances promoted by crops shape the weed community, influencing the productive performance of the crops. Among the practices, irrigation can directly affect the establishment of some weed species, and a better-adapted community can intensify the degree of interference on the crop. This study aims to evaluate the changes caused by two irrigation systems (high and low water application rate) in the weed community over three onion crop cultivars (*Allium cepa* L.), and how these changes affect productivity, water use and system interference period. The γ, α, β-diversity were altered by onion cultivation over the three years of cultivation. The system with higher water supply (micro-sprinkler) favored the diversity and weed richness, mainly in the second year of cultivation compared to the system with water restriction (drip). The dominant weed species in the first crop cycle changed compared to the last cycle for both irrigation systems. The change in the weed community between the years of cultivation affected the commercial bulb productivity and water use efficiency of onion cultivated under drip and micro-sprinkler. For drip irrigated onion crops, the reduction in water use efficiency is even more drastic. The relative yield of the onion was influenced by the duration of the coexistence period or weed free, irrespective of the irrigation systems. Growing periods of weed interference significantly reduced onion production in all years. In the drip system, the critical period of prevention (PCPI) ranged from 25 to 36 DAE in 2016, 12 to 28 DAE in 2017 and 16 to 89 DAE in 2018 based on the 5% level of acceptable yield loss. In the micro-sprinkler system the PCPI ranged from 06 to 24 DAE in 2016, 10 to 62 DAE in 2017 and 24 to 65 DAE in 2018. The duration of the PCPI depends on the irrigation system used and the composition of the weed community. Irrigation systems influence the beginning and end of PCPI. Weeds reduce the sustainability of the irrigated onion cultivation system when they are not controlled.

Key words: Dominance, drip, interference, micro-sprinkler, richness.

RESUMO

SOUZA, Matheus de Freitas. **Efeito do manejo da água no solo sobre a interferência de plantas daninhas no sistema de cultivo de cebola.** 2019. 89f. Tese (Doutorado em Fitotecnia) - Universidade Federal Rural do Semi-Árido (UFERSA), Mossoró-RN, 2019.

Práticas agrícolas funcionam como filtro ecológico de Weeds, selecionando aquelas mais adaptadas ao agrossistema. As características das espécies infestantes e as perturbações promovidas por cultivos moldam a comunidade de Weeds, influenciando o desempenho produtivo das culturas. Dentre as práticas, a irrigação pode afetar diretamente o estabelecimento de algumas espécies de Weeds, e uma comunidade melhor adaptada pode intensificar o grau de interferência sobre a cultura. Este estudo tem como objetivos avaliar as alterações provocadas por dois sistemas de irrigação (Micro-sprinkler - alta e Drip - baixa taxa de aplicação de água) na comunidade de Weeds ao longo de três safras de cultivo da cebola (*Allium cepa* L.), e como essas mudanças afetam a produtividade, uso da água e período de interferência dos sistemas. A γ, α, β-diversidade foram alteradas pelo cultivo de cebola ao longo dos três anos de cultivo. O sistema com maior suprimento de água (Micro-sprinkler) favoreceu a diversidade e riqueza de Weeds, principalmente no segundo ano de cultivo comparado ao sistema com restrição hídrica (Drip). A espécie de planta daninha dominante no primeiro ciclo de cultivo mudou comparado ao último ciclo para os dois sistemas de irrigação. A mudança na comunidade de Weeds entre os anos de cultivo afetou a produtividade de bulbos comerciais e eficiência no uso da água (EUA) da cebola cultivada sob Drip e Micro-sprinkler. Para cultivos de cebola irrigados por Drip, a redução na eficiência no uso da água foi ainda mais drástica. O rendimento relativo da cebola foi influenciado pela duração do período em convivência com as Weeds, independentemente dos sistemas de irrigação. Períodos crescentes de interferência de Weeds reduziram significativamente a produção de cebola em todos os anos. No sistema de Drip, o período crítico de prevenção (PCPI) variou de 25 a 36 DAE em 2016, 12 a 28 DAE em 2017 e 16 a 89 DAE em 2018 com base no nível de 5% de perda de rendimento aceitável. No sistema de Micro-sprinkler o PCPI variou de 06 a 24 DAE em 2016, 10 a 62 DAE em 2017 e 24 a 65 DAE em 2018. A duração do PCPI depende do sistema de irrigação utilizado e da composição da comunidade infestante em cada ano-safra. Os sistemas de irrigação influenciam o início e o fim do PCPI. Weeds reduzem a sustentabilidade do sistema de cultivo da cebola irrigada quando elas não são controladas.

Palavras-chave: Dominância, Drip, interferência, Micro-sprinkler.

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CHAPTER II

GENERAL INTRODUCTION

Agricultural systems can promote species selection in weed communities, and the intensity of disturbance and stress define which plants will demonstrate better adaptation to the ecosystem (PLAZA et al., 2015). In conventional vegetable crops, the disturbance degree caused is high compared to other more conservative systems, such as perennial and cereals crops cultivated under no-tillage (PLAZA et al., 2015).

The high disturbance in conventional vegetable crops is associated with the intense number of operations carried out for soil preparation. High yield crops are frequently submitted to the tillage to avoid soil compaction (MCPHEE et al., 2015). In these systems, the soil is sprayed into tiny particles to prepare the beds, allowing the crop development (HOYT et al., 1994; CRITTENDEN et al, 2015; BUTLER et al, 2016.). For those whose commercial product develops below ground, the soil preparation must be meticulous in guaranteeing a product with high quality. Onion is an example (*Allium cepa* L.). This culture has as primary raw material the bulbs that develop below ground (OKU et al., 2019).

Despite the high disturbance caused by conventional onion crops, the stress level is low due to the high inputs supply such as water and nutrients provided for the crop growth (CORGAN, KEDAR, 2018, RAO, 2016, SILVERTOWN et al. , 1992, GRIME, 1977). However, some studies have shown that a reduction in the water supply at some crop development stages can result in high yield and quality of harvested bulbs similar to systems with full irrigation. For example, SEMIDA et al. (2017) reported that foliar application of salicylic acid allowed reducing the applied water depth by 40%, recommending this practice for onion farmers. WAKCHAURE et al. (2018) studied the feasibility of lowering water supply associated with the plant bioregulators and concluded that it was possible to implement the water deficit without decreasing productivity. However, imposing water stress may alter the weed community, since the low-stress condition as commonly is used for onion crops no longer performed.

Changes in the weed communities may decrease system sustainability (LEON et al., 2017; WOOD et al., 2015). Crops systems with less water availability in the soil enhance the dominance of weeds more adapted to water stress environments, and this would reduce the diversity of farming systems (WOOD et al, 2015; KAUR et al, 2018). Ecosystems with a lower variety of species are less to be able to provide ecologically beneficial crop services (WOOD et al., 2015). Also, a better-adapted community, especially in conditions of more significant stress (such as water deficit) can be extremely competitive because of the already scarce resource in the environment. MACLAREN et al. (2019) observed that in 14 vineyards in the Western Cape of South Africa, those who used only herbicides had a reduction in the diversity and richness of weed species compared to crops with summer mowing. Besides, the authors reported greater competition in systems with lower diversity and wealth. WEYERS et al. (2018) reported that alfalfa cultivation (*Medicago sativa*) for three consecutive years reduced weed diversity and crop yield relative to other crops that used rotation between alfalfa crops.

The use of fewer inputs in agriculture maintaining high yields is a crucial point for greater sustainability of the system (GOLD et al., 2016). For the onion, studies have shown that there are solutions to reduce applied water without yield and quality loos. However, altering the cropping system can promote changes in other structures of the agro-system, for example, the weed community (PLAZA et al., 2015, WOOD et al., 2015). These interactions should be understood so that other problems do not affect the sustainability of cultivated areas. We hypothesize that water applied in conventional onion culture systems can alter weed dynamics over the years and that these changes in the weed community can affect productivity, water efficiency, and period for weed control.

This study aims to evaluate the changes caused by two irrigation systems (high and low rate of water application) in the weed community over three onion cultivation crops (*Allium cepa* L.) and how these changes affect productivity, water use efficiency and period for weed control. To simulate the different amounts of water applied, we use drip and micro-sprinkler systems for three years. In particular, we analyzed the following questions: 1) Can the quantity of water supply to change the weed community over the years in onion cultivation? 2) What are the factors related to this change? 3) Can weed communities influence the productivity and water use of onion culture systems? 4) Does the period of crop interference change due to the irrigation method implement? Based on the results, we hope to elucidate issues that may help to optimize onion cultivation in different water regimes.

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CHAPTER I – IRRIGATION MANAGEMENT IN THE DYNAMICS AND INTERFERENCE OF WEEDS IN ONION

ABSTRACT

Agricultural practices act as ecological filter of weeds, selecting those more adapted to the agrosystem. The stress and disturbances conditions due to cultivation preparations shape the weed community, influencing the productive performance of the crops. Among the practices, irrigation can directly affect the establishment of some weeds, and a better-adapted community can intensify the interference degree on the agricultural cultures. This study aims to evaluate the changes caused by two irrigation systems (high and low water application rate) on the weed community over three onion seasons, and how these changes affect the yield and efficiency of irrigated onion. The γ, α, β, diversities were altered by onion cultivation over the three seasons. Irrigations system with higher water supply (micro-sprinkler) favored the diversity and weed richness, especially during second cultivation year compared to the system with water restriction (drip). The dominant weed species in the first crop season changed compared to the third in both irrigation systems. The different weed community between the seasons affected the yield of commercial bulbs and water use efficiency in onion cultivated under drip and micro-sprinklers. The intense infestation of weeds and the presence of C4 species more negatively affect the onion grown in drip irrigation. Weeds reduce the sustainability of irrigated onion when they are not controlled.

Key words: *Allium cepa*, diversity, dominance, drip, micro-sprinkler.

1. INTRODUCTION

Cultivation practices can promote species selection on weed communities, and the intensity of disturbance and stress define which plants will demonstrate better adaptation to the agroecosystem (PLAZA et al., 2015). In conventional horticultural crops, the disturbance degree caused is very high compared to other more conservative systems, such as perennials and cereals grown under no-tillage (PLAZA et al., 2015).

The high disturbance caused in conventional horticultural crops is due to the excessive number of operations carried out to provide ideal conditions in the soil. High yield crops are intensively tillage before planting to avoid soil compaction (MCPHEE et al., 2015). In these systems, the ground is pulverized into tiny particles to permit the formation of beds. This procedure improves the growth and development of crop (HOYT et al., 1994; CRITTENDEN et al., 2015; BUTLER et al., 2016). For species whose commercial product develops under the soil, the preparation of the ground must be meticulous in guaranteeing final quality. Onion (*Allium cepa* L.) is an example. The most valuable raw material in this crop is bulbs that develop during most of the cycle under the soil (OKU et al., 2019).

Onion is a multipurpose vegetable that is consumed fresh and as processed products (Manohar et al., 2017). More than 85.5 million tonnes of onions were produced worldwide, covering about 4.3 million hectares of land. Onion yield in Brazil is close to that of other countries such as the Republic of Korea (66.15 t ha^{-1}), the USA (56.13 t ha^{-1}), the Netherlands (51.64 t ha^{-1}), Japan (46.64 t ha^{-1}) and Egypt (36.16 t ha^{-1}) (FAO, 2012).

Despite the high disturbance caused by onion crops, the level of stress is low due to the high supply of growth resources as water and nutrients that are provided for the crop development (Corgan, Kedar, 2018, RAO, 2016, SILVERTOWN et al. 1992, GRIME, 1977). However, some studies have shown that water restriction at some crop development stages can result in a yield and quality bulbs similar to the systems with full water supply. For example, SEMIDA et al., 2017 reported that foliar applications of salicylic acid allowed reducing the applied water in 40%, recommending this practice for onion farmers. WAKCHAURE et al. (2018) studied the viability of the water reduction used in the onion aided by bio-regulators, concluding that it is possible to restrict the water without yield onion loss. However, the imposition of water stress can change the weed community, since the low-stress system as is commonly used for onion crops will not be realized. Also, farmars have preferred the use of dripping to onion fields, due to the lower water applied to the system compared to the micro-sprinklers. This practice is even more expressive in semi-arid regions.

These changes in the weed community may represent a reduction in the sustainability of the systems (LEON et al., 2017; WOOD et al., 2015). An agricultural crop with less water availability to favor vegetables may also intensify the dominance of some weeds more adapted to water stress environments, and this would reduce the diversity of agrosystems (WOOD et al., 2015; KAUR et al., 2018). Ecosystems with lower species richness have a lower possibility for that other plants provide ecologically beneficial services to crops (WOOD et al., 2015). In addition, a better-adapted community, especially under more stressful conditions (such as water deficit), can be extremely competitive because of the already scarce resource in the environment. MACLAREN et al., 2019 observed that in 14 vineyards in the Western Cape of South Africa, those that used only herbicides had a reduction in the diversity and richness of weed species compared to crops with mechanical handling in summer. Besides, the authors reported greater competition in systems with lower weed diversity and richness. WEYERS et al. (2018) reported that alfalfa (*Medicago sativa*) for three consecutive years reduced weed diversity and crop yield relative to other crops that used rotation between alfalfa crops.

The reduction in growth resources in agriculture without to affect the yield is a crucial point for greater sustainability of agricultural systems (GOLD et al., 2016). For the onion, studies have demonstrated that there are solutions to reduce applied water without changing the bulbs yield and quality. However, altering the cropping system can promote changes in other structures of the agrosystem such as weed community (PLAZA et al., 2015, WOOD et al., 2015). These interactions should be understood so that other problems do not affect the sustainability of the crop systems. We hypothesize that the amount and way of water application in onion cultivation systems may alter weed dynamics and that these changes in the community may affect yield and water efficient use.

This study aims to evaluate the changes caused by two irrigation systems (high and low water application rate) on the weed community over three onion seasons, and how these changes affect the yield and efficiency of irrigated onion. To simulate the different amounts of water applied, we use drip and micro-sprinkler systems for three years. The specific objectives aimed asked these questions: 1) Does the amount of water applied to change the weed community over the years in onion cultivations? 2) What are the factors related to this change? 3) Can weed communities influence the yield and water use of irrigated onion systems? Based on the results, we hope to elucidate issues that may help to optimize onion cultivation in different water regimes.

2. MATERIAL AND METHODS

2.1 Description of field area and onion cultivation

Field studies were carried out at the experimental farm located at latitude 5º 03'37 "S and longitude of 37º 23'50" W Gr, from July to November 2016, 2017 and 2018. The approximate altitude is 72 m, the climate, according to Thornthwaite, is classified as DdAa '(Carmo Filho et al., 1991). The experimental area was under fallow for ten years. Before fallow, the field was cultivated with cashew to produce chestnut and pseudo-fruit. The average meteorological data during the conduction of experiments were collected and are shown in Appendix I. Climatological data between crop seasons were also measured and shown Appendix II. The soil of the experimental area was classified as Abrupt Eutrophic Red-Yellow Latosol, sand-free texture (EMBRAPA, 2006). Samples were collected for physicochemical analysis, and the results are presented in Appendix III.

The cultivation of onion was conducted as commonly is carried out by the local farmers. The conduction system was conventional, performing the tillage and formation of beds with rotating hoe in the three years of cultivation. Each bed has 1.20 m wide and 20 cm high. Fertilization was performed according to the needs of onion (HIGASHIKAWA et al., 2017) and based on soil analysis.

Pre-planting fertilization was performed with 180 kg ha^{-1} of P_2O_5 (simple superphosphate), 3.0 kg ha^{-1} zinc (zinc sulfate) and 1.10 kg ha^{-1} of boron (boric acid). Also, cover fertilization with 165 kg ha^{-1} of N (MAP) and 30 kg of K_2O ha^{-1} (KCl) were applied in two fertigations throughout the crop cycle, with the aid of a tank of derivation. This fertilization was used for all the years of cultivation. Cultural treatments and phytosanitary control were carried out according to the technical recommendations and needs of crop.

The onion used in the conduction of the experiments was the "Rio das Antas" hybrid due to its adaptation to the climatic conditions of the region. This hybrid was used in all years. Direct and manual seeding with three seeds was carried out in July to ensure the plant population in all experimental area. The spacing used was 10 cm between rows and 6 cm between plants. Ten days after the emergency, the thinning was performed to obtain a population of 890 thousand plants ha^{-1}. The area sown with onion totaled 240 m^2.

2.2 Irrigation of experiments

The specifics procedures used for each irrigation system (drip and micro-sprinkler) in onion crop were established to evaluate the effects of irrigation systems on weed community, productivity, and water use efficiency. In the drip system, tapes were spaced 0.20 m between lines with 0.30 m between drippers. The micros-sprinklers were spaced 1.0 m x 1.0 m apart. The dripper flow rate was 1.5 L h^{-1} and micro-sprinklers 54 L h^{-1}. After sowing the seeds, initial irrigation was carried out by conventional spraying to raise soil moisture near 80% of the field capacity. The water required for this procedure was calculated as follows:

1) A composite sampling of the soil in all experimental area was performed;

2) Current soil moisture was calculated by the difference between the soil weight before and after drying in forced circulation oven for 12 hours (± 105ºC) as described by DOBRIYAL et al. (2012);

3) The soil field capacity was estimated by the difference between the weight of the soil previously dried in forced circulation oven and soil weight 72 hours after being soaked with water;

4) The conversion to the volume of water required to raise the area moisuere to 80% of the field capacity was performed based on the soil density of 1.4 kg dm^{-3};

5) Volume of irrigated soil considered was 30 cm, average value explored by roots of onion during their cycle;

The furthers irrigations for water supply were calculated considering the specific slides for each irrigation system (drip or micro-sprinkler). The applied water was estimated considering the daily evapotranspiration calculated in the area (ETo) and the coefficients (Kc) for onion at different development stages (MAROUELLI et al., 2005). This procedure was performed by the method of HARGREAVES & SAMANI (1985), and the daily values for the three years of cultivation are shown in Appendix IV.

The total applied water in 2016, 2017, and 2018 were 667, 683, 688 mm during 110 days of onion cultivation. The onion cycle was on average close to 120 days in the three years; however, MAROUELLI et al. (2005) recommend suspending irrigation ten days before of harvesting to improve the maturation phase of onion.

In the micro-sprinkler system, the daily applied water (1-day irrigation interval) was provided during the time to supplement the required amount according to the previous day's ETc. The time was calculated considering the spacing of micro-sprinklers, the flow rate, and the efficiency of the system. For micro-sprinkler, we established the effectiveness of 80% (KOUMANOV et al., 1997).

The water provided in the drip was calculated based on the values determined for the micro-sprinkler. However, to emphasize the differences between irrigation systems, the applied water in the drip was 50% lower compared to micro-sprinkler. The daily water supplied in drip was based on the dripper and tape spacing, flow rate, the efficiency of the system. The efficientness was established as 95% (CAMP, 1998). This procedure was repeated in 2016, 2017, and 2018.

2.3. Treatments and experimental design

Three experiments (2016, 2017 and 2018) were conducted to evaluate weed dynamics and their effects on onion cultivated under two irrigation systems. The research was conducted in a subdivided plot with three replicates. The factors were: 1) irrigation systems as the plot (drip irrigation – smaller applied water and micro sprinkler – higher applied water); 2) time to start weed control as subplot (0, 12 and 24 days after emergence of the crop). The dates to control weeds (subplot factor) was based on the period before the weed interference (data already reported in the literature).

2.4. Weed community

The density of weed infestation was evaluated at 12 and 24 days after emergence of the crop (DAE). The population assessment was evaluated in 2 sub-samples using a square with 0.25 m^{-2} in each subplot. The infestation density of each species was measured on each sub-sample. Subsequently, the sub-samples were grouped, totalizing a composite sample for each replicate in each irrigation system. The weed density was estimated to plants m^{-2}. This procedure was similar for 2016, 2017, and 2018.

2.5. Onion harvest and water efficient use in the irrigation systems

The onion was harvested 120 days after sowing when the plants showed a yellowish leaf during maturation stage. The single harvest at the same moment for all experimental unit was possible because no anticipation or delay between treatments was not evidenced. The useful area of each plot was 2.7 x 1 m (length x width). The bulbs in each useful area were collected and classified according to the diameter in commercial and non-commercial (LUENGO et al., 1999). Subsequently, the commercial bulbs yield per hectare was estimated, considering the total weight and number of bulbs harvested.

The water use efficiency (WUE) of the treatments was estimated as studied by WIT (1958) and discussed in more recent works (PEREIRA et al., 2002, ZWART, BASTIAANSSEN, 2004, HSIAO et al., 2007), as:

$$WUE = \frac{Yield}{System\ water\ consumption}$$

where: Yield was expressed as kg/hectare, and water consumption of the system as mm of applied water. The water consumed by the drip and micro-sprinkler system was considered as the total water provided during 110 days of onion cultivation. The calculation was performed for each year at different periods for weed control as established by the treatments.

2.6. Statistical analysis

2.6.1. Changes in diversity, richness, dominance, uniformity and composition of weeds

The diversity of species in drip irrigation and micro-sprinkler systems was evaluated by γ, α, β-diversity indices (WHITTAKER, 1960). The α-diversity is the total number of species in a habitat, γ-diversity is the total number of species observed in all habitats, and β-diversity is the number of species exclusive in an environmental gradient. The α and β-diversity values were compared between the years using the Wilcoxon test due to the non-normal distribution of the data. To identify species whose status increased, decreased, or remained stable between 2016, 2017 and 2018 in each irrigation system, the density of each weed were compared between years using two-part Wilcoxon test, which is the most powerful statistical test to analyze non-normal data when a large proportion of zeros occurs (TAYLOR; POLLARD, 2009).

To evaluate the species diversity and dominance in the weed community between the systems and years of onion cultivation, Shannon-Wiener and Margalef (H 'and D) diversity indexes, Simpson's dominance index (λ), and Pielou uniformity index (J ') were calculated as described by TRAVLOS et al. (2018) from the densities of each species in each treatment. The variables were tested for homogeneity (Levene test) and normality (Shapiro-Wilk test) of data. The values for the Shannon-Wiener (H '), Margalef (D), Simpson (λ) and Pielou (J') indices were transformed into sine-arc before the analyzes to normalize the data. After normalization, the mean values of the indices were compared by the confidence interval at the level of significance ≤0.05.

To understand the changes occurring in the weed community, an approach similar to that described by FRIED et al. (2009) was used. The Multiple Correspondence Analysis (MCA) was applied to group (Ward criteria) through the dimensions obtained by weed species and families density in each irrigation system and year. Besides, the species were classified according to their photosynthetic cycle (C4 or C3)/size (erect or procumbent) and growth habit (annual or perennial)/propagation (seed or vegetative) to group by MCA according to the respective dimensions.

2.6.2. Onion yield and water use efficiency (WUE)

Data of yield (commercial bulbs in ton ha^{-1}) and water use efficiency (WUE in kg/hectare/mm) were submitted to homogeneity (Levene test) and normality (Shapiro-Wilk test) analysis. The Analysis of Variance (ANOVA) between the years x irrigation system x period for weed control was used to detect if there was an interaction between them. After this procedure, Tukey's post-hoc test was applied to find differences between the means of each treatment. The level of significance for all tests considered a p-value ≤0.05.

3. RESULTS AND DISCUSSION

3.1. Weed density and γ, α, β-diversity

The γ-diversity in the drip system in 2016 was 50 and 57% lower compared to 2017 and 2018, respectively (Table 1). The α-diversity was higher in 2018 compared to 2016 (50%, p-value <0.03), but differences between 2016 and 2017 were not observed for the drip system (Table 1). Contrary to the diversity indexes γ and α diversity, β-diversity did not differ between all years (Table 1).

Table 1. Diversity γ, α and β of weed species in onion crop cultivated in different irrigation systems (drip and micro-sprinkler) in 2016, 2017 and 2018. Mossoró - RN, 2019.

System		2016	2017	2018	p-value (2016-2017)	p-value (2017-2018)	p-value (2016-2018)
Drip	γ-diversity	6	9	14			
	α-diversity	5 ±0.4	7 ±0.8	10.0 ±0.6	0.11	0.11	0.03*
	β-diversity	2 ±0.2	1 ±0.4	2 ±0.2	0.93	0.96	0.92
Micro-sprinkler	γ-diversity	10	12	13			
	α-diversity	7 ±0.2	7 ±0.8	10 ±0.4	0.34	0.02*	0.02*
	β-diversity	2 ±0.8	1.0 ±0.4	1.0 ±0.2	0.92	0.91	0.46

The total for γ, α and β-diversity (mean ± standard error). For comparisons of α and β-diversity, the non-parametric Wilcoxon statistic and the p-value are shown. *indicates significant comparisons by the Wilcoxon test.

The increase in γ-diversity indicates that a higher number of species was observed after two cycles of onion cultivations, and this increase resulted in a higher α-diversity. In 2016, the first disturbance occurred in the ecosystem after ten years under fallow. However, after two cropping cycles, agricultural practices such as soil preparation, application of synthetic fertilizers and irrigation made the environment favorable to the germination of a higher number of species (KAUR et al., 2018). Besides, these agricultural practices alter chemical and physical soil properties such as pH and temperature, factors that can break the dormancy and quiescence of some seeds. Thereby, the new environmental conditions stimulated the establishment of new weed species, increasing the diversity in the areas cultivated with onion (FENNER et al., 2017). Despite the more significant number of species observed in the year 2018, the presence of exclusive species in each onion season (β-diversity) was not different.

In the micro-sprinkler system, γ-diversity increased 16 and 23% between 2016 to 2017 and 2016 to 2018, respectively (Table 1). The α-diversity was similar in 2016 and 2017 (p-value <0.34) in the micro-sprinkler (Table 1). However, in this irrigation system, an increase (30%) for α-diversity occurred in 2018 (p-value <0.02) compared to 2016 and 2017 (Table 1).

The lower increase of γ-diversity and α-diversity among the years in the micro-sprinkler compared to the drip shows that the soil water disponible directly affected the germination of some weed species. In 2016, more species germinated in the areas under micro-sprinkler. The higher applied water in the micro-sprinkler may have favored the germination of species with higher sensitivity to lower soil water potential. Studies already have shown that weed species exhibit different germination capacities concerning the water potential (YUAN et al., 2018, BAJWA et al., 2018, MAHMOOD et al., 2016, SARANGI et al., 2016). Possibly, some weed species were not able to germinate when exposed to the lowest water potential reached by drip irrigation. However, in a system with higher water applied, some plants were able to germinate, allowing greater γ-diversity and α-diversity in the micro sprinkler system in the first cycle of onion cultivation.

The number of weed species identified in 2016, 2017, and 2018 in the drip was equal to 17 (Table 2). Among all species, *Aechynomene rudis* (p-value <0.03), *Blainvillea* spp. (p-value <0.02), *Ipomoea purpurea* (p-value <0.02), *Mollugo verticillata* (p-value <0.03), and *Sida* spp (p-value <0.03) had their infestation density reduced between 2016 and 2018 in the drip (Table 2). On the other hand, other species such as *Amaranthus hybridus* (P-value <0.02), *Centroococcus pascuorom* (p-value <0.03), *Chloris barbata* (p-value <0.03), *Digitaria horizontalis* (P-value <0.02), *Eragrostis pilosa* (p-value <0.02), *Hybanthus calceolaria* (p-value <0.03), *Jacquemontia tammifolia* (p-value <0.02), *Portulaca oleraceae* 02), and *Richardia brasilienais* (p-value <0.02) increased their infestation between 2016 and 2018 (Table 2). Only two species (*Merremia aegyptia* and *Senecio brasilienais*) emerged only in

2017 in the drip (Table 2). *Waltheria indica* was the only weed with constant infestation density between 2016/2017 (p-value <0.91), 2017/2018 (p-value <0.12) and 2016/2018 (p-value <0.07) for the drip system (Table 2).

Table 2. Mean values (mean ± standard error) for weed species density (plants m^{-2}) between 2016 and 2018 in onion cultivated under drip system. Mossoró - RN, 2019.

Species	Density (plants m^{-2})			p-value			[a]Status (2016 to 2018)
	2016	2017	2018	2016/ 2017	2017/ 2018	2016/ 2018	
Aechynomene rudis	3 ±0.5	3 ±0.4	0 ±0.0	0.99	0.03*	0.03*	(-)
Amaranthus hybridus	0 ±0.0	0 ±0.0	4 ±0.2	na	0.02*	0.02*	(+)
Blainvillea spp	8 ±1.5	0 ±0.0	0 ±0.0	0.02*	Na	0.02*	(-)
Centrocema pascuorom	0 ±0.0	0 ±0.0	20 ±5.8	na	0.03*	0.03*	(+)
Chloris barbata	0 ±0.0	0 ±0.0	57 ±9.2	na	0.03*	0.03*	(+)
Digitaria horizontalis	0 ±0.0	4 ±0.3	1157 ±59.1	0.01*	0.02*	0.02*	(+)
Eragrostis pilosa	0 ±0.0	0 ±0.0	43 ±13.2	na	0.02*	0.02*	(+)
Hybanthus calceolaria	0 ±0.0	4 ±0.6	11 ±2.23	0.02*	0.06	0.03*	(+)
Ipomoea purpurea	10 ±0.8	4 ±0.3	0 ±0.0	0.02*	0.01*	0.02*	(-)
Jacquemontia tamnifolia	0 ±0.0	0 ±0.0	5 ±0.8	na	0.02*	0.02*	(+)
Merremia aegyptia	0 ±0.0	4 ±0.34	0 ±0.0	0.02*	0.02*		Appeared just in 2017
Mollugo verticillata	144 ±9.0	101 ±22.0	44 ±3.9	0.49	0.05*	0.03*	(-)
Portulaca oleraceae	0 ±0.0	0 ±0.0	5 ±0.8	na	0.02*	0.02*	(+)
Richardia brasilienais	0 ±0.0	34 ±9.7	363 ±126.5	0.03*	0.05*	0.02*	(+)
Senecio brasilienais	0 ±0.0	5 ±0.84	0 ±0.0	0.03*	0.03*		Appeared just in 2017
Sida spp	9 ±2.2	0 ±0.0	0 ±0.0	0.04*	Na	0.04*	(-)
Waltheria indica	11 ±2.2	15 ±3.0	5 ±1.1	0.91	0.02*	0.07	Constant

[a]Status: '-': decreasing species; '+': increasing species. Wilcoxon's non-parametric statistics and p-value are shown. *indicates significant comparisons by the Wilcoxon test. na: density did not change between years.

After three seasons with onion cultivated under drip irrigation did not favor the establishment of 5 weed species, causing a reduction in infestation density. Only the *Mollugo verticillata* was found in 2018, while the other species (4) were not observed in the experimental field. The reduction of weed infestation in cultivated areas was caused by the lower adaptation of the species to the crop conditions in which the crop was conducted along years. Another factor is related to the establishment of other better-adapted species, which, by increasing their density, increase interspecific competition among weeds (BORGY et al., 2016). Both phenomena may have contributed to the species *Aechynomene rudis*, *Blainvillea* spp., *Ipomoea purpurea*, and *Sida* spp. disappeared from crop fields in 2018. In addition to practices adopted for onion cultivation, the increase in infestation density of nine other species might have impaired the growth and establishment of the species observed in the first cycle of onion cultivation.

A total of 20 weed species were observed between 2016, 2017 and 2018 in onion cultivated uner micro-sprinkler (Table 3). Cultivation of three onion seasons (2016-2018) in this system reduced the infestation density for 5 species, *Blainvillea* spp. (p-value <0.02), *D. aegyptium* (p-value <0.02), *I. purpurea* (p-value <0.02), *M. verticillata* (p-value <0.03), *Sida* spp. (p-value <0.02) (Table 3). Most species, *A. rudis* (p-value <0.02), *A. hybridus* (p-value <0.02), *C. pascuorom* (p-value <0.02), *C. barbata* (P-value <0.02), *H. calceolaria* (p-value <0.02), *I. triloba* (p-value <0.02), *J. tammifolia* (P-value <0.02), and *R. brasiliensis* (p-value <0.02) had an increase in infestation density after three cycles (Table 3). Other species such as *P. oleracea* (p-value <0.15, 0.10, 0.33), *S. obtusifolia* (p-value <0.27, 0.38, 0.55), and *W. indica* (p- value <0.65; 0.07; 0.11) presented constant density between 2016 and 2018 (Table 3). For *M. aegyptia* and *S. brasiliensis*, infestations were only observed in the year 2017 (Table 3).

Among the five species that reduced their infestation in the micro-sprinkler, four, *Blainvillea* spp., *D. aegyptium*, *I. purpurea*, *M. verticillata*, and *Sida* spp., showed the same behavior in onion cultivated in drip irrigation. This result shows that the lower soil water potential was not the limiting factor for the establishment of these weed species. Other disturbances in the onion agroecosystem should be responsible for the low adaptability of the species mentioned above. For example, disorders in fruit orchards, such as crop management operations and increased soil fertility, have negatively affected native species and favored exotics (JUAREZ-ESCARIO et al., 2018).

The species *Blainvillea* spp., *D. aegyptium*, *I. purpúrea*, *M. verticillata*, and *Sida* spp., are annual and propagate through seeds, and such characteristics may be unfavorable to a system with constant soil preparation (SANTÍN-MONTANYÁ et al., 2018). Some species are favored by intense soil development; however, *Blainvillea* spp., *D. aegyptium*, *I. purpurea*, *M. verticillata*, and *Sida* spp did not adapt to the fields cultivated with onion. Probably, soil preparation operation buried the seeds of these weed species, reducing the germination in both irrigation systems. *D. aegyptium* seeds are photoblastic positive; therefore, the buried seeds promoted by tillage may have impaired the light stimulus necessary for germination of this species (Benvenuti et al., 2019; Chaouhan et al., 2018). Also, in tillage systems, higher soil exposure to solar radiation may increase soil temperature, as well as maximum and minimum temperature fluctuations, and this phenomenon may impair the germination of some weeds (BENVENUTI et al. al., 2019). For example, the species *I. purpurea* has the germination inhibited when the soil temperature reaches values ≥35 º C, or when fluctuations reach 17/32 ºC (JHA et al., 2015). This condition easily occurred in the circumstances where our experiments were conducted, affecting the established of this species.

Table 3. Mean values (mean ± standard error) for weed species density (plants m^{-2}) between 2016 and 2018 in onion cultivated under the micro-sprinkler system. Mossoró - RN, 2019.

Species	Density (plants m^{-2})			p-value			[a]Status (2016 to 2018)
	2016	2017	2018	2016/ 2017	2017/ 2018	2016/ 2018	
Aechynomene rudis	0 ±0.0	5 ±0.8	7 ±0.8	0.02	0.15	0.02	(+)
Amaranthus hybridus	4 ±0.3	12 ±2.7	67 ±23.5	0.04	0.03	0.02	(+)
Blainvillea spp	12 ±2.5	0 ±0.0	0 ±0.0	0.02	na	0.02	(-)
Centrocema pascuorom	0 ±0.0	0 ±0.0	32 ±9.1	na	0.03	0.03	(+)
Chloris barbata	11 ±0.8	10 ±0.8	37 ±1.8	0.32	0.03	0.02	(+)
Dactyloctenium aegyptium	5 ±0.4	0 ±0.0	0 ±0.0	0.02	na	0.02	(-)
Digitaria horizontalis	0 ±0.0	10 ±4.12	267 ±10.9	0.02	0.03	0.02	(+)
Eragrostis pilosa	0 ±0.0	0 ±0.0	60 ±20.4	na	0.03	0.03	(+)
Hybanthus calceolaria	0 ±0.0	5 ±0.8	8 ±1.5	0.02	0.05	0.02	(+)
Ipomoea purpurea	5 ±0.84	4 ±0.6	0 ±0.0	0.31	0.02	0.02	(-)
Ipomoea triloba	0 ±0.0	5 ±0.0	12 ±2.9	na	0.03	0.03	(+)
Jacquemontia tamnifolia	0 ±0.0	0 ±0.0	29 ±14.7	na	0.04	0.04	(+)
Merremia aegyptia	0 ±0.0	4 ±0.3	0 ±0.0	0.03	0.03		Appeared just in 2017
Mollugo verticilata	181 ±52.5	54 ±30.8	5 ±1.0	0.03	0.19	0.03	(-)
Portulaca oleracea	6 ±0.9	4 ±0.7	11 ±3.0	0.15	0.1	0.33	Constant
Richardia brasiliensis	0 ±0.0	4 ±0.7	6 ±0.9	0.02	0.16	0.02	(+)
Senecio brasiliensis	0 ±0.0	4 ±1.1	0 ±0.0	0.03	0.03		Appeared just in 2017
Senna obtusifolia	3 ±0.5	5 ±0.8	4 ±0.0	0.07	0.02	0.02	Constant density
Sida spp	6 ±0.8	0 ±0.0	0 ±0.0	0.02	na	0.02	(-)
Waltheria indica	16 ±3.9	16 ±3.1	8 ±1.5	0.65	0.07	0.11	Constant

[a]Status: '-': decreasing species; '+': increasing species. Wilcoxon's non-parametric statistics and p-value are shown. *indicates significant comparisons by the Wilcoxon test. na: density did not change between years.

The species that increased their density in the drip also demonstrated similar behavior in the micro-sprinkler. This fact indicates that for of these species, regardless of the irrigation system, the disturbances promoted by onion cultivation favor the occurrence them. A similar result was reported in fields cultivated with wheat and rice, in Jiangsu-China region, where areas with and without chemical fertilization restriction with P or K promoted an increase in weed diversity and density (JIANG et al., 2018). This fact demonstrates the resilience of some weeds to different stress conditions. Nonetheless, other species were not shown this resilience in environments with water restrictions. The *A. rudis* proved to be more adapted to systems with higher water availability since it had an increase in infestation density only in well-irrigated areas (micro-sprinkler). This species belongs to the Fabaceae, families whose species has been described as highly adapted to irrigated environments (PERRY et al., 1998). Therefore, the water restriction caused by the lower applied water in the drip disadvantaged the occurrence of this species.

The constant infestation for *W. indica* in the two irrigations systems in all years indicates that this species adapted to the disturbances and stress promoted by onion cultivations. High resilience demonstrated by *W. indica* in this work was also reported for other environmental conditions with high disturbance and stress (DAEHLER; GOERGEN, 2005). Practices as burning, burning + herbicide application, and burning + manual weeding were used to restore a field dominated by *C. ciliares*, a highly aggressive grass. However, in these areas after these management practices, the occurrence of *W. indica* was recorded in all treatments, indicating the high resilience and adaptability of this species to different environmental conditions (DAEHLER and GOERGEN, 2005).

P. oleracea showed a different behavior to *W. indica*, and only in the areas irrigated by micro-sprinkler was observed a constant density during the three cycles of onion cultivation. In the drip, *Portulaca oleracea* was found only in 2018. Seeds of this species have moderate tolerance to water restriction conditions (CHAUHAN; JOHNSON, 2009). Therefore, the germination of *P. oleracea* seeds in both systems was possible. On the other hand, the high soil temperature (35/25 ºC day/night) can inhibit the germination of *P. oleracea* seeds (40%). This condition of soil temperature is easily detected in the experimental areas where the onion was cultivated under drip, inhibiting the germination of the species. Differently, in the micro-sprinkler, the higher soil moisture may reduce soil temperature (LIU et al., 2017; NICOLAI-SHAW et al., 2017), favoring the germination of *P. oleracea* seeds during all years.

3.2. Changes in weed diversity, richness, dominance and uniformity

There was no difference for the diversity (H ') and richness (D) between weed communities in the drip system between 2016, 2017, and 2018 (Figure 1). For micros-sprinkler, H 'and D were higher in 2017 compared to the other evaluated years (Figure 1). There were no differences in the years 2016 and 2018 for D; however, the H 'calculated in 2018 was higher than in 2016 (Figure 1).

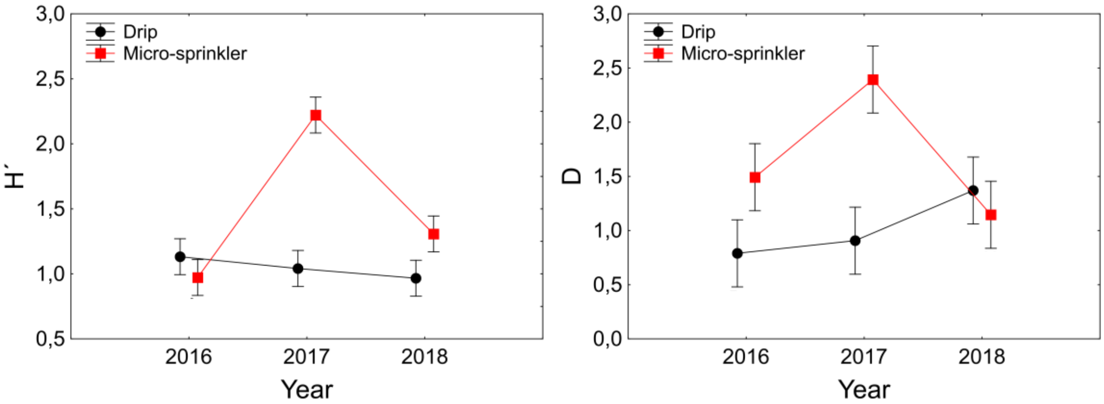

Figure 1. Shannon-Wiener (H') diversity index and Margalef's (D) richness for weed communities in drip and micro-sprinkler irrigated in the years 2016, 2017, 2018. Bars indicate the mean confidence interval at p-value ≤ 0.05. Mossoró - RN, 2019.

The similarity in H 'and D values for weed communities in drip irrigated areas after three cycles of onion cultivation indicates that this system is more conservative (PENG et al., 2018). Even altering the weed species among years, the diversity and richness were not affected by the cultivation of onion under the drip. Conversely, the micro-sprinkler system promoted an increase in weed diversity and richness in 2017, but this increase did not prevail in the subsequent year. In 2017 under micro-sprinkler, greater uniformity for weed species density was observed compared to 2016, where the *M. verticillata* predominated compared to the other species. In 2018, the lowest uniformity occurred due to the dominance of *D. horizontalis*, *C. barbata*, and *E. pilosa*. This behavior of weed community in the micro-sprinkler is evidence that the transition between the population of 2016 and 2018 occurs gradually in systems with higher water availability (PENG et al., 2018, JIANG et al., 2018).

H 'was higher in the areas irrigated by micro sprinkler compared to drip in 2017 and 2018 (Figure 1). In 2016, the difference between the systems was not significant (Figure 1). For index D, the micro-sprinkler showed higher values compared to drip in 2016 and 2017, not detecting differences in the year 2018 (Figure 1). Despite the higher number of species in the micro-sprinkler (10) relative to drip (6) in 2016, no differences were found between irrigation systems for H '. This fact is a result of the high density for the species *M. verticillata* in the first year of cultivation in the micro-sprinkler, reducing the diversity index. A reverse effect was observed in the year 2018 for drip and micro-sprinkler. Even with a similar number of species among the systems, the lower water availability favored the occurrence of *D. horizontalis* in relation to the other species, decreasing the H 'index in the drip. The highest weed richness (D) was detected in the areas irrigated by micro-sprinkler (10) compared to drip (6). This behavior is related to the occurrence of species whose seeds have higher germination in highly moist soils and was not identified in the drip, such as *D. aegyptium*, *Chloris Barbata* and *P. oleracea* (CHAUHAN et al., 2018, CHAUHAN, JOHNSON, 2009, BURKE et al., 2003).

The value of λ and J was different between the evaluated years for the drip system, following the decreasing order 2016> 2017> 2018 (Figure 2). In micro-sprinkler, λ and J alternated with the crop cycle, with the highest value in 2017, followed by 2018 and 2016 (Figure 2). The λ and J index was higher in the drip than in the micro sprinkler only in 2016 (Figure 2).

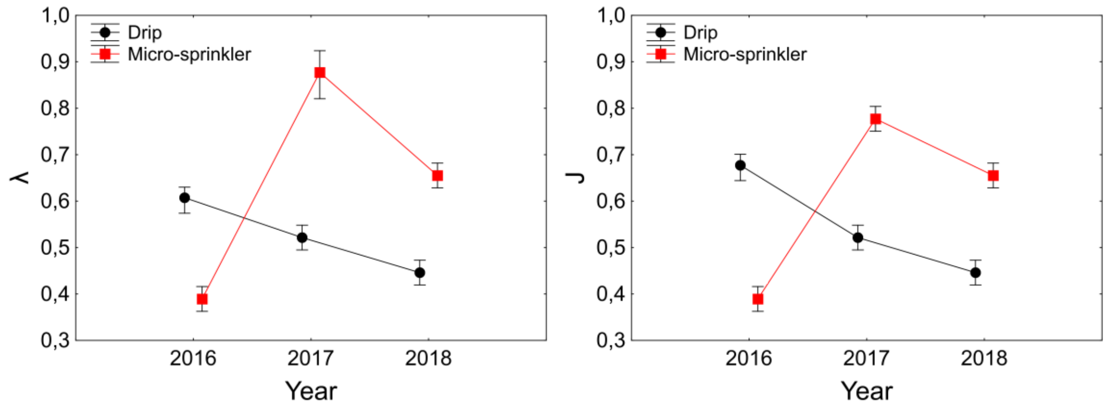

Figure 2. Simpson dominance index (λ) and uniformity (J) for weed communities in drip and micro-sprinkler irrigated in the years 2016, 2017, 2018. Bars indicate the mean confidence interval at p-value ≤ 0.05. Mossoró - RN, 2019.

The lower values for the Simpson index (λ) indicates the dominance of a few species in the field (MATOS et al., 2017). The gradual reduction to λ in the drip after successive onion seasons demonstrated that the cultural practices favored specific weed species. Also, lower water availability in the drip system was a key factor to increase the dominance of some species because less species dominance occurred in fields irrigated by micro-sprinkler. The alternating behavior of the indexes λ and J in the micro-sprinkler system among years confirm that the transition between weed communities observed in 2016 and 2018 take place gradually. Conversely, this phenomenon was not observed for drip irrigated areas.

3.3. Understanding the changes in the diversity, richness, dominance, and uniformity of the weed community

The minimum cumulative variance established for the dimensions was 90% in correspondence analysis (CA). The qualitative and quantitative values for CA are shown in Appendix V to IX. Drip irrigation systems in 2016 and 2017 and micro-sprinkler in 2016 showed high similarity concerning *M. verticillata*, *D. aegyptium*, *Diodella teres*, and *Sida* spp

(Figure 3). The micro-sprinkler during 2017 was positioned very close to the central point of the X, Y, and Z axes, and the species *M. aegyptia*, *S. brasiliensis*, *Blainvillea* spp., and *W. indica* were the weeds closest to this system and year (Figure 3).

Drip-irrigated onion cultivation underwent few changes while species and their infestation density between 2016 and 2017. The same behavior was not observed for micro-sprinkler. The central position between the dimensions for micro-sprinkler in 2017 indicates that similar niches of weed species are shared between 2016 and 2018, confirming the gradual transition of weed communities (WOOD et al., 2015). On the contrary, the water limitation imposed by the drip allowed the germination only of the species best-adapted to the lowest water potential of the soil, permitting a similar weed community between 2016 and 2017 in the drip.

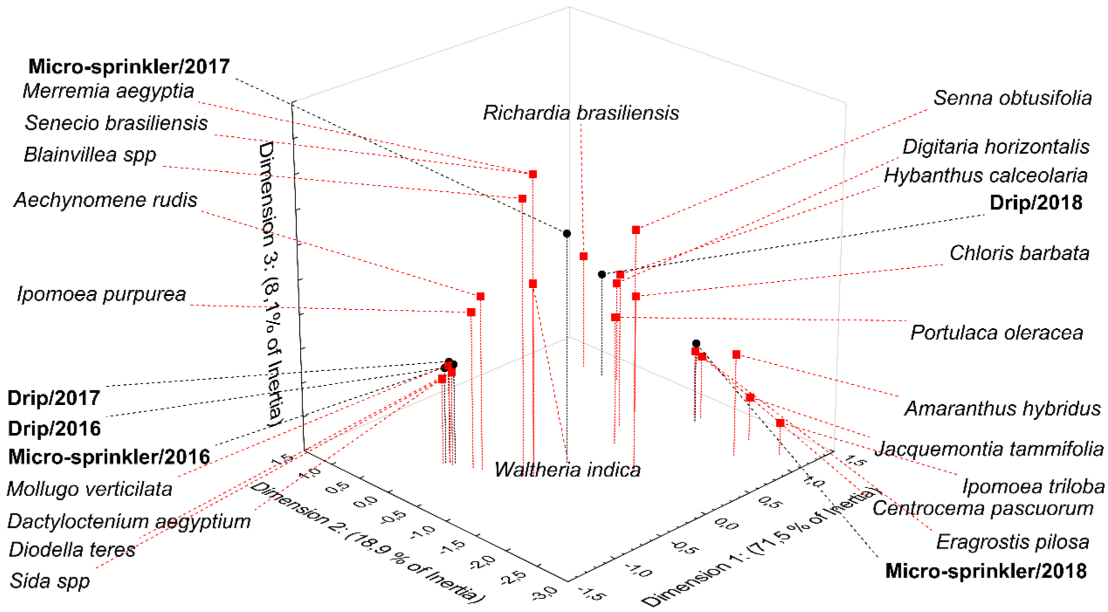

Figure 3. Distribution of weed species according to the irrigation systems and cultivation years based on the species density for three dimensions obtained from Correspondence Analysis (CA). Mossoró - RN, 2019.

In 2018, differences in weed density were observed between drip and micro-sprinkler systems. The species *R. brasiliensis*, *S. obtusifolia*, *D. horizontalis* and *H. calceolaria* were grouped close to the drip (Figure 3). Other species such as *J. tamnifolia*, *I. triloba*, *A. hybridus*, *P. centrocema* and *E. pilosa* were grouped close to the micro-sprinkler (Figure 3). The species *P. oleracea* and *C. barbata* were positioned between the drip and micro-sprinkler conducted in 2018 (Figure 3). After three successive onion cycles, species adapted to high disturbance and moderate stress, such as *D. horizontalis*, which represented 70% of the total infestation, dominated areas under drip irrigation. Although the *D. horizontalis* dominate in micro-sprinkler, other species such as *A. hybridus* (12%) and *E. pilosa* (11%), *C. pascuorum* (6%) and *J. tamnifolia* (7%) were also verified in areas cultivated by micro-sprinkler. The lower soil moisture in the drip limited the establishment of species, mainly ruderal species, which were not well adapted to tolerate moderate water stress (SOJNEKOVÁ; CHYTRY, 2015).

For the evaluation of the distribution of families in different years and irrigation systems, three dimensions were chosen. The families of weed species were equally distributed as to their occurrence density in drip systems in 2018 and micro-sprinkler in 2017/2018 (Figure 4). For onion cultivated in drip and micro sprinkler in 2016 and drip in 2017, the Molluginaceae family predominated compared to the others identified (Figure 4). Cultivation for three successive years of onion increased dominance and reduced uniformity of distribution of weed species, but the importance of families was benefited by consecutive cycles. Systems with a greater diversity of families can favor a greater variety of ecological services. For example, the Fabaceae family has an important role in nitrogen cycling, since, under favorable conditions, some species can fix atmospheric nitrogen, increasing soil fertility (SOPER et al., 2019). The higher density for individuals of this family after successive onion cycles may favor the quality of cultivated soils, especially if kept in the system during the off-season (DÍAZ et al., 2016). Also, other families may be host to natural enemies, assisting in pest and disease management (ALTIERI et al., 2018).

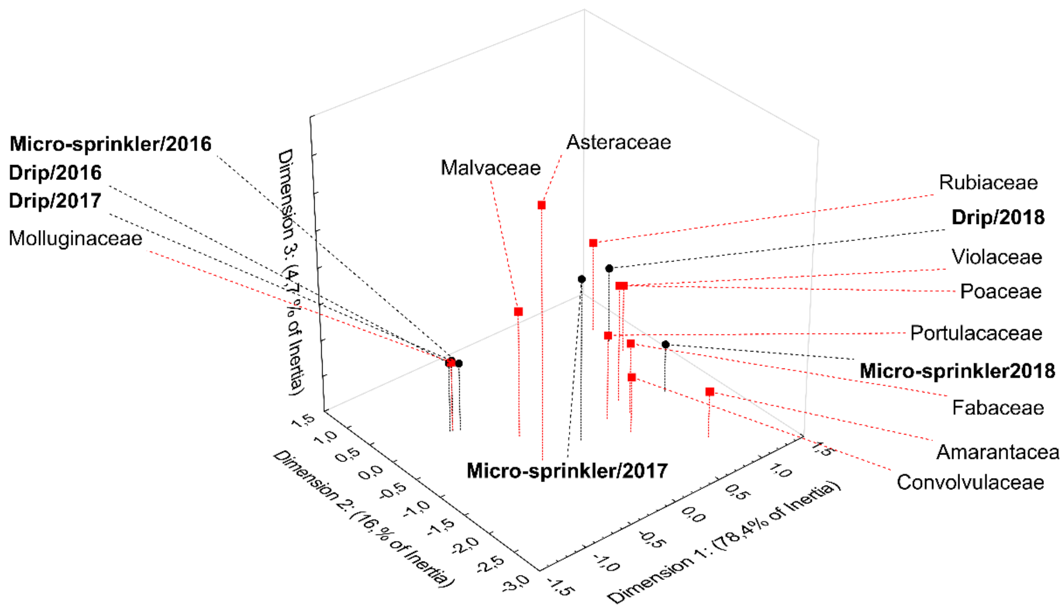

Figure 4. Distribution of weed families according to the irrigation systems and cultivation years based on the species density for three dimensions obtained from Correspondence Analysis (CA). Mossoró - RN, 2019.

The species with the highest importance concerning infestation density for drip and micro-sprinkler systems in 2016 and drip in 2017 were C4/procumbent and annual habit/propagation by seeds (Figure 5). Onion cultivation under the micro-sprinkler in 2017 favored C3/erect, annual and perennial habit/propagation by seeds (Figure 5). In 2018, the most important species were C3/procumbent, C4/erect, perennial habit/propagation by seeds and vegetatively (Figure 5).

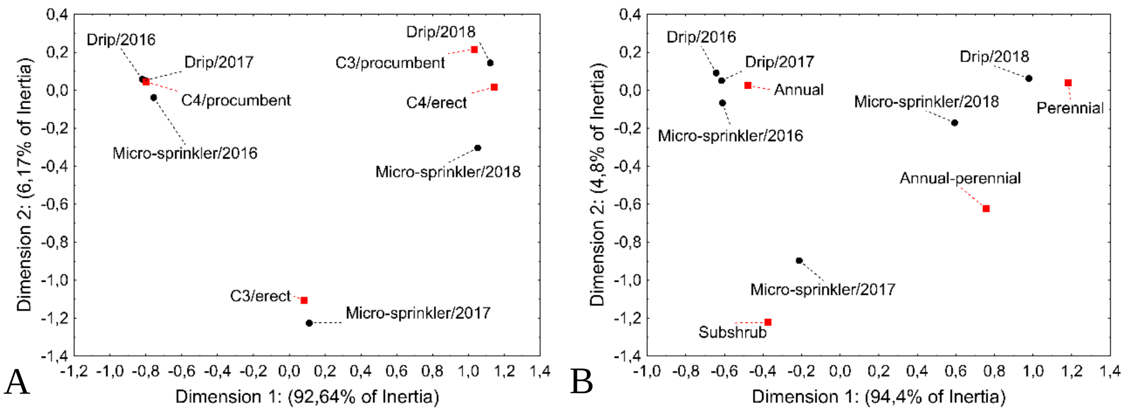

Figure 5. Distribution of weeds according to the photosynthetic cycle/size (A) and habit/ propagation (B) in different irrigation systems and cultivation years based on the species density for two dimensions obtained from the Correspondence Analysis (CA). Mossoró - RN, 2019.

The annual habit and seed propagation are prominent features in pioneer species of secondary succession (FEDERICA et al., 2017; BOLDT-BURISCH et al., 2019). Plants with these characteristics emerge firstly in areas submitted to high disturbance after periods in equilibrium (FEDERICA et al., 2017). The first disturbance caused by the removal of previous vegetation allowed species with pioneering characteristics to appear in the area. After the first cultivation year, new species infested rapidly the areas irrigated by micro-sprinkler. In this system, the increase of soil fertility and conditions of low water stress allowed to the weed with ruderal habits and C3, such as *A. rudis*, *I. purpúrea*, *I. triloba*, and *M. aegyptia* to establish in the field.

In 2018, annual species had their importance substantially reduced, predominating those weeds with perennial habit and propagated via seeds and vegetative. The dominant species in 2018 in both irrigation systems are remarkable in competitive-stress-tolerant plants (LEE et al., 2010; CORGAN et al., 2018). Among these characteristics, the type of propagation was the most crucial factor to select species after successive cycles. The constant soil tillage for construction of beds favored the species with vegetative propagation due to the greater dispersal of their propagules (KONING et al., 2019, ATWATER et al., 2017, PEERZADA et al., 2017).

Another interesting fact is related to the relationship between photosynthetic cycle and size plant of the most common species in 2018. Sure, the light competition also contributed to species selection over the years. Although the onion has a short stature, this culture can efficiently cover the canopy due to the short spacing between the crop lines used in this work (HUSSAIN et al., 2017; UZO; CURRAH et al., 2018). This fact increased the selection pressure (light factor) on C4 species with procumbent growth that dominated the field in 2016. After three cultivation seasons, only the C4/Erect and C3/Procumbent species predominated in cultivation systems, both in drip and micro-sprinkler.

3.4. Interference degree of the weed communities on onion culture

There was interaction by the combined analysis among years * irrigation system * period for weed control (p-value ≤0.01) for the commercial onion bulb yield (Appendix IX). Commercial onion bulb yield was similar between drip and micro-sprinkler systems in 2016 when weeds were controlled from 12 days after emergence of the crop (DAE) (Figure 6). At the same period for weed control, the micro-sprinkler system provided higher bulb yield in 2017 (13%) and 2018 (12%) compared to the drip (Figure 6).

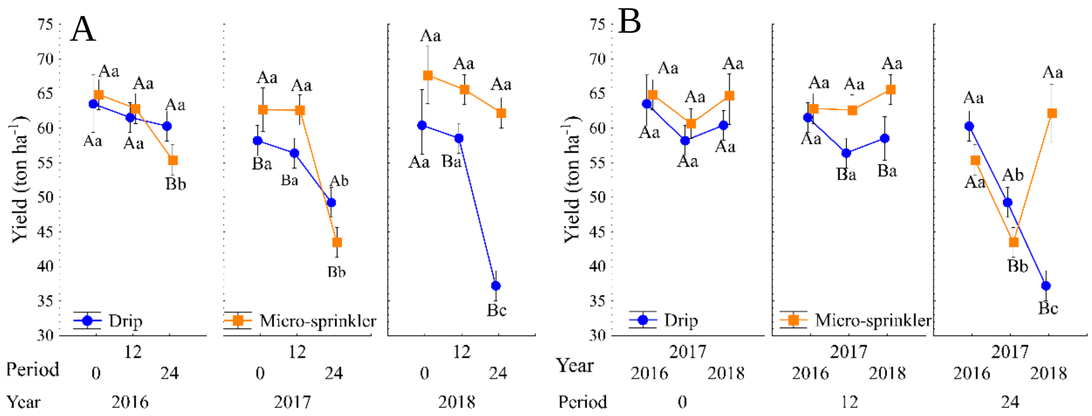

Figure 6. Commercial onion bulbs yield in systems irrigated under drip and micro-sprinkler in 2016, 2017 and 2018. Capital letters differ the irrigation systems and lowercase letters the period for weed control into the year (A) or year into the period for weed control (B). Bars represent the standard deviation. Mossoró - RN, 2019.

When control started at 24 DAE, the yield in drip was higher than micro-sprinkler in 2016 (8%) and 2017 (18%) (Figure 6). However, in 2018 was observed a higher value (40%) for the micro-sprinkler system compared to the drip, when the control started at 24 DAE (Figure 6). In 2016, no differences were detected between irrigation systems when the control was performed at 12 DAE (Figure 6). During 2017, the presence of weeds up to 24 DAE reduced the bulbs yields in the areas irrigated by micro-sprinkler (Figure 6). In the last year of onion cultivation, micro-sprinkler provided higher yields compared to drip when control was established at 12 (12.5%) and 24 (68.4%) DAE (Figure 6). There were no differences in yield for micro-sprinkler among the periods for weed control in 2018 (Figure 6). In the drip in 2018, the yield was lower (55%) when the control started at 24 than at 12 DAE (Figure 6).

The weed community showed to be a determining factor in the interference degree on the onion. In areas under micro-sprinkler in 2017, weed diversity and richness was higher compared to other years, with the presence of species observed both 2016 and 2018. This fact was detrimental to the bulbs yields because it was substantially reduced when the weeds remained during 24 DAE. Although the higher species richness contributes for the agrosystem sustainable (GIBSON et al., 2017; PERRONE et al., 2015), the high diversity of weed species affected the onion growth and development when not controlled them. In 2017, a broader niche was exploited by all weed species; therefore, the resources available for the onion crop was lower, rising the competition intensity. An ecological concept provides that mixtures of subordinate species (weed species) affect dominant species (crops in agricultural systems) because of the sum of negative effects of each taxonomic, functional and phylogenetic class (GIBSON et al. al., 2017). This concept was evidenced for onion cultivated under micro-sprinkler during 2017.

The dominant weed species in the system altered the interference degree on the onion cultivated under the drip. In the first year, drip irrigated areas were dominated by the Mollugo verticillata. After two cycles, the dominant weed was Digitaria horizontalis, and this change had a direct impact on the onion bulb yield. The continuous cultivation in this irrigation system served as an ecological filter (MARIOTTE et al., 2014; BORGY et al., 2016), selecting only weeds with better water use efficiency. This change in flora in drip-irrigated fields negatively affected the onion crop, increasing the competition intensity by the limited resource (water). Under these conditions, it is crucial that weeds in the onion crop be carefully controlled to avoid significant losses on yield.

A significant interaction by combined analysis (p-value $\leq$0.001) was observed for years * irrigation system * period for weed control when the water use efficiency (WUE) of systems was evaluated (Appendix X). The WUE in the micro-sprinkler was reduced only in the year 2017, when weed control started at 24 DAE (Figure 7). In the other treatments for micro-sprinkler, no changes were observed concerning the WUE (Figure 7). For the drip system, when weeds were controlled from 12 DAE, no differences were detected about WUE (Figure 7). However, at 24 DAE, the WUE in the drip system was drastically reduced after tree onion seasons (Figure 7). A reduction of 20% (2016 to 2017) and 36% (2016 to 2018) in the WUE occurred in fields under the drip system (Figure 7). Only in 2016, the presence of weeds at 24 DAE did not affect the WUE in the drip (Figure 7). Regardless of the period for weed control or cultivation year, the WUE was higher in the drip than micro-sprinkler (Figure 7).

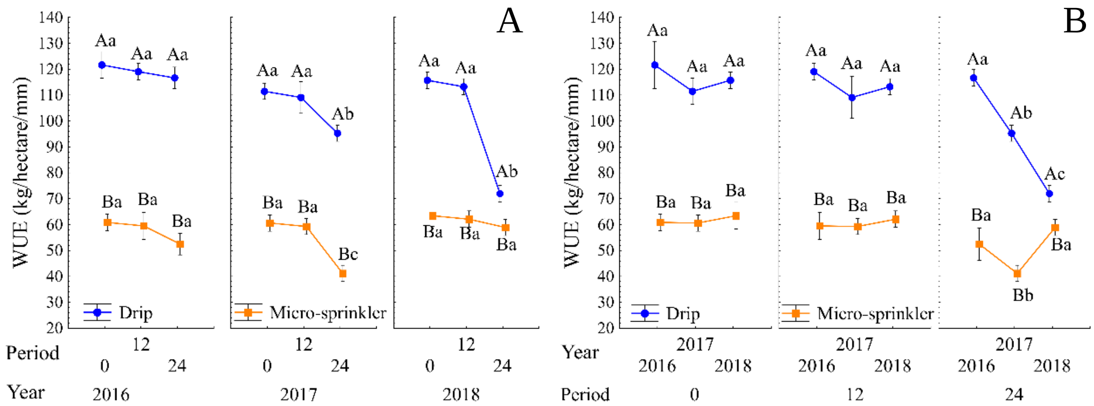

Figure 7. Water use efficiency of systems under drip and micro-sprinkler in 2016, 2017 and 2018. Capital letters differ the irrigation systems and lowercase letters the period for weed control into the year (A) or year into the period for weed control (B). Bars represent the standard deviation. Mossoró - RN, 2019.

The farmers choose to use of drip due to their higher efficiency than systems such as sprinkler and micro-sprinkler (KOUMANOV et al., 1997). Drip allows crops to reach high yields, maximizing the use of water, a resource often limiting to semi-arid regions, similar to those used to conduct our experiment. For the onion, this scenario was no different. When weeds were controlled at 12 DAE (usually period in which weed management should be started), the drip system was 50% more efficient compared to micro-sprinkler in all years. Gains related to localized irrigation on the onion crop may optimize the water used for agricultural production. However, as observed in 2018, this efficiency in drip systems can be compromised if weed control is not carried out.

Cultivation practices such as high planting density in drip irrigated maize crop have been reported by EL-HENDAWY et al. (2008) as able to reduce the WUE of system. Fertilization was also a factor that reduced the WUE of drip irrigated crops. AUJLA et al. (2005) observed that the lower nitrogen fertilization reduced the WUE of cotton crop in different applied water rates. In addition to the many factors already described in the literature, the non-control of weeds and the dominance of species well adapted to water scarcity conditions were also factors that decreased the sustainability of the onion crop systems regarding water use. The presence of grasses such as *D. horizontalis* and *C. barbata* exerted intense competition on the onion by the water applied in the drip system, reducing the WUE of this system by 36%. Probably, the presence of weeds for periods higher than 24 DAE would make the drip system less efficient than the micro-sprinkler.

Our results demonstrated that successive onion cultivation exerts selection pressure on the weed community. Drip and micro-sprinkler systems shared similar niches relative to the species occurring in 2016 and 2018. In both irrigation methods, the weed community was different from 2016 to 2018. However, micro-sprinkler (high water supply) allowed a higher diversity and richness, and lower dominance of some weed species, especially in 2017. In this year and micro-sprinkler system, the importance of the identified weeds was more uniform, occurring species both in 2016 and 2018. This fact indicates a gradual transition throughout the cycles of onion cultivation. This different behavior allowed us to confirm our first hypothesis; the dynamics of the weed community is affected by the irrigation method used during successive cycles of onion cultivation. Also, we identified which factors were related to this change in weed flora. Species with C4/Erect, C3/procumbent, perennial, and propagated via seeds-vegetatively are favored by the cultivation practices adopted in the onion crop, regardless of the irrigation system used. Finally, we identified that the interference degree exerts by dominant weed population reduce the water use efficiency of onion crop systems, making it less sustainable to the farmers. For onion irrigated under drip, the decrease in water use efficiency is more drastic, confirming our second hypothesis.

4. CONCLUSIONS

The dynamics of weeds are altered by the water management system in onion cultivation. Micro-sprinkler provides greater diversity and richness, and less dominance compared to drip management systems. The conditions of disturbance and stress promoted by three years of onion cultivation, in both irrigation systems, favor plants with C4 photosynthetic cycle, erect, perennial and vegetatively propagated. In the micro-sprinkler, the transition of the weed communities among years take place gradually. The higher level of stress in the drip management stimulates the dominance of the *Digitaria horizontalis*. Non-control of weed at 12 and 24 days after crop emergence reduces the yield and water use efficiency in onion crops. Besides, this reduction in productivity indexes is aggravated by the greater diversity and uniformity in the micro-sprinkler systems (high water supply). Differently from the micro-sprinkler, in drip systems (low water supply), dominance is the factor that intensifies the harmful effects of the weed community on the yield and water use efficiency in onion crops.

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CHAPTER II – WEED INTERFERENCE ON ONION (*Allium cepa* L.) IN DIFFERENT IRRIGATION SYSTEMS

ABSTRACT

Weed management is essential in vegetable crops, constituting the main production cost. Crop control strategies can help minimize weed interference. This practice can be implemented by improving agricultural management. An adequate supply of water for cultivation may favor crop growth, suppressing weeds. Field experiments were conducted during 2016, 2017, and 2018 to evaluate the effects of drip and micro-sprinkler irrigation on the critical period for weeds control in onion (*Allium cepa* L.). Three sigmoids models (Boltzmann, Gompertz, and Logistic) were tested to estimate the critical period for weeds control (CPWC) based on an acceptable yield loss of 5%. Increasing periods of weed interference significantly reduced onion production. In drip system, the CPWC was 11, 17, and 74 days for 2016, 2017, and 2018 respectively. In micro-sprinkler, the CPWC was 18, 53, and 45 days in 2016, 2017, and 2018, respectively. Irrigation management and weed community influenced the CPWC in onion crop. The irrigation management can reduce the period for weed control, consequently the costs with weed management. However, specific situations involving the weed community should be evaluated to recommend the best appropriate irrigation system.

Key-words: *Allium cepa*, drip, weed interference micro-sprinkler.

1. INTRODUCTION

Weed management is an essential component for the productive success of onion culture (*Allium cepa* L.). However, this management is difficult due to two factors. First, this crop presents slow initial growth and tubular leaf architecture, characteristics that make the onion uncompetitive in the initial periods (HERRMANN et al., 2017; WILLIAMS et al., 2007). Finally, there are few herbicides for post-emergence application, requiring manual weed control in many situations, increasing production costs (HERRMANN et al., 2017; MELANDER et al., 2015).

Studies have shown that weeds competition, even in a short time or low weeds density, reduce onion productivity by up to 96% (BOND; BURSTON, 1996). If coexistence persists throughout the cycle, productivity reduction can reach 100% (SANKAR, LAWANDE, 2011). The main damage caused by weed interference on onion crop is the reduction in bulb diameter and weight (HAQUE et al., 2011). Therefore, defining the critical period for weed control (CPWC) is essential to avoid losses due to competition or allelopathy (KNEZEVIC et al., 2015).

An alternative to assist the chemical methods of weeds is to adopt cultural control methods (BLACKSHAW et al., 2007). This last method favors crops growth promoting weed control (CHAUHAN et al., 2015). Among the practices used, the localized supply of growth resources, such as water and nutrients, allows the rapid establishment of crops, consequently, can minimize the harmful effects of weeds community (KAUR et al., 2018). For example, TURSUN et al. (2015) reported that increasing the localized nitrogen fertilization reduced CPWC in cotton. Another practice that can reduce CPWC is the short spacing between rows since it is possible to accelerate the closure of the canopy (DATTA et al., 2017; TURSUN et al., 2016).

The reduction of CPWC through cultural practices is a solution to reduce the interventions to control weeds, decreasing the herbicide application. Thereby, alternatives based on cultural management are a way to ensure greater economic and environmental sustainability of crops. However, cultural practices must be fully understood, considering the dynamism and complexity involving the weed community. Cultural weed management poorly implemented can result in substantial losses of productivity to the farmers (reference). For example, CPWC in maize under the no-tillage was lower than in conventional systems. However, in this same study for soybean cultivation, no pattern was observed between the systems and CPWC (HALFORD et al., 2001). PRICE et al. (2018) evaluating CPWC in cotton under different cropping systems observed that the effect of conventional planting and cover crop on CPWC varied between the years, attributing this effect to the weed community occurring in each crop season.

The cropping system is a crucial factor in the degree of weed interference. One point to be considered in irrigated crops is the system type implemented for the water supply. Currently, there is a worldwide concern about the management and conservation of water resources. This fact increased the use of localized irrigation in many crops to optimize the use of water in rural properties (MAHGOUB et al., 2017). Among the methods of localized irrigation, the drip has shown excellent performance (MAHGOUB et al., 2017). Another commonly used system for onion culture is micro-sprinkler (MAHGOUB et al., 2017). Several studies have demonstrated that these irrigation systems are capable of ensuring high yields in onion culture (reference). However, there is no information on the degree of weed interference in drip or micro-sprinkler onion. Weeds can significantly reduce the amount available in each system to the onion; therefore, the degree of weed interference in drip irrigation and micro-sprinkler systems may be different. Consequently, weed control periods are different for each irrigation system. Thereby, we hypothesized that the irrigation system adopted in the onion crop might alter the degree of weed interference and critical period of prevention. Our objective was to determine the critical period for weed control in onion cultivated under two irrigation systems (drip and micro-sprinkler) in three season crops.

2. MATERIAL AND METHODS

2.1. Description of the area and onion cultivation system

Field studies were conducted at the experimental farm located at latitude 5º 03'37 "S and longitude of 37º 23'50" W Gr, from July to November 2016, 2017 and 2018. The approximate altitude is 72 m and climate, according to Thornthwaite, is classified as DdAa '(Carmo Filho et al., 1991). The experimental field was cultivated with cashew for the production of fruits and nuts for five years. After this activity, the area was under fallow for ten years. The average meteorological data during the period of the experiments were collected and shown in Appendix I and Appendix II. The soil of the experimental area is classified as Abrupt Eutrophic Red-Yellow Latosol, sand-free texture (EMBRAPA, 2006). Samples were collected for physicochemical analysis. The results of the analysis are shown in Appendix III.

The onion cultivation was conducted as commonly is carried out by the farmers of the region. The conventional system, with tillage, and formation of beds by rotating hoe was implemented in the three years of cultivation. Each bed was 1.20 m wide and 20 cm high.

Fertilization was performed according to the needs of onion (HIGASHIKAWA et al., 2017) and based on soil analysis.

Pre-planting fertilization was performed with 180 kg ha^{-1} of P_2O_5 (simple superphosphate), 3.0 kg ha^{-1} zinc (zinc sulfate), and 1,10 kg ha-1 of boron (boric acid). In addition, cover fertilization with 165 kg ha^{-1} of N (MAP) 30 kg of K_2O ha^{-1} (potassium chloride) was applied in two fertigations during the crop cycle by a tank of derivation. This fertilization was used for all the years of cultivation. Cultural practices and phytosanitary control were carried out according to the technical recommendations and needs of the crop.

The onion used in the conduction of the experiments was the hybrid "Rio das Antas" due to its adaptation to the climatic conditions of the region. This hybrid was used in three years of experimentation. Three-seeded manual seeding was carried out in July in the three years. The spacing used was 10 cm between rows and 6 cm between plants. After ten days of the emergency, the thinning was done to guarantee a population of 890 thousand plants ha^{-1} in an experimental area.

2.2. Irrigation of experiments

The peculiar procedures of each system were established to evaluate the effects of drip and micro-sprinkler irrigation on the weed community and onion yield. In the drip irrigated system, dripping hoses were spaced 0.20 m between lines with 0.30 m between drippers. The micro-sprinklers were spaced 1.0 m x 1.0 m. The flow rate of drippers was 1.5 L h^{-1}, and the micro-sprinklers 54 L h^{-1}. After sowing onion, initial irrigation was carried out by conventional spraying to raise soil moisture near 80% of the field capacity in all experimental area. The water required for this procedure was calculated as follows:

1) A composite soil sampling was performed in all experimental area;

2) Soil moisture was calculated by subtracting the soil weight before and after drying in a forced air oven for 12 hours (± 105ºC), as described in the greenhouse method (DOBRIYAL et al., 2012);

3) The soil field capacity was estimated subtracting the weight of the dried soil and soil soaked with water and drained during 72 hours;

4) The conversion to the water volume to be applied, considering a humidity to 80% of the field capacity, was performed based on the approximate soil density of 1.5 kg dm^{-3};

5) The soil depth considered was 30 cm, maximum average value explored by onion roots in the cycle;

The future irrigations during the onion cycle were calculated according to each irrigation system (drip or micro-sprinkler). The water applied was estimated considering the daily evapotranspiration (ETo) and the coefficients (Kc) for onion culture at different development stages (MAROUELLI et al., 2005). The calculation of ETo was performed by the HARGREAVES & SAMANI (1985) method. The daily values for the three years of cultivation are shown in Appendix IV.

The required water calculated in 2016, 2017, and 2018 were 667, 683, and 688 mm during 110 days of onion cultivation. The onion cycle is approximately 120 days. However, MAROUELLI et al. (2005) recommend suspending irrigation ten days before harvesting (considered the maturation stage of an onion).

In the micro-sprinkler system, the 1-day irrigation shift was used throughout the crop cycle. The daily applied water varied according to the ETc value of the previous day. The irrigation time was calculated according to the spacing of the micro-sprinklers, their flow, and efficiency of the system. An efficiency of 80% was considered for micro-sprinkler (KOUMANOV et al., 1997).

The water applied in the drip was determined based on the amount of water used in the micro-sprinkler. The time and duration of the irrigations in the drip system were equal to the micro-sprinkler system. Drip efficiency was established as 95% (CAMP, 1998). Considering the previous procedures, the spacing between drippers and irrigation hoses plus the flow of the drippers, the water to be applied in the drip system was 50% smaller than in the micro-sprinkler. This procedure was repeated for the three years of onion cultivation.

2.3. Treatments and experimental design

Three experiments were conducted (2016, 2017, and 2018). The split-plot scheme was adopted in three years in randomized blocks (DBC), with three replications. Two factors were used. The first factor (plot) was composed of irrigation systems (micro-sprinkler with higher applied water than dripping). The second factor (sub-plot) was constituted by six periods of control and coexistence between crop and weed.

The treatments of the second factor were implemented immediately after the emergence of onion: (i) plots were maintained without weeded during 0, 12, 24, 36, 48, 60 and 120 DAE to evaluate the beginning of critical period for weed control (INITIAL-CPWC); (ii) plots were weeded during 0, 12, 24, 36, 48, 60 and 120 days after emergence (DAE) to determine the end of critical period for weed control (END-CPCW). The size of each experimental plot was 2.70 x 0.80 m (eight onion rows). The useful area was 2.0 x 0.60 m, considering all the borders.

2.4. Data collecting

The main weeds species that occurred in field experimental area during 2016, 2017, and 2018 were: *Amaranthus hybridus, Blainvillea spp., Tridax procumbens, Soliva pterosperma, Ipomoea purpurea, Ipomoea triloba, Merremia aegyptia, Jacquemontia tamnifolia, Aeschynomene rudis, Senna obtusifolia, Centrocema Pascuorom, Sida spp., Waltheria indica, Mollugo verticillata, Chloris barbata, Dactyloctenium aegyptium, Eragrostis pilosa, Digitaria horizontalis, Andropogon leucostachyus, Portulaca oleracea, Hybanthus calceolaria* and *Richardia brasiliensis*. Weeds were collected in two sub-samples to compose a sample in each experimental unit. Each sub-sample was performed at 0.5 m^2 squares randomly positioned in the useful area of each plot. After identification and counting of weeds, they were stored in paper bags to determine the dry matter, using a forced circulation oven (62 ± 5 ° C).

The onion harvest was performed 120 days after emergence when the plants demonstrated yellowish leaves (popping stage). After harvest, the bulbs were left in the field to reaching the maturation for ten days. After this procedure, the bulbs of each plot were classified according to their diameter (non-commercial and commercial bulbs, CEAGESP, 2001). The yield was estimated for t ha-1, considering the number and weight of commercial bulbs in each experimental plot. For regression analysis, the relative yield (%) was calculated comparing to the control treatment (free of weeds during the whole cycle for two irrigation systems).

2.5. Statistical analyses

The data were submitted to the Bartlett test and Shapiro-Wilk test to confirm the assumptions of homogeneity of variance and normality of the residues. Density and dry matter of weeds were evaluated descriptively. The relative yield (%), The beginning of CPWC (INITIAL-CPWC), the critical period for weed control (CPWC), the end of CPWC (END-CPCW) and non-commercial bulbs were submitted to ANOVA to test the significance ($P < 0.05$) between years, treatments, and their interactions. The Boltzmann (Equation 1), Logistic (Equation 2) and Gompertz (Equation 3) sigmoid models were tested to define the periods of interference in the different irrigation systems.

$$\text{Boltzmann (1): } y = y0 + \frac{a - y0}{1 + e^{-\left(\frac{x - x0}{b}\right)}}$$

$$\text{Logistic (2): } y = y0 + \frac{a - y0}{1 + \left(\frac{x}{x0}\right)^{b}}$$

$$\text{Gompertz (3): } y = y0 + (a - y0)e^{-e^{-\left(\frac{x - x0}{b}\right)}}$$

The model fit evaluations were determined by the root mean square error (RMSE), determination coefficient (R^2), and Akaike's information criterion (AICc). The AICc is used as the most consistent criterion to compare the best fit between the models (SPIESS; NEUMEYER, 2010; KNISS et al., 2011). Besides, the RMSE and R^2 were utilized to aid in the decision of the best model. RMSE values close to 0 and R^2 to 1 indicate a low residue; therefore, good accuracy of the model compared to the data observed. The confidence interval of the mean ($P <0.05$) compared the beginning of CPWC (Initial-CPWC), the critical period for weed control (CPWC), the end of CPCW (End-CPCW) and non-commercial bulbs among water management adopted within each year. Data analysis and graph construction were performed using software R version 3.4.4 (R Development Core Team, 2018).

3. RESULTS AND DISCUSSION

3.1. Weed dynamics

Cultivation years, irrigation systems, and weed control time influenced weed density and total dry matter (Figure 1 and Figure 2). Weed density did not vary greatly at 12, 24, 36, 48, 60, and 120 DAE when cultivated in 2016 and 2017, regardless of the irrigation system (Figure 1A Figure 1B). In 2016, the maximum and minimum weed density in drip irrigated areas was 260 and 252 plants m^{-2} (Figure 1A). In this irrigation system in 2017, the maximum and minimum density was 975, and 1,052 plants m^{-2} (Figure 1A). In the micro-sprinkler, the maximum and minimum weed density were 160 and 232 plants m^{-2} in 2016 and 885 and 1,192 plants m^{-2} in 2017 (Figure 1B). Unlike the initial years, in 2018, a great variation was observed for weed density in both irrigation systems (Figure 1A and Figure 1B). At 12 DAE, infestation density in drip was 4,265 $m^{-}2$ plants, reducing 93.9% (256 plants m^{-2}) at 120 DAE (Figure 1A). In the micro-sprinkler, the variation in weed density during the cycle was higher compared to the drip (Figure 1A and Figure 1B). At 12 DAE, drip infestation density was 7,869 plants m^{-2}, reducing 96.9% (250 plants m^{-2}) at 120 DAE (Figure 1B).

In 2016 and 2017 cultivating onion, the weed density suffered little variation. In particular, during the season of 2016, the weed density in the irrigated area by both systems was very low compared to the other years (2017 and 2018). This behavior may be a response to actions in previous years. After ten years of fallow, the system may have to reach an ecological balance, and even after the first disturbances in the system, few species were able to germinate and colonize the area. This fact may be associated with ecological memory that ensures greater environmental resilience (JOHNSTONE et al., 2016). Areas with few perturbations over time (similar to that used in this work) have the highest resilience to the first disturbances (JOHNSTONE et al., 2016). In 2016, in addition to the low density, the species that germinated were those predominant in the fallow area, indicating this effect of ecological memory in the experimental area.

In the last crop cycle (2018), the weed density at the beginning of the onion cycle was extremely high. The constant changes promoted by agricultural systems favor conditions that allow higher germination of species (NICHOLS et al., 2015). In onion crop, frequently soil tillage and fertilization may promote seed dormancy breaking of several species (NICHOLS et al., 2015; GABA et al., 2017). For example, the reduction of soil pH by fertilizers with acid reaction (urea) can break the dormancy of numerous weed species (FLORENTINE et al., 2018; NOSRATTI et al., 2017). Besides, soil inversion, as implemented in onion cultivation, may favor soil temperature oscillation, a primary factor for seed dormancy of some species (LIYAGE et al., 2017; FOOTITT; FINCH-SAVAGE, 2017, NICHOLS et al., 2015). Both practices were used during the three years of onion cultivation and increased the germination of many species at the beginning of the cycle. Despite the initial high density in 2018 for both irrigation systems, the infestation decreased 120 DAE. This fact is a result of the competition among the weed community, prevailing only the best-adapted (HANZLIK, GEROWITT FAHAD, et al., 2015; TURSUN et al., 2015).

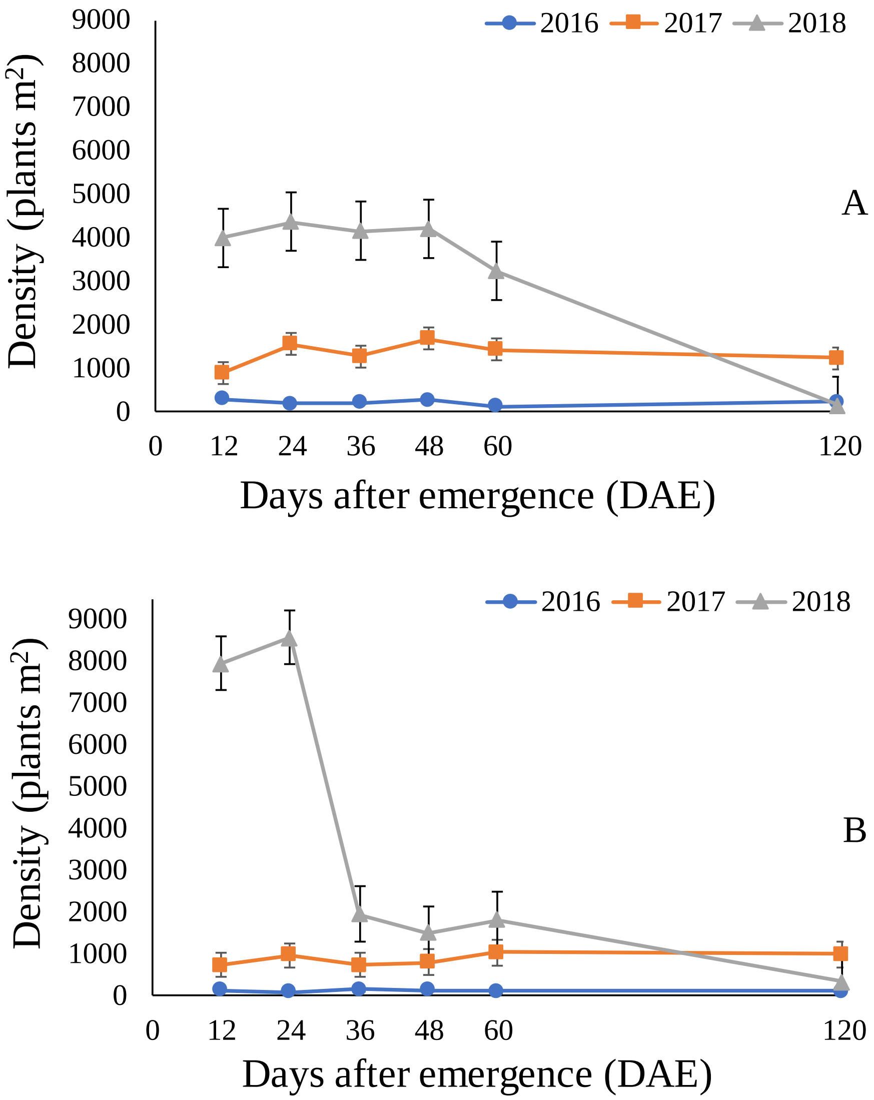


Figure 1. Weed density (plants m^{-2}) identified in the onion fields cultivated in drip system (A) and micro-sprinkler (B) at 12, 24, 36, 48, 60, and 120 days after emergence of the crop, measured in 2016, 2017 and 2018. Bars indicate the standard error of the mean. Mossoró-RN 2019.

The total dry matter of weeds increased continuously up to 120 DAE in both irrigation systems when the onion was planted in 2016 and 2017 (Figure 2). In the third year of cultivation (2018), weed dry matter reached the maximum value at 60 DAE in both irrigation systems, drip 4000 g m^{-2} and micro-sprinkler 3583 g m^{-2}, reducing to 2888 g m^{-2} at the drip and 2732 g m^{-2} in the micro-sprinkler (Figure 2A and Figure 2B).

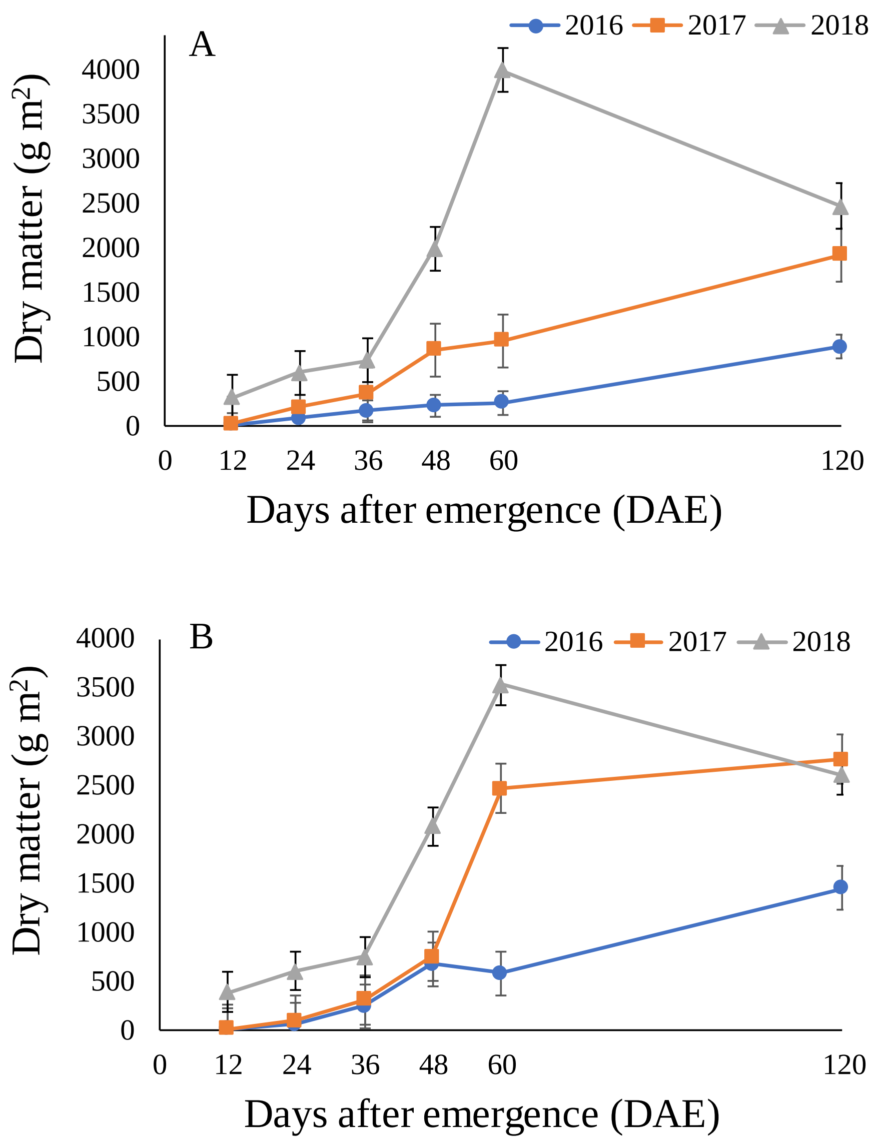
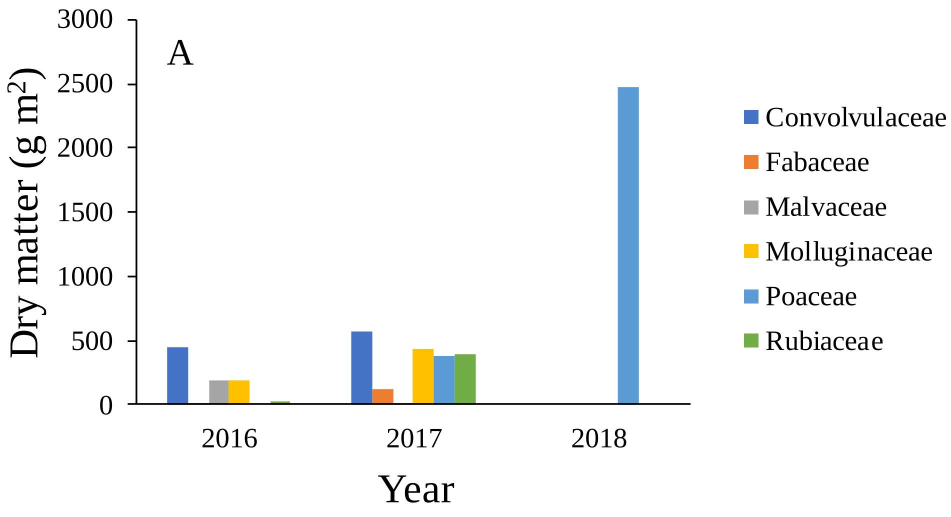


Figure 2. Total dry matter (g m^{-2}) of weeds identified in the onion fields cultivated in drip system (A) and micro-sprikler (B) at 12, 24, 36, 48, 60 and 120 days after emergence (DAE), measured in 2016, 2017, and 2018. Bars indicate the standard error of the mean. Mossoró-RN 2019.

The higher accumulation of weed biomass over the onion cycle is a response to the vegetative growth of the species over time. The dry matter variation between the years of cultivation is linked to two factors, the density and weed species. In 2018, the highest density of plants was observed up to 60 DAE compared to the years 2016 and 2017. Consequently, the more significant presence of weeds in 2018 resulted in higher accumulated dry matter. Several studies have also correlated the increase in weed density with the highest accumulation of dry matter in different crops, such as maize (Tursun et al., 2016), cotton (TURSUN et al., 2015) and melon (BERTUCCI et al., 2018). However, at 120 DAE, a different behavior was observed between the years. The weed density in 2016, 2017, and 2018 were very close; however, the accumulated dry matter in 2017 and 2018 was higher than in 2016 for both irrigation systems. This fact is associated with the weed species predominate in each year and their ability to accumulate matter.

After 120 DAE of coexistence between crop and weeds, the weed dry matter was grouped according to the families in the two irrigation systems. Six families were identified in drip, and eight in micro-sprinkler, considering all three years of cultivation (Figure 3A and 3B). In 2016, the highest dry matter accumulation was observed for Convolvulaceae in drip irrigation (Figure 3A). In micro-sprinkler, Convolvulaceae, Molluginaceae, and Malvaceae families accumulated higher dry matter than other families (Figure 3B). In 2017, a higher uniformity for weed infestation among the families was observed in the drip system, but in micro-sprinkler, there was the dominance of Poaceae for dry matter accumulation (Figure 3A and 3B). In micro-sprinklers during 2018, the dry matter accumulation to Poaceae was higher than other families, reaching 94% of the total dry matter (Figure 3B). In drip, only the Poaceae was observed at 120 DAE, accumulating 2888 g m^{-2} (Figure 3A).

The onion cultivation along three years favored the occurrence and growth of Poaceae. This dominance resulted in a higher dry matter accumulated in 2018 compared to 2016 and 2017. The species that predominate in 2017 and 2018 in the drip and micro-sprinkler were *Chloris barbata*, *Dactyloctenium aegyptium*, *Eragrostis pilosa*, *Digitaria horizontalis*, all with C4 carbon fixation cycle (ELMORE & PAUL, 1983). C4 plants can use water efficiently (YAN et al., 2015), accumulating dry matter even under conditions of low soil water potential. This fact explains high dry matter gain up to 60 DAE in both irrigation systems. The dry matter reduction from 60 DAE in 2018 was due to foliar senescence, after flowering, of the Poaceae species that dominated the area. In drip, the decline was more significant compared to micro-sprinkler due to the smaller water available.



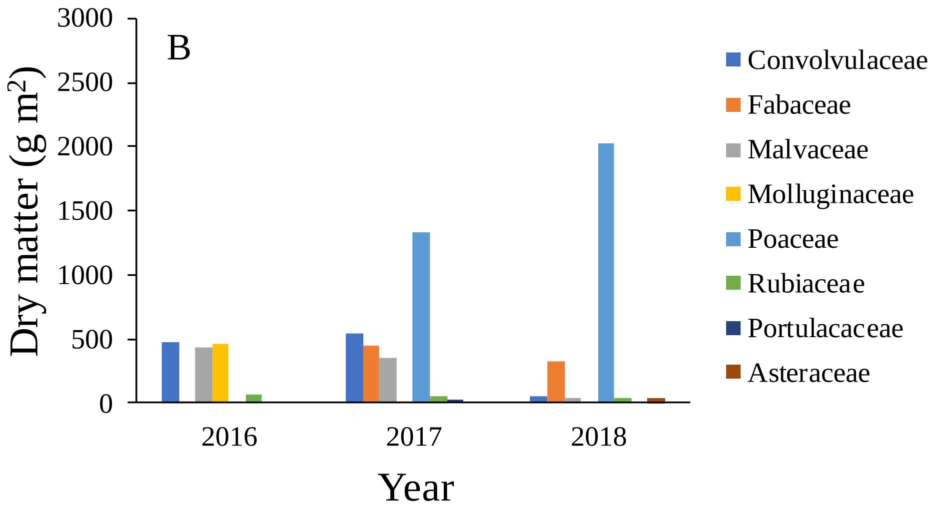


Figure 3. Weeds dry matter (g m-^{2}) classified by family at 120 DAE in onion fields cultivated in drip system (A) and micro-sprinkler (B) in 2016, 2017 and 2018. Mossoró-RN 2019.

In fact, the favoring of some species or families, as observed in onion cultivation, has already been reported in several farming systems (MACLAREN et al., 2019, TAUTGES et al., 2017, GANTOLI et al., 2013, KORRES, SINGH et al., 2014; NORSWORTHY, 2015). According to Juárez-Escario et al. (2012), in the fields with intense agricultural activity, weed population change is expected over time due to the adaptation to the disturbances and stresses specifically in each crop. The predominance of Poaceae occurred due to high disorder and low-stress conditions during successive onion crops (NAGASE et al., 2013). The disturbance promoted by soil tillage, the low stress resulting from the supply of inputs (water and nutrients), and the high luminosity and temperature environmental conditions allowed C4 weeds (grasses) to dominate other C3 (RAMESH et al., 2017).

3.2. Weed interference

The parameters of three models (Boltzmann, Gompertz, and Logistic) to estimate the relative yield of onion, with and without weed competition, in drip and micro-sprinkler system in 2016, 2017 and 2018 are shown in Table 1 and Table 2.

Table 1. Parameters (mean ± standard deviation) of sigmoid models (Boltzmann, Gompertz, and Logistic) to estimate the relative yield, without and with competition between onion and weeds during 120 days for the drip system. Mossoró - RN, 2019.

Year	Sigmoide	Condition	Parameters			
			y0	A	X0	b
2016	Boltzmann	With competition	27.9 ±5.3	105.0 ±6.1	57.4 ±3.9	-18.8 ±6.2
		No competition	27.4 ±5.1	98.8 ±1.9	17.4 ±1.5	5.5 ±1.1
	Gompertz	With competition	30.4 ±3.6	108.8 ±8.7	64.7 ±3.8	-25.9 ±10.0
		No competition	30.2 ±3.6	99.2 ±2.1	14.7 ±1.3	7.3 ±1.4
	Logistic	With competition	15.1 ±2.9	101.3 ±2.2	66.9 ±5.8	2.5 ±0.63
		No competition	30.4 ±2.8	100.2 ±1.9	17.2 ±1.0	-3.3 ±0.5
2017	Boltzmann	With competition	11.9 ±7.6	137.2 ±32.8	29.9 ±15.3	-32.1 ±11.6
		No competition	9.5 ±7.0	100.3 ±1.5	12.2 ±1.3	5.6 ±1.1
	Gompertz	With competition	16.5 ±6.4	183 ±96.5	25.9 ±35.8	-64.9 ±39.3
		No competition	18.3 ±3.2	100.4 ±1.6	10.8 ±0.9	6.4 ±1.27
	Logistic	With competition	-9.4 ±15.3	100.8 ±2.31	62.0 ±9.1	1.6 ±0.26
		No competition	18.7 ±2.42	100.9 ±1.6	13.1 ±0.6	-3.3 ±0.50
2018	Boltzmann	With competition	2.3 ±2.9	103.1 ±4.6	26.7 ±1.3	-5.9 ±1.1
		No competition	-8.9 ±8.7	96.7 ±4.3	30.6 ±2.9	12.1 ±2.5
	Gompertz	With competition	3.2 ±2.7	106.9 ±6.3	30.2 ±1.3	-9.3 ±1.8
		No competition	0.4 ±5.6	97.9 ±4.4	26.9 ±2.2	15.4 ±2.5
	Logistic	With competition	0.7 ±2.4	100.2 ±2.4	26.7 ±0.79	4.7 ±0.32
		No competition	1.4 ±2.6	100.5 ±3.7	32.9 ±1.5	-2.9 ±0.36

*y0 and A= minimum and maximum relative yield respectivly; b= slope of the curve; X0= inflection.

Table 2. Parameters (mean ± standard deviation) of sigmoid models (Boltzmann, Gompertz, and Logistic) to estimate the relative yield, without and with competition between onion and weeds during 120 days for the micro-sprinkler system. Mossoró - RN, 2019.

Year	Sigmoide	Condition	Parameters			
			y0	a	X0	B
2016	Boltzmann	With competition	6.7 ±6.8	113.8 ±19.7	8.3 ±4.3	-19.8 ±6.9
		No competition	6.7 ±6.6	96.7 ±2.8	13.1 ±1.1	2.8 ±2.4
	Gompertz	With competition	7.9 ±5.8	140.4 ±50.1	38.7 ±16.2	-38 ±20.2
		No competition	7.6 ±5.8	96.7 ±2.9	11.8 ±0.7	3.1 ±3.0
	Logistic	With competition	3.1 ±14.0	96.3 ±5.1	45.7 ±7.4	-2.16 ±0.65
		No competition	7.5 ±5.7	96.8 ±3.0	12.8 ±1.0	6.0 ±4.8
2017	Boltzmann	With competition	6.2 ±14.9	133.6 ±61.3	31.9 ±26.1	-28.6 ±20.4
		No competition	-146.1 ±459	102.6 ±7.63	-11.45 ±64.1	20.4 ±12.8
	Gompertz	With competition	10.9 ±9.4	163.7 ±123.8	34.5 ±42.4	-51.8 ±50.2
		No competition	-65.5 ±276.1	102.7 ±7.8	-5.5 ±53.9	21.3 ±12.1
	Logistic	With competition	18.4 ±4.12	101.58 ±7.1	59.9 ±31.2	1.6 ±0.72
		No competition	12.09 ±3.51	109.5 ±13.7	20.2 ±5.31	-1.5 ±0.6
2018	Boltzmann	With competition	2.5 ±6.4	98.6 ±4.5	51.5 ±2.4	-8.5 ±2.2
		No competition	1.6 ±4.5	91.6 ±5.3	39.5 ±1.9	5.7 ±1.6
	Gompertz	With competition	3.1 ±2.5	100.3 ±2.0	55.8 ±0.9	-11.8 ±1.1
		No competition	3.3 ±1.5	98.1 ±2.3	36.9 ±0.7	8.5 ±0.9
	Logistic	With competition	1.5 ±4.5	97.1 ±2.5	51.3 ±1.7	5.8 ±1.0
		No competition	2.6 ±2.6	97.9 ±3.86	40.1 ±1.2	-6.7 ±1.1

*y0 and A= minimum and maximum relative yield respectivly; b= slope of the curve; X0= inflection.

The parameters values referring to the minimum (y0) and maximum (A) relative yield were close between the models tested into each year and irrigation system (Table 1 and Table 2). The highest variation among the models was observed for the parameters that indicate the slope of the curve (b) and inflection (X0), both for drip (Table 1) and micro-sprinkler (Table 2). Choosing the model based on parameter values is not a valid strategy. The critical period for weed control is defined by a theoretical assumption regarding an acceptable loss of crop yield. Therefore, the selection of better fit model will allow us to more accurately infer the beginning of CPWC (Initial-CPWC), the end of CPWC (End-CPCW) and critical period for weed control (CPWC).

All the models tested in drip showed a small difference for RMSE and R^2 values (Table 3).

Table 3. Akaike criterion (AICc), root mean square error (RMSE) and determination coefficient (R^2) for selecting the best fit sigmoidal model to estimate the relative onion production, without and with the competition with weeds, in the system of dripping. Mossoró - RN, 2019.

Year	Sigmoide	Condition	RMSE	R^2	AICc
2016	Boltzmann	With competition	0.48	0.99	125.9
		No competition	0.45	0.99	
	Gompertz	With competition	0.51	0.98	126.7
		No competition	0.45	0.99	
	Logistic	With competition	0.39	0.99	119.8*
		No competition	0.36	0.99	
2017	Boltzmann	With competition	0.35	0.98	119.7
		No competition	0.36	0.98	
	Gompertz	With competition	0.52	0.98	121.1
		No competition	0.28	0.98	
	Logistic	With competition	0.34	0.99	115.7*
		No competition	0.30	0.99	
2018	Boltzmann	With competition	0.61	0.97	133.5
		No competition	0.63	0.98	
	Gompertz	With competition	0.59	0.97	133.4
		No competition	0.64	0.97	
	Logistic	With competition	0.42	0.99	122.6*
		No competition	0.41	0.99	

*Indicates the best model according to Akaike test. RMSE = root mean square error. R^2 = coefficient of determination. AICc = Absolute value of the Akaike test.

However, Logistics models presented the lowest values for RMSE in 2016 (with competition: 0.39, without competition: 0.36), 2017 (with competition: 0.34, without competition: 0.30) and 2018 (with competition: 0.41, without competition: 0.42) compared to the Gompertz and Boltzmann models (Table 3). The R^2 value for all models in the drip system was above 0.95 (Table 3). For the AICc test, the Logistic model presented the lowest absolute value compared to Gompertz and Boltzmann for each year (Table 3). Therefore, the Logistic model was chosen to describe the relative yield of the onion during the periods with and without coexistence with weeds.

All the models tested in micro-sprinkler also showed similar RMSE and R^2 values (Table 4).

Table 4. Akaike criterion (AICc), root mean square error (RMSE) and determination coefficient (R^2) for selecting the best fit sigmoidal model to estimate relative onion production, without and with the competition with weeds, in the system of a micro-sprinkler. Mossoró - RN, 2019.

Year	Sigmoide	Condition	RMSE	R^2	AICc
2016	Boltzmann	With competition	0.75	0.99	139.1*
		No competition	0.75	0.99	
	Gompertz	With competition	0.77	0.99	140.1
		No competition	0.78	0.99	
	Logistic	With competition	0.77	0.99	139.9
		No competition	0.78	0.98	
2017	Boltzmann	With competition	2.62	0.93	146.2
		No competition	1.00	0.95	
	Gompertz	With competition	1.72	0.92	145.5
		No competition	1.74	0.91	
	Logistic	With competition	0.88	0.98	128.9*
		No competition	0.87	0.98	
2018	Boltzmann	With competition	0.87	0.94	143.2
		No competition	0.89	0.94	
	Gompertz	With competition	0.32	0.99	116.2*
		No competition	0.33	0.99	
	Logistic	With competition	0.61	0.96	131.3
		No competition	0.61	0.96	

*Indicates the best model according to Akaike test. RMSE = root mean square error. R^2 = coefficient of determination. AICc = Absolute value of the Akaike test.

The duration of weed competition or weed-free period influenced the relative yield of onion, regardless of irrigation systems (Figure 4). Onion yields at three years were significantly reduced due to the increase of weed interference periods. The most significant reduction in relative yield occurred in 2018 for drip and micro-sprinkler, with values close to 0% (Figure 4). In 2016 and 2017, the relative yield was lower in the micro-sprinkler (9 and 12%) than in drip (35 and 19%) after 120 in competition with weed (Figure 4).

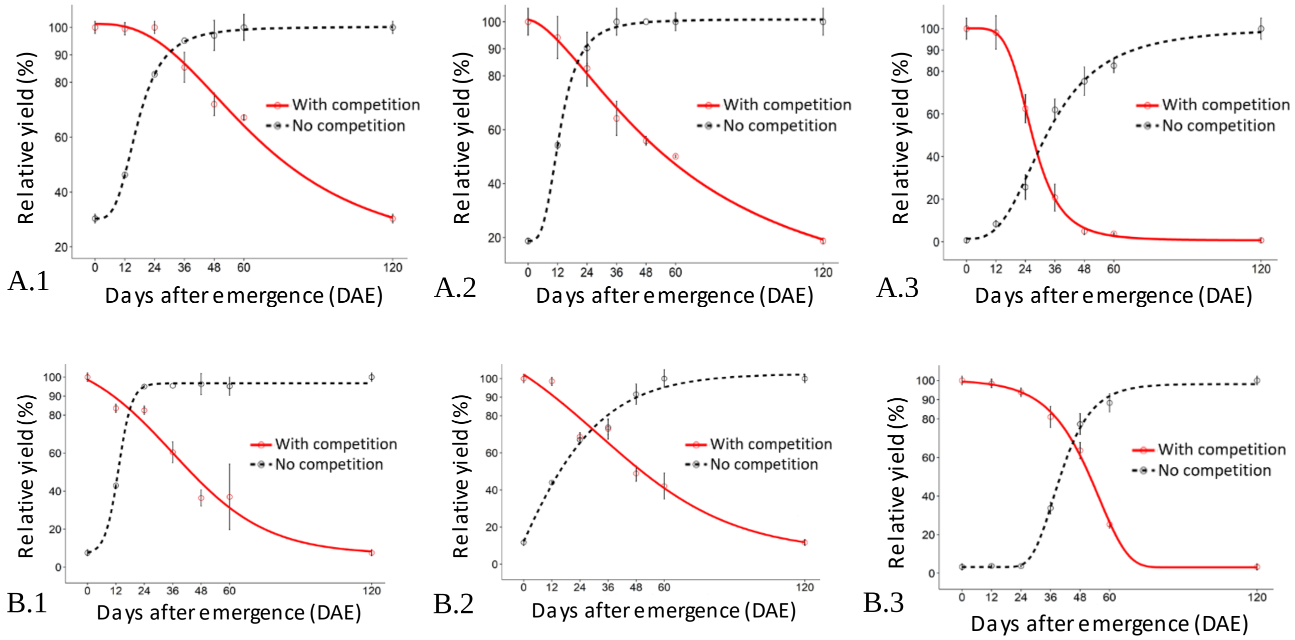


Figure 4. Relative yield (%) of onion at 0, 12, 24, 36, 48, 60 and 120 after emergence (DAE) in drip (A) and micro-sprinkler (B) between 2016 (1), 2017 (2) and 2018 (3). Mossoró - RN, 2019.

Initial-CPWC, End-CPCW, and CPWC were estimated with an acceptable yield loss of 5%. The Initial-CPCW for onion irrigated by drip in 2016 was at 26 DAE (Figure 5A). End-CPCW for this same treatment was equivalent to 38 DAE (Figure 5B), totaling 13 days of CPWC (Figure 5C). The Initial-CPWC and End-CPWC in drip were smaller in 2017 compared to 2016 (Figure 5A). This fact resulted in a similar CPWC between 2016 and 2017 (Figure 5C). The highest CPWC for drip system was observed in 2018 (74 days) compared to 2016 and 2017 (Figure 5C). In the last year, extensive End-CPWC, equivalent to 90 DAE, raised the CPWC in the onion cultivated under drip (Figure 5B).

In micro-sprinkler, there was no difference in 2016 (7 DAE) and 2017 (12 DAE) for Initial-CPWC (Figure 5A). In 2018, a delay was observed for Initial-CPWC, reaching 23 DAE (Figure 5A). In 2016 for micro-sprinkler the End-CPWC was equivalent to 26 DAE, resulting in the lowest CPWC (18 days) among the other years (Figure 5C). The highest CPWC in micro-sprinkler was observed in 2017 (53 days), followed by the year 2018 (45 days) (Figure 5C). Among the drip and micro-sprinkler systems, CPWC was similar in 2016 (Figure 5C). However, in 2017, CPWC was lower in drip irrigated areas (36 days difference) compared to micro-sprinkler (Figure 5C). This behavior reversed in 2018. In the last year, micro-sprinkler management provided lower CPWC value than drip, with 29 days difference between systems (Figure 5C).

The interference periods of irrigation systems varied among the years. This behavior is a reflection of the predominant community in each year and systems. In 2016, weeds accumulated little dry matter in both drip and micro-sprinkler. In addition to the low infestation density, the families Molluginaceae and Convolvulaceae that predominated in drip and micro-sprinkler in 2016 are less competitive by growth resources. The main species of the Molluginaceae family observed was *Mollugo verticillata*, a C4 species with low growth rate quickly suppressed by crop canopy cover (MHLANGA, 2016). The species Convolvulaceae interfere more in the harvesting process than competing by nutrients and water (SINGH et al., 2012). Thus, the low infestation density and presence of uncompetitive species resulted in a short period for weed management (CWPC) in 2016 for both irrigation systems.

The low CPWC was not observed during 2017 in areas under micro-sprinkler. In that year for this system, the total dry matter accumulated by weeds was higher than 2016. Besides, the species belong to the Poaceae family dominated the areas. Unlike the families Molluginaceae and Convolvulaceae, grasses (Poaceae) have a high competitive ability for water and nutrients due to rapid vegetative growth and high water use efficiency (Pinto et al., 2016). GALON et al. (2018) evaluated the competitive capacity of the species *Urochloa plantaginea* (Poaceae) and *Euphorbia heterophylla* in sorghum and reported a higher competition between the crop and *U. plantaginea*. This family also demonstrated high ability to reduce soybean yield (even in low infestation density) compared to other weed families (GUGLIELMINI et al., 2017). Consequently, grasses accumulating more dry matter reduced the availability of water and nutrients for onion crop. This higher interference degree promoted by weed community extended CPWC in areas irrigated by micro-sprinkler.

Again, there was a change on weed interference period for the last season of onion cultivation. In 2018, the period required to control weeds in drip was more prolonged than in micro-sprinkler. In this year, the plants were able to accumulate up to 2x more dry matter compared to 2016 in both irrigation systems. Another critical factor observed was the high infestation of Poaceae species, dominating both drip and micro-sprinkler system. In drip, the dominant species was *Digitaria horizontalis*, an aggressive species concerning the ability to absorb growth resources, even in unfavorable conditions such as water depletion. (SAITO, 2010a; SAITO et al., 2010b). This Poaceae occurred almost exclusively in the drip. In this system, the water applied was smaller compared to micro-sprinkler. Therefore, the combination of these factors (more competitive community and less resource availability) resulted in the extensive CPWC in onion cultivated under drip irrigation, surpassing in 29 days compared to micro-sprinkler. Another important observation is the increase in the aggressiveness of competition verified in 2018 in both irrigation systems. The relative yield of onion in drip and micro-sprinkler approached 0%, values much lower than the years 2016 (30 and 10%) and 2017 (20 and 12%) for drip and micro-sprinkler respectively.

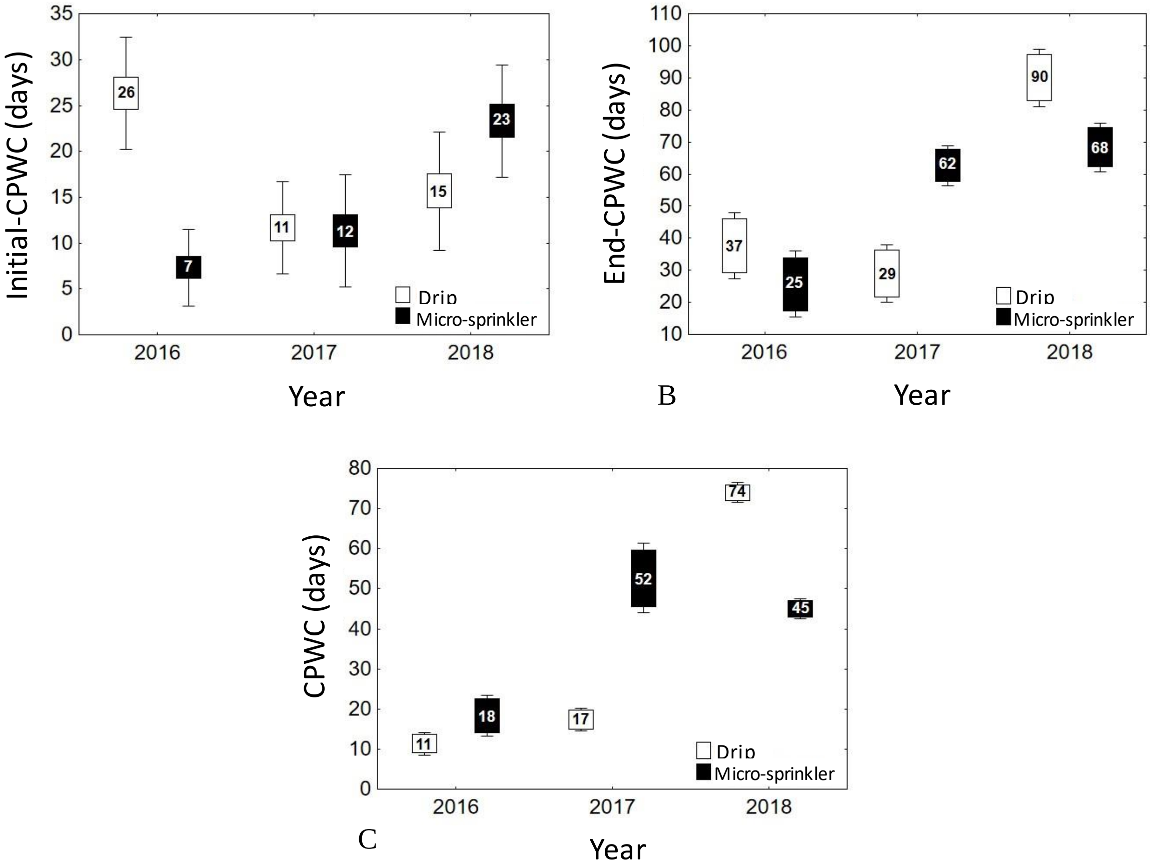


Figure 5. The beginning of CPWC (A: Initial-CPWC), The end of CPWC (B: End-CPWC) and the critical period for weed control (C: CPWC) in the two irrigation systems during 2016, 2017, 2018. Values into each box represent the days for the variable. Differences are shown in bars by the mean confidence interval at significance level ≤0.05. Mossoró - RN, 2019.

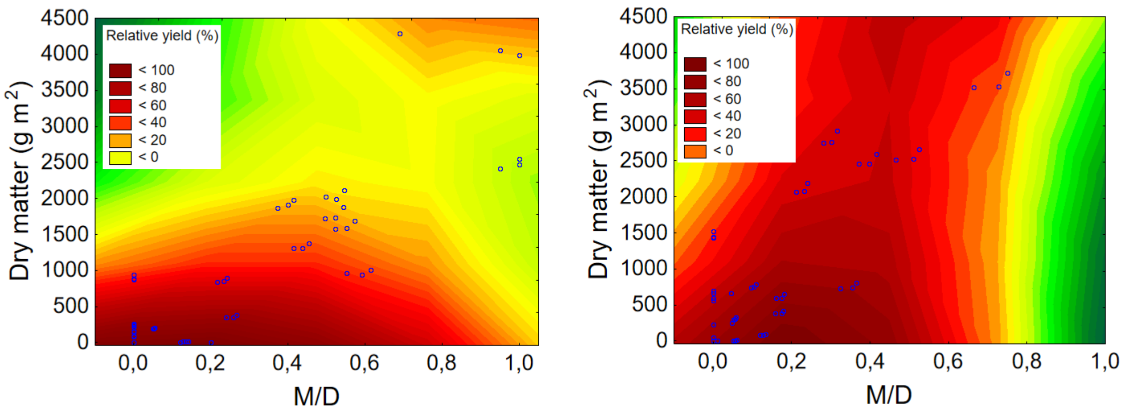
The main difference observed between the years and systems was the increase in monocotyledonous infestation (Poaceae) in cultivated areas, as well as the infestation intensity. The correlation between onion relative yield and characteristics as dry matter and weed density and monocotyledon/dicotyledon ratio was able to emphasize the increase in the interference degree in onion culture. The rise in the weed dry matter linearly reduced the relative yield of onion in both irrigation systems, resulting in values of -0.83 and -0.75 for drip and micro-sprinkler, respectively (Table 5). However, linear correlations were not significant between relative yield and weed density for any irrigation system (Table 5). Although studies associated the increase in infestation density with the lower crop yields (CHAUHAN et al., 2015; Shahzad et al., 2016), for onion crop, this variable was not representative. The ability of the weed community to accumulate dry matter was the variable that best describes the loss of productivity of onion. This fact is caused by higher absorption of nutrients from the soil that are absorbed to constitute the structural compounds or provide energy for plant growth (GALAL & SHEHATA, 2015). Consequently, weeds accumulating more dry matter reduce the availability of resources to the onion, intensifying competition.

Table 5. Pearson correlations between variables relative yield of onion (%), density (plants m^{-2}), relation monocotyledonous/dicotyledonous (M/D), and dry matter of weeds (g m^{-2}) in drip and micro-sprinkler during 2016, 2017, and 2018. Mossoró - RN, 2019

Variable	Drip Relative Yield	Micro-sprinkler Relative Yield
Dry matter (g m^{-2})	-0.83*	-0.75*
M/D	-0.73*	-0.45*
Density (plant m^{-2})	-0.14	0.29
Relative Yield	1.00	1.00

*Significant correlations at p-value ≤0.05.

In drip, the correlation between relative yield and M/D was significant (-0.73), but linearity was lower compared to weed dry matter (Table 5). In micro-sprinkler, although significant, the correlation between relative yield and M/D did not demonstrate high linearity (Table 5). The significant correlations between relative yield and M/D were negative for both irrigation systems (Table 5). This fact indicates that the higher accumulation of dry matter and increase in monocotyledon population reduces the onion yield, with higher linearity for drip (Figure 6). This behavior between relative yield and M/D ratio in drip system may be associated with the ability of monocotyledons to withstand soil water limitation conditions (BELLASIO et al., 2018; PATTERSON, 2018) reference). In situations with lower water supply, such as dripping, the presence of monocotyledons (Poaceae) was a factor that aggravated competition with onion, resulting in higher productivity losses as the M/D ratio increased in cultivated areas.



A B

Figure 6. Relative yield (%) of onion as a function of weed dry matter and monocotyledonous/dicotyledonous ratio (M/D) in drip (A) and micro-sprinkler (B) systems during 2016, 2017 and 2018. Mossoró - RN, 2019

The results of this study show how dynamic are the agro-systems. The weed community has changed in number, family, and importance between water management systems and onion season crops. These changes in the weed community directly affected the critical period for weed control. Certain conditions, such as the high predominance of Poaceae species after two onion crops, were more unfavorable to the drip system. When this family does not dominate the agricultural areas, the localized irrigation, even supply a smaller water volume, favored the crop growth. This practice in the cited condition had repercussions on better cultural control of weeds, reducing the critical period for weed control. However, the lower supply of water by drip can be extremely damaging to onion culture when grasses are the principal weed. Under these conditions, the water restriction appears as a factor that intensifies the competition between onion and invasive plants, increasing the number of interventions for weed control. The irrigation management can reduce the period for control and costs with weed management in onion crops. However, specific situations involving the weed community should be evaluated to recommend the most appropriate irrigation system.

4. CONCLUSIONS

The presence of weeds during increasing periods reduces onion yield, and absence of plants control can result in 100% loss of onion yield when more competitive communities dominate the field. Irrigation management and invasive population plants affect the interference degree between weeds and onion crops. Weeds species belong to the Poaceae family are more competitive with onion by growth resources in both irrigations systems. The critical period for weed control in drip increased during the growing years, with values of 11 (2016), 17 (2017), and 74 (2018) days. In micro-sprinkler, the critical period for weed control was 18 (2016), 53 (2017), and 45 (2018) days. The irrigation system that favors cultural control and reduces the critical period for weed control varies according to the dominant community.

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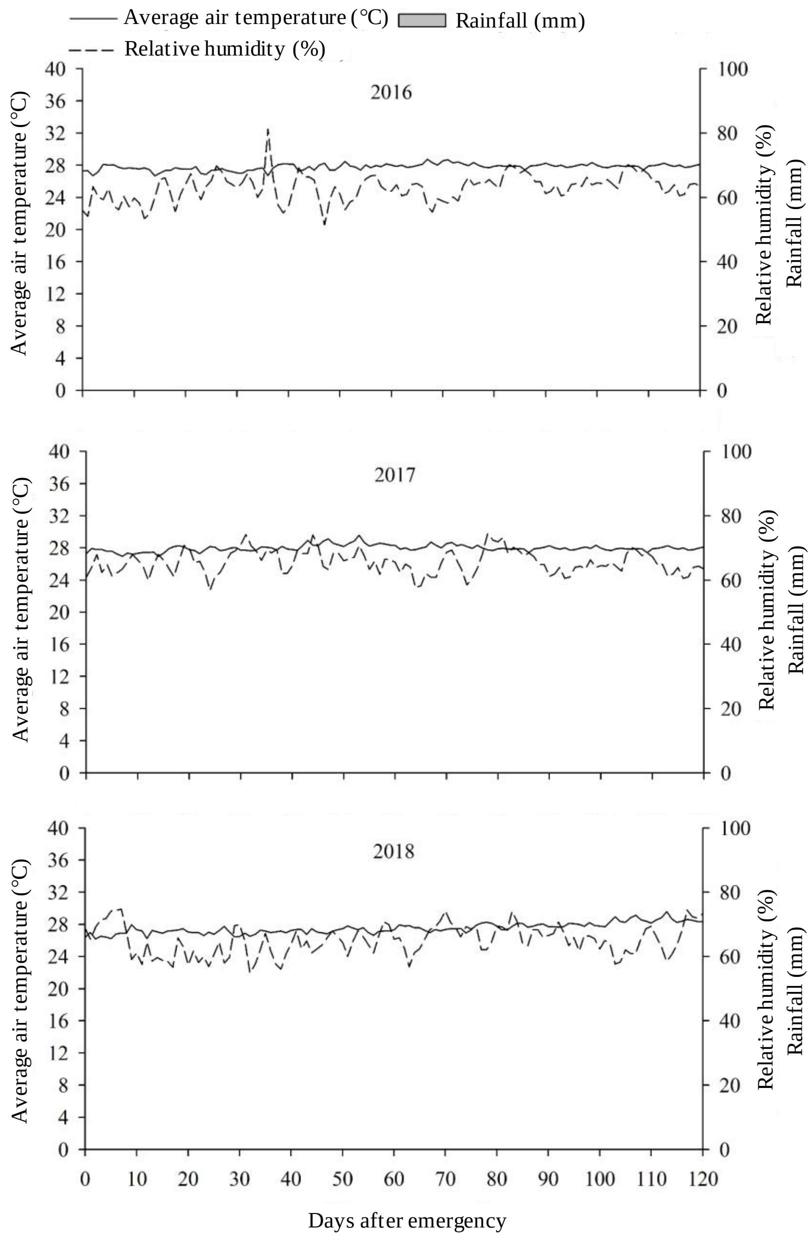
FINAL CONSIDERATIONS

Onion cultivation is characterized by intensive soil preparation and high use of water and fertilization, which exert intense selection pressure on the weed communities, as discussed in this study. In general, weeds with a C4/erect, C3/erect, perennial and vegetatively-propagated are favored by the cultivation practices adopted in the onion, regardless of the irrigation system used. The predominance of these species reduces yield, water use efficiency, and increases the critical period for weed control.

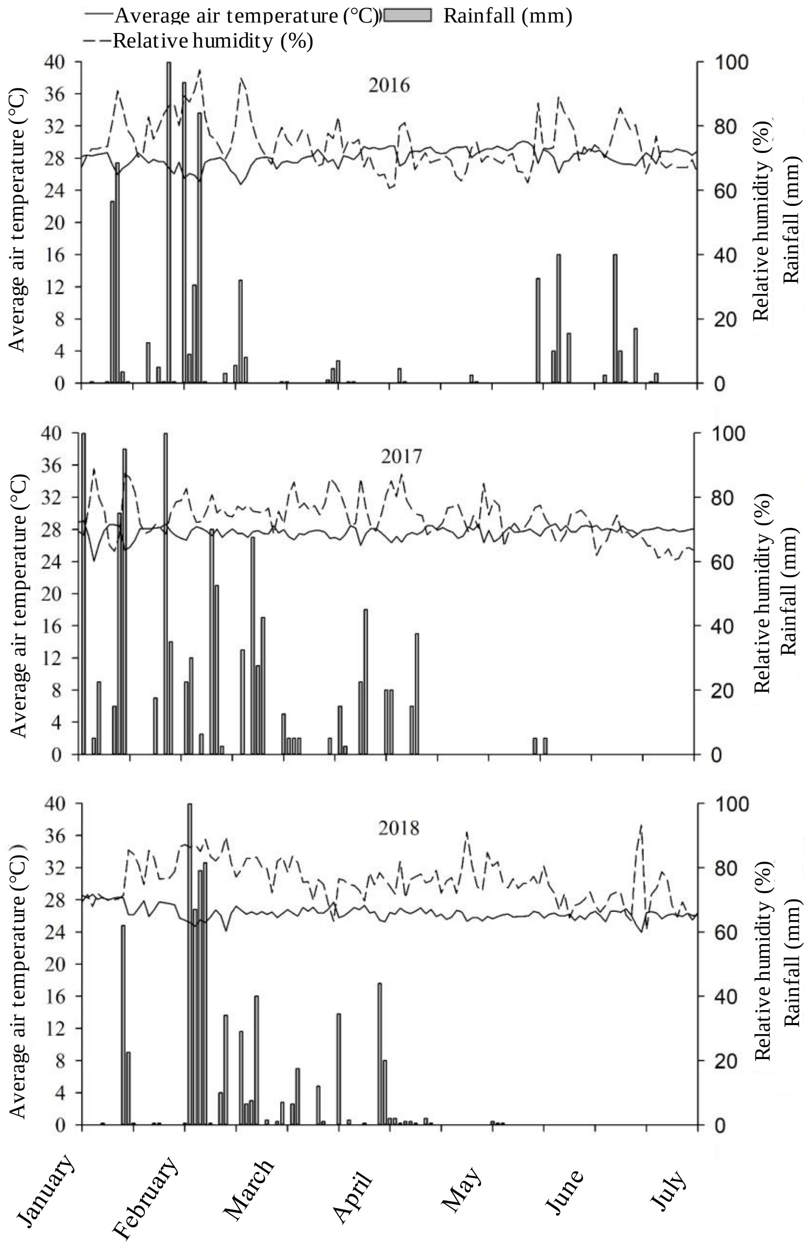
The cultural control of weeds using localized irrigation (drip) was efficient to reduce the interference degree during two seasons crops (2016 and 2017), but this irrigation system can be extremely harmful to the onion when grasses are the dominant weed. Under these conditions, the localized irrigation appears as a factor that intensifies the competition between onion and weeds, increasing the number of interventions for weed control.

APPENDIX

Appendix I. Average air temperature (° C), relative humidity (%) and rainfall (mm) during the onion crop cycle in 2016, 2017 and 2018. Data obtained from the weather station at the field experimental. Mossoró - RN, 2019.



Appendix II. Average air temperature (° C), relative humidity (%) and rainfall (mm) during the off season in 2016, 2017 and 2018. Data obtained from the weather station at the field experimental. Mossoró - RN, 2019.



Appendix III. Physical-chemical analysis of soil cultivated with onion in the years 2016, 2017, 2018. Mossoró - RN, 2019.

Year	N	OM	K	P	Na	Ca	Mg	pH	EC
	$g\ kg^{-1}$	$g\ kg^{-1}$	-------mg dm^{-3}-------			--cmol$_c$ dm^{-3}--		H_2O	ds m^{-1}
2016	0.14	7.23	52.01	4.47	8.1	2.10	0.55	6.50	0.06
2017	0.22	9.78	58.8	3.0	4.8	1.00	1.80	5.63	0.07
2018	0.31	8.21	68.8	3.5	4.7	1.20	1.40	5.83	0.08

Texture			
Textural class	Sand (%)	Silt (%)	Clay (%)
Clayed-Sand	72	4	24

OM= Organic matter; EC= Electrical conductivity.

Appendix. Daily evapotranspiration (ETo) values during the cultivation cycle of onion in 2016, 2017 and 2018. Mossoró - RN, 2019.

Day	Development cycle	Eto			kc	Roots depth (Z)	Irrigation turn	Etc		
		2016	2017	2018				2016	2017	2018
1	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
2	Sowing	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
3	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
4	Sowing	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
5	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
6	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
7	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
8	Sowing	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
9	Sowing	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
10	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
11	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
12	Sowing	5.1	5.2	5.4	1.1	30.0	1.0	5.4	5.5	5.6
13	Sowing	5.1	5.2	5.4	1.1	30.0	1.0	5.4	5.5	5.6
14	Sowing	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
15	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
16	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
17	Sowing	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
18	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
19	Sowing	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
20	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
21	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
22	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
23	Sowing	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
24	Sowing	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
25	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
26	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
27	Sowing	5.1	5.2	5.4	1.1	30.0	1.0	5.4	5.5	5.6
28	Sowing	5.1	5.2	5.4	1.1	30.0	1.0	5.4	5.5	5.6
29	Sowing	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
30	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
31	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
32	Sowing	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
33	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
34	Sowing	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
35	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
36	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
37	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
38	Sowing	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4

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39	Sowing	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
40	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
41	Sowing	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
42	Sowing	5.1	5.2	5.4	1.1	30.0	1.0	5.4	5.5	5.6
43	Seedlings	5.1	5.2	5.4	1.1	30.0	1.0	5.4	5.5	5.6
44	Seedlings	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
45	Seedlings	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
46	Seedlings	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
47	Seedlings	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
48	Seedlings	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
49	Seedlings	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
50	Seedlings	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
51	Seedlings	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
52	Seedlings	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
53	Seedlings	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
54	Seedlings	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
55	Seedlings	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
56	Vegetative	5.9	6.0	6.2	0.9	30.0	1.0	5.0	5.1	5.3
57	Vegetative	5.1	5.2	5.4	0.9	30.0	1.0	4.3	4.4	4.6
58	Vegetative	5.1	5.2	5.4	0.9	30.0	1.0	4.3	4.4	4.6
59	Vegetative	6.7	6.9	7.1	0.9	30.0	1.0	5.7	5.8	6.0
60	Vegetative	5.9	6.0	6.2	0.9	30.0	1.0	5.0	5.1	5.3
61	Vegetative	5.9	6.0	6.2	0.9	30.0	1.0	5.0	5.1	5.3
62	Vegetative	6.7	6.9	7.1	0.9	30.0	1.0	5.7	5.8	6.0
63	Vegetative	5.9	6.0	6.2	0.9	30.0	1.0	5.0	5.1	5.3
64	Vegetative	6.7	6.9	7.1	0.9	30.0	1.0	5.7	5.8	6.0
65	Vegetative	5.9	6.0	6.2	0.9	30.0	1.0	5.0	5.1	5.3
66	Vegetative	5.9	6.0	6.2	0.9	30.0	1.0	5.0	5.1	5.3
67	Vegetative	5.9	6.0	6.2	0.9	30.0	1.0	5.0	5.1	5.3
68	Vegetative	6.7	6.9	7.1	0.9	30.0	1.0	5.7	5.8	6.0
69	Vegetative	6.7	6.9	7.1	0.9	30.0	1.0	5.7	5.8	6.0
70	Vegetative	5.9	6.0	6.2	0.9	30.0	1.0	5.0	5.1	5.3
71	Vegetative	5.9	6.0	6.2	0.9	30.0	1.0	5.0	5.1	5.3
72	Vegetative	5.1	5.2	5.4	0.9	30.0	1.0	4.3	4.4	4.6
73	Vegetative	5.1	5.2	5.4	0.9	30.0	1.0	4.3	4.4	4.6
74	Vegetative	6.7	6.9	7.1	0.9	30.0	1.0	5.7	5.8	6.0
75	Vegetative	5.9	6.0	6.2	0.9	30.0	1.0	5.0	5.1	5.3
76	Bulbification	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
77	Bulbification	6.7	6.9	7.1	1.1	30.0	1.0	7.0	7.2	7.4
78	Bulbification	5.9	6.0	6.2	1.1	30.0	1.0	6.2	6.3	6.5
79	Bulbification	6.7	6.9	6.6	1.1	30.0	1.0	7.0	7.2	6.9
80	Bulbification	5.9	6.0	5.8	1.1	30.0	1.0	6.2	6.3	6.1
81	Bulbification	5.9	6.0	5.8	1.1	30.0	1.0	6.2	6.3	6.1

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82	Bulbification	5.9	6.0	5.8	1.1	30.0	1.0	6.2	6.3	6.1
83	Bulbification	6.7	6.9	6.6	1.1	30.0	1.0	7.0	7.2	6.9
84	Bulbification	6.7	6.9	6.6	1.1	30.0	1.0	7.0	7.2	6.9
85	Bulbification	5.9	6.0	5.8	1.1	30.0	1.0	6.2	6.3	6.1
86	Bulbification	5.9	6.0	5.8	1.1	30.0	1.0	6.2	6.3	6.1
87	Bulbification	5.1	5.2	5.0	1.1	30.0	1.0	5.4	5.5	5.3
88	Bulbification	5.1	5.2	5.0	1.1	30.0	1.0	5.4	5.5	5.3
89	Bulbification	6.7	6.9	6.6	1.1	30.0	1.0	7.0	7.2	6.9
90	Bulbification	5.9	6.0	5.8	1.1	30.0	1.0	6.2	6.3	6.1
91	Bulbification	5.9	6.0	5.8	1.1	30.0	1.0	6.2	6.3	6.1
92	Bulbification	6.7	6.9	6.6	1.1	30.0	1.0	7.0	7.2	6.9
93	Bulbification	5.9	6.0	5.8	1.1	30.0	1.0	6.2	6.3	6.1
94	Bulbification	6.7	6.9	6.6	1.1	30.0	1.0	7.0	7.2	6.9
95	Bulbification	5.9	6.0	5.8	1.1	30.0	1.0	6.2	6.3	6.1
96	Bulbification	5.9	6.0	5.8	1.1	30.0	1.0	6.2	6.3	6.1
97	Bulbification	5.9	6.0	5.8	1.1	30.0	1.0	6.2	6.3	6.1
98	Bulbification	6.7	6.9	6.6	1.1	30.0	1.0	7.0	7.2	6.9
99	Bulbification	6.7	6.9	6.6	1.1	30.0	1.0	7.0	7.2	6.9
100	Bulbification	5.9	6.0	5.8	1.1	30.0	1.0	6.2	6.3	6.1
101	Maturation	5.9	6.0	5.8	0.8	30.0	1.0	4.4	4.5	4.3
102	Maturation	5.1	5.2	5.0	0.8	30.0	1.0	3.8	3.9	3.8
103	Maturation	5.1	5.2	5.0	0.8	30.0	1.0	3.8	3.9	3.8
104	Maturation	6.7	6.9	6.6	0.8	30.0	1.0	5.0	5.1	4.9
105	Maturation	5.9	6.0	5.8	0.8	30.0	1.0	4.4	4.5	4.3
106	Maturation	5.9	6.0	5.8	0.8	30.0	1.0	4.4	4.5	4.3
107	Maturation	6.7	6.9	6.6	0.8	30.0	1.0	5.0	5.1	4.9
108	Maturation	5.9	6.0	5.8	0.8	30.0	1.0	4.4	4.5	4.3
109	Maturation	6.7	6.9	6.6	0.8	30.0	1.0	5.0	5.1	4.9
110	Maturation	5.9	6.0	5.8	0.8	30.0	1.0	4.4	4.5	4.3
111	Maturation	5.9	6.0	5.8	0.8	30.0	1.0	4.4	4.5	4.3
112	Maturation	5.9	6.0	5.8	0.8	30.0	1.0	4.4	4.5	4.3
113	Maturation	6.7	6.9	6.6	0.8	30.0	1.0	5.0	5.1	4.9
114	Maturation	6.7	6.9	6.6	0.8	30.0	1.0	5.0	5.1	4.9
115	Maturation	5.9	6.0	5.8	0.8	30.0	1.0	4.4	4.5	4.3
116	Maturation	5.9	6.0	5.8	0.8	30.0	1.0	4.4	4.5	4.3
117	Maturation	5.1	5.2	5.0	0.8	30.0	1.0	3.8	3.9	3.8
118	Maturation	5.1	5.2	5.0	0.8	30.0	1.0	3.8	3.9	3.8
119	Maturation	6.7	6.9	6.6	0.8	30.0	1.0	5.0	5.1	4.9
120	Maturation	5.9	6.0	5.8	0.8	30.0	1.0	4.4	4.5	4.3

Kc = Coefficient of the culture according to its development stage.

Appendix V. Coordinates, quality and inertia of the three dimensions obtained through Correspondence Analysis for Year/irrigation system and weeds species. Mossoró - RN, 2019.

Year/irrigation system	Coordinates			Quality	Inertia Dimension 1	Inertia Dimension 2	Inertia Dimension 3
Drip:2016	-0.84	0.07	-0.10	0.98	0.18	0.00	0.02
Drip:2017	-0.81	0.04	-0.01	0.96	0.14	0.00	0.00
Drip:2018	1.16	0.42	0.05	1.00	0.45	0.23	0.01
Micro-sprinkler:2016	-0.79	-0.02	-0.04	0.90	0.10	0.00	0.00
Micro-sprinkler:2017	-0.16	-0.95	1.83	1.00	0.00	0.10	0.86
Micro-sprinkler:2018	1.10	-1.27	-0.33	1.00	0.13	0.66	0.10
Weeds	Coordinates			Quality	Inertia Dimension 1	Inertia Dimension 2	Inertia Dimension 3
Blainvillea spp.	-0.55	-0.82	2.47	0.94	0.00	0.01	0.24
Ipomoea purpurea	-0.74	-0.25	0.77	0.87	0.00	0.00	0.03
Aechynomene rudis	-0.71	-0.36	1.02	0.83	0.00	0.00	0.04
Sida spp.	-0.86	0.08	-0.25	0.48	0.00	0.00	0.00
Waltheria indica	-0.32	-0.64	1.09	0.98	0.00	0.02	0.15
Mollugo verticilata	-0.81	0.05	-0.07	1.00	0.40	0.01	0.02
Senecio brasiliensis	-0.50	-0.93	2.82	0.94	0.00	0.01	0.11
Merremia aegyptia	-0.50	-0.93	2.82	0.94	0.00	0.01	0.11
Digitaria horizontalis	1.19	0.20	-0.02	1.00	0.40	0.04	0.00
Portulaca oleracea	0.35	-1.00	0.37	0.92	0.00	0.02	0.01
Richardia brasiliensis	1.18	0.77	0.19	1.00	0.10	0.16	0.02
Hybanthus calceolaria	0.60	-0.71	0.75	0.95	0.00	0.01	0.03
Amaranthus hybridus	0.88	-2.22	0.00	1.00	0.01	0.32	0.00
Jacquemontia tammifolia	1.16	-2.08	-0.85	1.00	0.01	0.11	0.04
Centrocema pascuorum	1.18	-1.26	-0.57	1.00	0.01	0.06	0.03
Chloris barbata	0.88	-0.56	0.23	0.97	0.02	0.03	0.01
Eragrostis pilosa	1.18	-1.15	-0.53	1.00	0.03	0.10	0.05
Senna obtusifolia	0.11	-1.68	2.00	0.97	0.00	0.03	0.08
Dactyloctenium aegyptium	-0.83	-0.03	-0.13	0.12	0.00	0.00	0.00
Diodella teres	-0.83	-0.03	-0.13	0.12	0.00	0.00	0.00
Ipomoea triloba	1.15	-2.59	-1.02	1.00	0.00	0.06	0.02

Appendix VI. Eigenvalues, inertia (%), percentage accumulated and Chi-square for the dimensions obtained through Correspondence Analysis (AC) for weeds species. Mossoró - RN, 2019.

Number of dimensions	Eigenvalues	Inertia (%)	Accumulated inertia (%)	Chi-quadrado
1	0.91	71.54	71.54	5029.43
2	0.24	18.90	90.44	1328.38
3	0.10	8.08	98.51	567.96
4	0.01	1.04	99.55	73.15
5	0.01	0.45	100.00	31.31

Appendix VII. Eigenvalues, inertia (%), percentage accumulated and Chi-square for the dimensions obtained through Correspondence Analysis (AC) for weed families. Mossoró - RN, 2019.

Number of dimensions	Eigenvalues	Inertia (%)	Accumulated inertia (%)	Chi-quadrado
1	0.86	92.64	92.64	4730.98
2	0.06	6.16	98.81	314.82
3	0.01	1.19	100.00	60.89

Appendix VIII. Coordinates, quality and inertia of the three dimensions obtained through Correspondence Analysis for Year/irrigation system and weeds families. Mossoró - RN, 2019.

Year/irrigation system	Coordinates			Quality	Inertia Dimension 1	Inertia Dimension 2	Inertia Dimension 3
Drip:2016	-0.84	0.06	-0.03	1.00	0.18	0.01	0.00
Drip:2017	-0.81	0.05	-0.01	0.99	0.14	0.00	0.00
Drip:2018	1.16	0.35	0.06	1.00	0.47	0.21	0.02
Micro-sprinkler:2016	-0.75	0.01	-0.06	0.97	0.09	0.00	0.01
Micro-sprinkler:2017	-0.04	-1.19	1.23	1.00	0.00	0.20	0.77
Micro-sprinkler:2018	1.02	-1.05	-0.33	1.00	0.12	0.58	0.20
Famílias	**Coordinates**			**Quality**	**Inertia Dimension 1**	**Inertia Dimension 2**	**Inertia Dimension 3**
Asteraceae	-0.49	-1.21	2.45	0.99	0.00	0.04	0.62
Convolvulaceae	0.38	-1.47	-0.22	0.99	0.00	0.16	0.01
Fabaceae	0.57	-1.12	-0.02	0.98	0.01	0.10	0.00
Malvaceae	-0.41	-0.60	0.74	0.93	0.00	0.03	0.17
Molluginaceae	-0.81	0.06	-0.04	1.00	0.41	0.01	0.01
Poaceae	1.16	0.06	-0.06	1.00	0.46	0.01	0.02
Portulacaceae	0.35	-1.04	0.18	0.90	0.00	0.03	0.00
Rubiaceae	1.17	0.71	0.26	1.00	0.10	0.18	0.09
Violaceae	0.61	-0.81	0.62	0.94	0.00	0.02	0.04
Amarantacea	0.85	-2.21	-0.35	1.00	0.01	0.41	0.04

Appendix VII. Coordinates, quality and inertia of the three dimensions obtained through Correspondence Analysis for Year/irrigation system and photosynthetic cycle/size. Mossoró - RN, 2019.

Year/irrigation system	Coordinates		Quality	Inertia Dimension 1	Inertia Dimension 2
Drip:2016	-0.82	0.06	1.00	0.18	0.01
Drip:2017	-0.80	0.05	1.00	0.14	0.01
Drip:2018	1.12	0.15	1.00	0.45	0.11
Micro-sprinkler:2016	-0.76	-0.04	1.00	0.10	0.00
Micro-sprinkler:2017	0.11	-1.23	0.93	0.00	0.70
Micro-sprinkler:2018	1.05	-0.30	0.95	0.13	0.16
Ciclo Fotossintético/Porte	**Coordinates**		**Quality**	**Inertia**	**Inertia**
C3/erect	0.08	-1.11	2.45	0.00	0.91
C3/procumbent	1.03	0.22	-0.22	0.10	0.06
C4/procumbent	-0.80	0.04	-0.02	0.42	0.02
C4/erect	1.14	0.02	0.74	0.48	0.00

Appendix IX. Eigenvalues, inertia (%), percentage accumulated and Chi-square for the dimensions obtained through Correspondence Analysis (AC) for photosynthetic cycle/size and Growth habit/propagation type. Mossoró - RN, 2019.

photosynthetic cycle/size				
Number of dimensions	Eigenvalues	Inertia (%)	Accumulated inertia (%)	Chi-quadrado
1	0.86	92.64	92.64	4300.61
2	0.06	6.16	98.81	314.22
3	0.01	1.19	100.00	3.55
Growth Habit/propagation type				
Number of dimensions	Eigenvalues	Inertia (%)	Accumulated inertia (%)	Chi-quadrado
1	0.55	91.53	91.53	3021.09
2	0.04	7.21	98.74	237.91
3	0.01	1.26	100.00	41.66

Appendix X Coordinates, quality and inertia of the three dimensions obtained through Correspondence Analysis for Year/irrigation system and Growth habit/propagation type

Year/irrigation system	Coordinates		Quality	Inertia Dimension 1	Inertia Dimension 2
Drip:2016	-0.65	0.11	1.00	0.18	0.06
Drip:2017	-0.62	0.03	1.00	0.13	0.00
Drip:2018	0.97	0.11	1.00	0.52	0.09
Micro-sprinkler:2016	-0.60	-0.04	1.00	0.09	0.00
Micro-sprinkler:2017	-0.16	-0.94	0.89	0.00	0.55
Micro-sprinkler:2018	0.62	-0.35	0.93	0.07	0.28
Growth habit/propagation type	**Coordinates**		**Quality**	**Inertia**	**Inertia**
Anual:Sementes	-0.49	0.03	1.00	0.30	0.01
Perene:Sementes	0.44	-0.79	0.94	0.02	0.64
Perene:Sementes-Vegetativa	1.20	0.09	1.00	0.68	0.05
Anual:Sementes-Vegetativa	0.42	-1.27	0.72	0.00	0.29

Appendix XI. Analysis of variance for commercial onion bulb productivity between the factors: Year (2016, 2017 and 2018), System (drip and micro-sprinkler) and Time (Period for weeds control). Mossoró - RN, 2019.

Sources of variation	Sum of squares	Degree of freedom	Mean square	F-value	p-value
Block (Year)	49.9	6.0	16.7	2.47	0.12
Year	286.9	2	143.5	42.91	≤0.01*
System	320.8	1	320.8	95.94	≤0.01*
Error (a)	100.8	2	50.4	15.07	≤0.01*
Period	1465.5	2	732.7	219.15	≤0.01*
Year*System	476.7	2	238.4	71.29	≤0.001*
Year*´Period	188.9	4	47.2	14.12	≤0.01*
System*Period	0.1	2	0.1	0.02	0.98
Year*System*Period	504.8	4	126.2	37.74	≤0.01*
Error (b)	93.6	28	3.3		

*significant values for the analysis of variance by the test F. P-values are shown to demonstrate the level of significance.

Appendix XII. Analysis of variance for water use efficiency between the factors: Year (2016, 2017 and 2018), System (drip and micro-sprinkler) and Time (Period for weeds control). Mossoró - RN, 2019.

Block (Year)	Sum of squares	Degree of freedom	Mean square	F-value	p-value
Year	370.5	6.0	61.7	8.70	0.04*
System	816.8	2	408.4	57.55	≤0.01*
Error (a)	34633.7	1	34633.7	4880.25	≤0.01*
Period	346.0	2	173.0	24.38	≤0.01*
Year*System	2825.5	2	1412.7	199.07	≤0.01*
Year*´Period	1164.3	2	582.1	82.03	≤0.01*
System*Period	626.9	4	156.7	22.08	≤0.01*
Year*System*Period	319.8	2	159.9	22.53	≤0.01*
Error (b)	1205.6	4	301.4	42.47	≤0.01*
Block (Year)	198.7	28	7.1		

*significant values for the analysis of variance by the test F. P-values are shown to demonstrate the level of significance.