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Generating data via operational monitoring of backpack equipment on small farms

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Abstract.
The Brazilian coffee industry, a global leader in production and exports, faces the challenge of increasing production efficiency to meet growing worldwide demand while preserving natural resources. Precision Agriculture (PA) offers essential tools for this data-driven sustainable intensification; however, its adoption in regions with rugged topography and by family-based growers is severely limited by the scarcity of accessible technologies, particularly for spatial yield measurement. The semi-mechanized harvesting system, predominant in mountainous regions, lacks validated methods for generating yield maps, thereby limiting site-specific crop management. This study was conducted in a commercial coffee plot (Coffea arabica L.), covering 1.1 ha, which is representative of the terrain and semi-mechanized production systems typical of mountainous regions. The central objective was to develop and simulate approaches for generating data to estimate yield using the rotation (RPM) of a portable backpack shaker as an indirect indicator (proxy variable), transforming simple operational data into low-cost agronomic intelligence. As the research is currently in the preliminary results stage, with experiments and validations still ongoing, initial analyses indicate that the data acquisition system, consisting of a backpack harvester with an embedded GNSS system, demonstrated robustness under field conditions. The survey monitored seven machines, recording a raw database of 35,259 spatial points. After filtering to exclude idleness (RPM = 0) and performing outlier treatment, 30,182 useful points remained, ensuring the retention of a consistent database. Exploratory data analysis indicates that it is possible to identify intermittency patterns in engine operation, corresponding to plant switching and operator maneuvers. The initial application of geoprocessing techniques on the filtered data allowed for the generation of maps, interpolated on a 3x3 meter regular grid, which estimated yield ranges between 25 and 100 bags per hectare. These maps evidenced spatial variability and yield density per operator and for the total plot. These indicators suggest that the approaches are viable for transforming the backpack shaker into an activity sensor, generating valuable information. As this is an ongoing study, the next experimental steps involve refining the operational state classification models to increase mapping accuracy and validating the tool as a support for manual fleet management. It is expected that the final consolidation of these results will democratize access to PA, offering a scalable solution for optimizing management in small and medium-sized coffee holdings.

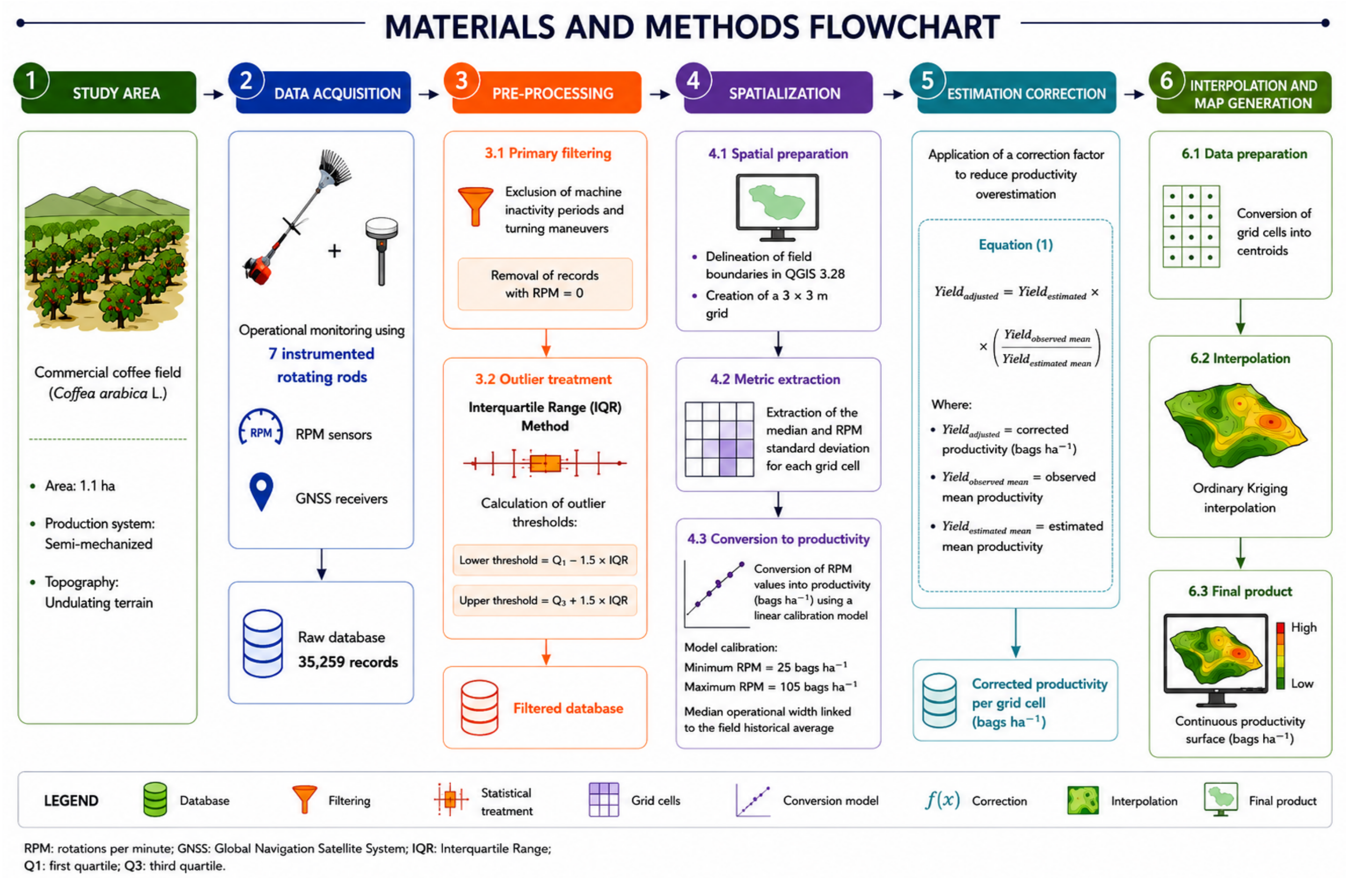
Keywords: Precision coffee growing; semi-mechanized harvesting; yield mapping; sustainability; family farming

INTRODUCTION

The need to increase global food production by up to 70% by 2050 requires the sustainable intensification of agricultural systems (Falcon et al., 2022). In the coffee sector, Brazil stands out as the world's largest producer and faces the challenge of implementing Precision Agriculture (PA) in mountainous regions, where family farming predominates (CONAB, 2025). In these areas, harvesting is often performed using portable semi-mechanized backpack harvesters, which operate independently and lack commercially available systems for spatial data acquisition and georeferenced monitoring (Martello et al., 2022).
To address this technological gap through accessible and low-cost tools (Dibbern et al., 2024), this study presents the preliminary development of a harvest monitoring methodology. Therefore, the objective of this work was to validate preprocessing workflow for engine rotational speed (RPM) data as a proxy variable for the spatial estimation of coffee yield.

MATERIAL *AND METHODS*

A pilot experiment was conducted in a 1.1-ha commercial coffee field located in a mountainous region. Seven portable backpack harvesters were instrumented with GNSS receivers and magnetic sensors to record geographic position and engine rotational speed (RPM). The raw spatial database (35,259 records) was subjected to statistical filtering, and outlier identification and removal were performed using the Interquartile Range (IQR) method. The entire methodological framework, from raw field data acquisition to spatialization into a regular 3 ×



3 m grid using QGIS 3.28 software, is summarized in the operational flowchart presented in **Figure 1**.

Fig 1. Flowchart of the data acquisition, preprocessing, and spatial interpolation procedures employed to estimate coffee yield from operational harvesting data.

RESULTS *AND DISCUSSION*

The primary filtering of null records resulted in the exclusion of 5,077 inconsistent operational data points. This step mitigated data distribution asymmetry, increasing the overall mean harvesting rotational speed from 95.74 to 111.85 RPM while reducing the interquartile range from 129 to 117 RPM. The noise treatment procedure successfully isolated severe acquisition failures associated with individual sensors, resulting in a consolidated database containing 30,182 valid records, as shown in **Figure 2**.

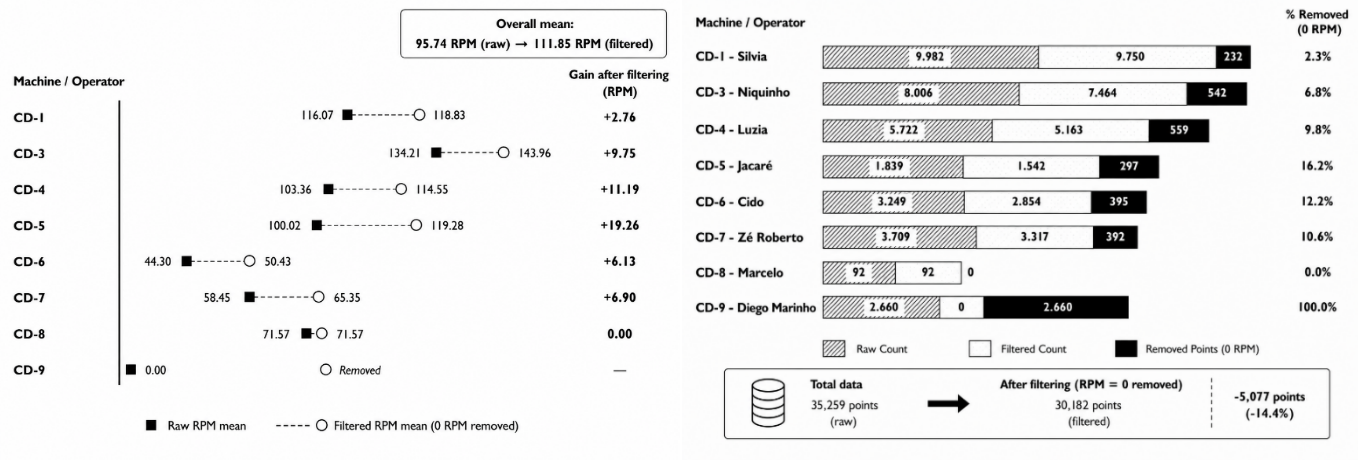


Fig. 2 Comparison of operational records and mean rotational speed (RPM) before and after primary data filtering, highlighting the exclusion of records with RPM = 0 and the resulting impact on operational performance indicators across operators/machines.

The yield transfer function derived from rotational speed data served as a proof of concept, since harvesting operations are still ongoing and the final calibration equation is currently under development. The processed data were interpolated using Ordinary Kriging and subsequently converted into yield (bags ha^{-1}) using the following correction function:

$$Yield_{corrected} = Yield_{estimated} * \left(\frac{Mean_{observed}}{Mean_{estimated}}\right) \tag{1}$$

The preliminary yield map highlighted the spatial variability of estimated productivity throughout the field. The rotational speed (RPM) of the portable coffee harvester was used as a proxy variable for crop yield, providing a preliminary representation of the spatial distribution of productivity, as shown in **Figure 3**.

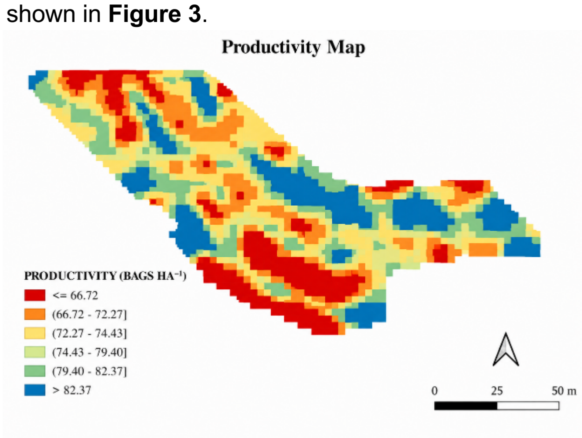


Fig. 3. Spatial distribution of estimated coffee yield (bags ha^{-1}), generated through Ordinary Kriging interpolation of operational harvesting data.

CONCLUSIONS

The partial results indicate that the mechanical rotational speed (RPM) of portable harvesting equipment, combined with GNSS positioning data, has the potential to serve as a viable variable for spatializing crop yield in semi-mechanized coffee production systems without dedicated yield monitoring equipment. The IQR-based filtering workflow and the 3 × 3 m grid-cell modeling approach proved to be consistent and effective for data processing and spatial representation. The next stages of the project will focus on refining the algorithms used to classify engine operating states and on conducting predictive validation under field conditions.

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