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The spatial and temporal independence of Italian Zucchini production

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ABSTRACT. It is necessary to know the production variability of experimental units in a protected environment, both in terms of space and throughout different harvests. This knowledge helps reduce experimental error and increases result reliability in combination with the adoption of appropriate experimental techniques and cultural management. The objective of this study was to characterize the spatial and temporal independence of Italian Zucchini fruit production as cultivated in a protected environment. The study used production data from exploratory experiments under protected cultivation in the Department of Plant Sciences of the Federal University of Santa Maria. Different units sizes were simulated on the basis of known production values for the number of plants per row. To verify the independence or randomness of fruit production, a test run was applied to the units within the rows of individual and grouped harvests and in the same unit between individual and grouped harvests. There was a greater randomness of production in units with a higher number of plants. Using a lower number of harvests randomizes the production of units as the harvests are carried out. Groupings of harvests and units formed by four and five basic units are the most efficient combination for reducing non-randomness in the production of Italian Zucchinis.

Keywords: randomness, protected cultivation, experimental accuracy, experimental planning, plot size, test of uniformity.

Independência espacial e temporal da produção de abobrinha italiana

RESUMO. O conhecimento da variabilidade da produção entre as parcelas experimentais em ambiente protegido, tanto no espaço, quanto ao longo das diferentes colheitas, se faz necessário, pois possibilita a redução do erro experimental, aumentando a confiabilidade dos resultados, com a adoção de técnicas experimentais e manejos culturais apropriados. O objetivo deste estudo foi caracterizar a independência espacial e temporal da produção de frutos entre parcelas de abobrinha italiana, cultivadas em ambiente protegido. Foram utilizados dados de produção de experimentos em branco realizados em cultivo protegido no Departamento de Fitotecnia da Universidade Federal de Santa Maria. Com os valores da produção individual, foram simulados diferentes tamanhos de parcelas, conforme o número de plantas na linha de cultivo. Para verificar a independência ou aleatoriedade da produção de frutos, foi aplicado o teste de sequências entre parcelas dentro da linha, em colheitas individuais e agrupadas, e da mesma parcela entre colheitas individuais e agrupadas. A aleatoriedade da produção entre parcelas é favorecida quando estas são formadas por um maior número de plantas. A realização de um menor número de colheitas torna a produção das parcelas aleatória com o decorrer das colheitas realizadas. Agrupamentos de colheitas e parcelas formadas por quatro ou cinco unidades básicas é a combinação mais eficiente para redução da não aleatoriedade da produção em cultivos de abobrinha italiana.

Palavras-chave: aleatoriedade, cultivo protegido, precisão experimental, planejamento experimental, tamanho de parcela, ensaio de uniformidade.

Introduction

Horticulture is a highly intensive activity. It requires sophisticated technology and is constantly changing, demanding a higher quality of technical information than other fields. The cultivation of vegetable crops is characterized by a need for less physical space; however, it is widely used both in space and time (FILGUEIRA, 2003).

No matter how well-controlled an experiment is, there are always random variations within the same treatment, and these variations are known as the experimental error (STEEL et al., 1997). The higher the experimental error, the lower the probability of having significant differences between the treatment's mean. According to Storck et al. (2011), if the causes of the error are known, the error can be controlled and maintained at an acceptable level.

One way to reduce experimental error arising from unit heterogeneity is good experimental planning with an appropriate experimental design, number of repetitions, size and form of units and sample sizes. In protected cultivation experiments, the following factors become a source of variability and contribute to the growth of heterogeneity among units: the presence or absence of harvested fruits, the difference in air temperature due to row positions, damage caused to plants by fruit harvesting, small differences in the quantity of irrigation water, drainage differences, trampling between rows, presence of insect pests, diseases and weeds (COUTO et al., 2009; LOPES et al., 1998; LORENTZ et al., 2005; LÚCIO et al., 2008; ZANARDO et al., 2010).

One method for evaluating experimental area heterogeneity is the use of uniformity testing or exploratory experiments. In these cases, the individual plant production data are collected to identify the existing area variation (STORCK et al., 2011). Based on the data generated in exploratory experiments, the productivity behavior within the units or harvests can be identified. It is necessary to know the production variability of experimental units within the protected environment, both in terms of space and different harvest times because the dependence of experimental units is very often disregarded or ignored. There are not many studies that would identify the production behavior while observing the tendencies within the environment, with the objective of reducing experimental error and ensuring higher reliability of results and which would adopt appropriate experimental techniques and cultural management.

The objective of this study was to characterize the spatial and temporal dependence of Italian Zucchini fruit production within a protected environment.

Material and methods

This study employed Italian Zucchini fruit production data from two exploratory experiments that were performed in plastic greenhouses at the Department of Plant Sciences of the Federal University of Santa Maria. The experiments were carried out at coordinates 29º 43’ 23” S and 53º 43’ 15” W and an altitude of 95 m. The climate of this region is classified as Cfa humid subtropical with no dry season and a hot summer according to the Köppen classification (MORENO, 1961).

The first experiment was performed during the summer/autumn and the second in the winter/spring of 2001. Both experiments were composed of eight rows of 20 plants, and each plant constituted a basic unit (BU). The first experiment included 12 harvests and the second one had 30 harvests.

The plants were identified by row number and by their position inside the row. The values of fresh fruit biomass (FFB, in g) per individual BU and at sizes of 1, 2, 4 and 5 BU per unit were simulated for the rows.

To verify the randomness of data distribution, a run test was applied to characterize the spatial and temporal dependence of production (BEAVER et al., 1974; COSTA NETO, 2002) among units within the row in individual and grouped harvests and to the same unit between individual and grouped harvests.

For each harvest unit and grouping size, a median value was calculated for the formation of classes (1 and 2). Class 1 was formed by elements below the median (n) and class 2 was formed by the elements above the median (m) where the signs “-” and “+” were adopted, respectively. The elements equal to the median were included in class 1.

The n elements of class 1 and the m elements of class 2 were numbered on the basis of the order in which they occurred. The number of equal symbols were preceded and followed by different symbols or by no symbol to determine the number of sequences, or in other words, the “c” value.

When the number of units per row was lower than 20, the test was carried out with a determination of the least significant difference (LSD), which is equal to double the lowest value between α1 p ($c \leq c_1$) and α2 p ($c \geq c_2$) (tabulated by the run test). The sequence was considered random when the LSD was higher than 5% and non-random when it was lower than 5%. When the number of units per row was higher than 20, the test was completed by using an approximation of the normal distribution based on the equation $Z = c - E(c)/\sqrt{V(c)}$, where c is the number of observed sequences, $V(c) = 2{\star}m{\star}n(2{\star}m{\star}n - m - n) / (m + n)^2 \star (m + n - 1)$ and $E(c) = 1 + (2{\star}m{\star}n / m + n)$. The assumption of randomness was rejected if $z > |z\ \alpha/2|$ at a 5% probability level.

Results and discussion

There were cases of non-random fresh fruit biomass (FFB) distribution within the rows during the first cultivations in summer-autumn and the second cultivation during winter-spring. These cases were composed of units of one or two plants, and they included individual or grouped harvests (Table

1). These results may have occurred as a result of environmental influences and plant rotation, in which the production is concentrated in rows, contrary to what happened in units of more than two plants and with the harvest groupings in which the variability was lower in space and time. While evaluating the air temperature distribution in a protected environment, Furlan and Folegatti (2002) verified the distribution to be non-homogeneous and noted that opening the side curtains provided isotherms in which higher air temperatures occurred in the center of the protected environment. In the evaluation of Italian Zucchini growth dynamics, Strassburger et al. (2011) found that the availability of solar radiation during the cultivation period strongly affected the production and distribution of dry matter, as well as all the culture growth indexes of Italian Zucchini. The growth rates of zucchini plants and their fruits are higher when the available solar radiation is higher. Considering the influence of these factors on the development of the plant culture, it is possible that the lack of randomness observed in smaller row units was caused by environmental variations.

While evaluating the harvest totals in the first experiment, there was randomness in the production regardless of the unit size. However, there were rows without randomness in the second experiment that were formed by units of one BU, the difference of which could be explained by a higher number of harvests.

In the experimental units composed of one or two BU, a higher number of percentage of zero values was observed. In other words, there were units with no row production (Tables 2 and 3). The lack of production per plant had a direct influence on the results of the sequence test, giving rise to rows with lack of randomness. In other words, within the units composed of two plants, a lack of production by one plant influenced the neighboring plant. The same pattern occurred in the units that yielded no harvest, where in some cases the groupings had a lower randomness than the individual harvests. According to Couto et al. (2009), smaller unit sizes are often used in vegetable crops experiments because of area limitations, which reflect data dispersion problems by the emergence of zero values in the variables indicating fruit production.

Table 1. Percentage of rows with spatial and temporal independence for different sizes of units and groupings of Italian Zucchini fruits (*Cucurbita pepo)* harvests in two plastic greenhouse experiments. Santa Maria, Rio Grande do Sul State, 2012.

		no. of basic units per plot			
Experiment	Harvests	1	2	4	5
	Spatial Grouping				
1st	Individual	98.96	98.66	100	100
	2 in 2	97.92	95.83	100	100
	3 in 3	100	90.62	100	100
	4 in 4	95.83	95.83	100	100
	6 in 6	100	100	100	100
	Total	100	100	100	100
2nd	Individual	96.25	96.66	100	100
	2 in 2	96.66	96.66	100	100
	3 in 3	98.75	98.75	100	100
	5 in 5	100	93.75	100	100
	6 in 6	97.50	97.50	100	100
	10 in 10	100	95.83	100	100
	15 in 15	93.75	87.50	100	100
	Total	87.50	100	100	100
	Temporal Grouping				
1st	Individual	98.75	96.25	100	100
	2 in 2	100	100	100	100
	3 in 3	100	100	100	100
	4 in 4	100	100	100	100
2nd	Individual	94.38	95.00	82.50	93.75
	2 in 2	100	98.75	100	100
	3 in 3	100	100	100	100
	5 in 5	100	100	100	100
	6 in 6	100	100	100	100
	10 in 10	100	100	100	100

Different simulations showed that the growth of a unit's size and/or harvest groupings led to a reduction in the number of zeros in rows, with an increased average, median and standard deviation and reduction of the coefficient of variation (CV%). Spatial evaluation indicated that the sizes of four and five BU in the unit provided values of CV%, which was similar to the harvest groupings of the units with one and two plants. However, these results did not represent lack of randomness behavior within the rows (Tables 2 and 3).

To overcome the problem of lack of randomness in the production of FFB at certain points in the row, the best option is to use units formed by four and five BU. However, because there is often a lack of space for experiments, units formed by two plants and groupings of the total harvests can be a way to reduce experimental error within the rows. Carpes et al. (2010) found similar results in which the variances became homogeneous, starting with the harvest grouping with the presence of units with no fruits ready to be harvested. Thus, they reduced interference, preventing the disruption by zero values of variance estimations between the harvests. Moreover, Feijó et al. (2005) suggest using units with six plants and groupings of the initial half of the productive period to estimate experimental error with a greater precision for Italian Zucchini experiments.

Table 2. Medium, median and standard deviation (S.D.) in grams, percentage of zero and coefficient of variation (CV%) of the spatial evaluation of fresh Italian Zucchini (*Cucurbita pepo*) fruit biomass in rows of different unit sizes and harvest groupings in summer-autumn. Santa Maria, Rio Grande do Sul State, 2012. 1st Experiment.

Basic Units (BU) per plot	Grouping	Medium	Median	S.D.	% Zero	CV%
	Individual	92.09	51.96	122.38	61.88	132.88
	2 in 2	184.18	148.39	179.93	38.44	97.69
1 BU	3 in 3	276.28	241.59	232.22	26.09	84.05
	4 in 4	368.37	360.85	262.68	17.92	71.31
	6 in 6	552.55	550.53	353.11	11.56	63.90
	Total	1105.11	1154.00	613.17	9.38	55.49
	Individual	184.18	151.31	167.84	40.83	91.13
	2 in 2	368.37	333.90	238.74	16.04	64.81
2 BU	3 in 3	552.55	503.91	318.80	5.63	57.70
	4 in 4	736.74	717.67	352.62	2.92	47.86
	6 in 6	1105.11	1072.31	467.06	0.00	42.26
	Total	2210.21	2216.25	783.51	0.00	35.45
	Individual	368.37	339.58	228.61	22.08	62.06
	2 in 2	736.74	731.21	315.92	3.75	42.88
4 BU	3 in 3	1105.11	1094.59	448.26	0.63	40.56
	4 in 4	1473.48	1554.17	464.22	0.00	31.51
	6 in 6	2210.21	2303.31	662.49	0.00	29.97
	Total	4420.43	4381.75	1094.03	0.00	24.75
	Individual	460.46	437.17	270.82	18.23	58.82
	2 in 2	920.92	920.28	374.85	2.08	40.70
5 BU	3 in 3	1381.38	1410.34	536.92	0.78	38.87
	4 in 4	1841.84	1880.38	604.26	0.00	32.81
	6 in 6	2762.77	2800.31	850.29	0.00	30.78
	Total	5525.53	5547.06	1503.60	0.00	27.21

Table 3. Medium, median and standard deviation (S.D.) in grams, percentage of zero and coefficient of variation (CV%) in the spatial evaluation of fresh Italian Zucchini (*Cucurbita pepo*) fruit biomass from rows of different unit sizes and harvest groupings in winter-spring. Santa Maria, Rio Grande do Sul State, 2012. 2nd Experiment.

Basic Units (BU) per plot	Grouping	Medium	Median	S.D.	% Zero	CV%
	Individual	188.77	159.85	167.99	43.54	88.99
	2 in 2	377.55	357.92	245.38	22.08	64.99
	3 in 3	566.32	552.53	307.78	13.13	54.35
1 BU	5 in 5	943.87	956.70	395.61	4.27	41.91
	6 in 6	1132.65	1153.79	446.43	2.50	39.42
	10 in 10	1887.75	1909.02	632.74	0.83	33.52
	15 in 15	2831.62	2948.72	852.29	0.31	30.10
	Total	5663.24	5826.50	1454.35	0.00	25.68
	Individual	377.55	349.10	235.49	23.33	62.37
	2 in 2	755.10	744.56	344.07	7.75	45.57
	3 in 3	1132.65	1128.98	434.62	2.63	38.37
2 BU	5 in 5	1887.75	1903.57	559.73	0.63	29.65
	6 in 6	2265.30	2298.05	654.44	0.25	28.89
	10 in 10	3775.49	3801.27	920.66	0.00	24.39
	15 in 15	5663.24	5749.03	1212.02	0.00	21.40
	Total	11326.48	11450.75	1967.80	0.00	17.37
	Individual	755.10	730.24	331.93	10.25	43.96
	2 in 2	1510.20	1492.43	482.03	1.83	31.92
	3 in 3	2265.30	2274.74	606.10	0.00	26.76
4 BU	5 in 5	3775.49	3733.94	762.30	0.00	20.19
	6 in 6	4530.59	4556.60	966.54	0.00	21.33
	10 in 10	7550.98	7482.25	1256.33	0.00	16.64
	15 in 15	11326.48	11292.44	1741.67	0.00	15.38
	Total	22652.95	22865.13	2616.99	0.00	11.55
	Individual	943.87	926.94	368.38	7.40	39.03
	2 in 2	1887.75	1861.55	547.52	0.83	29.00
	3 in 3	2831.62	2825.24	701.66	0.00	24.78
5 BU	5 in 5	4719.36	4640.19	883.36	0.00	18.72
	6 in 6	5663.24	5602.25	1085.57	0.00	19.17
	10 in 10	9438.73	9293.94	1483.06	0.00	15.71
	15 in 15	14158.09	14016.47	2052.83	0.00	14.50
	Total	28316.19	28100.69	3205.52	0.00	11.32

During the evaluation of randomness in harvests of the units in the time the influence of the total number of harvests was verified (Table 1). With a smaller number of harvests, there was a greater tendency to observe random production values, which can be verified by the frequency of high randomness percentage values in the first experiment (12 harvests) in comparison to the second one (30 harvests).

In the first experiment, an absence of randomness was observed in the temporal production of individual harvests, regardless of the size of the BU. A rotation occurred among low and high fruit production values, which concentrated in lower production values during the first harvests, intermediate and final ones.

A total randomness in the time of production was observed in the first experiment in all of the harvest groupings. However, there were some units formed by two BUs during the second experiment that exhibited a lack of randomness among harvests grouped two by two, which indicated that fruit production was concentrated mainly in the first half of the productive period.

While grouping the harvests every three in three, compliance with randomness occurred. However, this grouping in different sizes of unit was very close to non-randomness based on the high number of formed sequences, showing a rotation among groups of three harvests with greater and smaller fruit production and also a concentration of production between the tenth and fifteenth harvests.

The low number of harvests and, consequently, the sequences formed in the first experiment may have influenced the randomness of the grouping production. This situation was not verified in the second experiment, even with a higher number of harvests and sequences (30). This result is based on the work of Lorentz et al. (2005), who suggested a low number of harvests instead of total production to achieve homogeneous production and faster and more reliable experiments.

The first experiment showed a lack of randomness in individual harvests with units of one and two BU. The second experiment resulted in a lack of randomness at all unit sizes when simulated in the individual harvests. Both experiments were predominated by a high percentage of units with no production and high coefficients of variation for the individual harvests. However, the unit sizes from four and five BUs in the second experiment showed coefficient of variation and percentage of zero values lower than those in the first experiment. These results did not present the problems of high randomness, indicating that the number of harvests may have been more influenced than the variability of the data (Tables 4 and 5).

To minimize the observed lack of randomness in the temporal production of FFB within the units, it is possible to reduce the number of harvests and avoid using the data from individual units. Using harvest groupings and experimental units of more than two plants were the most efficient combinations for reducing non-randomness in the cultivation of Italian Zucchini. This result is attributed to tendencies within the rows, in space or throughout the harvests over time.

Regardless of the cultivation period or the form of randomness evaluation (temporal or spatial), the factors that lacked randomness did not depend on the variability of production, but on how this production was distributed within the rows or in the harvests, forming the sequences above and below the median.

Generally, for different cultivation periods and situations in which some rows were lacking randomness, this result was not associated with the use of smaller unit sizes. In these cases, the class 1 and 2 sequences did not happen by chance; they was caused by the low number of formed sequences. This result shows that the use of smaller unit sizes can help concentrate production in specific regions within the rows. This trend can be attributed to temperature variations, humidity and damage caused during harvests and/or crop handling, among other factors.

The higher the size of the experimental unit in BU numbers, the smaller the number of units within the rows. Because the sequence test was based on the number of observed sequences, the bigger the size the simulated unit is, the smaller the number of sequences within the rows are and, therefore, the higher the probability of obtaining the results for rows with random production.

Table 4. Medium, median and standard deviation (S.D.) in grams, percentage of zero and coefficient of variation (CV%) for the temporal evaluation of fresh Italian Zucchini (*Cucurbita pepo*) fruit biomass in rows with different unit sizes and harvest groupings during the summer-autumn season. Santa Maria, Rio Grande do Sul State, 2012. 1st Experiment.

Basic Units (BU) per plot	Grouping	Medium	Median	S.D.	% Zero	CV%
	Individual	92.09	36.77	131.47	61.88	142.76
1 BU	2 in 2	184.18	135.55	188.89	38.44	102.56
	3 in 3	276.28	252.41	202.65	26.09	73.35
	4 in 4	368.37	316.72	229.50	17.92	62.30
	Individual	184.18	121.48	213.16	40.83	115.73
2 BU	2 in 2	368.37	297.94	320.04	16.04	86.88
	3 in 3	552.55	519.28	332.61	5.63	60.19
	4 in 4	736.74	618.16	412.13	2.92	55.94
	Individual	368.37	303.24	349.89	22.08	94.98
4 BU	2 in 2	736.74	609.53	553.97	3.75	75.19
	3 in 3	1105.11	1063.70	548.71	0.63	49.65
	4 in 4	1473.48	1242.88	741.40	0.00	50.32
	Individual	460.46	378.20	421.90	18.23	91.63
5 BU	2 in 2	920.92	777.88	668.73	2.08	72.62
	3 in 3	1381.38	1355.08	646.80	0.78	46.82
	4 in 4	1841.84	1586.47	895.79	0.00	48.64

Table 5. Medium, median and standard deviation (S.D.) in grams, percentage of zero and coefficient of variation (CV%) for the temporal evaluation of fresh Italian Zucchini (*Cucurbita pepo*) fruit biomass in rows of different unit sizes and harvest groupings during the winter-spring season. Santa Maria, Rio Grande do Sul State, 2012. 2nd Experiment.

Basic Units (BU)per plot	Grouping	Medium	Median	S.D.	% Zero	CV%
	Individual	188.77	130.70	225.26	43.54	119.33
	2 in 2	377.55	314.73	343.28	22.08	90.92
1 BU	3 in 3	566.32	492.44	449.53	13.13	79.38
	5 in 5	943.87	853.68	543.62	4.27	57.59
	6 in 6	1132.65	1053.09	519.32	2.50	45.85
	10 in 10	1887.75	1877.31	536.05	0.83	28.40
	Individual	377.55	289.18	380.06	23.33	100.66
	2 in 2	755.10	636.36	604.47	7.75	80.05
2 BU	3 in 3	1132.65	982.26	814.14	2.63	71.88
	5 in 5	1887.75	1697.74	995.99	0.63	52.76
	6 in 6	2265.30	2040.61	940.69	0.25	41.53
	10 in 10	3775.49	3690.04	936.22	0.00	24.80
	Individual	755.10	577.93	677.63	10.25	89.74
	2 in 2	1510.20	1272.33	1106.92	1.83	73.30
4 BU	3 in 3	2265.30	1984.65	1526.94	0.00	67.41
	5 in 5	3775.49	3399.90	1878.49	0.00	49.75
	6 in 6	4530.59	4040.18	1743.81	0.00	38.49
	10 in 10	7550.98	7474.70	1612.09	0.00	21.35
	Individual	943.87	739.30	823.91	7.40	87.29
	2 in 2	1887.75	1590.41	1356.37	0.83	71.85
5 BU	3 in 3	2831.62	2434.41	1887.82	0.00	66.67
	5 in 5	4719.36	4266.09	2324.08	0.00	49.25
	6 in 6	5663.24	5127.28	2148.13	0.00	37.93
	10 in 10	9438.73	9257.09	1967.29	0.00	20.84

Conclusion

There is greater randomness of production in units with a higher number of plants.

Units composed of two basic units grouping harvest totals or units of four or five BU, in any grouping of harvests, generate rows with randomness in the production of FFB in the units.

A lower number of harvests randomizes the production of units while the harvests are carried out.

Harvest groupings and units formed by four and five basic units are the most efficient combination for reducing non-randomness for Italian Zucchini production. This efficiency is attributed to tendencies within the rows and associated with the space or time of the harvests.

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