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Development of a Batch Type Weighing System for Garlic Bulb's Yield Monitoring

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ABSTRACT

Yield monitoring is one of the parts of the precision agriculture that is best documented in practice and allows varying inputs according to the expected field outputs depending on spatially variable yield goals. The present study introduced a batch type Weighing System (WS) for the garlic bulbs yield monitoring. This WS includes a four-sector cylindrical container, rotary blades, a digital transmitter and array of two load cells for mass measurements. Electronic boards were used to control the WS and transfer the mass and georeferenced data. A LabVIEW interface was also developed to do the real-time signal processing. This WS was tested under laboratory and field conditions. Three factors including blades Rotation Speed (RS), Stop Time (ST) of blades, and Fraction of Stop Time (FST) were defined to find optimum load cell output. The lab tests were done to find the optimum value for these factors and the optimized WS was tested in the field condition. On the basis of WS outputs and actual weight of bulbs, the relative mean standard errors were determined as 1.94% in the lab and 4.26%, in the field. To demonstrate the spatial variability of crop-yield in the field, a yield map was plotted in ArcGIS using the data that were acquired by the WS and a GPS. The data recorded by the use of garlic yield monitoring system can be used in experimental studies to provide the basis for developing efficient nutrient management protocols and improve the management of garlic fields.

Keywords: *Allium sativum,* Load cells, Precision agriculture, Yield map.

INTRODUCTION

Allium sativum, commonly known as garlic, is a species in the onion genus. Total garlic production in the world is reported about 30 million tons (FAO, 2019). In this ranking, Iran is the 16th in the world. In the process of producing garlic in Iran, the only mechanized stage is the tillage, other stages are completely traditional and done manually. Fortunately, in recent years, Precision Agriculture (PA) and related technologies has been growing faster than past decades in Iran. Precision agriculture is a farming management strategy based on observing, measuring, and responding to inter and intra-field variability in crops to ensure profitability, sustainability, and protection of the environment. Precision agriculture, also known as site-specific crop and field management, can help in managing crop production inputs such as fertilizer, seed, and pesticides in an echo-friendly way. Precision agriculture can reduce environmental loading by applying agro-chemicals only where they are needed, and when they are needed. These benefits to the environment come from more targeted use of inputs that reduce losses from excess applications and from reduction of losses due to nutrient imbalances, weed escapes, insect damage, etc. (Bongiovanni and Lowenberg-DeBoer, 2004). Yield monitoring systems are important factors of precision agriculture. They indicate the spatial variability of crop yield in fields and, so, they have become an essential component in modern harvesters. The

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underlying concept of precision agriculture is to accept the existence of spatial variability to manage that variability to minimize environmental impacts or optimize economic returns (Chung *et al.*, 2016).

Crop yield is the most important piece of information for crop management in precision agriculture because it is one of the first means to define, quantify, and characterize the within-field variability in crop production and, so, yield monitoring is applied for measuring, spatially referencing, and mapping yield variation within fields (Usha and Singh, 2013). Although the first commercial yield monitoring systems (YMS) were designed for grains in the early 1990s, some systems have been gradually developed for specialty crops such as potato, tomato, sugar beets, onion and etc. (Bagherpour *et al.*, 2015; Kabir *et al.*, 2018; Ota *et al.*, 2019; Qarallah *et al.*, 2008). The large diversity in the biophysical properties and harvesting methods of specialty crops as well as the smaller market compared to the grains have provided little incentive for companies to concentrate on developing YMS for these crops.

For specialty crops, direct mass flow rate sensors, cumulative weighing, and batch weighing have been reported as a categorization for different methods of mass flow rate measurement (Ehsani and Karimi, 2010). In the continuous-weigh yield monitoring system developed for tomatoes harvester, the mass of the tomatoes was measured on the crop delivery conveyor belt (Pelletier and Upadhyaya, 1999). A yield monitoring system for sugarcane harvesters was installed in the elevator of a sugarcane harvester and consisted of a weight plate supported by load cells. Average error in field evaluations was reported as high as 8% (Molin and Menegatti, 2004).

The impact type of mass flow rate sensor, which is widely used for grain yield monitoring, has an impact plate that is supported by a load cell (Zhou *et al.*, 2014). Impact velocity and the load cell output can be used to calculate the crop mass flow rate. The ratio of an object velocity before and after an impact is defined as the coefficient of restitution. In order to improve the calculation accuracy, the crop coefficient of restitution must be determined precisely. Another impact-type YMS was developed for weighing individual onion bulbs (Qarallah *et al.*, 2008). Due to the dependency of the crop restitution coefficient to moisture content and crop maturity, impact-type YMS is accompanied by large amount of errors (Chung *et al.*, 2016).

Cumulative Weighing System (WS) measures the total weight of the harvested crop over time. This WS are commonly installed under container or a hauling truck, which are generally located at the end of harvesting machine. High sensitive, powerful, and costly load cells are some of the limiting factors for implementation of cumulative WS.

Some researchers developed a volume based mass flow sensor to estimate the total mass by a LIDAR (light detection and ranging) sensor. This system was able to measure the mass with an average error of 7% in lab condition and 10% in field tests. In addition to the high level of errors, this sensor is costly (Jadhav *et al.*, 2014).

In a batch type weighing system, the continuous flow of crop is converted into batches and the mass of each batch is recorded before delivering to the wagon. A weigh-bucket type yield monitoring system for harvested tomato has been designed and improved (Abidine *et al.*, 2003; Cerri *et al.*, 2004). In another study, two commercial pistachio harvester were equipped with similar batch WS. Validations of this weighing system indicated weighing prediction standard errors of approximately 0.9 kg with highly accurate individual tree identification (Rosa *et al.*, 2011).

In brief, mass flow rate sensors measure the mass of the crop as it moves on a conveyor, and they have provided relatively accurate yield measurements for a wide range of crops. Batch weighing systems have been developed for a variety of crops and usually provide accurate measurements.

Many yield-monitoring systems use optical sensors, cameras, or some similar sensors to measure the volume or volumetric flow rate of the crop. The output of these sensors is in such forms as images or reflectance spectra, which require more sophisticated processing compared to a load cell signal.

Harvesting is one of the most difficult and labor-intensive stages of garlic production and needs a lot of effort. When the garlic reaches the desired maturity in the field, a harvester linked to the tractor goes through the field. Although there is no particular complexity in garlic traditional harvesting methods, the working principle in mechanized harvesting is that the digging shovel digs up the bulbs and soil. The harvester has two front leaf lifters and an adjustable shoe for lifting the garlic heads. This machine pulls the garlics out of the soil by two V-shaped belts and deliver the crops to the topping unit. A vibration system is employed to eliminate the excess of soil. In the topping unit, the leaves are removed from bulbs by a precise disc cutting system. Finally, the leaves are crashed down onto the ground from the back and the bulbs are fallen into a large bin at the rear of the harvester. Based on the harvesting method and the high mass flow rate of harvested crop, counting or weighing the individual bulbs is a very sophisticated process. Therefore, because of having more time for measuring and recording the data, batch type weighing is a good choice for solving this issue.

Precision farming tools help producers make more knowledgeable management decisions. However, for specialty crops, lack of a yield monitoring system is one of the main restrictions in applying precision agriculture. Literature review shows that there is no scholarly work available on garlic yield monitoring system. Furthermore, investigation of yield monitoring methods indicates that there are some limitations in the mentioned methods including high error level, the complexity of some methods, and destructive damages to the crops in the weighing process.

Therefore, the aim of this study was to design and develop an efficient batch type yield monitoring system capable of automatically acquiring yields of garlic and evaluate the accuracy of this system in the fields.

MATERIALS AND METHODS

Construction and Installation of Electronic Components

In order to achieve the batch weighing system goals, a continuous motion mechanism with an accurate stop control was designed (Figure 1). In this system, a cylindrical container with 50 cm diameter was made for maintaining the bulbs, then, four rotating blades transfer them between the sectors of cylindrical container. These blades were attached to a rotating shaft driven by a 12V DC worm gear motor (PN01007-SPK, Nissan, Japan), which provides suitable torque for moving materials and was capable of working with tractor battery power in the field. However, in the laboratory, a power supply (PS302D, DAZHENG, China) was used to actuate the motor and other electronic components.

Figure 1 indicates the weighing system schematic as well as its prototype. It is visible that the container floor was divided into four equal sectors that consisted of entrance sector (1), stabilizing sector (2), weighing sector (3), and discharge sector (4). Stabilizing sector made a delay in the system for input bulbs from the harvester to become stable. Then, in the weighing sector, the mass of garlic bulbs was measured on a weighing plate, which is supported by two load cells (BM6G, Zemic, China). The weighing plate is loaded by garlic bulbs, and the last sector in the mass measurement process was the discharge or output segment, where the floor plate of this sector was cut and emptied. This sector was connected to a sloping surface and, at this stage, the bulbs were led out of the machine after weighing for packaging.

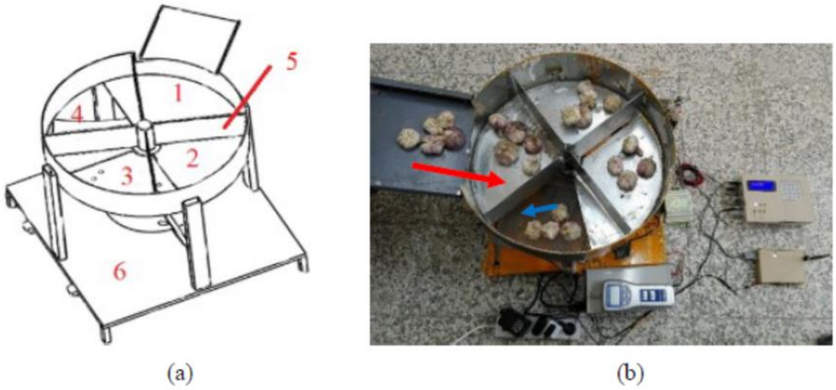

Figure 1. The garlic Weighing System (WS) from the top view: (a) Designed sample and (b) Prototype, consisting of entrance sector (1), stabilizing sector (2), weighing sector (3), discharge sector (4), clockwise rotating blades (5) and chassis (6).

To achieve a uniform distribution of weighing force, the weight of bulbs was determined using two load cells attached to the supporting plate. Figure 2 (a) shows the position of the load cells on the WS under weighing plate. These two points were considered at equal distance from the center of mass of the plate, which was calculated by SolidWorks software [Figure 2 (b)]. Accordingly, the responses of two load cells were completely close to each other.

This weighing system was linked to a single row garlic harvester machine (Rahimi *et al.*, 2017). This apparatus was attached to a tractor and extracted the garlic bushes from the ground by means of a triangular blade and two pull-out V-belts that reliably grasped the garlic leaf. Finally, a steel blade cut the leaves accurately and threw the bulbs in a basket (Figure 3). The required power for moving the extraction belts and the cutting unit was provided by the carrier wheels. In order to achieve optimum harvesting performance, an effective forward speed and a linear speed ratio, which was defined as the extraction belts speed over the forward speed, were considered 3.6 km h^{-1} and 1.2, respectively, and the average mass flow rate within the garlic harvester was approximately 3.5 kg s^{-1}.

Weighing Process Explanation

The movement and, therefore, angular velocity of garlic bulbs, which were delivered by rotating blades from one sector to the next, was a major concern to measure the weight precisely. Its means that every things related to the stabling of the position of bulbs such as blades Rotation Speed (RS), Stop Time (ST) of blades, and Fraction of Stop Time (FST) to recording weight are crucial. So, these three practical parameters were selected for WS (RS: 20, 30 and 40 rpm), (ST: 1, 2 and 3 s),

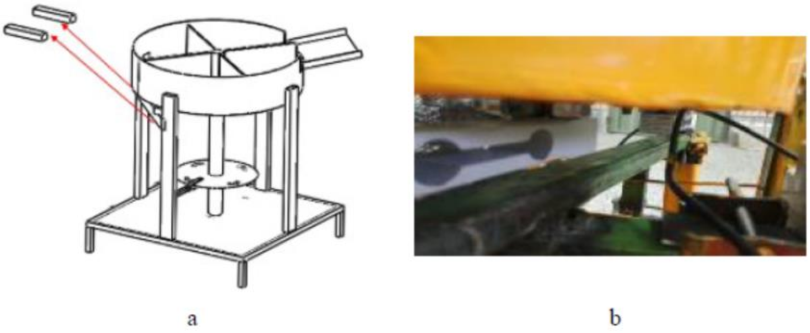

Figure 2. Load cells position on schematic and prototype.

Figure 3. Single row garlic harvester machine (Rahimi *et al*., 2017).

and (FST: 0.4, 0.6 and 0.8). In other words, ST is the whole time that crops stop on load cell plate for weighing, and FST is the weight registering moment. These values were defined based on optimum material flow rate of the garlic harvesting machine. The system was defined to operate with a command from the controller to adjust variable parameters. Then, the bulbs were entered into the first sector thorough an inclined surface. After passing ST, a blade delivers the bulbs to the second sector to give them a short time for stabilizing. In the third sector, after passing FST (the time passed after bulbs entering into weighing sector e.g. 0.4×3 s=1.2 s), the mass data was recorded. Finally, the blades pushed the material out of WS through the discharge inclined surface. Optimum value of S, ST, and FST was obtained in laboratory tests and these optimized values for mentioned parameters were used in the field tests.

Electronics Boards and the Data Logging Software

Two kinds of electronics boards were used in this study: controller board and transceiver antenna board. The controller was designed for manual adjustment of variable parameters like RS, ST, and FST. It received the sensor’s response (realizing the exact stopping position of blades on sectors) and, after that, mass data of the transmitter was sent by antenna. The chart of weighing procedure is shown in Figure 4.

To achieve this goal, a program was written in C++. The mass data were delivered to transmitter antenna board with 2.4 GHz band operation (nRF24L01, Semiconductor Nordic Company, China), then converted to an appropriate format for transmitting. The transmitted data was received by another antenna. The receiver antenna board converted the data once again and transferred them to LabVIEW software. Mass data was recorded in a laptop and shown in Excel number format in LabVIEW. The signal processing operations such as putting low pass filter and online data monitoring was done in the LabVIEW software. The weighing data were shown online in the software.

The yield monitoring system was evaluated under the lab and field conditions. In the field, the developed weighing system was attached to a single row harvesting machine designed by Rahimi *et al* (2017). The field test was done in the Shahid Bahonar University of Kerman Research

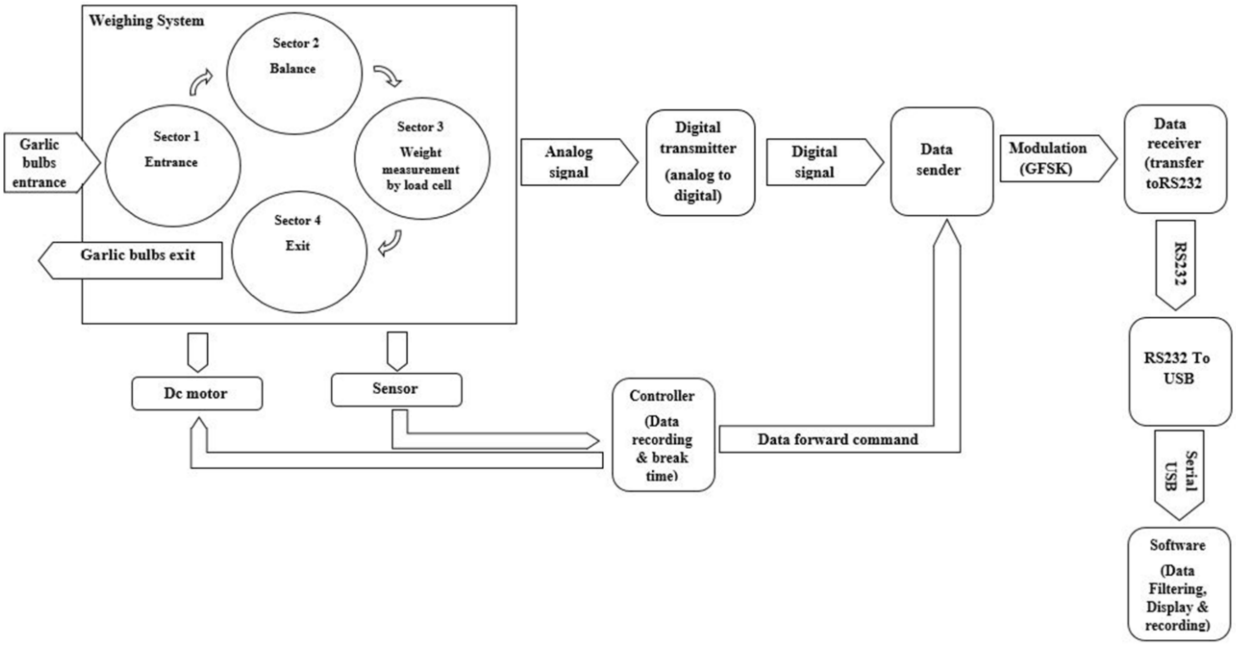

Figure 4. The flow chart of weighing process.

Farm. Garlics were planted in rows, 40 cm apart between rows and 15 cm within the row, for growing maximum sized bulbs. The field size was 23 m×30 m. The starting points were the same for all furrows. First of all, the software clock was synchronized with the GPS clock (76CS, GARMIN, USA). Collection of the data began with adjusting the garlic harvester on the furrow. Simultaneously, with harvesting operation, the GPS was registering points (set to 1-second recording) and, when the operation was finished on each furrow, instantly the registering of points was done by the GPS. However, there is a short time between the first batch harvest (its position) and recording its weight, which was called lag time. The amount of lag time was calculated, so, lag time was considered in collecting batch’s weights and position.

These adjustments were immediately controlled by an operator. After each batch weighing of bulbs by the system, this batch was weighed with digital scale (FG-5020, Lutron Electronic Enterprise CO, Taiwan). This weighing was done in order to obtain actual weight of bulbs and calculate the error of yield monitoring system.

In order to signal smoothening, noise cancelation was done by digital filters. For instance, low pass filter was used to enhance the outcome signal. However, it was better to identify the range of noises before using software filters; therefore, a mechanism was designed to demonstrate vibrations in the field condition.

In the present study, for the purpose of removing unwanted impulse noise from the garlic harvester outputs, the frequency response of the field roughness was determined by operating the WS in the field before harvest (Pelletier, 2001). Then, the cross sensitivity of the vibrations on the yield monitor responses was examined. For this purpose, a load cell (TCLZ-NA, Sokki Kenkyujo, Japan) with capacity of 10 kN was installed under the yield monitoring system in the harvester and mass data was recorded by running repeated trials with an empty container (Figure 5). Load cell responses was transferred to LabVIEW software by transceiver antenna. This calibration then became the baseline for all of the field tests.

Median average function was used for load cell responses by LabVIEW software

Figure 5. Load cell installation on prototype under YMS.

and the average value was obtained as 72.5 kg ha^{-1}. This value was subtracted from the load cell responses and large amounts of errors due to environmental vibration were diminished (Error indicates the difference between load cell response and the actual mass of batches measured with digital scale.)

The location of the harvested points associated with weight data were Geo-referenced by a handheld GPS data mounted on the harvester and interpolation technique was employed to estimate the value for cells from a limited number of sample data points and generate continuous surfaces. Interpolation type and data computation of crop yield maps is important for precision crop production. To generate the final yield map in ESRI ArcGIS10.3 software, the yield points were interpolated using the kriging method that has proven useful and popular in many fields as the most commonly form of interpolator (Bhunia *et al.*, 2018). Since kriging interpolator uses a Gaussian process governed by covariance, it yields the most likely intermediate values (in comparison with other techniques such as Inverse Distance Weighted (IDW), spline and natural neighbors) (Souza *et al.*, 2016). Under suitable assumptions, kriging gives the best linear unbiased prediction of the intermediate values (Betzek *et al.*, 2017). The developed methods allow more objective mapping of yield zones, which are an important data layer in algorithms for prescribing variable rates of production inputs.

Statistical analyses were performed on the experimental data of garlic weight that were gathered by the YMS in the lab in order to determine the effective parameters of the system in garlic bulbs weighing. As mentioned before, in this study, independent parameters were blades Rotation Speed (RS), Stop Time (ST) of blades and Fraction of Stop Time (FST). The effect of these parameters on the performance of the YMS was evaluated in terms of the accuracy of the weighted values. Weighing data were analyzed by SAS 9.3 software, using factorial experiment based on a completely randomized design. Duncan's multiple range test was also used to measure significant differences between pairs of means.

RESULTS AND DISCUSSION

The average value of yield in the field was recorded about 1,092 kg ha^{-1} with standard deviation of 232 kg ha^{-1}. The minimum and maximum field yield were 739.7 and 1832.6 kg ha^{-1}, respectively. The results of ANOVA showed that the third-order interaction of RS, ST and FST was significant at 1% level. In addition, second-order interaction of RS and ST as well as RS and FST on error percentage were significant (at 5% level). Figure 6 presents the distribution of independent parameters and their levels versus error percentage. The least value of error (0.56) belonged to RS: 30 (rpm), ST: 3 (s), and FST: 0.6, but since it had no significant difference with error values of

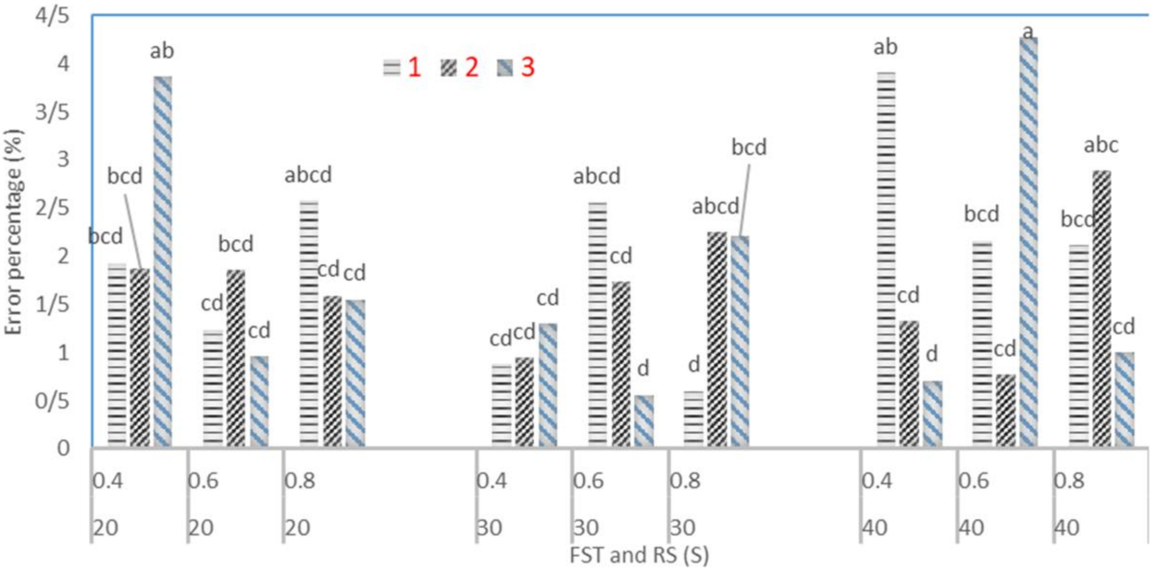

Figure 6. Third-order interaction effect of blades rotation speed (RS: 20, 30 and 40 rpm), stop time (ST: 1, 2 and 3 s) of blades and fraction of stop time (FST: 0.4, 0.6 and 0.8) on the YMS error percentage. Different letters above the columns indicate significant difference (P< 0.05).

RS: 40 (rpm), ST: 3 (s) and FST: 0.4, the second one was selected as optimal condition for field tests due to the higher rotation speed and, therefore, higher field efficiency.

The values of measured data versus actual weight under lab and field conditions are indicated in Figures 7 and 8. Field tests were conducted under optimal condition, which resulted in laboratory tests [RS: 40 (rpm), ST: 3 (s) and FST: 0.4]. The measured weight was well correlated with the actual weight of the bulbs in the lab (R= 0.994) and field tests (R= 0.973), which approve the proper accuracy of the GYMS. Other researchers also observed good correlation between sensor mass flow rate estimation and platform scale weighing system output (Maharlouie *et al.*, 2012).

Comparison between lab and field error levels and fluctuations are shown in Figure 9, which shows that the field error level and its average is obviously higher than the lab error. This means that some factors such as field anomalies and roughness affected harvester vibrations and increased the error level. The vibrations were caused by the bumps, dips, and other field anomalies, during the traveling of the garlic harvester in the field, introducing transient harmonics into load cell response and, consequently, measurement errors. Similar results obtained for pistachio yield monitoring system, and the highest error value for this batch type system in manual harvesting, was reported about 3% (Asadi and Maghsoudi, 2020).

The GYMS, was successfully tested in the lab (less than 2% error) and in the field condition (less than 4.3% error) and the results showed an acceptable performance of this low cost yield monitoring system. The field error was more than the lab error because the lab tests were conducted in static conditions, thus noises were less than field tests. Other researchers at the university of Florida have also developed wagon-based silage YMS (Lee *et al.*, 2005). Four 4,500 kg shear beam type load cells were used for measuring wagon mass and a capacitance type moisture sensor to transmit moisture information. This system also reported errors less than 5% with good coefficient of determination.

It is recommended to conduct further studies to investigate the feasibility of using this mechanism for measuring the mass of

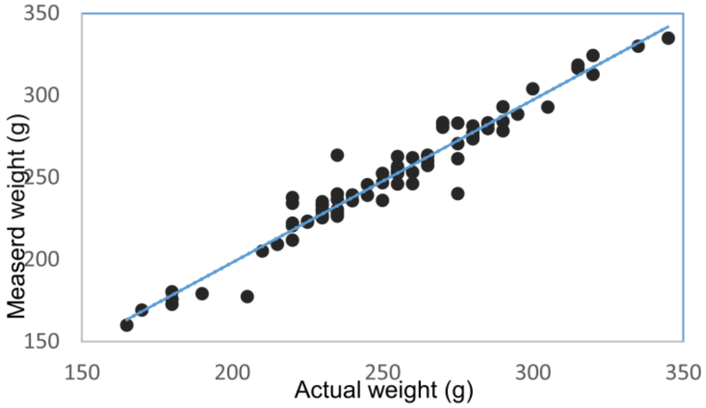

Figure 7. Values for measured weight versus actual weight under lab conditions.

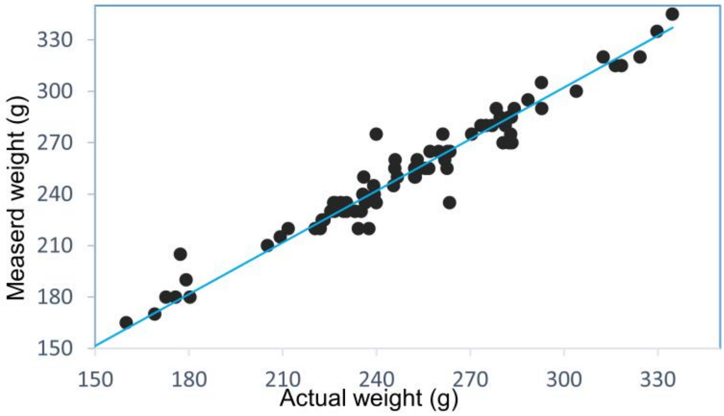

Figure 8. Values for measured weight versus actual weight under field conditions.

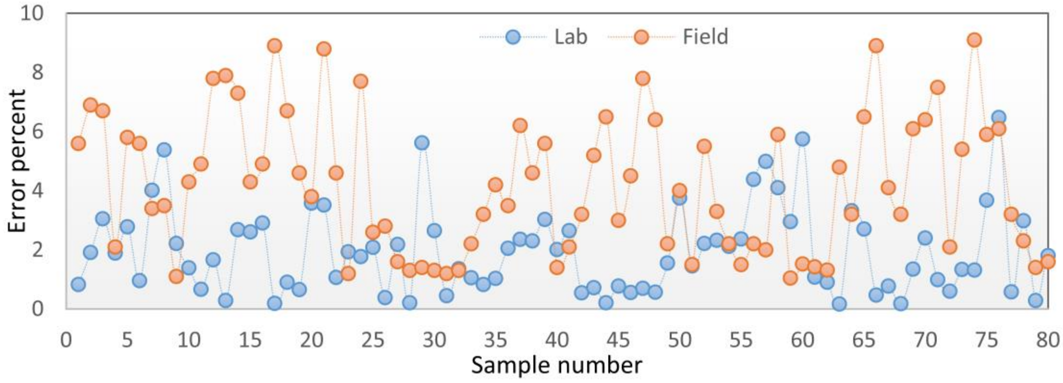

Figure 9. Comparison of errors in the lab and field tests.

other specialty crops (potato, onion, leek, …) and determine the optimum practical parameters for mass flow prediction.

Figure 10 shows a garlic yield map of a field where the system was tested on June 22, 2016. The harvested area of experimental field was approximately equal to 690 m^2. The average travel speed was 3.6 km h^{-1} and the width of this single row harvester was 1 m, which was pulled by a tractor in the field.

In fact, the prepared yield map reflected the spatial variation of the different factors of the production process, so, the knowledge of such variations is important in decision making of that same production process and approve the use of this system in achieving the precision agriculture goals. Yield

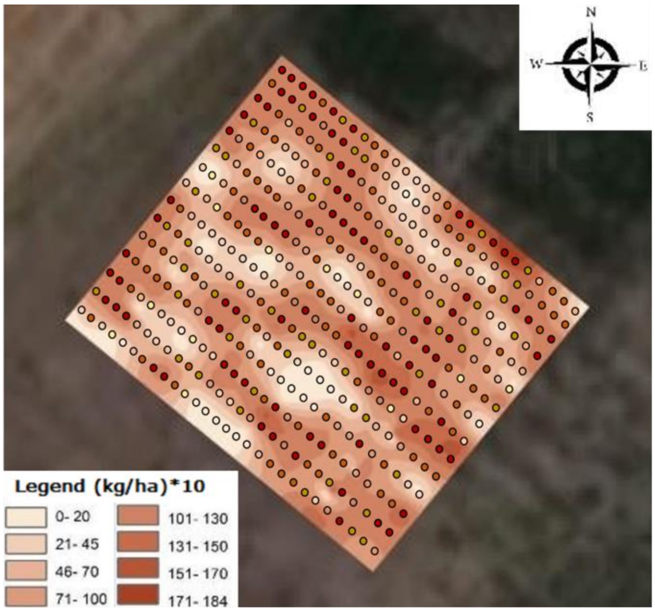

Figure 10. Converting raw points to final interpolated yield map of garlic field after data processing.

variability is clearly visible in the map, which indicates that more site-specific crop management of the field would be needed in the future. In general, the southeast portion of the field had substantially lower yields than the other parts of the field. Yield maps reflect different sources of yield variation such as systematic and random errors caused by the harvest and mapping procedures used (Maestrini and Basso, 2018).

It is noteworthy that spatial variability, in addition to depending on the operating conditions of the YMS and its systematic and random errors, is also related to management, as well as environmental issues within a cropping season such as soil and water condition, landscape, pest attacks, etc. Furthermore, it is proved that in annual and perennial crops, the yield temporal variability is often more powerful than the yield spatial variability, which can create some difficulties for long- and short-term analyses (Liu *et al.*, 2021).

CONCLUSIONS

A low-cost batch type WS was developed as a part of a yield monitoring system for garlic harvesting machines and was tested under lab and field conditions. Continuous weighing of batches and simplicity are the advantages of this system, which simplify measuring spatial yield variability. This system accomplished properly the lab tests with average error of 1.94%. The field results also provided relatively good results with average error of 4.26%. This simple batch type system performed well under field condition. The static and dynamic measuring error in determining the mass of 4.5% is acceptable in comparison with other harvesting machines (Jadhav *et al.*, 2014; Lee *et al.*, 2005; Molin and Menegatti, 2004).

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توسعه یک سیستم توزین دسته‌ای برای پایش عملکرد محصول سیر

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چکیده

پایش عملکرد یکی از مهمترین بخش‌هایی است که به طور عملی در کشاورزی دقیق مستند شده است و اجازه می‌دهد تا نهاده‌ها را با توجه به خروجی‌های مورد انتظار مزرعه‌ای که برای تعیین اهداف عملکرد متغیر مکانی استفاده می‌شود، تغییر داد. مطالعه حاضر یک سیستم توزین نوع دسته‌ای (WS) را برای پایش عملکرد غده‌های سیر معرفی می‌کند. این WS شامل یک مخزن استوانه‌ای چهاربخشی، تیغه‌های چرخان، یک فرستنده دیجیتال و دو بارسنج برای اندازه‌گیری جرم است. از بردهای الکترونیکی برای کنترل WS و انتقال جرم و داده‌های زمین مرجع استفاده شد. یک رابط کاربری در نرم‌افزار LabVIEW نیز برای انجام پردازش سیگنال بی‌درنگ توسعه داده شد. این WS در شرایط آزمایشگاهی و مزرعه مورد آزمایش قرار گرفت. سه عامل شامل سرعت چرخش تیغه‌ها (RS)، زمان توقف (ST) تیغه ها و کسری از زمان توقف (FST) برای یافتن خروجی بهینه لودسل تعریف شد. آزمون‌های آزمایشگاهی برای یافتن مقدار بهینه برای این عوامل انجام شد و سپس عملکرد WS بهینه شده در شرایط مزرعه بررسی شد. بر اساس خروجی‌های WS و وزن واقعی غده‌های سیر، میانگین خطاهای استاندارد نسبی ۱/۹۴% در آزمایشگاه و ۴/۲۶% در مزرعه تعیین شد. برای نشان دادن تنوع مکانی عملکرد محصول در مزرعه، در نهایت یک نقشه عملکرد در ArcGIS با استفاده از داده هایی که توسط WS و GPS به دست آمده بود ترسیم شد. داده‌های ثبت‌شده با استفاده از سیستم پایش عملکرد سیر می‌تواند در مطالعات تجربی برای ایجاد مبنایی برای توسعه پروتکل‌های مدیریت مواد مغذی کارآمد و بهبود مدیریت مزارع سیر استفاده شود.