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PLOT SIZE UNDER FIELD CONDITIONS TO DETERMINE SOYBEAN AGRONOMIC CHARACTERISTICS

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ABSTRACT - Within the field of performance of agricultural experimentation we have some obstacles related to conducting experiments, the biggest of which is the comparison between treatments with the greatest possible precision, in order to arrive at safe conclusions from the observed results. The objective of this work was to evaluate the relationship between the plot sizes and the stand determination, height at maturation, as well as soybean yield. Three areas were cultivated with soybean for this purpose. In the plant stand determination 18 plot sizes were tested, at the plant height at maturation 14 sizes were tested, and 10 sizes were tested for productivity. The characteristics measurement was performed in triplicate for each plot size, randomly distributed within each area. The characteristic mean for each plot size allowed the adjustment subjective of two regression models, one facing up and one facing down. At the point where the difference among the adjusted models reached the value of the sample standard deviation, the ideal minimum plot size was determined. The evaluation of 14.3 linear m is required in the soybean plants stand determination. It is necessary to quantify 26 plants to guarantee an ideal estimate of the soybean plants at maturity height. It is necessary crop 22 m^2 plot to safeguard an ideal estimate of soybean yield.
Keywords: *Glycine max* (L.) Merrill, agricultural experimentation, experimental planning, productivity.

TAMANHO DE PARCELAS EM CONDIÇÃO DE CAMPO PARA DETERMINAÇÃO DE CARACTERÍSTICAS AGRONÔMICAS DE SOJA

RESUMO - Dentro da área de atuação da experimentação agrícola temos alguns obstáculos relacionados à condução de experimentos, sendo que o maior deles é a comparação entre tratamentos com a maior precisão possível, no intuito de se chegar a conclusões seguras a partir dos resultados observados. O objetivo deste trabalho foi avaliar a relação que existe entre o tamanho da parcela e a determinação do estande, da altura na maturação e também da produtividade da soja. Para tanto foram cultivadas três áreas com soja. Na determinação do estande de plantas foram testados 18 tamanhos de parcela, na altura de plantas na maturação foram testados 14 e para produtividade testaram-se 10 tamanhos de parcela. A medição das características em cada tamanho de parcela foi realizada em triplicata, distribuídas ao acaso dentro de cada área. A média da característica para cada tamanho de parcela possibilitou o ajuste de dois modelos de regressão, um voltado para cima e outro voltado para baixo. No ponto em que a diferença entre os modelos ajustados atingiu o valor do desvio padrão amostral, determinou-se o tamanho mínimo ideal da parcela. Exige-se a avaliação de 14,3 m lineares na determinação do estande de plantas de soja. Para garantir uma estimativa ideal da altura de plantas de soja na maturação deve-se quantificar 26 plantas. Deve-se colher a parcela com 22 m^2 para garantir uma estimativa ideal da produtividade de soja.
Palavras-chave: *Glycine max* (L.) Merrill, experimentação agrícola, planejamento experimental, produtividade.

INTRODUCTION

Brazil is the world's largest soybeans (*Glycine max* L. Merril) producer, with production higher than 114 million tons, obtained with the cultivate in more than thirty and four million hectares in the 2016/17 harvest, with an average yield of 3,364 kg ha-1 (CONAB, 2018). This yield is basically due to research work carried out with the soybean crop, which helps in the new cropping technologies development and the obtaining of new genetic materials,generating resistance and greater productivity (CARRÃO-PANIZZI et al., 2012).

The experimental planning is required for the execution of efficient research works, being necessary to carry out, analyze, process and disseminate the results, which may have errors. The ideal plot size determination is a measure of reducing the error generated in the research process, since the plot size has directly influence on the accuracy and precision of the obtained experimental data. Due to this, the plot size determination has been the object of studies in different cultures, such as pigeonpea (SANTOS et al., 2016), papaya (SCHMILDT et al., 2016), strawberry (COCCO et al., 2009), black oats

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(CARGNELUTTI FILHO et al., 2014), millet (BURIN et al., 2015), among others.

There are different methods for the ideal plot size determination for soybean experiments, among which we can highlight the methods of Smith, Relative Information, Hatheway, Pimentel Gomes, Visual Inspection of the Maximum Curvature with the Variation Coefficients (VC), Modified Maximum Curvature of the VC, Segmented Linear Model of the VC with Plateau Response, Segmented Quadratic Model of VC with Plateau Response and also the Method of VC Maximum Curvature (CARGNELUTTI FILHO et al., 2011). However, all these methods are related to the variation generated among and, or within the basic units studied (accuracy of measurements), leaving aside the question of the measurements accuracy (measured value near to the real value).

The measurements accuracy cannot be accepted from quantification at blank experiments, since the area total productivity would be obtained by the sum of the basic units productivity. Since each basic unit has a productivity estimate and an error associated with it, then the total productivity error would have all the productivity errors of the basic units. To overcome this difficulty it was necessary to implant an experiment with the treatments randomly distributed within a larger area, which would be represented.

The plot size determination in soybean correlates with the area of its determination, influenced by its environmental conditions, with the cultivated genotypes, in addition to being influenced by the method employed for its determination. This requires the ideal plot size determination in more than one crop area or experiment, for the different characteristics to be evaluated, thus ensuring results with greater confidence (CARGNELUTTI FILHO et al., 2009).

No studies were found in the literature that obtained real or average values to compare with the obtained estimative. Therefore, the objective of this work was to evaluate the relationship between the plot sizes in field condition and the stand determination, height at flowering and maturation, as well as soybean yield.

MATERIAL AND METHODS

The measurements of the experiment were carried out in three areas cultivated with soybean, located within the coordinates 24º 33' of latitude and 54º 34' of longitude with 260 meters of the average altitude.

The Köppen's climatic classification for the region is subtropical (type Cfa) with average temperature lower than 18ºC in the coldest month (mesothermic) and 22ºC in the warmest month, with hot summers and well distributed rains during the year. The predominant soil classification in the region is clayey Red Eutroferric Latosol (EMBRAPA, 2008).

The areas cultivated with soybean were seed on corn remain, after this corn has been cut for the silage production. The soybean seeding was carried out on September 27th, 2016 under no-tillage system, with a 250 kg.ha^{-1} of the formulated 00-20-20 at the base fertilization and 0.5m of the spacing between lines. The cultural dealings were carried out where necessary, according to the proper culture development.

The characteristics plant stand, plant height at maturation and productivity were quantified at the three areas. Measurement of the plant stand was performed in triplicates at plot sizes of 0.5; 1.0; 1.5; 2.0; 2.5; 3.0; 4.0; 5.0; 7.5; 10.0; 15.0; 20.0; 25.0; 30.0; 40.0; 50.0; 75.0 and 100.0 linear meters.

The information to determine the plant stand (number of plants m^2) was collected with the aid of a tape measure, which was extended to the soil according to the size of each plot and the plants inserted therein were accounted for. Subsequently, the values obtained were transformed to plants m^2, thus determining the plant stand for each size plot. With plant stand data of all treatments the plot-weighted average and sample standard deviation were obtained, these represent the average plant stand and its deviation of each evaluated area.

For the characteristic plants height at maturation 1; 2; 3; 4; 5; 10; 15; 20; 25; 50; 75; 100; 150 and 200 plants were measured, constituting 14 treatments or plot sizes. The maturity plants height was determined with the aid of a tape measure inserted close to the soil surface and extended to the apex of the plant main stem, repeating the procedure for each plant in according to the mentioned treatments. The result was expressed in centimeters (cm) per plant. With data of the plant height at maturation of all treatments, the plot-weighted average and sample standard deviation were obtained, to represent the mean plant height and its deviation of each evaluated area.

The productivity was obtained from harvest in triplicate of 4; 10; 20; 40; 80; 120; 368; 736; 1472 and 2944 m^2 of soybean areas, constituting 10 treatments. The Harvesting of the treatments was mechanized with the aid of a cabin New Holland 8050 harvesters with 13 feet platform. The harvested material was collected at the elevator foot, before being sent to the grain tank, with the aid of a plastic bag tied at this position of the machine.

The weight of the harvested material was obtained with the help of a mobile balance with a precision of 5 kg, arranged under the axle of the truck, and the areas of 4, 10, 20 and 40 m^2 was weigh in the laboratory with a precision of 0.01 kg. The weight data were transformed into productivity when divided by the parcel area that originated them. For the results analysis, these were extrapolated to kg ha^{-1}.

The productivity of each area was obtained for a division of the amount produced delivered at the cooperative and the total area harvested, which was 3.0 ha for each area evaluated. The results were tabulated and submitted to the normality analysis and variance homogeneity. Afterwards, they were submitted to regression analysis, in which it was possible to adjust two distinct logarithms models for each measured characteristic in each area.

At the first model, which was adjusted subjectively, ensuring that it was faced down, points smaller than the weighted average were used together with the four points obtained from the determination of the largest plots size. While in the second model, also mounted subjectively, ensuring that it was facing up, points greater than the weighted average were used together with the four points obtained from the determination of the largest plots of each characteristic.

The value of the sample standard deviation was obtained for each area in the evaluation. At the point where the difference between the adjusted models reached the value of the sample standard deviation, the ideal minimum plots size for accuracy was determined.The statistical analyzes were performed with the aid of statistical software R (R Development Core Team, 2011).

RESULTS AND DISCUSSION

The evaluated plants stand in area 1 made it possible the preparation of Figure 1A and estimation of the sample standard deviation value corresponding to 3.298 plants per linear meter for this characteristic. When the logarithmic models (faced down and faced up) have the sample standard deviation value in their difference, we had with size plots of 14.3 linear meters. Thus, the ideal plot size to generate the average plants stand information in this area is 14.3 linear meters. The second area cultivated with soybean had a sample standard deviation of 2.205 plants per linear meters, in this case 9.9 linear meters being sufficient to reach the precision in determining the plant stand (Figure 1B).

The plant stand evaluation in the third area (Figure 1C) confirms what was already reported through Figure 1b, in this area the sample standard deviation was 2.442 plants per linear meters and the plot size to obtain accuracy in the determination was 13.9 linear meters. This sample standard deviation was intermediate for that obtained in area 1 and area 2, as well as the calculated plot size.

The plot size to determine the plants stand ranged from 9.9 to 14.3 linear meters, evidencing the existence of variation in the plants distribution in the areas where this characteristic was evaluated. The sample standard deviation is being used as an accessory unit in the evaluation of the relationship between the number of plants per linear meter and the plot size. Thus, it is assured that each area, depending on the distribution homogeneity of the plants inside, will require a larger or smaller size of plots to reach exactness in the obtained result, in accordance with the work of Cargnelutti Filho et al. (2009).

In the case of tractor-driven sowing machines, this plot size should be divided in the same proportion for each sowing line. So for a sowing machine with eight lines we must quantify at least 1.79m in each line, giving a total of 14.3 linear meters, so that we can accurately represent the correct plant stand for area 1. If it were in the area 2 it would be necessary to measure 1.24 linear meters and in area 3 we would measure 1.74 linear meters.With these results it is possible to extrapolate that, for determining the soybean plants stand one must count the number of plants present in 1.75 linear meters of each line of the sowing machine, guaranteeing the result accuracy.

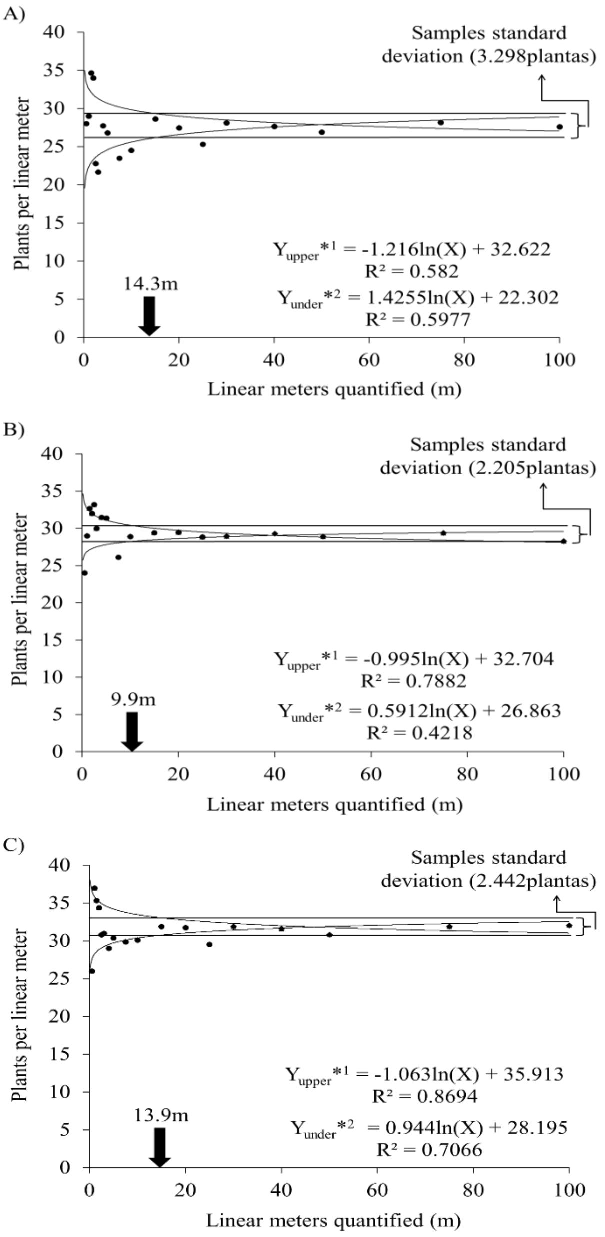


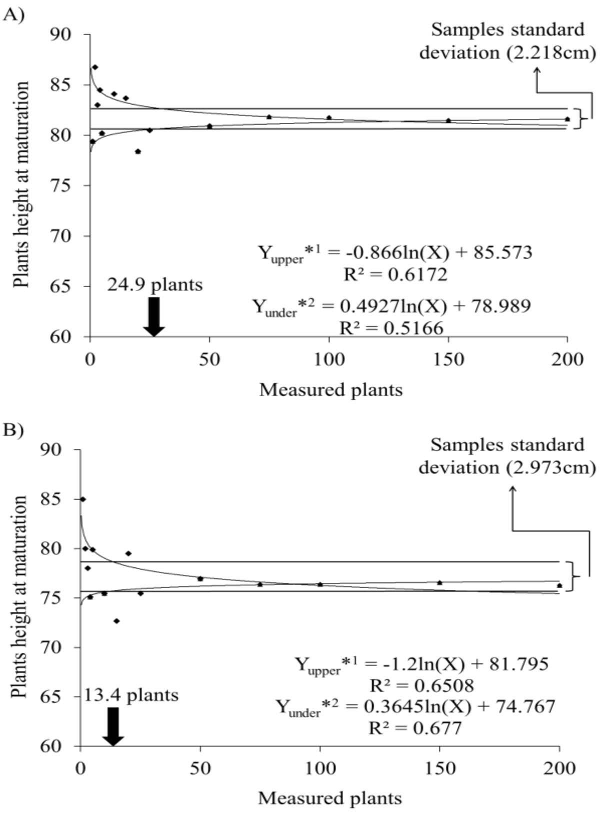
FIGURE 1 -Number of plants per linear meter quantified at the end of the soybean crop cycle on area 1 (A), on area 2 (B) and area 3 (C). Significant regression at $p < 0.05$ by the F test; 1 e 2 = equation facing up and down, respectively.

The Figure 2A shows the behavior of the relationship between plant height at maturity and the number of plants quantified. The measurement of 25 plants was sufficient to guarantee accuracy in determining the height of plants at maturity, this result was generated at the point where the curve with the face up was equal to the value 2,218 cm, plus the result obtained with the curve model face down. The value 2.218 cm corresponded to the standard deviation of the sample found with the data obtained in this area.

In area 2 (Figure 2B), it was necessary to measure only 14 plants to reach precision in determining the plants height at maturity. This value was lower than that obtained in area 1 (Figure 2A) due to the fitted models to the data, since the sample standard deviation, in both cases, were nearby. The adjusted model faced down had a smaller response variation when compared to the model faced up, since the value that multiplies the ln(X) in the model faced down had a lower magnitude (0.3645) when compared to the same coefficient of the model facing up (1.2).

For the third area, it was estimated that the height determination of 26 plants is necessary to guarantee accuracy of the soybean plants height quantification at maturity (Figure 2C). The variation between 14 and 26 plants for determination with accuracy safety for estimation of soybean plant height at maturation was dependent on the area to be quantified. In general, height determination of 26 plants guaranteed precision in the estimation, being a plausible value within the academic experimental conditions, but difficult to be followed when the experiment involves more than tens of hundreds treatments.

Cargnelutti Filho et al. (2009) have already demonstrated the need to measure at least 12 plants in each experimental unit to improve the accuracy of evaluation characters in soybean plants. With this result, it is evident that the studies that work with the variability of the plants height estimation, or the experimental accuracy of the estimates, have pointed to the evaluation of at least 12 plants. It is worth noting that measuring this number of plants in some areas may not guarantee the estimate accuracy, which may require measuring up to 26 plants.



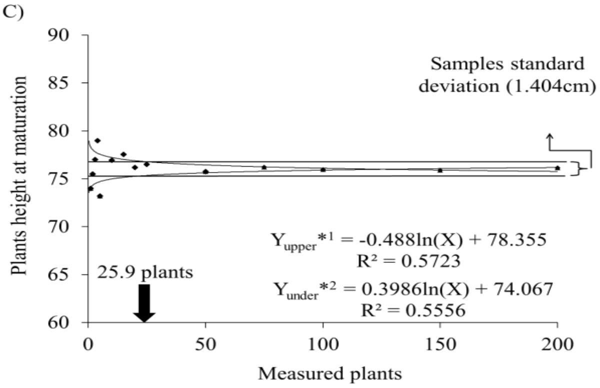


FIGURE 2 - Plant height quantified at the soybean maturation cultivated on area 1 (A), on area 2 (B) and area 3 (C). Significant regression at $p < 0.05$ by the F test; 1 e 2 = equation facing up and down, respectively.

The mechanical harvest of 17.3 m^2 guaranteed precision in the soybean yield determination in the first area evaluated (Figure 3A). The estimated value assures the determination of the actual value (2,667.5 kg ha^{-1}) more or less the sample standard deviation value (497.482 kg ha^{-1}), in this case 17.3 m^2 that generates a estimative of the productivity equivalent to 2,170.018 kg ha^{-1}, being in the range of $\mu \pm \sigma$.At the area 1 it was not possible to fit a logarithmic model faced up, because there was only one point above the productivity average. Thus, only the model faced down was used to determine the plot size that would guarantee accuracy of the productivity estimate.

The mechanical harvest of 22 m^2 guaranteed precision in the determination of soybean yield in the second evaluated area (Figure 3B). The difference of the generated productivity estimate by either the model faced down or the model faced up is less than 418.3 kg ha^{-1}, when the used area is larger than 22 m^2. This condition was adopted as the determination of plot size parameter that provides estimate with precision.

The mechanical harvest of 22.2 m^2 of soybean guaranteed precision in the determination of its yield, in the third area evaluated (Figure 3C). In this specific area, even with sample standard deviation lower than that obtained in area 1 and 2, the plot size estimate was nearby to the estimate in the other areas, making it possible to infer that the plot size of 22.2 m^2 provided a precision of the productivity estimate soybean in any of the three evaluated areas.

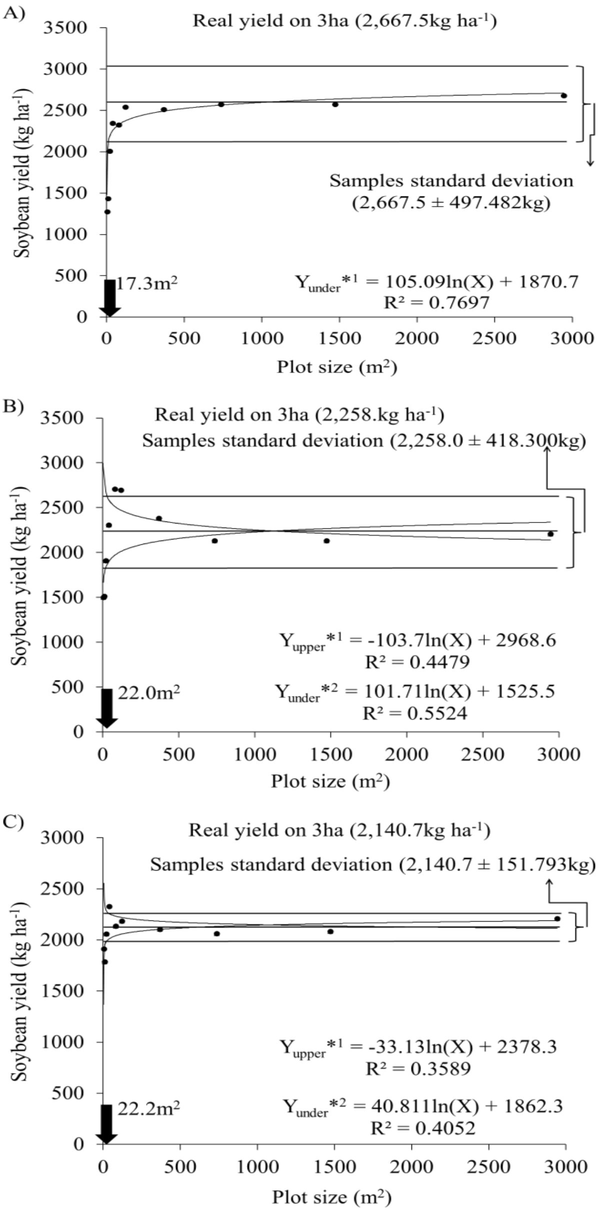


FIGURE 3 - Soybean productivity in function of the plot size employed in mechanical harvest, the soybean was cultivated on area 1 (A), on area 2 (B) and area 3 (C). Significant regression at $p < 0.05$ by the F test; 1 = equation facing down.

In the literature there are studies that aim to establish ideal plot size to determine the soybean yield, ensuring the estimated accuracy. Among them, it is possible to mention the work of Humada González (2012) determined that the optimum plot size, estimated via the maximum curvature of the productivity variation coefficient, for the soybean cultivar BMX POTENCIA will be near 5 m^2 the ideal for quantifying productivity.

Santos et al. (2012) report that if the heterogeneity of the environment (soil) is large, the larger the plot size or the number of repetitions will tend to be. Also according to the work carried out by Carvalho et al. (2016) the simulated plot sizes do not interfere with the experimental quality atthe evaluation of the soybean crop. Smaller parcels may be used in trials to reduce costs for assemble experiments.

It should be noted that in all these studies the determination of the optimal plot size is based on the accuracy of the measurements.To achieve accuracy in the productivity determination estimates it is necessary parcels with 22 m^2, when this is affirmed, besides guaranteeing accuracy precision in the determinations is also guaranteed for a mechanical harvest.

The ideal plot size estimates for agronomic characteristics in the soybean crop showed contrasts among the characteristics and among the crop areas (or experiment), which may require different plot sizes to be used for evaluations. However, in an attempt to unify a recommendation that meets most of the experiments the indication was used that in order to quantify the soybean plants stand 14.3 linear meters must be evaluated. The plants height determination to have experimental accuracy should contain the measurement of at least 26 plants within the experimental unit. The soybean yield must be performed in a useful area of at least 22 m^2, to obtain accuracy in the estimation.

The width of the plot to be used should also be weighted by the researcher, since parcels with a 22 m^2 area with only 4 lines will require 23 m long by 2 m wide (0.5 m between lines, neglecting a line of each side and 0.5 m at the ends of the plot) giving total area of 46 m^2, if we harvest 22 m^2 we use only 47.82% of the area. Parcels with 10 lines, following the same calculation purpose, generates the use of 67.69% of the area. This is the indication of using plots varying from 8 to 12 lines, guaranteeing use around 68% of the total area at the experiment.

Under normal conditions of experiments carried out with the soybean crop, we worked with plots of four lines with 5 m in length, these experiments are very well accepted in the scientific community. To be sure, Storck et al. (2010) have evidenced that 76.4% of the competition trials of soybean cultivars have high and very high precision and only 6.9% have low accuracy. However, for the researcher besides the experiment precision, information is required that portrays the genotypes reality for the decision making and with this precision guarantee and accuracy in the evaluated estimates.

CONCLUSIONS

The appropriate plot size for evaluating the soybean plants stand should be 14.3 linear meters, and it should be evenly distributed among the experimental unit lines.

The estimative of soybean plant height at maturation should be performed in 26 plants within the experimental unit.

The plot size ideal for evaluating soybean yield should be 22 m^2, so that the researcher will have precision and accuracy in the obtained estimate with mechanical harvest.

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