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Mechanical Operation Assessment of Maize Crop using CUSUM Chart

Chandan Nagar[1], Mujahida Sayyed [2], Aman Ekka[3] and R. P. Ahirwar[4]

[1,3]Departement of Statistics, JNKVV, Jabalpur
[2]Departement of Statistics,College of Agriculture, GanjBasoda (Vidisha), Jawahar Lal Nehru Krishi Vishwa Vidyalaya, Jabalpur, India. E-Mail: mujahida.sayyed@gmail.com
[3]Departement of Agriculture Economics and Farm Management, College of Agriculture, GanjBasoda (Vidisha), Jawahar Lal Nehru Krishi Vishwa Vidyalaya, Jabalpur

Abstract: Understanding the operational quality of maize harvesters offers valuable insights for management to optimize resource performance while minimizing costs. This study aimed to assess the mechanized maize harvesting process using the CUSUM chart across different plot configurations. Treatments were based on existing plot shapes within the study area, categorized as either irregular or rectangular. Results indicated that the CUSUM control chart effectively identified process instabilities and contributed to maintaining operational quality.

Keywords: Grain harvester, CUSUM, machine performance.

INTRODUCTION

Maize (Zea mays L.) is one of the most widely cultivated cereal crops globally, playing a crucial role in food security, livestock feed, and industrial applications. Efficient maize harvesting is critical for ensuring high yields, minimizing losses, and optimizing overall productivity. One key measure of efficiency in maize cultivation **is time field efficiency,** as defined by the ASAE standard D497.6 (2009). This metric represents the percentage of effectively used time during field operations in relation to the total available time. Factors such as machine usage, operator habits, and field manoeuvrability all contribute to efficiency outcomes (Araldi et al., 2013).For maize fields, optimizing time efficiency is particularly important due to the large-scale nature of the crop. Rectangular plot shapes offer the best results, with platform width and block dimensions (length and width) playing a crucial role in reducing time losses and improving performance (Whitney, 1988). In an ideal scenario, the maize harvester spends most of its time working on the productive areas of the field, ensuring maximum output. However, in practice, terrain and plot irregularities make achieving this ideal difficult. Scroll speed is another critical factor in maize harvesting. It directly affects the combine harvester's capacity to process the mass of maize crops efficiently. Controlling scroll speed and maintaining acceptable crop loss levels is essential for meeting both regional and production-specific quality standards. Cunha & Zandbergen, (2007) and Magalhães et al. (2007) managed scroll speed and keeping crop loss within acceptable limits are vital for achieving quality standards specific to both regional and production requirements. A well-optimized scroll speed ensures that the maize harvest can proceed efficiently without compromising on quality or increasing waste.

To effectively monitor and enhance the efficiency of mechanized agricultural operations, such as maize harvesting, a variety of researchers (Chioderoli et al., 2012; Silva et al., 2013; Voltarelli et al., 2013; Voltarelli et al., 2014) have employed statistical process control (SPC) methodologies. In addition, Compagnon et al. (2012), Cassia et al. (2013), and Zerbato et al. (2013) have utilized quality indicators to assess operational

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performance. Control charts for individual values are commonly used to detect non-random variations or special causes of instability within the harvesting process. By identifying these fluctuations, operators can make timely adjustments to their methods, thereby ensuring more consistent and stable performance in harvesting operations. This proactive approach not only enhances operational efficiency but also contributes to better yield quality and overall productivity in agricultural practices.

To further enhance the operational efficiency of maize harvesting, advanced statistical methods such as **Cumulative Sum (CUSUM) control charts** have proven useful. Sayyed and Singh (2001) developing a CUSUM control chart specifically for Poisson variables under inspection errors. Their research highlighted the challenges of maintaining accurate process control in the presence of errors, a common scenario in practical applications. Sayyed, Singh, and Soni (2002) expanded the methodology to binomial proportions, presenting a CUSUM approach for processes where the outcomes are binary, such as defective versus non-defective products. This extension proved valuable for industries relying on categorical data, where inspection errors could severely impact quality monitoring. These charts, specifically the V-mask type, offer a method to monitor and detect minor, consistent changes in process performance over time (Follador, 2012). CUSUM allows for quicker detection of deviations, enabling timely adjustments to factors such as machine operation, operator performance, or environmental conditions. This approach helps maintain the quality and consistency of maize yields while also monitoring variables such as range and standard deviation (Montgomery, 2009). Sayyed et al. (2022) focused on the CUSUM chart's application for monitoring processes that require detecting shifts in only one direction (either an increase or a decrease), which is particularly useful in scenarios where only one type of deviation is critical to control.

MATERIAL AND METHODS

The experiment was conducted at the College of Agriculture, Ganj Basoda (M.P.), focusing on a maize trial. The soil in the study area is classified as black soil. This paper draws upon a portion of that research.

Table 1: Characteristics of the evaluated plots formats and their respective areas

Shape	*Irregular*	*Rectangular*
Area (Hec)	0.035	0.045
Length (m)	20	30
Width (m)	15	15

The maize harvest was carried out using a PREET-7049M Advanced combine harvester (model year 2010), equipped with a 5.00-meter-wide cutting deck and a tangential track system. With approximately 700 hours of operation, the harvester was employed to complete the maize harvest in plots characterized by mild relief. All harvest operations in these plots were completed within the same day.

During the monitoring of combine harvester operations, total losses were assessed at regular intervals throughout each plot's harvesting process. Circular frames, constructed with 0.22 m^2 hoops covered by shade screens resembling sieves, were used for measurement. Three identical hoops, covering a combined area of approximately 1.00 m^2, were set up for each assessment: one hoop was positioned at the center, between the rear axle, and the other two were placed outside the wheel tracks on the left and right. These hoops were deployed immediately after the harvester platform crossed predetermined points, ensuring accurate loss measurements. Harvest losses were determined by measuring the grains and pods collected above and below the screens during mechanical maize harvesting. Following Statistical Process Control (SPC) guidelines, eight samples were taken from each plot at random intervals every 20 minutes throughout the harvest. Additionally, 10 samples were collected in both the morning and afternoon using a digital meter to assess water content loss. The average daily water content across all analyzed plots was 2.7%.

The Cumulative Sum (CUSUM) control chart was utilized as a Statistical Process Control (SPC) tool to track harvest losses. In this approach, each sample is given equal weight, enabling continuous data collection and assessment. The method functions by accumulating statistics across multiple samples of size n, facilitating the early identification of process shifts and ensuring more consistent monitoring of harvest losses. The CUSUM (Cumulative Sum) method is applicable for constructing control charts for both individual observations and sample averages. When monitoring individual observations, the CUSUM statistic represents the cumulative sum of deviations between each observed value and the target value specified under the hypothesis. For situations with a sample size n>1, the statistic shifts to represent the cumulative sum of deviations of the sample mean from the target or nominal value. This approach allows for early detection of shifts in the process mean, enhancing process stability. To implement this approach, a V-mask CUSUM control chart, originally proposed by Barnard in 1959, was utilized for detecting changes in the process over time.

$$C_i = \sum_{j=1}^{i} y$$

$C_i = y_i + C_{i-1}$

Y_i is the standardized observation $y_i = (X_i - \mu_0)/\sigma$

In decision-making for a CUSUM control chart, a V-mask is used to evaluate control status by positioning its point near the latest data value, with its arms extending parallel to the horizontal axis. The process is deemed in control if all preceding cumulative sums lie within the V-mask arms; if any sums fall outside, the process is considered out of control.

When implementing the CUSUM chart, the V-mask should be applied at each new data point, with its arms extending backward toward the chart's origin. The V-mask's effectiveness in detecting shifts is determined by key parameters: the decision interval (h), slope (k), and the arms' distance (d) and angle. Adjusting these parameters affects the V-mask's sensitivity and overall performance in identifying process changes.

$$K = A \times \tan\theta$$

$$h = A \times d \times \tan\theta$$

In the context of the two equations, A represents the horizontal distance between successive points on the vertical scale when tracing the V-mask, measured in unit distances. This setup allows for tracking deviations in the process, with each point representing the cumulative sum of the data being analyzed.

The production unit being assessed, based on a recommended loss limit (LE) of 60 kg/ha (as per EMBRAPA, 2002), uses this threshold as a guideline for acceptable losses. The CUSUM control chart, with its V-mask model, allows for negative sample values. However, negative values are not considered problematic in this study because any value below the threshold of 60 kg/ha is seen as favorable, indicating losses that are lower than the acceptable limit set by the production unit. This makes it possible to interpret negative deviations as better-than-expected results

RESULT AND DISCUSSION

Figure 1 shows the Statistical Process Control (SPC) for total losses, where the irregular plot reveals consistent process stability over the evaluation period. Since all data points fall within the upper and lower boundaries of the V-mask, the process is determined to be in control. Notably, only samples 1 and 2 displayed cumulative sum values close to zero, reflecting minimal loss at these points. This suggests that, at the beginning of the evaluation, the losses were relatively low compared to other points in the process. As the cumulative sum reflects the accumulation of deviations, the proximity to zero in these two samples implies smaller deviations from the expected loss threshold, representing better performance in terms of reduced losses.

Figure 2 illustrates the process stability for total losses within a rectangular plot, where all data points remain within the V-mask's upper and lower limits. This alignment indicates sustained stability throughout the monitoring period, suggesting no special causes of variation impacted the maize harvesting process. The lack of data points outside the V-mask boundaries implies consistent, disturbance-free performance during the mechanical harvesting operation.

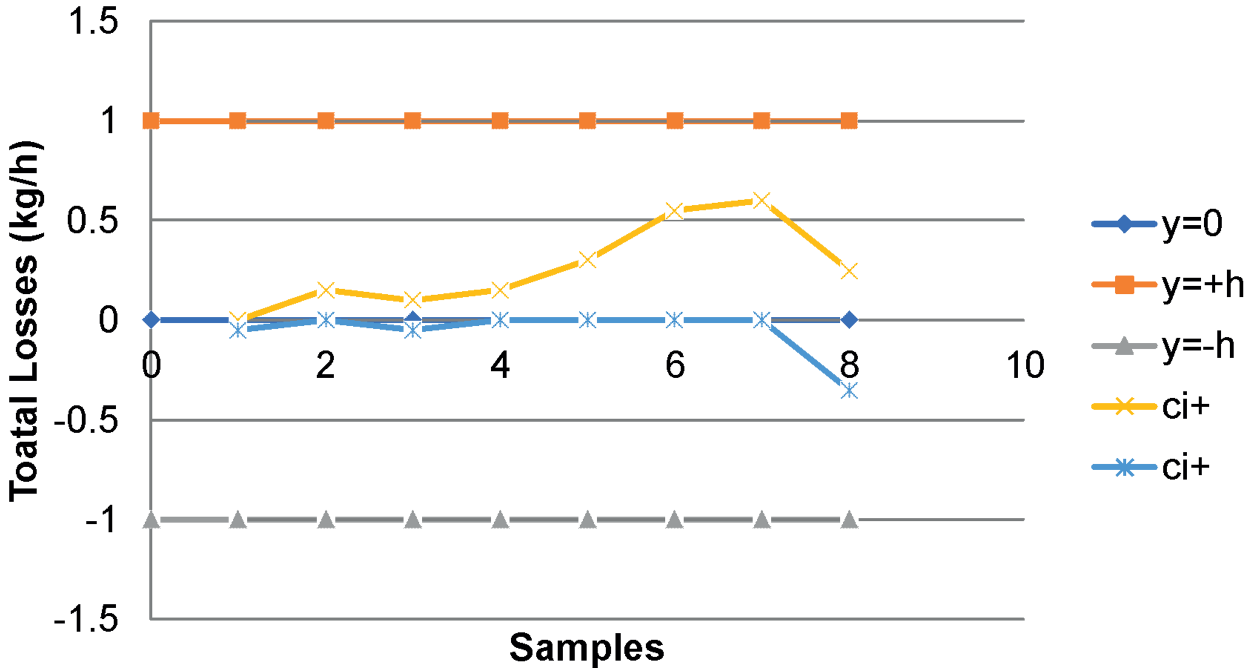

Fig. 1: CUSUM control charts for total losses in the maize mechanical harvesting in the irregular plot format

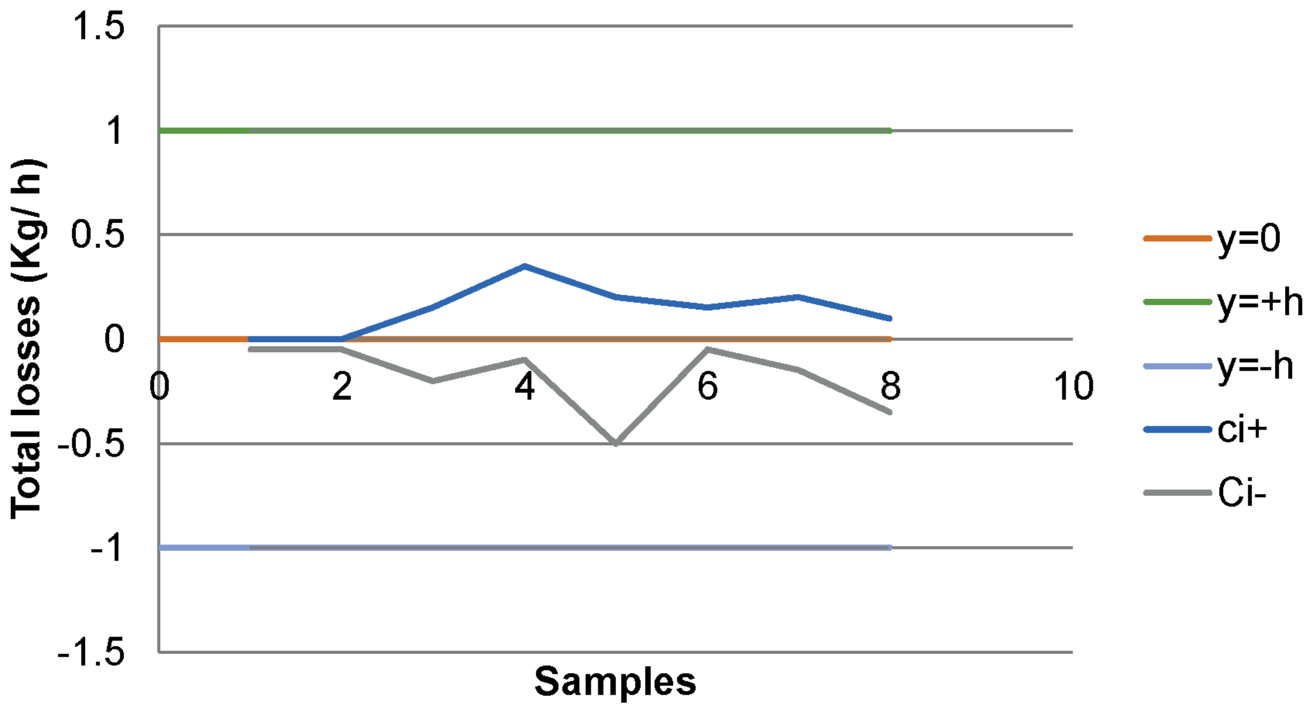

Fig. 2: CUSUM control charts for total losses in the maize mechanical harvesting in the regular plot format

CONCLUSION

The results indicate that the rectangular plot exhibited lower variability in total losses, signifying a higher quality process overall. While there was some instability in the total losses observed during the maize harvest in the rectangular plot, the majority of the data points remained below the specified loss limit. This demonstrates that, although fluctuations occurred, the losses were generally kept within acceptable thresholds, reflecting satisfactory performance.

The CUSUM control chart proved to be an effective tool for monitoring the maize harvesting process. It served as a valuable management instrument by quickly detecting small process misalignments and providing an early warning of deviations from the target. This early detection allowed for prompt corrective actions, ensuring minimal disruption to the process quality. Additionally, the CUSUM chart accurately identified the exact moments when these misalignments occurred, making it a reliable method for maintaining consistent process control and optimizing the efficiency of mechanical maize harvesting.

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