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Diagnosis of losses in the mechanized harvest of two cultivars of industrial tomato

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ABSTRACT: The production of industrial tomato in Brazil has been growing in the last years and the form of harvest adopted has been mechanized. The diagnosis of tomato fruit losses is fundamental to the harvesting process. The industrial process was destroyed and the statistical process control. The experiment was carried out in a field of 45 ha in an industrial tomato crop irrigated by central pivot in the municipality of Corumbá de Goiás, GO, Brazil. A sampling grid of 60 x 60 m (120 sample points) and 100 x 50 (84 sample points), respectively, were used as georeferenced samples to quantify weight loss and poisoning. As the main losses, in the mechanized harvest, the fruit of industrial tomato do not occur with mature fruit. A N901 cultivar had a lower quality relation than a HMX7885. The mechanical tomato harvesting process is influenced by the random power medium during a larger part of the operation. However, throughout the year, the tasks are not random, they are involved with the operation and the maintenance and maintenance of the process is necessary.

Key words: agricultural machinery; precision agriculture; spatial variability; statistical process control

Diagnóstico de perdas na colheita mecanizada de duas cultivares de tomate industrial

RESUMO: A produção de tomate industrial no Brasil vem crescendo nos últimos anos e a forma de colheita adotada tem sido a mecanizada. O diagnóstico das perdas de frutos de tomate industrial decorrentes do processo de colheita pode auxiliar na redução de desperdícios desta operação. O objetivo desde trabalho foi estudar as perdas de tomate industrial decorrentes do processo de colheita mecanizada utilizando a ferramenta da geoestatística e o controle estatístico de processo. O experimento foi realizado em um talhão de 45 ha em uma lavoura de tomate industrial irrigada por pivô central no município de Corumbá de Goiás, GO, Brasil. As amostras georreferenciadas para quantificar produtividade e de perdas foram coletadas utilizando uma malha amostral de 60 x 60 m (120 pontos amostrais) e 100x50 (84 pontos amostrais), respectivamente. As principais perdas, na colheita mecanizada, de frutos de tomate industrial ocorrem no solo com frutos maduros. A cultivar N901 apresentou em média uma perda de frutos menor em relação a HMX7885. O processo de colheita mecanizada de tomate industrial é influenciado por meio de causas aleatórias durante a maior parte da operação. Contudo, ao longo da colheita fatores não aleatórios podem causar falhas na operação, sendo necessário o monitoramento e ajustes constantes visando manter o processo sob controle.

Palavras-chave: máquinas agrícolas; agricultura de precisão; variabilidade espacial; controle estatístico de processo

Introduction

The tomato plant (*Solanum lycopersicum*) belongs to the Solanacea family and reports point its center of diversity in the Latin America, more precisely in the Andean region (Alvarenga, 2013). The tomato is considered a functional food, which in turn favors the sales growth of both the fresh and industrialized product (Schwarz et al., 2013).

The agricultural area of Goiás has about 2.4 million hectares and, from that territory, around 13.2 thousand hectares are destined to the implantation of crops from table and industrial tomato (IBGE, 2016). The State started to establish itself on this activity in Brazil in 1986, when the production of the fruit for processing purposes began, in order to meet the tomato products industries installed in Goiás. At that time, the average yield of the crop was less than 45 tons per hectare. In 2015 and 2016 the result almost doubled, reaching 89 tons. There are producers that can even obtain over 120 tons per hectare (Carvalho et al., 2016).

Precision Agriculture (PA) can be defined as a new form of administration or management of the agricultural production, not just as a set of tools for a localized crop handling (Ria et al., 2015).

As an adoption example of PA techniques for the knowledge of the spatial variability of production, the works of Cunha et al. (2014) and Reis et al. (2013) in the industrial tomato crop and Ferraz et al. (2012) in coffee can all be cited. Moreover, geostatistics is an important tool for analyzing data deriving from these surveys (Ferraz et al., 2012).

The industrial tomato harvesters cut off the plants near the ground, then collect the aerial part and detach the fruit afterwards by mechanical vibration (Embrapa, 2006). According to Reis et al. (2015), at the same moment when the branch containing the tomato fruit is submitted to the tread, a complex system of forces acts in the separation process of the tomato-peduncle.

Studies about the monitoring of the platform losses, in the internal mechanisms and the total losses, during the mechanical harvesting of tomatoes, are still scarce (Voltarelli et al., 2015). The losses evaluation in the mechanized harvest is important as a way of monitoring the wastes during this operation, because these losses possibly interfere in the total production of the crop (Casa & Evangelista, 2009).

Quality control is perfectly adaptable to the agricultural production system (Zerbato et al., 2013). The use of statistical process control (SPC) to evaluate and/or to monitor the quality of mechanized agricultural operations is still incipient in Brazil, however it is possible to find work with SPC tools applications in the mechanized harvesting of industrial tomatoes (Cunha et al. , 2014; Voltarelli et al., 2015).

This work has as the aim to study the fruit losses in the mechanized harvest of two hybrids of industrial tomato by using the geostatistics and SPC tools.

Materials and Methods

The study was carried out in the municipality of Corumbá de Goiás – GO (15°56’20”S and 48°51’58”W), in an altitude of 1.000 m, during the months of May and November of 2016. The region climate, according to the Köppen classification, is the Aw type – tropical, with defined seasons, dry winter and humid summer, with the average temperature of 22.7 °C and average annual rainfall of 1513 mm. The soil is classified as Red Latosol with sandy clay loam texture. The experimental area is 45 ha, irrigated by a central pivot and soil preparation conducted with a Tatu Marchesan® chisel plow and an AGRIMEC® textured land roller.

The planted industrial tomato cultivars were the HMX 7885 and the N901 hybrids, with spacing of 1.20 m between rows, 0.20 m between plants and density of 30.000 ha^{-1} plants. The beginning of the planting in the experimental area was on May 30, 2016, and the ending on June 5, 2016, and the mechanized harvest started on September 25, 2016, and ended on October 9 of the same year.

A 60 x 60 m sampling grid (Figure 1a) was used to quantify the yield with georeferenced points with a Garmin etrex VISTA

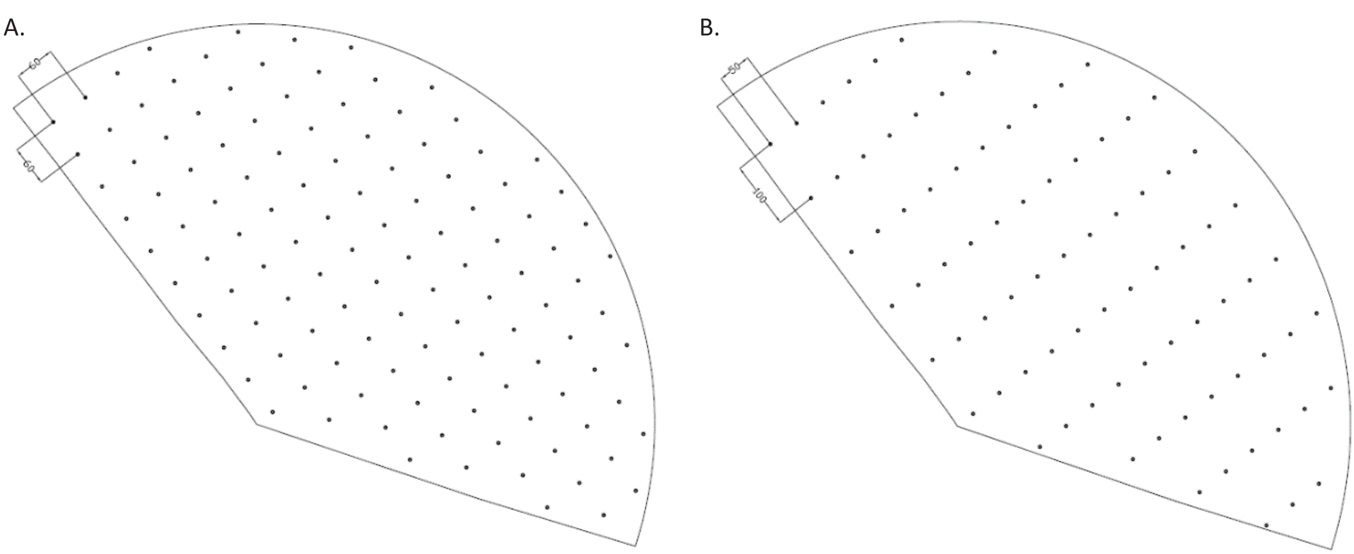

Figure 1. Sampling grid for quantifying yield of: industrial tomato (A) and losses in the mechanized harvest of industrial tomato (B)

GPS (global positioning system) signal receiver equipped with a real-time differential correction system via satellite and with the adjusted datum to the SAD 69 system, coordinates in the UTM (Universal Transverse Mercator) system, totaling 120 sample points. The yield was quantified in the week prior to the harvest (started on September 15, 2016) using a frame with an area of 1 m² at each point of the sample grid (Figure 1A). Initially, all fruit inside the frame were collected and then classified by their color into three classes: ripe (intense red), discolored (less than 50% of their surface being green) and green (more than 50% of their surface being green) (BRAZIL, 1989). The classified fruit were then placed in buckets and weighed in a manual digital scale with a 5 g resolution. Afterwards, from the classified fruit, 10 ripe, 10 discolored and 10 green fruit were selected and taken to the laboratory in order to determine: longitudinal length, transverse diameter with a Mitutoyo® digital calipers with 0.01 mm resolution; mean mass using the Shimadzu® BL-3200H model digital scale with accuracy of 0.01 g; medium volume with a Vidrolabor® measuring cylinder graduated in 0.5 mL and capacity of 1 L; and specific mass by the ratio between the mean mass of the fruit and its mean volume (Reis et al., 2015).

The harvesting process was performed with a GUARESI® self-propelled harvester, G-89/93 MS 40" model, with a FIAT-Iveco 129 kW engine, pickup platform with 1.5 m spacing and with the electronic picker of green fruit and clods turned off during the operation. The harvester was used with the engine rotation at 1800 rpm and a 4 km h^{-1} operating speed.

Due to the harvester velocity, a sampling grid was used for collecting samples from the tomato fruit losses in the mechanized harvest of 100 x 50 m (Figure 1B), with georeferenced points by a Garmin etrex VISTA GPS (global positioning system) signal receiver equipped with a real-time differential correction system via satellite and with adjusted datum to the SAD 69 system, coordinates in the UTM (Universal Transverse Mercator) system, totaling 84 points.

The tomato fruit losses from the mechanized harvesting process for both in the branch and in the soil as well as the totals were evaluated. The tomato fruit losses before the beginning of the harvest (pre-harvest) were not evaluated, because that even if detached from the branch, there was still the possibility of the harvester collecting them. The losses in the branch were consisted of tomatoes that were not detached from the branches by the tread system. The losses in the soil were composed from fruit lost in the pre-harvest, not collected by the harvester and from those that fell through the gap of the harvester conveyor belt. The total losses were composed by the sum of the losses both in the branch and in the soil. During the harvest, shortly after the passing of the harvester, the lost fruit were collected in the soil and in the branch at each point of the sampling grid using a 2.5 m² (1.25 x 2 m) frame. The fruit were collected, packaged and identified as soil or branch losses and then taken to the laboratory.

Afterwards, the fruit were classified by color into three classes: ripe (intense red), discolored (with less than 50% of their surface being green) and green (more than 50% of their surface being green) (BRAZIL, 1989), and then carried out the measurement from the longitudinal length, transverse diameter and normal diameter to the transverse diameter with a Mitutoyo® digital calipers with a 0.01 mm resolution, from the volume with a Vidrolabor® measuring cylinder graduated in 0.5 mL and with capacity of 1 L and from the mass with the Shimadzu® BL-3200H model digital scale with 0,01 g precision. Posteriorly, it was carried out the evaluation of the tomato shape by the analysis of its sphericity (Siqueira et al., 2012), by the Equation (1):

$$Sp = \frac{(a \times b \times c)^{\frac{1}{3}}}{a} \times 100 \quad (1)$$

where:

Sp - sphericity, %;
a - longitudinal length, mm;
b - transverse diameter, mm; and,
c - normal diameter to transverse diameter, mm.

The yield and losses data were analyzed by means of descriptive statistics using tables and graphs in electronic spreadsheet software, allowing to observe their trend. In order to determine the cost of industrial tomato fruit losses, the total losses were multiplied by the value of the used area in the experiment and by the amount paid by the industry to the producer, per ton of industrial tomato in the year 2016.

In order to verify and quantify the spatial distribution of the yield and losses, interpolation of data and construction of isolines map were employed to the geostatistical analysis. Using the software GS+ version 7.0 (Gamma Design Software®) (Robertson, 1998) for the fitting of the theoretical models to the variograms, the parameters nugget effect (C_0), threshold (C_0+C_1), structural variance (C_1) and reach (a) were established. The best model was selected based on the higher value of the coefficient of determination (R^2), smaller value of the sum of the squared deviations and greater degree of spatial dependence.

In the spatial dependence analysis, the spatial dependence index was calculated and classified (Seidel & Oliveira, 2016), in which the spatial dependence for the spherical model is: considered weak for values up to 7%, moderate when between 7% and 15%, and strong when above 15%; for the exponential model it is: considered weak for values up to 6%, moderate between 6% and 13% and strong if above 13%; and for the Gaussian model it is: considered weak for values up to 9%, moderate between 9% and 20% and strong if above 20% (Table 1), by Equation (2):

$$SDI_{MODEL}(\%) = FM\left[\frac{C_1}{(C_0 + C_1)}\right] \cdot \left(\frac{a}{q \cdot MD}\right) \cdot 100 \quad (2)$$

where:

SDI - spatial dependance index;
MF - model factor; and,

Table 1. Spatial dependance index.

Model	Classification		
	Weak	Moderate	Strong
Spherical	≤7%	7<IDE≥15%	>15%
Exponential	≤6%	6<IDE≥13%	>13%
Gaussian	≤9%	9<IDE≥20%	>20%

Source: Seidel & Oliveira (2016).

q.MD - corresponds to the fraction (q) reached from the maximum distance (MD) between sampled points.

In order to estimate the values in the non-sampled locations, for the attributes that showed spatial dependence, it was used an ordinary kriging interpolation employing the software GS+ 7.0 (Gamma Design Software®) (Robertson, 1998). From the estimated values for each attribute, the isolines map was elaborated in the Surfer®13 software for spatial detailing, allowing the spatial variability visualization.

The fruit loss data in the branch and in the soil were evaluated by means of statistical process control by using variables control charts and sequential graphs, in order to verify the randomness of the data and to identify possible variability causes in the mechanized harvesting process.

The quality analysis of the mechanized harvesting process was performed by means of an Exponentially Weighted Moving Average (EWMA) control chart, described by Montgomery (2012) according to Equation (3).

$$z_i = \lambda x_i + (1-\lambda) z_{i-1} \quad (3)$$

where:

z_i - weighted mean;

x_i - value of the measured characteristic; and,

λ - weight considered for the mean, fixated in 0.4.

For estimating the mean lines/rows and the limits of the EWMA control charts, the Equations (4), (5) and (6) were used (Montgomery, 2012):

$$CUL = \mu_0 + L\sigma\sqrt{\frac{\lambda}{(2-\lambda)}\left[1-(1-\lambda)^{2i}\right]} \quad (4)$$

$$ML = \mu_0 \quad (5)$$

$$CLL = \mu_0 - L\sigma\sqrt{\frac{\lambda}{(2-\lambda)}\left[1-(1-\lambda)^{2i}\right]} \quad (6)$$

where:

CUL - control upper limit;

ML - mean line;

CLL - control lower limit;

μ_0 - mean;

L - control limit width;

σ - standard deviation; and,

i - sample number.

For constructing the EWMA control chart, the Minitab®17 software was used. In the quality evaluation of the mechanized harvest, it were considered as a quality indicator variable the industrial tomato fruit losses resulting from the harvesting process in the soil and in the branch classified by the color in ripe, discolored and green. Points that fell outside the control limits (CUL and CLL) were interpreted as evidence that the process is out of control, indicating non-random patterns to the process. If the point was located between the CUL and the CLL, the process was under control, indicating random patterns to the process (Montgomery, 2012).

Results and Discussion

The data trend evaluation was performed by using the box-plot graph and the presence of outliers was detected. The data whose deviations were shown as greater than the limit of the Chauvenet rejection test were eliminated.

The Shapiro-Wilk test provided evidence ($p \leq 0.05$) that the studied attributes of yield and losses do not follow a normal distribution (Table 2). It was observed that the coefficients of variation (C.V.%) varied between 64.70 and 103.82%. In accordance to the classification proposed by Warrick & Nielsen (1980), the coefficient of variation value for all losses attributes are high (C.V.% > 60).

Analyzing the asymmetry (which refers to the deformation degree of a frequency curve) calculated according to the moment of asymmetry coefficient centered in the third order, being the defined as symmetrical when the measures of the central trend are equal, asymmetric positive when presenting a more elongated tail to the right and values over the mode, and asymmetric negative when presenting a tail farther to the left and mean lower than the median, classified as strong if the absolute value is higher than 1.0, moderate if between 0.15 and 1, 0 and weak if less than 0.15 (Toledo & Ovalle, 2008), all loss attributes were classified as strong.

It is observed that the total yield (117.36 t ha^{-1}) was higher than the average of the state of Goiás, which is 77.1 t ha^{-1} according to the Brazilian Institute of Geography and Statistics. The HMX7885 and N901 cultivars did not show a significant difference in the average yield of ripe fruit (Table 3); however, the discolored and green fruit and also the average total yield showed a significant difference at 5% of probability by the t test. The HMX7885 cultivar, which has a 110 to 120 days cycle (Soares & Rangel, 2012), showed lower total yield and the N901 cultivar, with a cycle between 120 and 130 days, had a higher total yield of, approximately, 17 t ha^{-1}. The fact that the hybrids have different cycles may have influenced

Table 3. Yield means comparison between cultivars (t ha^{-1}).

Cultivar	Rip	Dc	Grn	Total
HMX7885	68.16	22.34	21.20	111.70
N901	64.26	25.50	38.52	128.27
p-value	0.28	0.05*	0.00*	0.00*

Rip – ripe fruit yield; Dc – discolored fruit yield; Grn – green fruit yield; Total – all fruit yield. *significant at 5% de probability by the t test.

Table 2. Descriptive statistics of yield attributes and industrial tomatoes fruit losses (t ha^{-1}).

Attribute	Mean	MD	SD	SE	Min	Max	Kurt	Asy	C.V. (%)	P-Value
					Yield					
Rip	66.83	64.03	19.85	1.81	21.45	108.50	-0.42	0.06	29.71	0.1406
Dc	23.42	23.93	7.70	0.70	8.25	48.90	0.61	0.58	32.86	0.012
Grn	27.12	22.93	16.10	1.47	1.70	69.00	-0.69	0.53	59.38	0.000
Total	117.36	118.1	23.90	2.18	49.6	167.75	-0.16	-0.36	20.36	0.126
					Losses in the soil					
Rls	1.28	1.13	1.05	0.11	0.00	8.08	20.92	3.63	81.83	0.000
Dls	0.70	0.58	0.55	0.06	0.00	3.99	14.18	2.74	79.34	0.000
Gls	0.81	0.65	0.52	0.06	0.00	2.79	1.73	1.15	64.70	0.000
Tls	2.78	2.59	1.82	0.20	0.00	13.57	14.58	2.82	65.26	0.000
					Losses in branch					
Rlb	0.50	0.31	0.52	0.06	0.00	2.44	2.07	1.48	103.82	0.000
Dlb	0.21	0.16	0.20	0.02	0.00	0.83	0.63	1.10	94.59	0.000
Glb	0.27	0.21	0.25	0.03	0.00	1.43	5.26	1.87	90.41	0.000
Tlb	0.99	0.79	0.83	0.09	0.00	4.44	2.48	1.32	84.06	0.000
					Total losses in harvest					
Tl	3.77	3.54	2.16	0.23	0.00	15.14	8.48	2.06	57.20	0.000

Rip – ripe fruit yield; Dc – discolored fruit yield Grn – green fruit yield; Total – all fruit yield; Rls – ripe fruit loss in the soil; Dls – discolored fruit loss in the soil; Gls – green fruit losses in the soil; Tls – total losses in the soil; Rlb – ripe fruit losses in the branch; Dlb – discolored fruit losses in the branch; Glb – green fruit losses in the branch; Tlb – total losses in the branch; Tl – total losses; MD – median; SD – standard deviation; SE – standard error; Asy – asymmetry coefficient. Min – minimum value; Max – maximum value; Kurt – Kurtosis coefficient.

the physiological development of the fruit and influenced the green fruit significant difference.

In Table 4 it is observed that ripe and discolored tomato fruit of the N901 cultivar have a mean longitudinal length and volume higher than the fruit of the HMX7885 cultivar. The tomato fruit from the HMX7785 cultivar have a larger transverse diameter than the N901 cultivar.

The cultivars ripe fruit have longer longitudinal length, transverse diameter, mean volume, mean mass and a higher specific mean mass due to the ripe fruit having already reached maturation. The literature presents a wide range of the mean fruit mass values from tomato plants genotypes ranging from 30 to 107.34 g fruit^{-1} (Schwarz et al., 2013; Reis et al., 2015).

The total mean fruit loss at the harvest was of 3.77 t ha^{-1}, value below of what was found by Voltarelli et al. (2015) and Cunha et al. (2014), which obtained 5.0 t ha^{-1} and 7.52 t ha^{-1}, respectively. It was verified that, from the total lost, 2.69 t ha^{-1} (71.3%) are ripe and discolored fruit and that 1.08 t ha^{-1} (8.7%) are green fruit. It was observed that the greatest loss occurs in the soil and mainly of ripe fruit. In the branch, the main loss is also of ripe fruit.

The total loss of tomato fruit represented 3.21% (3.77 t ha^{-1}) in relation to the total mean yield (117.36 t ha^{-1}), of which 1.52% (1.78 t ha^{-1}) represents ripe tomato fruit and 1.69% (1.99 t ha^{-1}) the discolored and green fruits. Considering both the Ordinance No. 278 of November 30, 1988, of the Ministry of Agriculture Livestock and Supply, and that the ripe tomato fruit yield exceeded by 56.9% the total mean yield, all fruit could be utilized without resulting in discounts to the producer. The ton value paid to the producer in the year 2016 was of R$ 240.00. The losses in the experimental area represent R$ 904.80 ha^{-1} less in sales and a total of R$ 40,716.00 less in the experimental area.

Table 4. Mean values from the physical properties of the industrial tomato fruit.

	HMX7885			N901		
	Rip	Dc	Grn	Rip	Dc	Grn
a	53.13	47.78	40.81	75.11	66.70	51.02
b	40.29	36.68	31.47	40.22	37.73	30.50
Mv	78.57	39.49	27.71	88.93	54.59	32.18
Mm	73.73	35.70	24.74	86.40	52.51	29.07
Sm	0.94	0.90	0.89	0.97	0.99	0.91

a - longitudinal length (mm); b - transverse diameter (mm); Mv - mean volume (cm^{-3}); Mm - mean mass (g fruit^{-1}); Sm - specific mass (g cm^{-3}); Rip - ripe fruit; Dc - discolored fruit; Grn - green fruit.

In the geostatistical analysis, the theoretical semivariogram models fitted for the losses attributes are presented in Table 5. All data presented positive asymmetry and were transformed to avoid influence of high values in the estimations of neighborhood points (Yamamoto & Landim, 2013). It is observed that all the attributes from the fruit losses in the soil showed pure nugget effect (PNE), that is, total absence of spatial dependence. On the other hand, the losses of ripe, discolored, green and total fruits in the branch had spatial dependence, hence being the exponential and spherical models the ones that best fit to the data and so were used to represent the variograms and isolines maps (Table 5).

The spatial dependence degree between attributes of yield and losses in the branch that presented spatial dependence was classified as strong for the yield and the loss of ripe and discolored fruits, as moderate for yield of green and total fruits, losses of green fruit in the branch and for the total, both in the branch and in the harvest.

In the Figure 2 are presented the isolines maps for yield and in Figure 3 the maps of tomatoes fruit losses resulting from the mechanized harvesting process. Comparing the yield map of the green industrial tomato fruit (Figure 2C) with those of losses (Figures 3A, 3B, 3C and 3D), it was observed that the regions that showed the highest yield of green tomatoes were those who also presented the lowest loss of ripe, discolored, green and total fruits on the branch.

Table 5. Theoretical semivariogram models fitted for yield and losses attributes.

Atributes	Semivariogram	A	C_0+C	C_0	R^2	RSS	SDI	DD
				Yield				
Rip	Exponential	1221.00	581.60	210.00	0.97	1197.00	20.25	Strong
Dc	Exponential	120.00	0.63	0.04	0.77	0.00	29.54	Strong
Grn	Gaussian	433.01	316.00	132.20	0.97	758.00	15.58	Moderate
Total	Exponential	135.00	572.20	37	0.80	2535.00	7.81	Moderate
				Losses in the soil				
Rls	PNE	-	-	-	-	-	-	-
Dls	PNE	-	-	-	-	-	-	-
Gls	PNE	-	-	-	-	-	-	-
Tls	PNE	-	-	-	-	-	-	-
				Losses in the branch				
Rlb	Exponential	6330.00	0.25	0.10	0.90	0.00	19.26	Strong
Dlb	Exponential	6330.00	0.13	0.05	0.72	0.00	19.57	Strong
Glb	Spherical	100.00	0.05	0.00	0.50	0.00	14.25	Moderate
Tlb	Exponential	113.10	0.19	0.02	0.52	0.00	12.79	Moderate
				Total losses in the harvest				
Tl	Spherical	105.80	0.26	0.01	0.35	0.00	14.52	Moderate

A – reach; C_0+C – Threshold; C_0 – Nugget Effect; R^2 – determination coefficient; RSS – residual sum of squares; SDI – Spatial Dependence Index; DD – degree of dependency; Rls – ripe fruit loss in the soil; Dls – discolored fruit loss in the soil; Gls – green fruit losses in the soil; Tls – total losses in the soil; Rlb – ripe fruit losses in the branch; Dlb – discolored fruit losses in the branch; Glb – green fruit losses in the branch; Tlb – total losses in the branch; Tl – total losses; PNE – pure nugget effect.

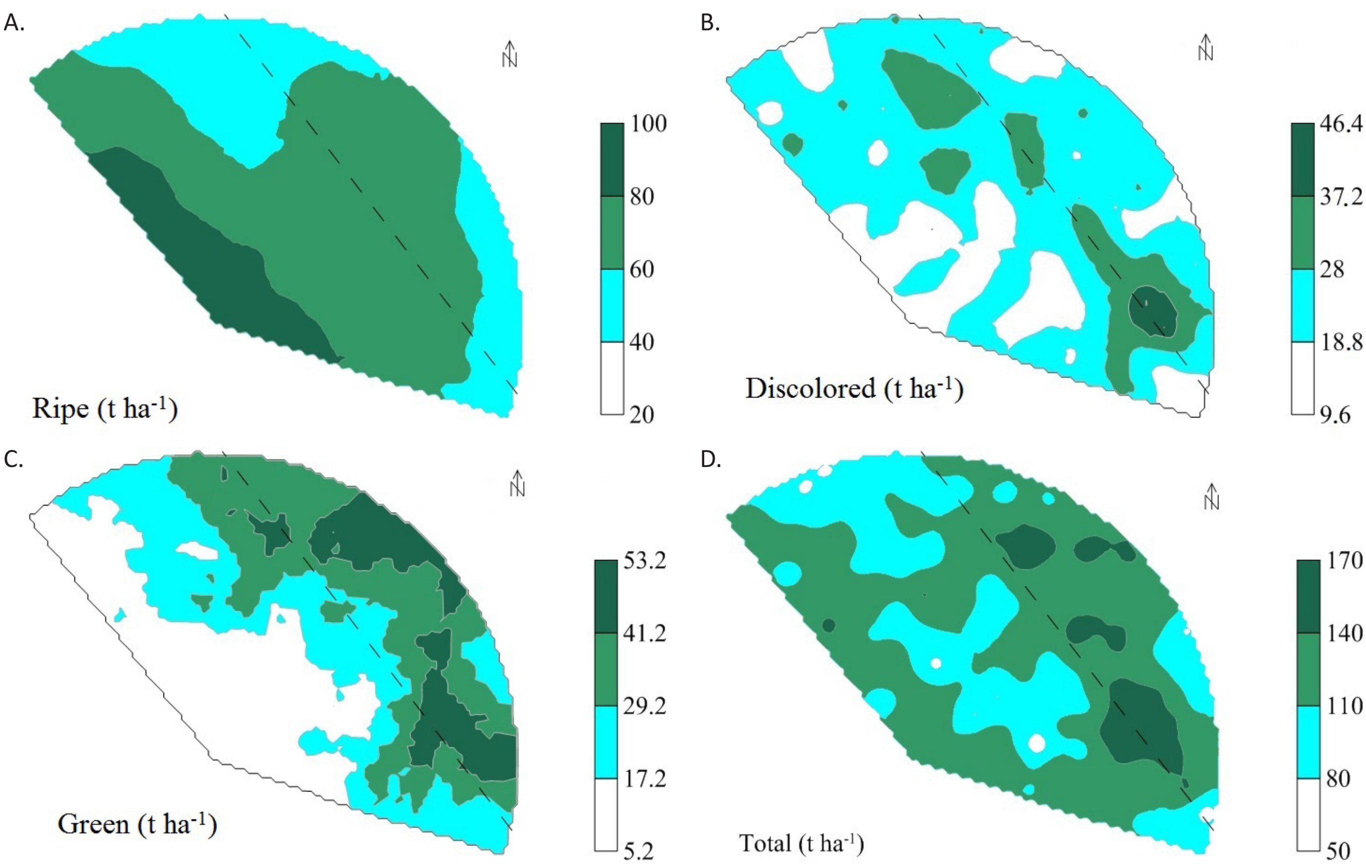

Figure 2. Isoline maps regarding the yield of ripe (A), discolored (B), green (C) and total (D) fruit.

According to Ripoli (1996) the losses of industrializable raw material in the field are an aspect of the processing quality that occurs in the work of the harvesters. Therefore, in the analysis of the control charts resulting from the mechanized harvesting of industrial tomato fruit, soil and branch losses were considered as an indicative variable of quality, in addition of taking into account the losses variability throughout the harvesting process.

The test plot represents individual observations in the order in which they were collected, being then used to search for variation evidences of special causes in the process by means of a data pattern search (Minitab, 2013). In the test plots analysis, it was verified that the industrial tomato fruits losses showed a pattern of non-randomness for the losses in the branch, since there was a grouping pattern for losses of discolored and total tomato fruits in the branch (Table

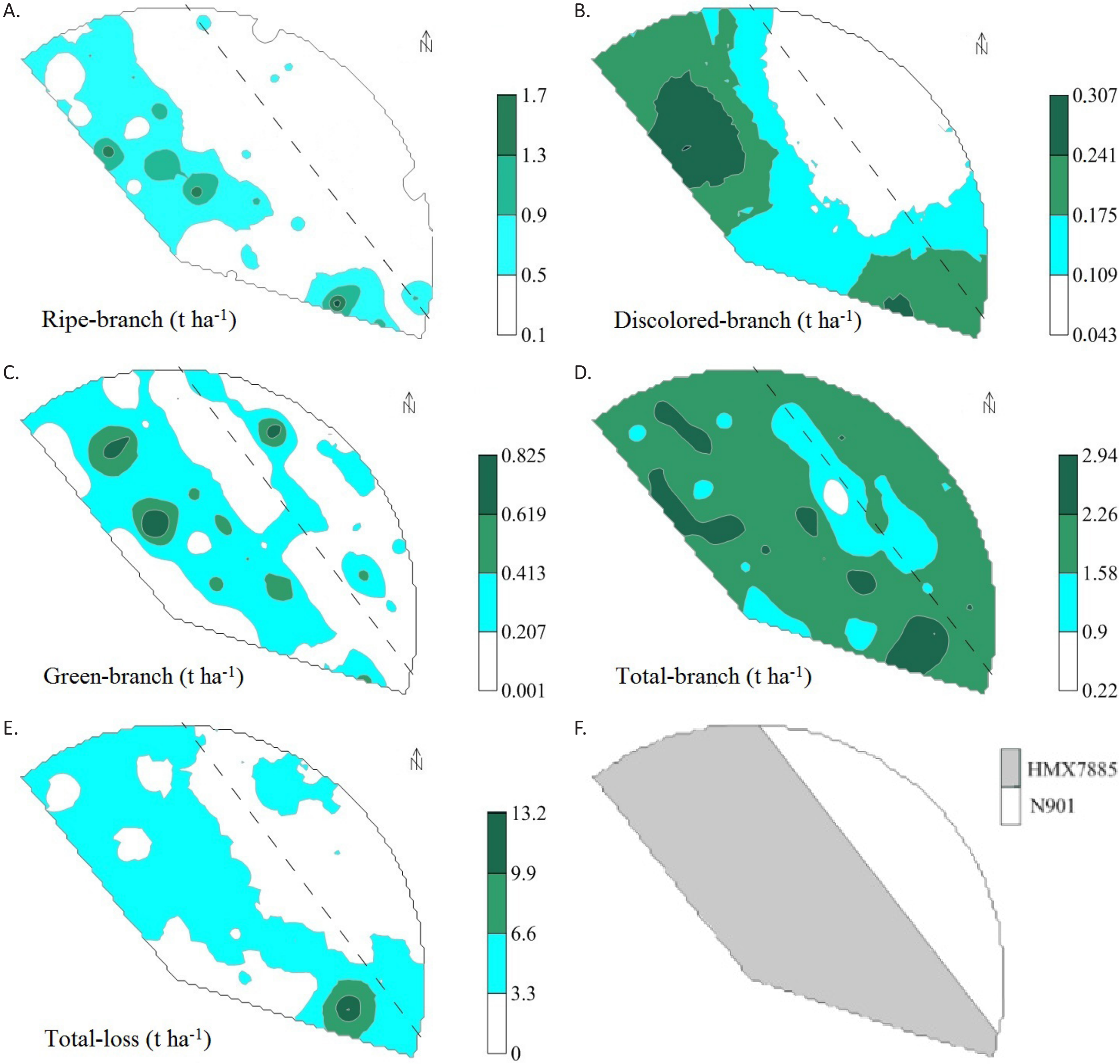

Figure 3. Isoline maps regarding the loss of: ripe fruit in the branch (A), discolored fruit in the branch (B), green fruit in the branches (C), total fruit in branch (D), total fruit losses (E) and map locating the planted cultivars (F).

6) characterized by the formation of groups of points in certain areas of the test plot. When monitoring the industrial tomatoes losses in the mechanized harvest, Voltarelli et al. (2015) observed that the red fruit losses in the treatments with electronic sensor turned off showed an oscillation pattern, which was not observed in this experiment.

Through the detection of the unpredictable behavior patterns of the samples, as well as changes in their behavior, the use of non-randomness patterns is an important tool for monitoring the process continuity over time. It is a way of verifying the variability of results (Minitab, 2013), and the process may or may not be predictable and, if necessary, changes or alterations must be made to improve them.

The losses of industrial tomato fruit in the branch were shown as under control for most of the points (Figure 4), indicating that the process operates with random causes in the majority of the harvesting operation. On the other hand, points 29 and 30 in the control chart for total branch losses (Figure 4A) are above the control upper limit, indicating a non-random cause. This instability may have occurred due to an operator error in the harvester deck control, an improper rotation control or the machine speed. This operation failure may result in the clods collection and increased branches flow in the elements of the harvester conveyor belt, causing undesirable losses.

The total losses were shown as outside of the Statistical Process Control, showing points 46, 47 and 49 as above the

Table 6. Standard probability values from the test plots for industrial tomato fruit losses resulting from the mechanized harvesting.

Quality indicators	G	M	T	O
Rls	0.94^{ns}	0.06^{ns}	0.92^{ns}	0.08^{ns}
Dls	0.25^{ns}	0.74^{ns}	0.53^{ns}	0.46^{ns}
Gls	0.19^{ns}	0.81^{ns}	0.17^{ns}	0.83^{ns}
Tls	0.14^{ns}	0.86^{ns}	0.33^{ns}	0.67^{ns}
Rlb	0.41^{ns}	0.59^{ns}	0.54^{ns}	0.46^{ns}
Dlb	0.02*	0.98^{ns}	0.43^{ns}	0.57^{ns}
Glb	0.09^{ns}	0.91^{ns}	0.64^{ns}	0.36^{ns}
Tlb	0.04*	0.96^{ns}	0.53^{ns}	0.46^{ns}
Tl	0.09^{ns}	0.91^{ns}	0.07^{ns}	0.93^{ns}

Rls – ripe fruit loss in the soil; Dls – discolored fruit loss in the soil; Gls – green fruit losses in the soil; Tls – total losses in the soil; Rlb – ripe fruit losses in the branch; Dlb – discolored fruit losses in the branch; Glb – green fruit losses in the branch; Tlb – total losses in the branch; Tl – total losses; Patterns: G – Grouping; M – Mixture; T – Trend; O – Oscilation; ns – not significant at 5% of probability; * significant at 5% of probability.

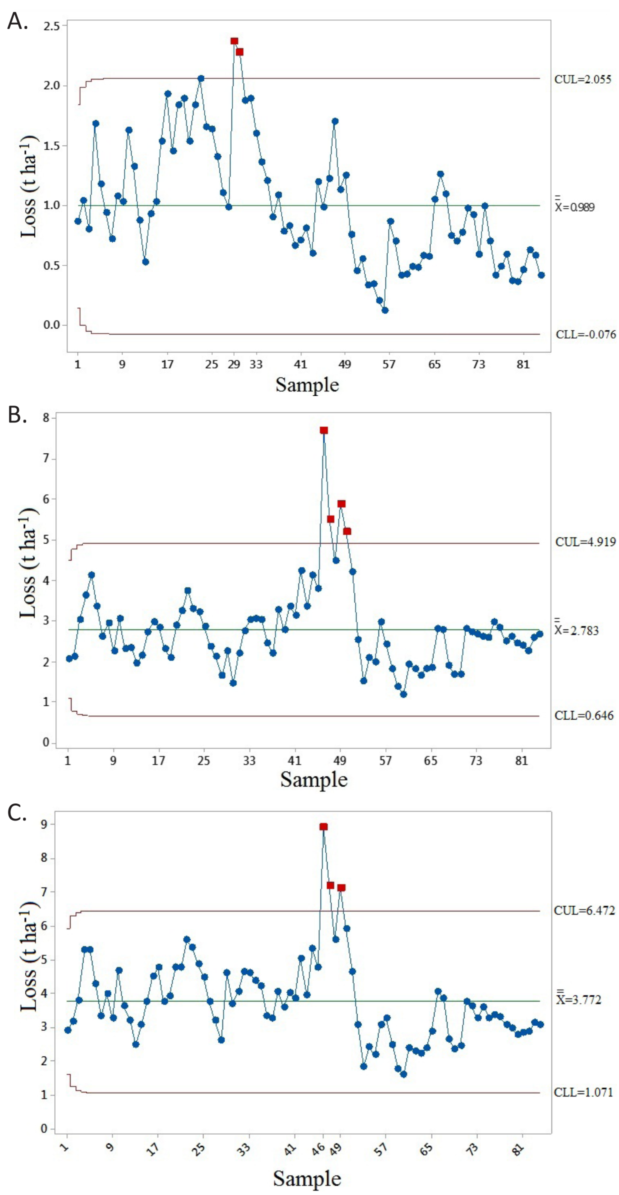

Figure 4. Weighted Moving Average Control Charts for attributes of total fruit loss in the branch (A), soil (B) and total (C).

control upper limit (Figure 4C), indicating that there may have been an operation error during the harvest, some mechanical failure or the branches dragging. Most of the points lie between the control limits, indicating that the process variability is due in large part to the random causes.

The fruits losses from N901 cultivar, except for the discolored fruit lost in the soil, are smaller in comparison to the HMX7885 (Table 7), both in the branch and in the soil. The N901 cultivar represents 44.78% and the HMX7885 represents 55.22% of the total mean loss of the industrial tomato fruits in the experimental area. The main loss, both in the branch and in the soil, in the two cultivars, is of ripe industrial tomato fruit.

It was observed that there is a significant difference at 5% probability by the t test between the cultivars fruit loss means of the ripe tomato in the branch and in the total lost in the branch, being the N901 cultivar the one that presents smaller significant loss. Due to the weight of the fruit force influencing the separation from its peduncle (Reis et al., 2015), a factor that may have influenced the difference of losses in the branch among the cultivars is the fact that the mean mass of the N901 cultivar fruits is greater than the HMX7885 (Table 4), thus being the N901 fruit easier to be separated by the trails system.

In Table 8 it is observed that the ripe and discolored fruits from the N901 cultivar lost in the branch and in the soil both showed mean longitudinal length and a mean transverse diameter lower than the HMX7885 cultivar.

The track mechanism of the industrial tomato harvester used has a deficiency in the tomato-peduncle separation of ripe and discolored fruits with less physiological development, which have a smaller longitudinal length and transverse diameter, and are shaped closer to a sphere. This fact may have influenced the losses of the ripe, discolored and green industrial tomato fruits in the branch and the smaller loss in the N901 cultivar, which has fruits with greater longitudinal length and less spherical shape. According to Melo & Vilela (2005), the choice of hybrids with characteristics appropriate

Table 7. Mean losses (t ha^{-1}) in the harvest between the HMX7885 and N901 cultivars.

	HMX7885		N901		p-value
	t ha^{-1}	%**	t ha^{-1}	%**	
Rlb	0.583	14.79	0.236	7.39	0.00*
Dlb	0.225	5.72	0.157	4.90	0.16
Glb	0.285	7.23	0.241	7.53	0.42
Tlb	1.093	27.74	0.633	19.82	0.00*
Rls	1.340	34.01	1.072	33.55	0.14
Dls	0.668	16.94	0.790	24.72	0.28
Gls	0.840	21.32	0.700	21.91	0.27
Tls	2.847	72.26	2.562	80.18	0.38
Tl	3.940	-	3.195	-	0.06

Rls – ripe fruit loss in the soil; Dls – discolored fruit loss in the soil; Gls – green fruit losses in the soil; Tls – total losses in the soil; Rlb – ripe fruit losses in the branch; Dlb – discolored fruit losses in the branch; Glb – green fruit losses in the branch; Tlb – total losses in the branch; Tl – total losses; (sum of the total fruits lost in the branch and in the soil); * significant at 5% of probability by the t test; **Losses percentage in relation to the the total loss per cultivar in the mechanized harvest.

Table 8. Shape of the tomato fruits lost in the branches and in the soil.

Shape	Rlb	Dlb	Glb	Rls	Dls	Gls
HMX7885 cultivar						
a	42.22	33.42	26.40	38.82	32.94	26.80
b	32.05	25.21	20.18	29.04	25.17	20.67
Es	82.71	82.30	83.05	82.01	83.29	83.94
Fpa	42	27	24	30	32	20
Fpb	35	24-32	16	20	20	20
Fpe	85	85	84	80	80	83
N901 cultivar						
a	44.78	42.12	33.17	43.69	40.43	32.46
b	25.12	25.14	20.96	23.73	23.97	19.96
Es	67.68	71.08	73.31	66.80	71.16	72.50
Fpa	48	39	24	40	38	32
Fpb	25	24	20	20	20	20
Fpe	70	70	72	70	64	71

a – mean longitudinal length (mm); b – mean transverse diameter (mm); Es – mean sphericity (%); Fpa – longitudinal length with highest frequency (mm); Fpb – transverse diameter with highest frequency (mm); Fpe – sphericity with highest frequency (%); Rlb ripe fruit loss in the branch; Dlb – discolored fruit loss in the branch; Rls – ripe fruit loss in the soil; Dls – discolored fruit loss in the soil.

to the mechanized harvest has been the result of varieties competition trials and the introduction of new cultivars should appear as an alternative for the selection of superior plants (Souza et al., 2012 ; Reis et al., 2015) with lower fruit losses potential in the mechanized harvest.

The space between the conveyors belts links of the industrial tomato harvester is 25 mm, this fact may have influenced the fruit losses in the soil. It was observed that the transverse diameter of the fruit analyzed in the soil was less than 25 mm for both discolored and green of HMX7885 cultivar, as well as for all fruit lost from the N901 cultivar.

According to Soares & Rangel (2012), the shape of the industrial tomato for the production of pulp is not relevant, thus, the ripe and discolored tomatoes lost in the branch and in the soil could be used in the pulp production industry.

Considering that the longitudinal length of less than or equal to 15 mm is considered by the industry a general defect, all industrial tomato fruit could be used in the industry without a producer discount because the average length of lost fruit of industrial tomatoes is higher to 15 mm.

Conclusions

During the industrial tomato fruit harvesting process, the highest occurrence of losses is from ripe fruit in the soil.

The N901 cultivar showed, in average, smaller losses due to its fruit having smaller sphericity and bigger mean longitudinal length in relation to the HMX7885.

The total loss of tomatoes represented 3.21% in relation to the average yield.

The spatial variability of the losses in the harvesting process is influenced by the cultivar, fruit maturation stage and the fruit shape.

The industrial tomatoes mechanical harvesting process suffers influence by random causes in most of the operation. It is important to carry out a constant monitoring throughout the harvest, since non-random factors can cause operation failures and require immediate intervention to avoid increased fruit losses.

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