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INFLUENCE OF TIMES AND METHODS OF BLACK OAT MANAGEMENT ON CORN DEVELOPMENT AND YIELD

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KEYWORDS

crimper-roller, straw crusher, desiccation, sowing quality.

ABSTRACT

This study aimed to evaluate the influence of management times and methods of black oat straw on corn crop development and yield under a no-tillage system for two crop seasons. A randomized block design was used with twelve treatments. They were arranged in a 3 x 4 factorial scheme with four replications, consisting of a combination between three methods (crushed, rolled, and desiccated) and four times (0, 10, 20, and 30 days before corn sowing). Black oat was evaluated for dry matter, while corn was for plant final population, height, stem diameter, ear insertion height, ear diameter, ear length, grain number per row, 1000-grain weight, and grain yield. All management methods and times interfered with corn crop yield components, but not all influenced final production. The method with the largest final corn population was not the same with an improved ear development. Such findings, however, may not be the same under highly favorable weather conditions.

INTRODUCTION

No-tillage has been a good alternative to increase crop yields. This crop production system involves minimum soil disturbance, soil surface straw cover, and crop rotation (Oliveira et al., 2013). These characteristics offer advantages for economic and sustainable agriculture, besides solving environmental problems in farmlands such as erosion processes, waste of chemical inputs, and transport of organic matter into water courses (Salomão et al., 2020). Accordingly, the practice has been propagated to reduce soil wear or degradation (Bertin et al., 2005).

In Brazil, corn is mostly cultivated under no-tillage, and its rotation with other crops has promoted great benefits to farmers (Medeiros & Calegari, 2007). Among the crops used in a rotation system, black oat is one of the main species used in rotation systems as a winter crop. The choice of this plant species is due to the ease of seed acquisition, rusticity, fast biomass formation, cycle suitability, and mainly large dry matter production (Ziech et al., 2015).

Furthermore, crop residues and cover crops should be managed as a function of summer crop sowing dates, which can be done by chemical or mechanical methods. Among the mechanical techniques, cutter, crimper-roller, disc harrow, rotary hoe, and straw crusher stand out. In turn, for chemical management, glyphosate is the herbicide with the highest operational capacity (Tabile et al., 2007). Another important factor related to cover crops refers to managing time, which can influence the plantability and agronomic performance of crops in a succession system (Franchini et al., 2015). In this context, depending on the amount of biomass produced, the sowing of subsequent crops can be impaired when done soon after desiccation (Balbinot-Junior et al., 2011). According to Modolo et al. (2019), black oat straw management anticipated by 30 to 40 days or at sowing facilitates straw cutting, but when performed in between, residues can be withered, reducing cutting efficiency and promoting straw clogging in seeders.

Given the above, this study aimed to evaluate the influence of black oat straw management methods and times on corn development and yield under a no-tillage system for two crop seasons.

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MATERIAL AND METHODS

The experiment was carried out in the experimental area of the Federal University of Technology - Paraná, campus Pato Branco, in the 2017/2018 and 2018/2019 crop seasons. The area is located at 26°16’36” S and 52°41’20” W, on a soil classified as Typic Hapludox (Soil Survey Staff, 2014), with a very clayey texture. The local climate is classified as a *Cfa* type, which stands for humid subtropical (Alvares et al., 2013). Figure 1 shows the average temperature and rainfall during the experimental period.

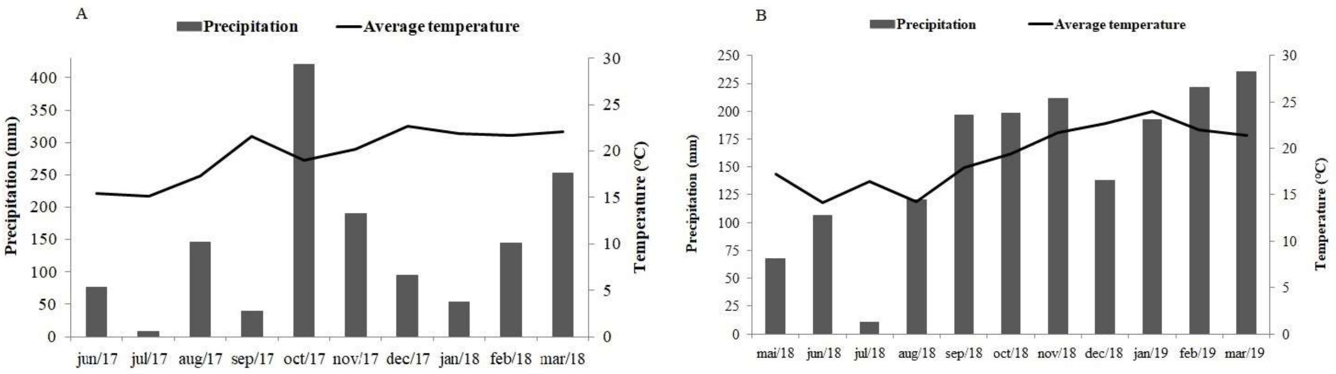

FIGURE 1. Rainfall (mm) and temperature (°C) in the 2017/2018 (A) and 2018/2019 (B) crop seasons. Source: Paraná Meteorological System (SIMEPAR).

A randomized block design was used with twelve treatments, which were arranged in a 3 x 4 factorial scheme, with four replications each. The treatments consisted of combining three black oat straw management methods (desiccated, rolled, and crushed) and four management times (0, 10, 20, and 30 days before corn sowing). The area was divided into four randomized blocks, totaling 48 experimental units. Each unit had 74 m^2 (3.7 x 20 m), and the central part was considered the useful area for evaluations (21 m^2).

The black oat cultivar used as a cover crop was EMBRAPA 139. The grass was sown at a density of 350 seeds m^{-2}, without sowing fertilization or topdressing. Its straw was managed using the following equipment: 1) tractor plus a straw crusher (Jan/Triton® 1800) with a 1.8-m cutting width for crushed straw; 2) tractor plus a crimper-roller (Triton®) with a 1.2-m working width for rolled straw; 3) sprayer (JACTO®) with a 12-m long bar and a 600-L tank for desiccated straw. Desiccation was made by applying the herbicide ZAPP QI (1.1 L ha^{-1}), using a 200 L ha^{-1} spray volume.

The corn hybrid used was Pioneer 30F53VYH (LEPTRA biotechnology). Its seeds were distributed longitudinally at a density of about five seeds per meter. Sowing fertilization and topdressing were carried out considering the soil analysis and grain yield expected (12 t ha^{-1}). Sowing fertilization consisted of 450 kg ha^{-1} of 08-20-15 NPK granulated formulation while topdressing was done with 200 kg ha^{-1} of urea (45% of nitrogen). Crop practices were carried out according to the recommendations for corn.

Corn sowing was carried out by a no-tillage seeder-fertilizer (Vence Tudo®, SA 14600 model), with a mechanical seed dispenser (horizontal disc), five planting rows spaced 0.70 meters apart, and lagged double-disc furrower with 356 mm (14”) diameter. A New Holland®, model TL85E, 4x2 FWA (front-wheel assist) tractor drove the seeder-fertilizer, with a maximum power of 57.4 kW (78 hp) at 2,400 RPM, with tire wheelset.

Black oat was analyzed for dry matter on corn sowing day. To do so, 0.5x0.5-m iron quadrats were thrown on the side of corn rows, collecting the straw within it, and later dried in an oven at 60 °C until reaching constant weight (Detmann et al., 2012) for further determinations.

Plant population was evaluated by counting the number of plants within the useful area of each experimental unit at the harvest time. Along with this, plant height was evaluated by measuring ten plants from each experimental unit.

During physiological maturation, corn ear insertion height was measured in ten plants within the useful area. In the same period and using the same plants, corn stem diameter was measured with the aid of a digital caliper, at the height of the second internode above the ground.

Corn yield components were measured on ten ears randomly collected from each experimental unit, evaluating ear diameter (with a digital caliper), ear length (with a millimeter-graded ruler), and number of grains per row. After manual threshing, ears were evaluated for 1000-grain weight, using eight 100-grain samples taken randomly from each plot (Brasil, 2009), weighed, and corrected for moisture to 13%. Finally, grain yield was obtained by weighing the grains harvested within the useful area of each experimental unit, and then extrapolating to one hectare. Grains were harvested manually, and kernels were threshed from ears by a grain thresher.

Data were subjected to analysis of variance. In case of significant difference ($p<0.05$), the means were compared by the Tukey’s test ($p\leq0.05$) for management methods, and by polynomial regression analysis for management time. Models were selected based on the highest R^2 and equation parameter significance ($p\leq0.05$), with analyses being performed by the statistical software Genes (Cruz, 2001). The data were also subjected to a principal component analysis, using the R statistical software (RStudio Team, 2020). To minimize scale effects, the data were transformed by subtracting the raw data from the mean and dividing by the standard deviation, generating standard scores (Zuber et al., 2017).

RESULTS AND DISCUSSION

Black oat dry matter averaged 4,508.38 kg ha^{-1} for desiccated straw; 4,140.56 kg ha^{-1} for rolled straw; and 3,477.93 kg ha^{-1} for crushed straw in the 2017/2018 crop season (Table 1).

TABLE 1. Averages of dry matter (Dm), final plant population (Pf), ear insertion height (Ei) in the 2017/2018 crop season, and stem diameter (Sd) in the 2018/2019 crop season as a function of black oat straw management method.

Management Method	Dm (kg ha^{-1})	Pf (pl ha^{-1})	Ei (cm)	Sd (mm)
Desiccated	4,508.38 a	65,952 b	146.24 b	22.82 a
Rolled	4,140.56 ab	67,470 ab	151.27 a	22.55 ab
Crushed	3,477.93 b	69,643 a	151.23 a	21.77 b

Means followed by different letters in the column diverge from each other by Tukey's test at 5% probability.

At the time of sowing, desiccated straw reached the highest dry mass volume. This is because plants remained upright for longer, reducing their contact area with the soil and hence with decomposing microorganisms. The opposite was observed for rolled straw, in which straw is cut, broken, and kept in closer contact with the soil surface, accelerating decomposition, and hence provinding an intermediate dry matter volume (Franchini et al., 2015; Modolo et al., 2019). The lowest dry mass was observed for crushed straw. This is because, in addition to having close contact with the soil, straw is fragmented into small pieces, considerably increasing the specific surface area of the residue, and also accelerating decomposition.

Concerning management time, in the 2017/2018 crop season, black oat managed on corn sowing day showed a higher dry matter content (5,643.80 kg ha^{-1}) due to the longer time that plants remained to accumulate biomass (Figure 2). However, this same behavior was not observed in the subsequent crop season (2018/2019) when no significant differences were observed among treatments, with the average dry matter being 3,957.50 kg ha^{-1}.

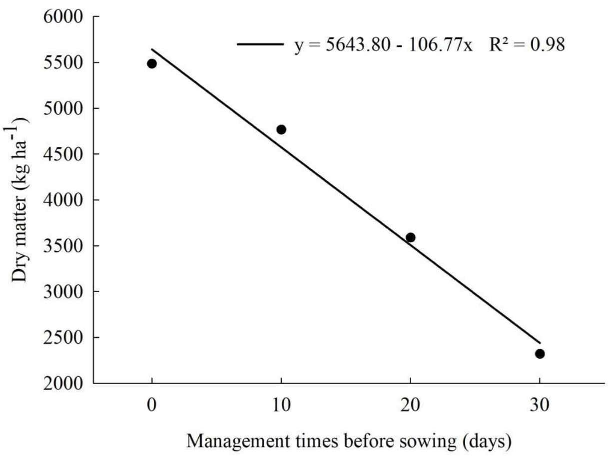

FIGURE 2. Dry matter of black oat straw (kg ha^{-1}) as a function of the management time in the 2017/2018 crop season.

A daily decrease of 106.77 kg ha^{-1} in black oat dry matter was observed after management, reaching 2,440 kg ha^{-1} after 30 days. Considering the maximum dry matter in our study, (4,508.38 kg ha^{-1}), we may infer that, once the management is carried out, producers should not wait for a period longer than 30 days due to the vulnerability of the soil to the action of raindrops and lateral water flow (Tartari et al., 2012).

In the 2017/2018 crop season, crushed straw showed a higher final plant population, but it did not differ statistically from rolled straw. In turn, desiccated straw management was the one with the lowest plant population but did not differ from rolled straw (Table 1). In the 2018/2019 crop season, no significant differences were observed for the plant population, whose average was 82,377 plants ha^{-1}.

In the 2017/2018 crop season, the largest plant population was found in crushed straw management. This discrepancy from the other methods is associated with an increased residue fragmentation, which becomes more homogeneously distributed over the soil surface. Such a condition reduces obstacles to seedling growth, at least if shading is lower, thus increasing surface temperature (Souza et al., 2016).

The largest plant population in the 2018/2019 crop season compared to the 2017/2018 crop season is related to better rainfall distribution during the corn crop cycle (Figure 1B). Since practically all seeds were deposited in the soil to germinate, the final plant stand was higher than expected. In turn, in the 2017/2018 crop season, rainfall was poorly distributed (Figure 1A).

Plant height showed no significant differences between both seasons, averaging 268.33 and 260.66 cm in the 2017/2018 and 2018/2019 crop seasons, respectively. However, rolled straw and crushed straw provided greater ear insertion heights than desiccated straw in the 2017/2018 crop season. This may be associated with the larger population found in this season, which increased shading hence plant vertical growth in search of sunlight (Santos et al., 2002).

In the 2017/2018 crop season, the highest ear insertion heights were observed in rolled straw and crushed straw methods, averaging 151.27 and 151.23 cm, respectively, while the lowest averaged 146.24 cm in desiccated straw (Table 1). In the 2018/2019 crop season, ear insertion heights showed no significant differences among treatments, averaging 159.58 cm.

In the 2017/2018 crop season, stem diameter did not vary significantly among treatments and averaged 24.4 mm. However, in the 2018/2019 crop season, desiccated straw had a higher average, but did not differ from rolled straw (Table 1). Larger stem diameters provide greater grain formation and better plant support (Gimenes et al., 2008).

Plant population also influenced stem diameter. In the first crop season, the final population was about 70,000 plants ha^{-1}, and the mean stem diameter was 24.4 mm. In the second crop season, the final population was 82,000 plants ha^{-1}, with a mean stem diameter of about 22 mm.

In the 2017/2018 crop season, both desiccated and rolled straw methods had larger ear diameters (48.13 and 48.07 mm, respectively) than crushed straw (46.69 mm) (Table 2). However, in the 2018/2019 crop season, ear diameter showed no significant differences among treatments, averaging 50.50 mm.

TABLE 2. Averages of ear diameter (Ed), ear length (El), grain number per row (Grr), and 1000-grain weight (Tgw) in the 2017/2018 crop season as a function of the black oat straw management method.

Management Method	Ed (mm)	El (cm)	Grr	Tgw (g)
Desiccated	48.13 a	16.13 a	33.93 a	324.03 a
Rolled	48.07 a	15.92 a	33.50 ab	321.73 ab
Crushed	46.69 b	15.30 b	32.43 b	314.50 b

Means followed by different letters in the column diverge from each other by Tukey's test at 5% probability.

As observed for stem diameter, plant population may also have influenced ear diameter. In the 2017/2018 crop season, crushed straw promoted the smallest ear diameters (46.69 mm on average). Such low performance may be related to the translocation of photoassimilates from the stem and leaves to the grains (Souza et al., 2016). The lowest ear diameters in crushed straw method suggest an impairment of production of photo-assimilates by competition for light (Vilela et al., 2012b; Souza et al., 2016).

In the 2017/2018 crop season, the longest ear lengths were observed for desiccated and rolled straw methods (16.13 and 15.92 cm, respectively) (Table 2). In the 2018/2019 crop season, this parameter showed no significant difference among treatments and averaged 15.30 cm.

Regarding grain number per row, management methods varied significantly in the 2017/2018 crop season, with desiccated straw reaching the highest values but not differing statistically from rolled straw (Table 2). In the 2018/2019 crop season, grain numbers per row showed no significant differences and averaged 30.55.

According to Vilela et al. (2012b), grain number per row is directly related to ear length. Our findings corroborate this statement since the largest number of grains per row in the 2017/2018 crop season was observed for the method with the longest ear lengths, namely desiccated straw, and rolled straw (Table 2). On the contrary, in the 2018/2019 crop season, significant differences were observed neither for ear length nor for grain number per row, corroborating the results of Vilela et al. (2012a).

In the 2017/2018 crop season, 1000-grain weight showed significant differences only for management methods. The highest values were observed in desiccated straw, with an average of 324.03 g (Table 2). On the other hand, in the 2018/2019 crop season, 1000-grain weight showed no significant differences among the treatments analyzed, averaging 348.48 g. The most significant 1000-grain weight found in the 2017/2018 crop season can be attributed to the set of parameters evaluated, among which ear diameter and length, as well as grain number per row (Table 2), showed the highest values in desiccated straw, contributing to 1000-grain results. Overall, the results of 1000-grain weight were higher in the second season. According to Caires & Milla (2016), any stress after flowering can affect grain weight; therefore, the lower value during the first crop season may have been due to lower rainfall in December 2017 and January 2018 (94 and 53 mm, respectively).

Average corn grain yield showed no significant differences between the 2017/2018 and 2018/2019 crop seasons, with values of 10,269.51 and 11,905.19 kg ha^{-1}, respectively. These averages are higher than the average yield of the Paraná State (9,484 kg ha^{-1}) (CONAB, 2020). Trogello et al. (2013) evaluated different vegetation cover management methods in corn crops and found no differences in crop yield.

Principal component analysis of the 2017/2018 crop season (Figures 3A and 3B) showed a high positive correlation between 1000-grain weight (Tgw), ear diameter (Ed), ear length (El), and grain number per row (grr). The analysis also points to a high correlation between final plant population (Pf), final plant height (Fph), and ear insertion height (Ei). However, both groups of variables were positioned in the opposite direction to PC 1, showing antagonism between them.

Plant height at 30 days (Ph30) and grain yield (Gy) had the highest scores on the positive axis of PC 2 (Figures 3A and 3C). Therefore, they were positively correlated to each other, i.e., taller plants at 30 days tend to be more productive at the end of the cycle.

Regarding PC 3, ear insertion height (Ei) and final plant height (Fph) showed the highest scores (Figures 3B and 3C); therefore, taller plants at the end of the cycle also tend to have higher ear insertion. However, both variables were negatively correlated with grain yield.

For the 2017/2018 crop season, the crop cover management with the highest final plant population (Pf) may not be the one with the highest grain yield (Gy). This finding is proved by the antagonistic behavior of variables such as final population (Pf), final plant height (Fph), and ear insertion (Ei), which were positioned in the negative portion of PC 1. On the other hand, variables like 1000-grain weight (Tgw), ear diameter (Ed), ear length (El), and grain number per row (Grr) were positioned in the positive portion of the axis (Figures 3A and 3B). The highly positive correlation between final population (Pf) and final plant height (Fph), along with their significant correlation with 1000-grain weight (Tgw), suggests that a large part of photoassimilates were used for cell elongation, preventing full ear development and grain filling (Vilela et al. 2012 ab; Souza et al., 2016). The same can be attributed to the other ear parameters, such as ear diameter (Ed), ear length (El), and grain number per row (Grr).

Another important result was an antagonistic behavior between dry matter (Dm) and final population (Pf), (Figure 3B); in this regard, the management methods with the highest dry matter (Dm) accumulation may not offer the best condition for plant development. Thus, an increased dry matter accumulation on the soil surface may provide obstacles to seedling growth, promoting shading and microclimate conditions that delay germination and hence plant growth (Souza et al., 2016).

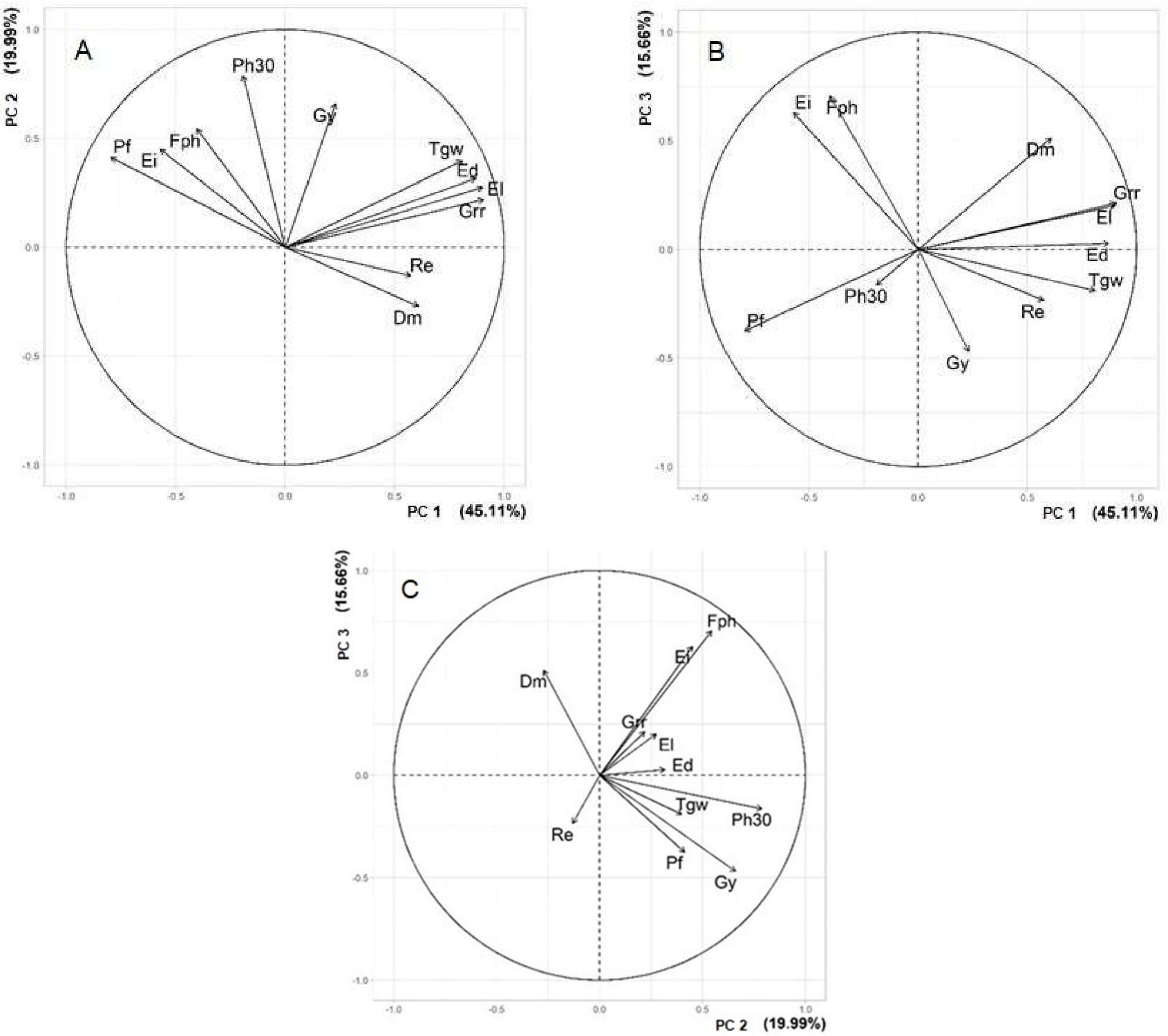

FIGURE 3. Scattering of the corn yield components in the principal component analysis for the 2017/2018 crop season (A, B, and C). Dm: Dry matter; Re: Number of rows per ear; Grr: Number of grains per row; Ei: Ear insertion height; Fph: Final plant height; El: Ear length; Ed: Ear diameter; Ph30: Plant height at 30 days; Pf: Final plant population; Tgw: 1000-grain weight, and Gy: Grain yield. PC 1 = First principal component; PC 2 = Second principal component; PC 3 = Third principal component.

In the 2018/2019 crop season, the parameters with the highest scores in PC 1 were: ear insertion height (Ei), final plant height (Fph), ear length (El), number of rows per ear (Re), number of grains per row (Grr), and grain yield (Gy). This axis shows a high positive correlation among ear formation-related variables, namely ear diameter (Ed), grain number per row (Grr), ear length (El), and the number of rows per ear (Re). It also highlights a strong positive correlation among grain yield (Gy), final plant height (Fph), and ear insertion height (Ei); therefore, taller plants at the end of the cycle have higher grain yields (Figure 4).

On the PC 2 axis, dry matter (Dm), plant height at 30 days (Ph30), and ear diameter (Ed) had the highest scores (Figures 4A and 4C). However, dry matter (Dm) and ear diameter (Ed) showed the opposite behavior in comparison with plant height at 30 days (Ph30) (Figure 4A). The angle between the lines connecting dry matter and plant height at 30 days was close to 180°, which shows their strong negative correlation, i.e., higher dry matter contents can generate shorter plants at 30 days.

On the PC 3, the final plant population (Pf) and 1000-grain weight (Tgw) showed the highest scores and positive correlation with each other (Figures 4B and 4C). Another variable positively correlated with these two variables was dry matter (Dm).

In the 2018/2019 crop season, ear formation-related parameters had a highly positive correlation (ear diameter, grain number per row, ear length, and the number of rows per ear). These variables were positioned in the positive portion of PC 1 and were negatively correlated with the final population, which is in the negative portion of PC 1 (Figure 4A). Accordingly, larger plant populations may interfere with the full ear development and grain filling (Vilela et al., 2012 ab; Souza et al., 2016).

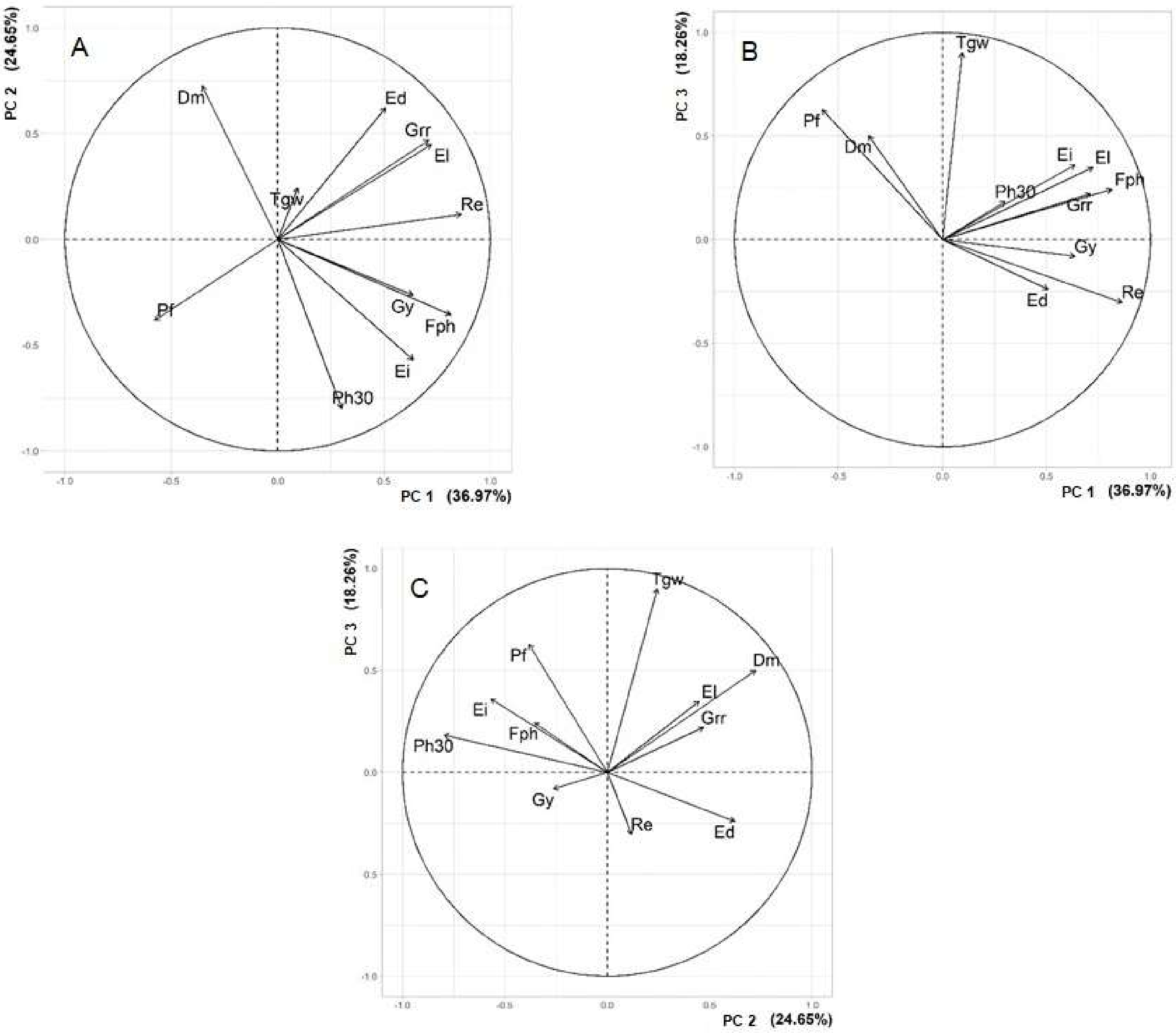

FIGURE 4. Scattering of the corn yield components in the principal component analysis for the 2018/2019 crop season (A, B, and C). Dm: Dry matter; Re: Number of rows per ear; Grr: Number of grains per row; Ei: Ear insertion height; Fph: Final plant height; El: Ear length; Ed: Ear diameter; Ph30: Plant height at 30 days; Pf: Final plant population; Tgw: 1000-grain weight, and Gy: Grain yield. PC 1 = First principal component; PC 2 = Second principal component; PC 3 = Third principal component.

Furthermore, significant antagonism between dry matter and plant height at 30 days was observed in the 2018/2019 crop season (Figure 4A). Thus, high dry matter amounts can interfere with plant development up to 30 days after germination. However, Souza et al. (2016) stated that, in the absence of drought, a positive correlation between dry matter and ear diameter suggests plant recovery from initial stress and satisfactory formation of ears, as observed in our study.

Unlike what was observed in the 2017/2018 crop season, a positive correlation between 1000-grain weight and final population was observed in the 2018/2019 crop season. Therefore, larger plant populations stimulate the formation of heavier grains, as opposed to the literature findings (Vilela et al., 2012 ab; Modolo et al., 2019). This result may be associated with a good water supply due to rainfall in the 2018/2019 crop season.

The expected grain yield (around 12,000 kg ha^{-1}) was virtually achieved in the 2018/2019 crop season. The good weather conditions and largest plant populations in the 2018/2019 crop season promoted an average grain yield almost 22% higher than in the first crop season. Conversely, despite the compensatory effect of some yield components, the average yield in the 2017/2018 crop season was about 15% lower than expected.

Lastly, in the 2017/2018 crop season, crushed straw promoted higher plant populations, but lower ear diameters, ear lengths, grain numbers per row, and 1000-grain weights; therefore, these yield components define the crop grain yield. Meanwhile, rolled straw and desiccated straw had lower plant populations, which was offset by yield components, equaling grain yield. However, none of these components showed significant differences in the 2018/2019 crop season.

CONCLUSIONS

The methods of vegetation cover management interfered with the final plant population in the 2017/2018 crop season and provided significant differences in ear insertion height, ear diameter, ear length, grain number per row, and 1000-grain weight, but not in corn grain yield.

In the 2017/2018 crop season, the vegetation cover management method with the highest final plant population did not have the highest grain production. This finding was observed by antagonistic behavior of some plant growth and population-related variables with grain filling and ear formation.

In the 2018/2019 crop season, ear formation and grain filling-related variables were strongly correlated with growth and plant population-related ones. Therefore, the photoassimilates produced were uniformly distributed between corn ears and stems than in the previous crop season. Such difference between seasons may be due to a highly favorable climate in the 2018/2019 crop season.

In terms of management time, black oat managed on the day of corn sowing reached higher dry matter contents in the first crop season.

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