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Maize yield components as affected by plant population, planting date, crop growing season and soil coverings in Brazil

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Abstract: The potential yield of annual crops is affected by management practices and water and energy availabilities throughout the crop season. The current work aimed to assess the effects of plant population and soil covering on yield components of maize. Field experiments were carried out during 2014-15 and 2015-16 growing seasons at areas grown with oat straw, voluntary plants and bare soil, considering five different plant populations (40,000, 60,000, 80,000, 100,000 and 120,000 plants ha⁻¹) and three sowing dates (15 Sep., 30 Oct., 15 Dec.) for the hybrid P30F53YH in Ponta Grossa, State of Parana, Brazil. Non-effects of soil covering or plant population on plant height at the flowering phenological stage were observed. Significant effects of soil covering on crop physiological and yield components responses throughout the 2014-15 season were detected. Influence of plant populations on yield components was evidenced, suggesting that from 80,000 plants ha⁻¹ the P30F53YH hybrid performs a compensatory effect among assessed yield components in such a way as to not compromise productivity insofar as plant population increases up to 120,000 plants ha⁻¹. It was noticed a positive trend of yield components and crop final yield as a function of plant density increments.

Keywords: *Zea mays* L; cropping system; sowing date; maize yield; multi-variates analysis

1. Introduction

Final productivity of a crop turns out to be an ultimate result of interactions among all their yield components at different agricultural ecosystems. Therefore, any environmental conditions that are conducive to variations in such components might be able to impinge significant impacts upon the expression of crop productivity at a specific-site.

For maize crop, the potential compensation among yield components might be expressed as a function of variations in plant population [1] and sowing dates [2], which will in turn condition prevailing regimes of meteorological variables throughout the whole crop growing season at a local scale [3]. Meteorological conditions in conjunction with management systems and plant populations lead to different productive potentials. [4], scrutinizing the influence of local meteorological variables associated with plant population densities, obtained coefficients of correlation of 0.93, 0.96, and 0.96 between crop productivity and cumulative solar radiation flux density, air temperature, and number of days of crop cycle, respectively. The same authors observed that different plant population densities, ranging from 75,000 and 120,000 plants ha⁻¹, culminated in maximum biological and economical yields for maize.

Impacts of local meteorological variables on maize crop growth and development may also be quite intensified by extreme environmental conditions, mainly regarding occurrence of thermal and water stress episodes throughout different physiological stages of the crop. Apart from the influence of climate and weather patterns, soil physical attributes along with agricultural management

practices can be conducive for the crop to express different productive potentials at a given specific-site [5].

Different agricultural practices with or without soil revolving operation associated with the presence and types of soil covering may also directly affect morphology and physiology of plants and yield components, as well as determine the productive potentiality of the crop in production fields. The soil physical attributes can also be consistently affected by different types of soil covering and agricultural management practices to be adopted, depending on action effective time of one or any other particular factor [6] conditioning yet soil organic carbon availability and its compartmentalization [7].

The soil covering and agricultural management practices strongly alter energy balance at soil surface, defining particular regimes of soil temperature at different depths, as well soil water storage [8] and, consequently, impact crop growth and development in turn [9]. The dynamics of water in the soil is influenced by water availability, evaporative demand of the atmosphere given by energy availability, water vapor saturation deficit, soil covering type, cropping system, and also by the sowing date at issue in order to govern local atmospheric conditions to a certain extend [9].

Throughout production cycle of crops whenever evaporative demand of the atmosphere is higher and occurrence of rainfall is not uniform and well distributed at a given site, it is largely evidenced the effect of different soil covering types on crop physiological responsiveness. In case of winter crops, the presence of mulch mitigates water losses caused by evapotranspiration along with the fact that rooting system of crops by generating bio-pores favor processes, such as infiltration and storage of water in the soil [10]. Lack of soil covering might enhance water losses in 8% average, apart from promoting fluctuations in soil temperature regime featured by variation amplitudes reaching up to 14.5°C [11]. Another important aspect with regards to sowing under straw from winter crops decomposition to be borne in mind in the face of sustainable agriculture turns out to be the suppressive action of weeds, which reduces competition periods with maize crop [12].

The physiological behavior of different crops might be changed owing to discrepancies in intraspecific competition, which is maximized by increases in plant population density. Allometry is conspicuously observed with frequency as a response of the plants to compensation ascribed to variations in plant population [13]. The relative indices of yield components and productivity have been used as a way to assess the effects of the plant population on productive potentiality of crops [14,15]. Usually conditions of less competition are to be used as a parameter for estimation of relative indices, such as Absolute Severity of Competition (ASC) [16,17] and Relative Productivity (RP) [15].

In view of operational difficulties linked to isolated assessments of only one single factor to be attributed to crop productivity, different methods have been reported in the literature aiming at finding responses from the generation of new relative variables [15] and also by means of multivariate methods [18].

Faced with the aforementioned problem, the aim of the current research was to assess the variability inherent to yield components of a corn hybrid grown under three different soil covering types and five plant population densities throughout two crop growing seasons at three distinct sowing dates, as well as identify and measure the impact of such factors on crop productivity at the region of Campos Gerais of Parana, Brazil.

2. Materials and Methods

The experiments were installed and conducted from April of 2014 at the Agricultural Experiment Station belonging to the Centro de Ensino Superior dos Campos Gerais – CESCAGE – at Ponta Grossa, State of Parana, Brazil (latitude 25° 10' 38" S; longitude 50° 06' 48" W; and altitude 820 m. The climate of Ponta Grossa is classified as *Cfb* according to Köppen, i.e., temperate climate with mean temperature of the coldest month below 18°C (mesothermal), with mild summers, mean temperature of the hottest month below 22°C e deprived of a well-defined dry season [19]. Soil of the experimental area was classified as a Typical Dystrophic Red Latosol.

In order to establish uniformity of the initial conditions of cropping system, soybean crop was sowed in October 2013 at the completely experimental area along with harvest been performed in

March 2014. On the basis of chemical analysis of soil (for soil layers ranging from 0 to 20 m-depth) from soil samples collected after soybean crop sowing date (Table 1), application of lime at surface was made shortly before implantation of subsequent winter crops at a dose of 1 Mg ha⁻¹ aiming to reach a base saturation (V%) equivalent to 60% so that soil covering formation could have taken place in the field.

Table 1. Results of soil chemical analysis from soil samples collected at the experimental area belonging to the CESCAGE. Ponta Grossa, PR, Brazil

Sand	Silt g kg ⁻¹	Clay	P mg dm ⁻³	C g kg ⁻¹	pH in CaCl ₂				
155	185	600	1.0	17.0	4.8				
Soil Sorption Complex									
Ca	Mg	K	Sum-of-bases (cmol _c kg ⁻¹)	Al	H +Al	Effective CEC	T	V %	
1,8	1,0	0,9	2,9	0.3	6.2	3.2	9,1	31.8	

The experimental design adopted to make possible to statistically analyze datasets was the one of randomized blocks in arrangement of subplots with three replications, taking into account that winter-type coverings (black oat (BO), fallow (F), without soil covering (WSC) constituted the plots, whereas plant population densities of 30F53YH maize hybrid (50%, 75%, 100%, 125% and 150% of the ideal population density corresponding to 80,000 plants ha⁻¹) constituted the subplots. The fallow-covering treatment referred to residue of the previous crop associated with voluntary plants of randomized occurrences, with variations of species and density complying with the seed banks of the area. Each plot had dimensions of 4.5 m x 5.0 m, and subplots had dimensions of 4.5 m x 10 m.

The experiment was replicated at three implantation times throughout two crop growing seasons (2014-15 and 2015-16). With the purpose of assessing variations of soil coverings and plant populations of the crop exposed to different meteorological conditions, field trials were carried out in light of three distinct sowing dates, with the first and last ones near the limits of climate zoning, and the third sowing date to be in between such a recommended period for the site in study. Thus, the sowing dates of maize crop were as follows: 15 September; 30 October; 15 December, meant to vary from year to year as a function of local climate and weather conditions prevailing at a specific-site.

In April of 2014 black oat crop was planted taking into consideration the row spacing 0.13 m at a density of 50 kg ha⁻¹ along the strips meant to receive such a type of soil covering. At the same time bare soil was managed by means of chemicals and/or manually at minimal intervals of 15-days without soil revolving operations. In the fallow plots, voluntary plants were assessed at three periods shortly before dissection: 30 days after black oat sowing, 45 days after first evaluation, and 7 days before dissection.

Chemical management of the experimental area with herbicides at both black oat and fallow plots was performed 30 days before sowing of the first sowing date. After management and shortly before sowings of each sowing date, production of dry mass was assessed in the field by collecting 0.5 x 0.5-m squares of plant material present at soil surface (3 sample squares per plot) and drying them in a stove in order to determine dry mass by means of a precision scale.

Planting of maize seeds in the field was done with a 5-row sower spaced at 0.45-m apart. The maximum plant population density corresponding to 120,000 plants ha⁻¹ was taken into account and, therefore, corrected for germination and seed vigor, demanding thinning 7 days after emergency in order to achieve the threshold of further plant population densities and to be allotted randomly in the subplots. Basic soil fertilization comprised 400 kg of a 10-20-20 formulation along with application in bands of 120 kg ha⁻¹ of urea between V4 and V6 phenological stages in light of haul applications. Further phytosanitary practices were adopted in accordance with crop conventional management practices for each sowing date.

The useful area of every single plot was considered to be comprised of 6 central rows of 8-m length. Morphological characteristics of the plants along with relative indices of growth and development from four marked plants, chosen randomly after implantation of the crop were evaluated. Such assessments

were made weekly after emergency up until V6 phenological stage. Shortly after such a phenological stage, further evaluations were performed throughout the following stages: tasseling (R1) and pre-harvest (physiological maturity – R6).

At the end of crop cycle harvest was performed in isolation for the 4 plants under assessment and further plants from the useful area of the plot had their cobs harvested and flailed separately to provide yield calculations. From the 4 cobs harvested separately the following maize yield components were assessed: plant height (from the ground to the insertion of the tassel), cob length (CL) and cob diameter (CD), mean number of rows per corn cob (MNRCC), number of grains per row (3 rows per cob) (MNGR), weight of a thousand seeds (WTS), total mass of grains per cob (afterwards adjusted for 13% moisture) (CGM), as well as weight and diameter of the stalk, straw mass either fresh or dry masses (samples kept for 48 hours in ventilated stove at 60°C).

With the purpose of comparing effects of plant population and soil covering types on crop maize yield components, absolute severity of competition (ASC) was calculated by means of equation 1 [16,17], whereas relative productivity (RP) was obtained through equation 2 [15].

$$ASC_i = \log \left(\frac{ME_l}{ME_i} \right) \quad (1)$$

Where: ME_l is the mass of grains of the cob from the smallest population and ME_i is the mass of grains of the cob from the population in analysis.

$$RP = \frac{P_l}{P_i} \quad (2)$$

Where: P_l is the productivity of grains from the smallest population and P_i is the productivity of the mass of grains from the population under scrutiny.

Meteorological data were monitored by an automatic weather station from Campbell Scientific Inc. installed at the experimental area of the field trials. The weather station constituted of a datalogger CR-1000, which recorded regimes of net radiation (R_n), global solar radiation (Q_g), photosynthetically active radiation (PAR), air temperature (T_{air}), soil temperature (T_{soil}) measured at 0.10, 0.20 and 0.30-m depth, air relative humidity (RH), and atmospheric pressure (P_{bar}). Meteorological variables were recorded within the interval of 15 minutes and integrated afterwards. Net radiometer with no dome model NR LITE, (Kipp & Zonen trademark), was installed and leveled at 1-m height at a grassed area. Q_g values were obtained by means of a silicon photodiode pyranometer fabricated by LI-COR, model LI-200X, with spectral responsiveness within 0.4 and 1.2 μm interval set up at 2-m height. PAR fraction was measured by means of a Quantum sensor, model LI-190SB (LI-COR trademark), with a spectral responsiveness within 0.4 and 0.7 μm interval, installed at 2-m height. Air relative humidity and air temperature were determined by the sensor HMP45C Temperature and Relative Humidity Probe fabricated by Vaisala, being installed at 2-m height inside the meteorological shelter. Atmospheric pressure was monitored by means of a sensor CS106, (Vaisala trademark). Records of rainfall were made by a bascule pluviometer model TB4, fabricated by the Hydrological Services Pty. Ltd., with a 0.254 mm precision and installed at 1.5-m height.

Water balance calculations were made throughout the entire maize crop growing season for each one of the sowing dates by means of the simplified Penman approach to determine potential evapotranspiration (ETo) [20]. Available water capacity (AWC) was calculated from soil physical attributes obtained from soil analysis taking into consideration unreformed samples collected at two different soil depths (0 – 10 cm; 10 – 20 cm). Cultural practices were performed in compliance with the schedule illustrated by the Figure 1.

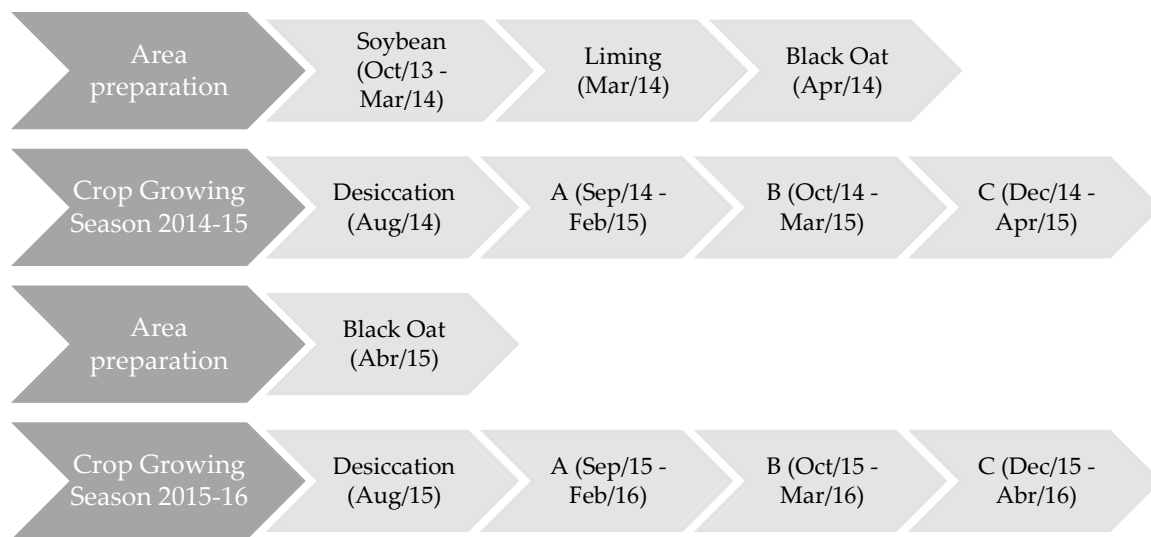


Figure 1. Schedule of activities conducted in the field throughout two crop growing seasons at Ponta Grossa, PR, Brazil.

The initial analysis of the data set obtained from the current study aimed at determination of dry phytomass production ascribed to distinct soil covering types. In this particular case, an exploratory scrutiny on experimental data was performed in order to come up with mean accumulation of dry mass and variability indices, such as standard deviation, average standard and coefficient of variation at each sowing date throughout both maize crop-growing seasons.

The effect of plant population, winter soil covering type and interactions between factors on final yield was previously tested by the application of F test. For sowing dates with significant interaction between plant population and soil covering type, experimental data were subjected to the Student-Neuman-Keuls (SNK-test), which highlighted multiple comparison among averages attributed to the treatments adopted herein in conjunction with control of rates of type I error in the trial in the face of a complete nullity hypothesis (H_0); however, considered to be flexible under partial H_0 .

Furthermore, it was applied to experimental data related to the corn crop yield, the multivariate analysis technique, more specifically the factor analysis method, whose main objective is to reduce the number of variables to a reduced number of factors, by extracting the maximum common variation of all variables and as places in a common score [21]. For such, we performed data correlation analysis on mean number of grains per row (MNGR), number of rows (NR), weight of a thousand seeds (WTS), cob length (CL), cob diameter (CD), cob grain mass (CGM) at each sowing date throughout the 2014-15 and 2015-16 growing seasons. Experimental data were standardized so that average 0 (zero) and standard deviation 1 (one) were meant to mitigate effects of numerical differences among variables in such a way as to make them dimensionless.

With the purpose of detecting combined effects of different treatments on response variables, the multivariate analysis of variance (MANOVA) was applied to experimental data [22]. Nevertheless, in order to guarantee its applicability with precision at a given site it is necessary to seek multivariate normality for scientific confirmation purposes, which was obtained from the test proposed by [23,24].

By applying MANOVA to the sowing dates throughout the 2014-15 and 2015-16 growing seasons, comparison among levels of the factor in study was made by means of orthogonal contrasts ($C_1 = 2Y_{NT} - Y_F - Y_{BS}$; $C_2 = Y_F - Y_{BS}$) along with application of the Pillai's trace statistic ($P \leq 0.05$). The Pillai's trace statistic assumes positive values ranging from 0 to 1, within which increasing values means that effects of factors are contributing more effectively among variables [25,26].

Finally, analysis of principal components (AMC) was taken into account to provide reduction of number of variables plus congregation of factor effects under scrutiny. In view of such a statistical tool, firstly experimental data set was grouped in compliance with sowing dates and crop growing

seasons. Thus, we considered the criterion of selection that was conducive to variance greater and/or equal to 70%, which in turn culminated in the utilization of CP₁ and CP₂ components for all possible combinations of sowing date and crop growing season factors.

3. Results and Discussion

3.1. Thermal, hidric and soil coverage aspects

Fluctuations as to the number of days between sowing and flowering were observed, being such a variation more pronounced when 75% of the plants presented effective emission of tassel. There was no effect of soil covering types and plant populations on flowering date of maize crop throughout none of the crop growing seasons (Table 2). The variation of sowing date generated reductions in the number of days between emergency and flowering with values of 84, 70, 62 days for sowing dates A, B, and C of 2014-15 growing season, as well as of 77, 63, 60 days for sowing dates A, B, and C of 2015-16 growing season, respectively, corroborating thus the outcomes obtained by [27] for the same phenological stage in light of different hybrids and sowing dates. The P30F53YH hybrid considered in the trials showed plants mean height corresponding to 2.23 m, which did not differ from that found by [28] (Table 2).

Table 2. Sowing dates, flowering dates, thermal constant (°C day) and mean plant height (m) for three different times throughout both the 2014-15 and 2015-16 crop growing seasons. Ponta Grossa, PR, Brazil.

Crop season	Sowing date	Flowering	Thermal constant °C day	Mean Plant Height m plant ⁻¹
2014-15	15/Sep/2014	08/Dec/2014	851.65	2.26
	30/Oct/2014	08/Jan/2015	815.77	2.40
	15/Dec/2014	15/Feb/2015	794.36	2.54
2015-16	15/Sep/2015	01/Dec/2015	834.29	1.98
	30/Oct/2015	01/Jan/2016	728.59	2.06
	15/Dec/2015	13/Feb/2016	776.26	2.12
Average	--	--	800.15	2.23

By means of the 5-day period sequential climatological water balance elaborated for two agricultural harvests we came up with soil water storage (SWS) and available water capacity (AWC) ratio (Figure 2). In the view of such a ratio it is possible to detect discrepancies between harvests (2014-15 and 2015-16), as well as significant variations in soil water availability during some critical periods as a function of sowing date. SWS/AWC ratios lower than 1 depict water deficiency at different soil layers.

Relationships between soil water availability and water-energy status in the atmosphere in such a way as to associate high availability with greater water use efficiency, highlighting the importance of an amount of water within the available easily water interval to assure potential yields in production fields have been a conspicuous target of concern in several scientific investigations dealing with irrigation and crop production [29,30]. Soil management practices impinge upon water availability to crop radicular system, which in turn affect crop productive potential, as well as its estimation in light of several modeling approaches [31]. The impact of water stress might interact with plant population density as demonstrated by [32], who found a parabolic physiological responsiveness between plant population and crop yield in conjunction with water use efficiency.

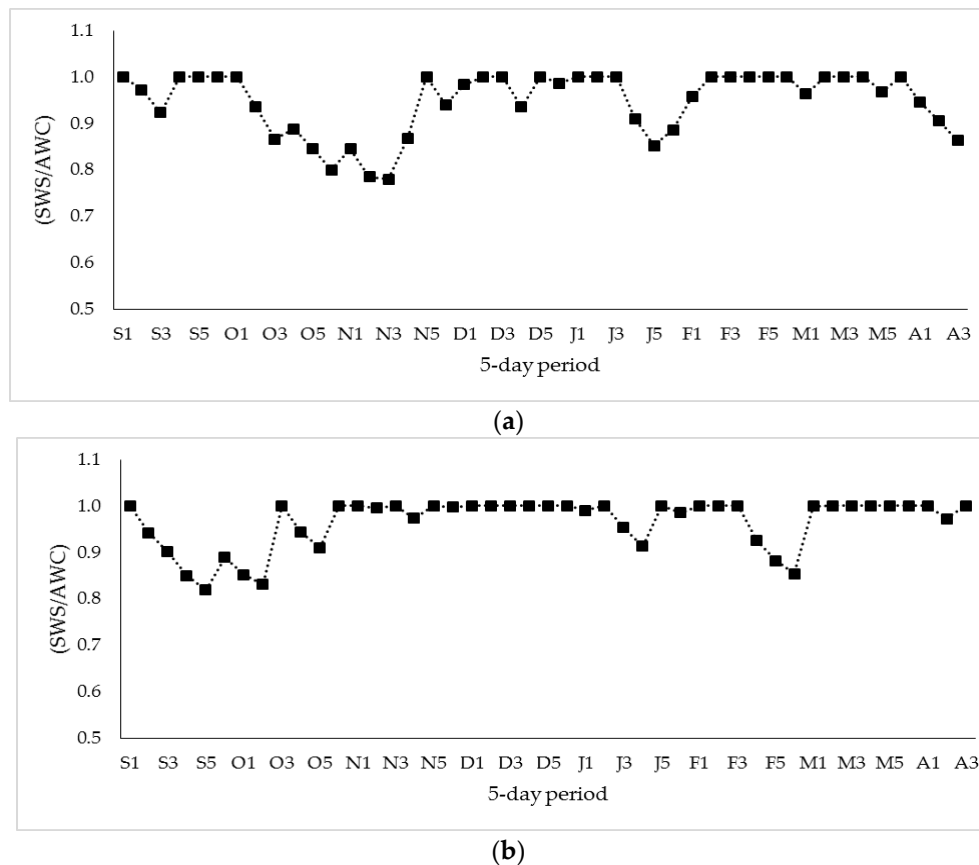


Figure 2. Soil water storage (SWS, mm) and available water capacity (AWC, mm) throughout the crop cycle for the 2014-15 (a) and 2015-16 (b) harvests. Ponta Grossa, PR, Brazil.

Assessing the dry mass produced by black oat and by fallow treatment soil covering before maize sowing throughout crop growing seasons, it was observed lower coefficients of variation for production of dry mass of black oat straw and fallow treatment throughout the 2014-15 than those obtained during 2015-16 growing season (Table 3). Similar results were finding by [33] assessing productions of dry matter of black oat straw under different doses and application times of nitrogen. Conversely, [34] came up with averages higher than 4.0 Mg ha^{-1} for productions of dry matter of black oat along with values higher than 1.0 Mg ha^{-1} for dry matter produced from fallow plots in a field trial conducted at the State of Parana, Brazil.

Table 3. Averages of production of dry mass (Mg ha^{-1}) at plots featured by black oat covering and by fallow treatment at different sowing dates throughout the 2014-15 and 2015-16. Ponta Grossa, PR, Brazil.

Sowing dates	Black oat dry mass (Mg ha^{-1})						
	15/Sep/2014	30/Oct/2014	15/Dec/2014	15/Sep/2015	30/Oct/2015	15/Dec/2015	
Average	2.84	2.81	2.92	2.74	2.66	2.73	
Stand. Deviation	0.20	0.24	0.22	0.24	0.28	0.27	
Average Stand. Error	0.09	0.11	0.10	0.11	0.12	0.12	
CV (%)	7.00	8.46	7.40	8.88	10.47	9.82	
	Fallow treatment dry mass (Mg ha^{-1})						
	Average	0.46	0.45	0.45	0.59	0.58	0.58
	Stand. Deviation	0.04	0.03	0.03	0.07	0.05	0.05
	Average Stand. Error	0.02	0.02	0.01	0.03	0.02	0.02
	CV (%)	7.34	6.54	7.14	11.13	9.12	9.42

Productions of dry matter from black oat straw and from the plots under fallow soil covering revealed significant differences between treatments throughout both crop growing seasons, with higher average productions for black oat straw treatment corresponding to 2.84 and 2.74 Mg ha⁻¹, respectively, throughout the 2014-15 and 2015-16 crop growing seasons, as opposed to productions of 0.46 and 0.59 Mg ha⁻¹ under fallow treatment, respectively, during both crop growing seasons (Table 3).

3.2. Assessment of productivity of maize crop

The effect of plant population, winter soil covering and interactions between factors on final yield was previously tested by the application of F test. A significant impact on yield was found for all plant populations irrespective of the sowing date. The opposite was observed by analyzing the soil covering types where a consistent interference was observed only during the 15/Dec/2014 sowing date. However, the effect of interaction between plant population and winter soil covering at the second and third sowing dates throughout the 2014-15 crop growing season, as well as at the first sowing date during the 2015-16 agricultural harvest (Table S1) was detected.

A comparative analysis between different soil covering types in the face of statistical breakdown of factor interactions resulted in differential responses of the crop given the influence of sowing dates and plant populations (Table 4). This suggests that there must not be a standard pattern of crop productivity under a specific soil covering type. Especially throughout the 2014-15 harvest, a proclivity towards a high productivity under black oat straw soil covering (BO) at the first sowing date (A) in contrast to soil covering with voluntary plants (F) for the third sowing date (C) was evidenced.

Table 4. Average of maize productivity (kg ha⁻¹) for the sowing dates with significant interaction between plant population and soil covering throughout the 2014-15 and 2015-16 crop growing seasons. Ponta Grossa, PR, Brazil.

Plant Population ² (plants ha ⁻¹)	Sowing date ¹								
	30/Oct/2014			15/Dec/2014			15/Sep/2015		
	NT ³	BS	F	NT	BS	F	NT	BS	F
40,000	3,530.8 a	3,618.5 a	2,420.5 a	5,393.9 b	7,148.0 a	6,136.0 ab	7,132.4 a	6,966.5 a	8,198.4 a
60,000	6,785.0 a	5,478.1 a	6,785.7 a	8,634.4 b	9,471.0 b	14,138.4 a	8,640.5 a	7,962.7 a	9,887.7 a
80,000	5,891.2 a	5,133.4 a	4,371.8 a	7,257.4 c	10,432.9 b	12,440.3 a	11,681.7 a	11,409.9 a	13,779.3 a
100,000	13,778.4 a	7,708.9 b	4,630.8 c	17,123.9 a	13,087.8 b	11,646.8 c	12,754.3 a	11,257.5 a	14,354.7 a
120,000	6,561.9 a	6,835.2 a	7,296.6 a	11,282.0 c	12,931.4 b	18,021.7 a	15,202.5 a	12,917.0 a	16,995.9 a

¹ Sowing date related to significant interactions obtained by F-test application (Table 1S). ² Averages followed by the same letters in the line did not differ from one another under the same plant population treatment by means of the SNK-test ($P \leq 0.05$). ³ Abbreviations refer to soil covering treatments at field trials: NT – Non-Tillage. BS – Bare Soil. F – Fallow.

Such a trend might be ascribed to a more prevailing availability of water in the soil at the third sowing date of 2014-15 season, from December to March, in comparison to the first sowing date from September through January. The water availability in the area can be expressed by SWS/AWC ratios (Figure 2). Given the protective characteristics of straw in conjunction with reduction in losses triggered by evapotranspiration rates as opposed to areas with little or non-protection at all during periods with a lesser water availability, soil covering type was conducive to better environmental conditions for the plants to develop initially. Conversely, at the third sowing dates growth and development of the plants coincided with a period of high soil water availability as pointed out by the climatological water balance approach. It is well known that relative growth rates of the plants at

plots with no soil coverings or with a lesser covering density tends to be higher as a function of a greater input of solar energy at the canopy level [8,9].

The winter soil coverings whenever correctly managed promote increase in soil water infiltration along with soil water storage as a consequence of depletions in evapotranspiration rates [35], as well as an increment in soil organic carbon contents. We may infer that in the face of soil water status at appropriate levels throughout the whole crop cycle during the 2015-16 agricultural harvest the potential protective effect of winter soil covering types might have been masked by soil water status.

The yield components, such as mean number of grains per row (MNGR), number of rows (NR), weight of a thousand seeds (WTS), cob length (CL), cob diameter (CD), cob grain mass (CGM) had distinct performances under the influence of each sowing date and soil covering type, as well the interaction between such yield components was demonstrated to be quite variable (Figure 3 to 5).

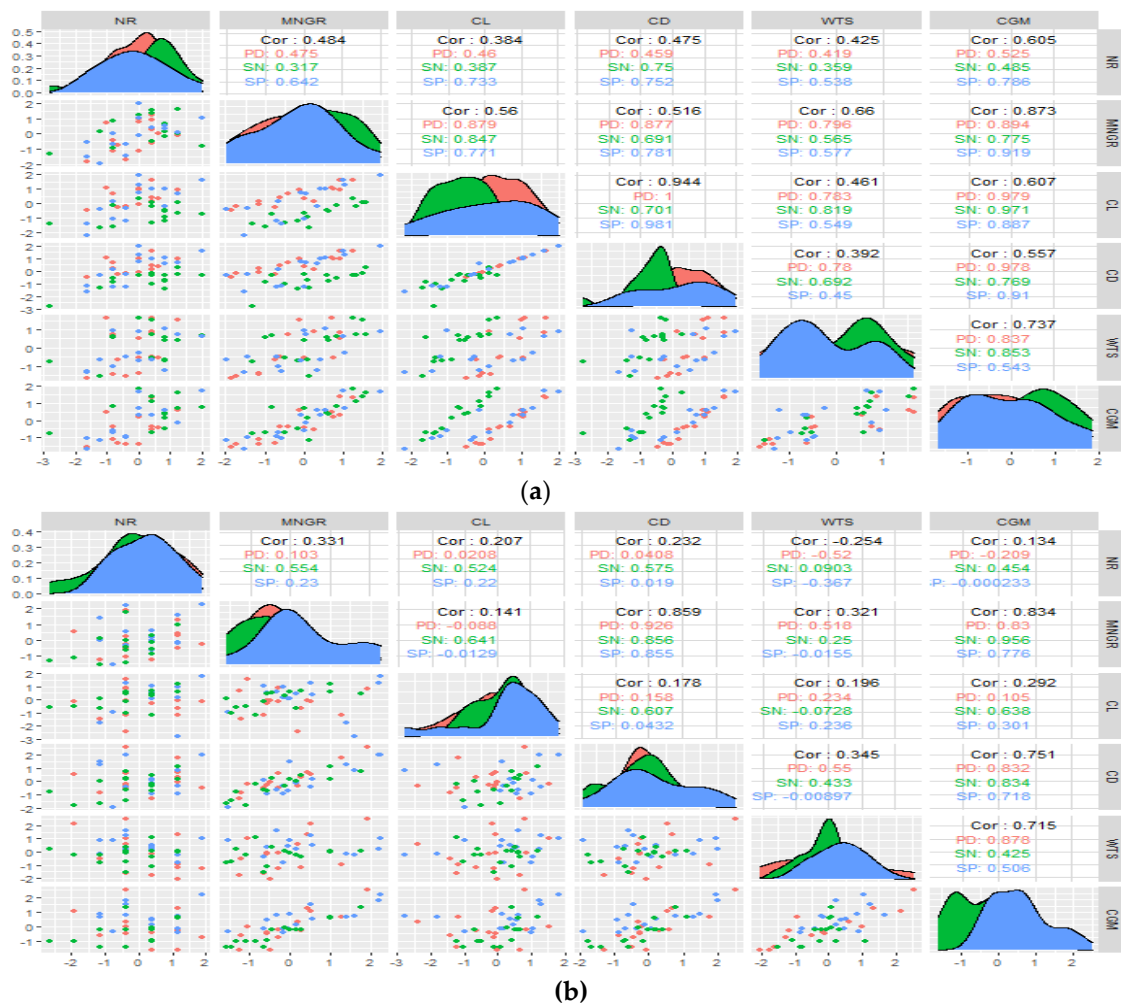


Figure 3. Matrix of correlation for all of yield components of maize for the September 15 sowing date throughout both 2014-15 (a) and 2015-16 (b) crop growing seasons ($r \geq 0.294$, p -value ≤ 0.05).

Although discrepancies in dry matter production due to the use of different soil covering types, [34] did neither find differences among morphological attributes (plant height, height of insertion of the cob, stalk diameter) nor among characteristics linked to the yield components (cob diameter, cob length, mean number of rows per cob, mean number of grains per cob) of maize crop as a function of soil covering type. This denotes that, many times, both morphological attributes and crop yield components are subjected to other sources of variation other than those ones imposed in the experiment under scrutiny.

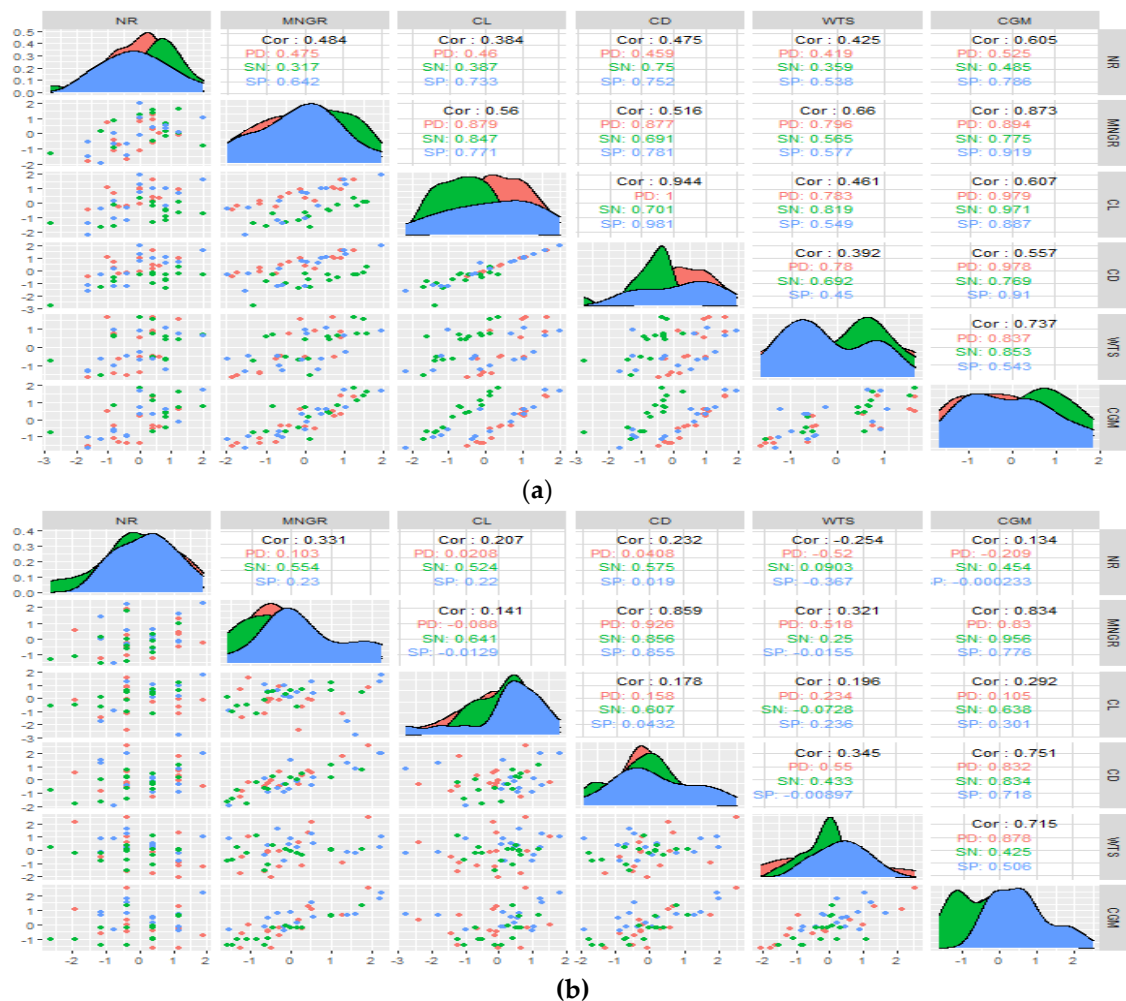


Figure 4. Matrix of correlation for all of yield components of maize for the October 30 sowing date throughout both 2014-15 (a) and 2015-16 (b) crop growing seasons ($r \geq 0.294$, p -value ≤ 0.05).

Cob grain mass (CGM) evidenced a strong correlation with all of response variables at issue. For the first sowing date throughout the 2014-15 crop growing season it was possible to verify a conspicuous distinction between bare soil (BS) treatment and other types of soil coverings, as well as in light of a correlation study between CGM and cob length (CL), a fact that might be confirmed by means of mean values obtained for each yield component (YC) (Figure 3a). In this particular study, even from the view of obtaining lower YC values, a thousand grain mass (TGM) was always higher resulting, as a consequence, in higher CGM values.

For both crop growing seasons in study, a reduction in coefficients of Pearson correlation (r) was observed whenever CGM was compared to all of other response variables from plots subjected to different sowing dates used in the present study. In spite of the fact that most of such coefficients showed to be significantly different from zero (p -value ≤ 0.05) variability inherent to YC substantially increased as a function of distinct sowing dates, whereas correlation degree decreased under the influence of sowing date treatments. Increases in variability make difficult, in an isolated manner, determination of YC in order to explain the cause of total variability of observed crop productivity at a given specific-site.

In general, reductions in mean number of grains per row along with cob grain mass were noticed as a function of increments in plant population density and sowing date (Figures 3, 4 and 5). In average, such reductions were of 5.6%, 15.4%, and 12.2% throughout the 2014-15 crop growing season, whereas for the 2015-16 harvest depletions were corresponding to 8.6%, 19%, and 22.1%, respectively, with regards to mean number of grains per row, weight of a thousand seeds, and cob grain mass.

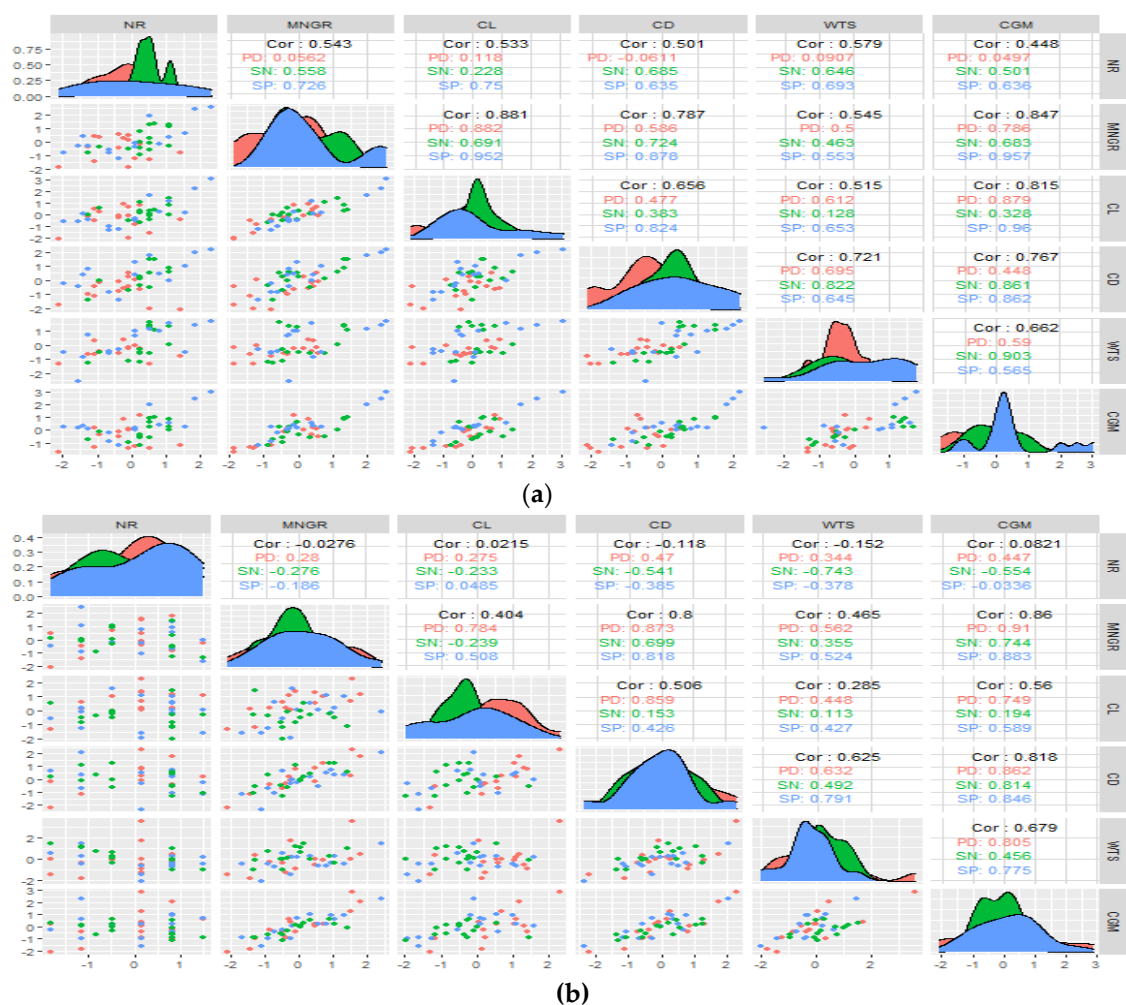


Figure 5. Matrix of correlation for all of yield components of maize for the December 15 sowing date throughout both 2014-15 (a) and 2015-16 (b) crop growing seasons ($r \geq 0.294$, $p\text{-value} \leq 0.05$).

Considering that the final crop productivity turns out to be a resulting of conjunct action of effects of yield components yoked to plant population, MANOVA comes to being a powerful tool to detect combined effects of different treatments on response variables evaluated from field trials. Nevertheless, in order to assure its applicability with precision at a given specific-site it is necessary to seek multivariate normality for scientific perspectives. This might be obtained from application of the test proposed by [23,24]. Such a test was ascribed to the three sowing dates under three distinct soil covering types throughout both 2014-15 and 2015-16 agricultural harvests, confirming multivariate normality for all combinations of the studied factors (Table 5).

By applying MANOVA to the sowing dates throughout both agricultural harvests (2014-15 and 2015-16) comparison among levels of the factor in study was made by means of orthogonal contrasts ($C_1 = 2Y_{NT} - Y_F - Y_{BS}$; $C_2 = Y_F - Y_{BS}$) along with application of Pillai's trace statistic [25,26] (Table 6).

The presence of a previous crop before maize implantation in the field might provide increments in profitability and crop yield, as well interfere on agronomical recommendations in conjunction with utilization of fertilizers, particularly nitrogen fertilizers. Either C_1 or C_2 contrasts demonstrated to be significant for the sowing date A throughout the 2014-15 harvest, whereas solely C_1 contrast turned out to be significant for the same sowing date throughout the following agricultural harvest. Effects of soil covering types provided averages of yield components (Figure 3 to 5) proportionally equivalent. Nevertheless, for cob grain mass (CGM) values consistent discrepancies among soil coverings were detected throughout both harvests, whilst the lowest CGM values were found in plots that received NT treatment. Such effect might be ascribed to the competition among corn plants for nitrogen generated from straw decomposition as preconized by [36], whose authors evidenced substantial reductions in maize yield components at plots receiving winter soil covering-type.

Table 5. Results of multivariate normality test on applied to the following variables: mean number of grains per row, mean number of rows per corn cob, number of rows per cob, cob length, cob diameter, a thousand grain mass, and cob grain mass under different soil covering throughout the 2014-15 and 2015-16 crop growing seasons. Ponta Grossa, PR, Brazil.

Sowing date	Soil covering type ¹					
	NT		BS		F	
	H ²	p-value	H	p-value	H	p-value
15/Sep/2014	2.199	0.375	8.181	0.067	3.455	0.303
30/Oct/2014	2.565	0.434	5.495	0.174	4.126	0.318
15/Dec/2014	4.878	0.262	8.424	0.070	7.617	0.050
15/Sep/2015	5.349	0.158	2.455	0.566	4.204	0.329
30/Oct/2015	4.147	0.2667	3.631	0.0468	7.089	0.054
15/Dec/2015	4.093	0.221	1.044	0.886	1.166	0.758

¹ Abbreviations refer to a soil covering treatments from field trials: NT – Non-Tillage. BS – Bare Soil. F – Fallow. ² H-statistic proposed by [23,24].

Table 6. Result of the Pillai's trace statistic applied to contrasts c_1 and c_2 of MANOVA for the sowing dates throughout the 2014-15 and 2015-16 crop growing seasons. Ponta Grossa, PR, Brazil.

Sowing date	c_1 (p-value)	c_2 (p-value)
15/Sep/2014	0.00825*	0.03572*
30/Oct/2014	0.18215	0.00455*
15/Dec/2014	0.00057*	0.00000*
15/Sep/2015	0.01919*	0.60900
30/Oct/2015	0.06305	0.52294
15/Dec/2015	0.07478	0.11544

* significant at 5% reliability by the Pillai's trace statistic.

Presence of remaining soil coverings also govern evapotranspiration rates in field productions, which usually are higher the more experimental plots are deprived of any soil covering-type. Conversely, under optimal water supply conditions (water balance positive throughout most of the crop growing season) and/or at irrigated areas the impacts of lack of soil coverings become less important as reported by [37,38], as long as soil water supply comes to being rather greater than crop maximum evapotranspiration and soil physical attributes along with soil status itself promote water storage within the soil profile in order to be available to the roots of the plants.

Under bare soil conditions energy balance is conducive to remarkable fluctuations in soil temperature at different depths [39] causing, thus, energy availability to be higher to trigger germination, emergency and initial development of maize plants. Such an evidence was confirmed by [40], whose scientific investigation demonstrated that soil temperature, energy availability and emergency speed of maize seedlings are directly correlated in such a manner as to provide the proposition of mathematical models capable of describing the dynamics of emergency of maize seedlings under production field conditions.

It is possible to notice by means of orthogonal contrasts, which allow detecting influences of different soil covering-types on maize yield components (Table 6), that the effect of such a factor considerably varies as a function of agricultural harvests, revealing, therefore, that eventual interactions occur owing to prevailing local atmospheric conditions throughout the whole crop growing season. Specifically, for the third sowing date of 2014-15 crop growing season either c_1 or c_2 highlighted significant statistical differences between contrasts, a fact that was not observed during

the next crop growing season. This might be explained by the existence of a significant interaction for the first crop growing season (Table 1S), contrasting with what was observed throughout the second season when only plant population impinged upon productivity, since there is a conspicuous interconnection between productivity and yield components under scrutiny.

From the Analysis of Principal Components (AMC) by proceeding analysis of variance with application of F Test for CP₁ (A-2014-15) and CP₂ (A-2015-16) we came across the inexistence of isolated effects of soil covering-types and also plant population-densities, as well as of effect of interaction between such factors on the main yield components. For CP₂ (A-2014-15) and CP₁ (A-2015-16) a significant effect of plant population on biological response of maize crop was examined (Figure 6). The outcomes obtained in our study agree with what was reported previously, once non-significant effects of soil covering-types were detected in isolation on productivity of maize crop for the first sowing date of 2014-15 season (Table 1S).

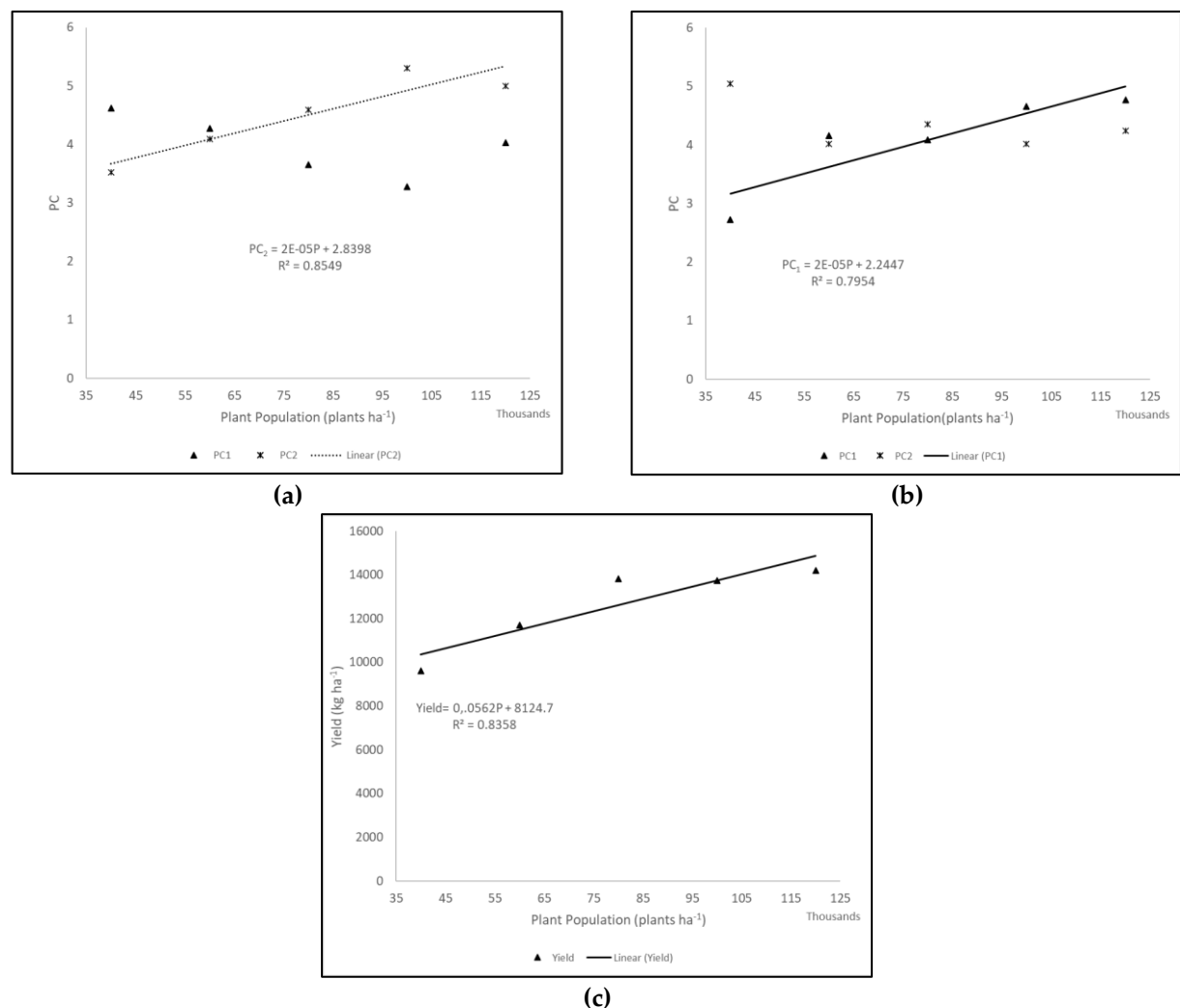


Figure 6. Performance of the principal components for the September 15 sowing date throughout the 2014-15 (a) and 2015-16 (b) crop growing seasons and productivity (c) for the first sowing date throughout the 2014-15 harvest. Ponta Grossa, PR, Brazil

The performance of CP₂ for the first sowing date throughout both crop growing seasons in study evidenced to be similar to productivity, being increasing with increments in plant population. Even in view of depletion of some yield components alone, the augmentation in number of plants resulted in compensational effect, leading to rises in productivity.

For CP₁ (B – 2014-15 and B – 2015-16) a significant effect of the plant population factor was acknowledged (Figure 7). Such results are in consonance with what illustrates Table 6, which highlighted absence of any significant effect of soil covering-types on maize crop yield components.

On the other hand, for CP₂ throughout both agricultural harvests we detected neither isolated effects of soil coverings and plant populations nor interaction effects between such factors.

For the sowing date C throughout the 2014-15 crop growing season, neither isolated effects of sowing dates and plant populations nor interaction effects for each one of the yield components under scrutiny were observed. However, for the 2015-16 crop growing season CP₁ revealed an increasing and linear response as a function of increments in plant populations (Figure 8).

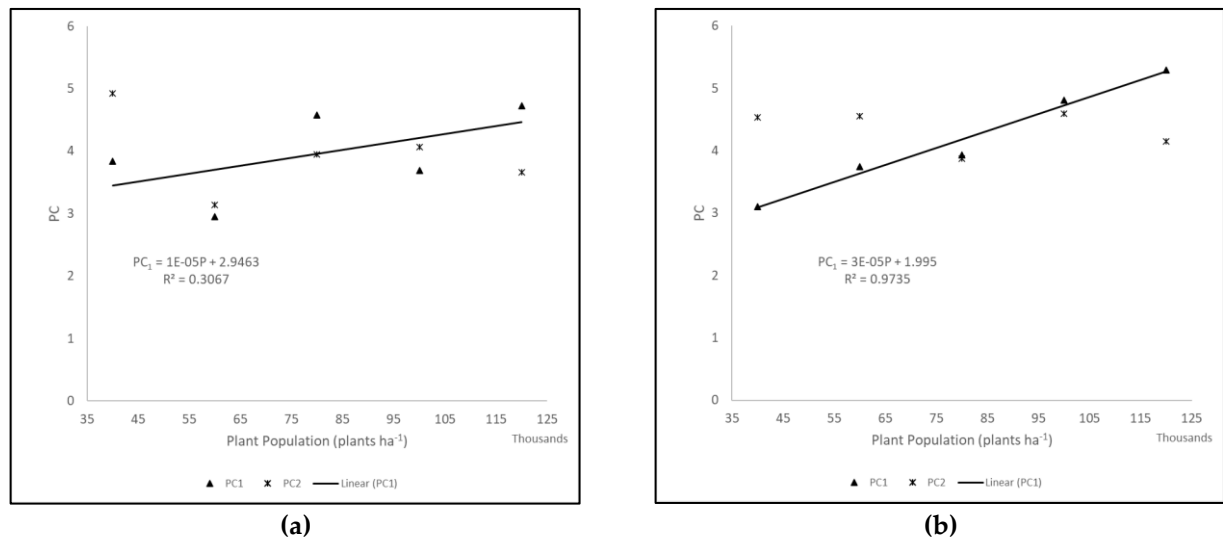


Figure 7. Performance of the Principal components for the October 30 sowing date throughout the 2014-15 (a) and 2015-16 (b) crop growing seasons.

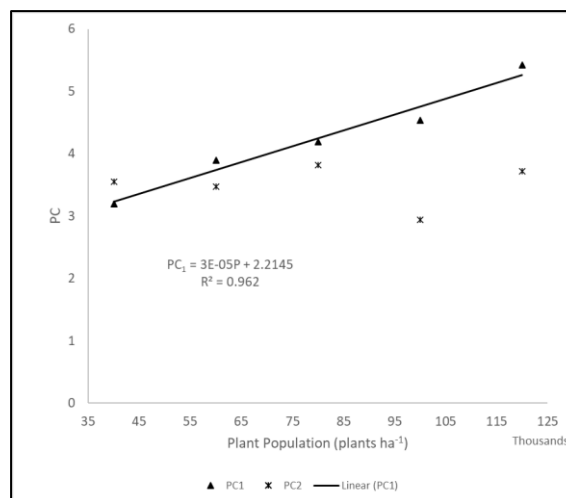


Figure 8. Performance of the principal components for the December 15 sowing date throughout the 2015-16 crop growing season. Ponta Grossa, PR, Brazil

The analysis of both relative indices, such as ASC and RP [15] culminated in distinct responses in the face of sowing date, crop growing seasons and soil covering-types factors. For the sowing dates of September and October of 2014-15 crop season, upward variations in ASC indicates that there was a drop in corn cob mass owing to increments in plant populations. Moreover, a substantial reduction in such a response variable under the influence of rises in plant populations were noticed, with stabilization being achieved from plant populations above 80,000 plants ha⁻¹ threshold (Figure 9).

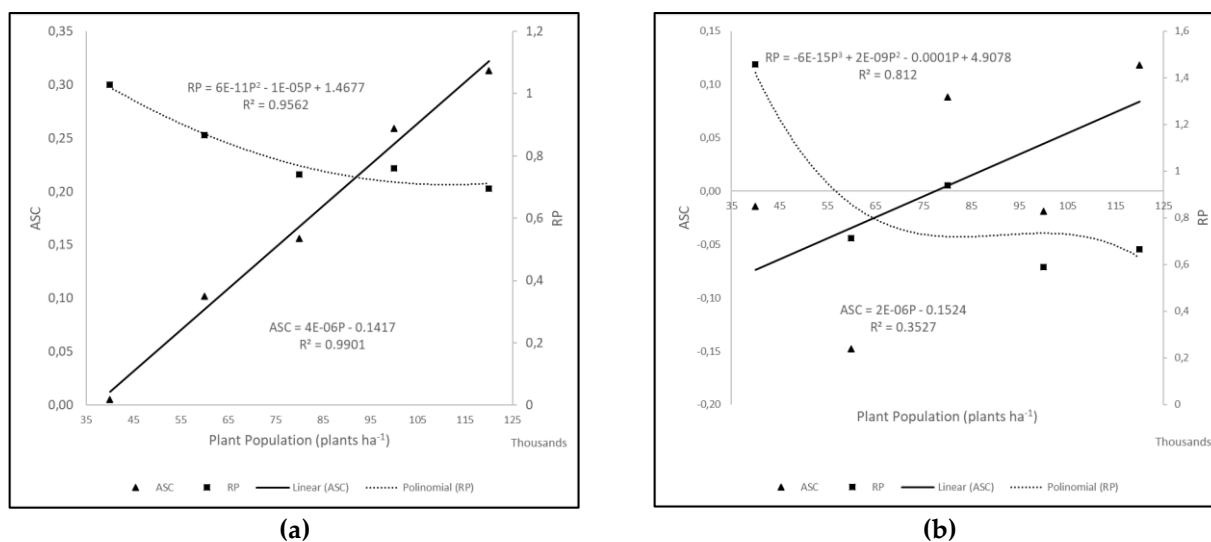


Figure 9. Variations in Absolute Severity of Competition (ASC) and Relative Productivity (RP) for the sowing dates of September 15 (a) and October 30 (b) throughout the 2014-15 crop growing season.

For the third sowing date of the 2014-15 crop growing season, performance of ASC was very variable as a function of soil covering-types. RP values pointed out a proclivity to depletions of such a response variable, leading to a minimal threshold plant population of roughly 120,000 plants ha⁻¹ (Figure 10).

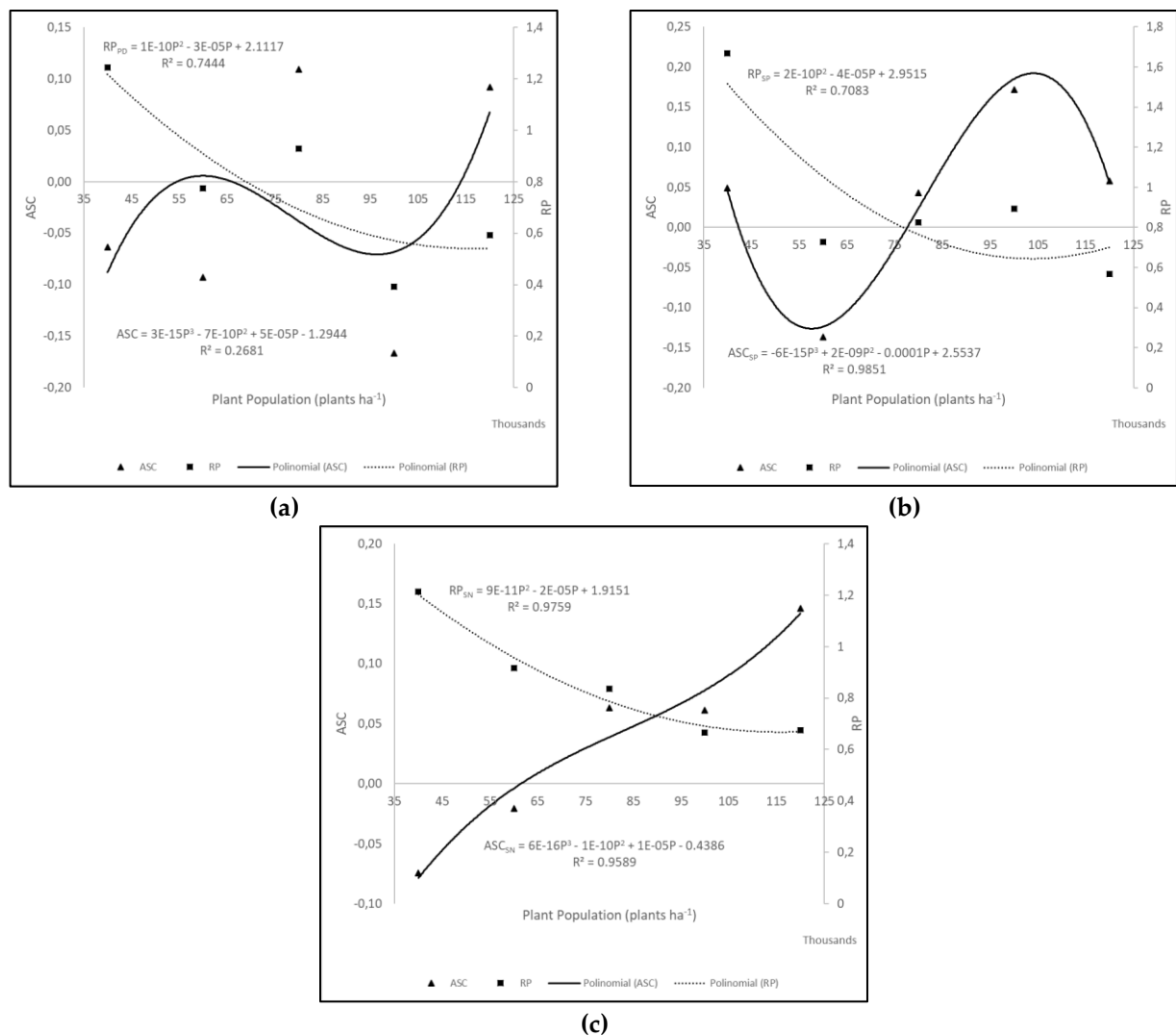


Figure 10. Variations in Absolute Severity of Competition (ASC) and Relative Productivity (RP) for the sowing date of December 15 throughout the 2014-15 crop growing season under Non-Tillage (a), Fallow (b) and Bare Soil (c) soil covering-types.

4. Conclusions

Soil coverings with straw and voluntary plants interfered on maize yield components. Under inadequate soil water supply conditions, black oat straw soil covering under no-tillage system accelerated crop development, whereas under adequate soil water supply conditions absence of soil covering-types anticipated emergency of seedlings, culminating in yield components that reflected rises in maize productivity.

The entire maize crop growing season was consistently affected by sowing dates, being reduced from the first (September 15) to the third (December 15) sowing date throughout both crop growing seasons. There were no effects of sowing date on mean height of maize plants.

Plant population factor exerted impacts on yield components and maize crop productivity. There was a compensational effect of yield components for the P30F53YH hybrid whenever plant population increased from 40,000 plants ha⁻¹ to 120,000 plants ha⁻¹.

Combinations of plant populations and soil covering-types resulted in distinct effects on the expression of maize relative productivity throughout both crop growing seasons under scrutiny, with a tendency of stabilization of relative productivity from plant populations above 80,000 plants ha⁻¹ threshold.

Use of techniques of multivariate analysis along with relative statistical indices allowed for detection of effects of soil covering-types, plant populations and sowing dates on yield components and productive potentiality of maize crop.

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Conflicts of Interest: Declare conflicts of interest or state, “The authors declare no conflict of interest.”

Appendix A

Table 1S. Summary of analysis of variance along with application of F test for productivity of maize hybrid (kg ha⁻¹) throughout the 2014-15 and 2015-16 crop growing seasons. Ponta Grossa, PR, Brazil.

2014-15 Growing season							
Source of variation	GL	QM – A*	F	QM – B	F	QM – C	F
Block	2	51667281.8	ns	4703484.2	ns	7472347.3	**
Soil covering	2	26906822.9	ns	19303287.7	ns	25921834.9	**
Plant population	4	33953657.2	**	37992849.3	**	94420644.5	**
Covering x population	8	2841944.3	ns	12721248.9	**	21122997.7	**
2015-16 Growing season							
Source of variation	GL	QM – A	F	QM – B	F	QM – C	F
Block	2	11890112.4	ns	13801189.3	ns	12096798.9	ns
Soil covering	2	24625516.7	ns	2700934.5	ns	615091.3	ns
Plant population	4	86012497.8	**	108474628.2	**	62163551.4	**
Covering x population	8	1088903.6	*	858792.6	ns	942175.5	ns

*Sowing date A: September 15; sowing date B: October 30; sowing date C: December 15; ns: non-significant; *: significant at 5% reliability; **: highly significant at 1% reliability.

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