Development and evaluation of an electronic system for measuring the performance of ploughs: a comparative study of three types of ploughs

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Abstract: A fundamental challenge facing researchers is to ensure the accuracy of measurements and their response to changes in field conditions. The aim of this study was to develop a cost-effective, accurate, and easy-to-install electronic system using the Arduino controller for measuring and recording key parameters of a tractor-implement system. The system was field-tested using three different plows (moldboard, chisel, and disc plow) in the silty clay soil of the College of Agriculture - University of Basra, Karma Ali site. The overall design of the system comprised two main components: the transmitter and the receiver. The transmitter system consisted of three sensors: an encoder sensor, an ultrasonic sensor, and a Load Cell. This system wirelessly transmitted signals to the receiving electronic system using the HC-12 module. The receiving system was responsible for receiving the transmitted signals and automatically saving the data to a Micro SD Card. The designer specified a memory card with a capacity of at least 2GB. The results of the experiments demonstrated a high level of agreement between the depth of plowing measured by the ultrasonic sensor and the depth measured using traditional methods (R-Squared = 0.9978). Similarly, the actual and theoretical forward speed values measured by the encoder sensor closely matched those obtained through traditional methods (R-Squared = 0.9941 and 0.9986, respectively). These findings validate the accuracy and reliability of the device. Furthermore, the study revealed that at a forward speed of 0.51 m s^{-1} and a plowing depth of 25 cm, the traction requirements for the moldboard, chisel, and disc plows were 14.3 kN, 11.25 kN, and 10.35 kN, respectively. The traction force increased by 72%-75% and 45%-50% when the plowing depth and forward speed were increased, respectively. The disc plow exhibited lower slip compared to the moldboard and chisel plows. Additionally, the study indicated that the tillage depth had a greater impact on slip percentage compared to the forward speed.

Keyword: Data acquisition system, Encoder sensor, wireless, Draft force, Slip

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1 Introduction

The initial stage of cultivating any crop involves a series of essential operations, which typically commence with the plowing process. Plowing, also known as tillage, is the practice of preparing the soil to create favorable conditions for seed germination and crop growth (Al-Suhaibani and Ghaly, 2010). The plowing process is recognized as one of the most labor-intensive agricultural operations, demanding substantial energy inputs on the farm (Jithender et al., 2017). Tractors and various plowing equipment are employed to perform these operations, involving the mechanical manipulation of soil. Consequently, it is

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crucial to understand the energy demands of the tractor-implement system. Extensive research and studies are conducted on diverse agricultural equipment to evaluate their performance and efficiency, aiming to attain the optimal utilization of these machines in agricultural practices. The objective is to achieve the highest level of effectiveness and productivity in utilizing agricultural machinery (Shin et al., 2022).

Inaccurate measurements of performance indicators such as slip, traction force, and tillage depth can lead to erroneous data, resulting in a distorted evaluation of agricultural machinery performance. Consequently, numerous researchers have directed their efforts towards developing various measurement systems that prioritize high accuracy and reliability. The aim is to ensure that the recorded data accurately reflect the true performance of agricultural machines, enabling a more precise assessment and analysis (Almaliki, 2017). In a study by Lu et al. (2013), an electronic system was developed using LabVIEW software to measure slip in agricultural tractors. The system consisted of a fifth wheel, a primary sensor, and both hardware and software components for slip measurement. The fifth wheel was considered as a reference for zero slip condition, and the slip of the front and rear wheels was evaluated by comparing it to this reference. This approach allowed for separate measurement of front and rear wheel slip. Advancements in the field of electronics have facilitated the development of affordable components that can be assembled into sensor systems, control mechanisms, and data storage units. This stands in contrast to commercially available electronic systems, which tend to be expensive and complex to operate (Fisher and Kebede, 2010; Fisher and Gould, 2012; Thalheimer, 2013; Teli and Mani, 2015; Tatović et al., 2016). Arduino, an open-source electronic model control system, has emerged as one of the most cost-effective options.

It is based on flexible and user-friendly hardware and software, making it accessible and easy to use (David et al., 2007). Due to its affordability and versatility, Arduino has garnered significant attention from researchers for numerous applications in the agricultural domain. In one study, the ATMEGA328 microcontroller (Arduino) was utilized to develop a cost-effective and efficient microcomputer system for calculating the area plowed by a tractor. The system incorporated a Hall sensor and a digital compass, enabling accurate measurement of the plowed area (Kadimi and Dheeraj, 2014). Almaliki et al. (2016) employed Arduino to create an electronic system that offered both low-cost and high-accuracy measurements of tractor performance. This system allowed for precise evaluation and monitoring of various performance parameters related to tractor operation. The measurement system described in the study includes a data logging system and flowmeter sensors for measuring fuel consumption, actual speed, theoretical speed, drawbar pull, and plow depth. This system allows for comprehensive monitoring and analysis of various parameters related to agricultural operations (Devika et al., 2014). Additionally, Manoj and Udupa (2015) developed a device that employs Arduino electronic controller to detect soil moisture levels. When placed in the field, the device can measure the moisture content in the soil, aiding in irrigation management and ensuring optimal conditions for plant growth.

A microcontroller-based system for automatic traction and slip control of a 2WD tractor was designed, developed and tested. Actual and theoretical speeds were obtained digitally through a Hall Effect controller set on the front and rear wheels of the digital wheel slip controller. The traction force was recorded using a three-point dynamometer placed between the tractor and the machine (Gupta et al., 2019). Shafaei et al. (2019) developed a precise digital instrument system to display, collect and store desired tractor performance parameters. The system was designed based on the technical capabilities of human-machine interface (HMI) technology by developing an auxiliary data acquisition unit with a touch-screen user interface to control different actions of the system for continuous measurement of tractor performance parameters (rear wheel slip, forward speed, fuel consumption, working depth, and traction force) at a data collection rate of up to 90 Hz. An electronic slip control and measurement device for 2WD agricultural tractors was developed to measure wheel slip online and study its performance under different field conditions. The measurement efficiency and maximum error of the slip meter were found to be above 99.9% and 60.02%, respectively (Das et al., 2020). Soylu and Çarma (2020) developed a control system that automatically adjusts the working depth of agricultural equipment attached to the tractor in order to maintain the slippage that occurs in agricultural tractors. The developed automatic control system continuously measures the slippage of the tractor's drive wheels and reduces the adjusted plowing depth according to the increase in the slippage value. Nataraj et al. (2021) developed an integrated digital display and microcontroller-based warning system to measure wheel slip, speed ratio, and engine torque.

The hardware system includes a magnetic pickup sensor to measure engine speed, load cells and amplifiers to measure and amplify the project sensor signals, proximity sensors for wheel slip, and a PTO torque converter to measure torque requirements. It is also equipped with alarms and LEDs to warn the operator when the slip and speed ratio are not in the desired range based on the algorithm, to maximize fuel efficiency and traction performance. Slip, speed ratio, and torque were measured with maximum absolute variation of 12.90%, 7.92%, 98.99%, and 11.57%, respectively. A system was developed to measure, display and store various tractor performance parameters namely geographic location, depth, speed, slip, fuel consumption, traction torque and speed. The outputs of the transducers were transmitted to a virtual interface based data acquisition system using radio frequency modules along with the sensors (Shrivastava et al., 2024). In a study by Singh et al. (2023), a sensor-based data acquisition system developed without modification of the tractor was evaluated under both static and dynamic conditions to measure the tractor performance parameters.

This paper aims to design an electronic system using the Arduino electronic controller that is cost-effective, accurate, and easy to install. This system is intended to measure and record various parameters, including drawbar pull, theoretical velocity, actual velocity, slip, and plowing depth. The system is designed to operate under three conditions: wet, normal, and dry. Furthermore, the paper includes field testing of the developed system using three different types of plows: moldboard plow, chisel plow, and disc plow. This testing allows for the evaluation of the system's performance and effectiveness across different plowing scenarios.

2 Materials and methods

2.1 Tractor-plow unite

The study involved two tractors, specifically the MASSEY FERGUSON /XTRA-440 tractor and the CASE JX75T tractor. Sensors were installed on the MASSEY FERGUSON /XTRA-440 tractor to measure theoretical speed, actual speed, slip, and traction force. This tractor was responsible for the towing process, and a load cell device connected the two tractors through a flexible cable. To test the locally manufactured electronic system on three types of plows (Mouldboard, chisel, and disc plow).

2.2 Field test site

The experiments were conducted at the Karma Ali site in the fields of the College of Agriculture at the University of Basra, specifically in silty clay soil. The field was divided into three sections. Before conducting the experiments, soil samples were taken to measure the initial properties, including soil texture, moisture content, bulk density, and soil resistance to penetration. The soil texture was determined by measuring the soil particulate content using the pipetting method described in Black (1965). Soil moisture was measured using the gravimetric method, which involved weighing samples before and after placing them in an oven at 105°C for 24 hours. The moisture content was then calculated as a percentage based on the dry weight, following the method described in Black (1965).The bulk density of the soil was determined using the Core Sample method described in Black (1965), and the calculation was performed according to Equation 2. The soil resistance to penetration was estimated using a digital soil penetration meter (Penetrologger) following the ASAE S313.2 standards (ASABE, 2009).

$$P_w = \frac{M_W}{M_S} \times 100 \tag{1}$$

Where,

P_W = soil moisture content (%),

M_W = water weight (Kg),

M_S = dry weight of soil (Kg).

$$\rho_b = \frac{M_S}{V_S} \tag{2}$$

Where,

ρ_b = soil bulk density (Kgm^{-3})

M_S = dry soil weight (Kg)

V_S = dry soil volume (m^{-3})

2.3 Data acquisition system

The system primarily consists of two components: the transmitter and the receiver. The transmitter system comprises three sensors: an encoder sensor, an ultrasonic sensor, and a Load Cell. These sensors provide input signals that are processed and programmed by the Arduino electronic controller based on predefined commands and system requirements. The transmitter system is powered by external rechargeable and replaceable batteries, specifically Li 3.7V/3800 mAh batteries. Additionally, a 5 V Power Supply is incorporated to convert AC input into DC power. The transmitter system wirelessly transmits signals to the receiving electronic system using the H-C 12 module (as shown in Figure 1).To ensure the smooth progress of the process, the transmitter system is equipped with a signal detector, represented by an LED indicator. This indicator provides visual feedback, signaling whether the process is functioning correctly or encountering issues. It helps the worker identify potential problems such as wire cuts, low battery, or sensor malfunctions, thereby preventing any unforeseen difficulties.

The primary function of the receiving system is to receive the transmitted signal from the transmitter system (as shown in Figure 2). The signal can be successfully transferred from the transmitter to the receiver over a considerable distance, typically not less than approximately 1 kilometer. The receiving system comprises several components, including the receiver module (H-C 12), a Micro SD card, an Arduino Uno electronic controller, a 5 V Power Supply, and rechargeable and replaceable external batteries (specifically Li 3.7 V/3800 mAh batteries).

One of the key features of the receiving system is its ability to automatically save data. This is achieved using a Micro SD card, which is selected by the designer and has a minimum capacity of 2 GB. The system stores the received data on the Micro SD card, ensuring that valuable information is securely recorded for further analysis and processing.

2.4 Measurement of the theoretical speed

To measure the theoretical speed of the tractor, a gear sensor system was installed on the rear axle. This speed sensing unit consists of an encoder sensor and two gears: a small gear with 8 teeth connected to the encoder axis and a large gear with 126 teeth fixed to the inner side of the tractor's rear axle (as shown in Figure 3).The gears are engaged with each other, creating a gear ratio of 15.75. The encoder sensor generates 360 pulses for each revolution of its movement. Considering the gear ratio of 15.75, the encoder will generate 5760 pulses for each revolution of the tractor's rear tires. By calibrating the system based on the diameter of the rear tire, the device achieves an accuracy of 0.84 mm per pulse. In other words, each pulse corresponds to a movement of the rear tire by 0.84 mm. This allows for precise measurement and calculation of the theoretical speed of the tractor based on the pulse count from the encoder sensor.

2.5 Measurement of the actual speed

The practical speed of the tractor, taking into account tire slippage, is measured as the speed at which the front tires move forward. Since the front tires are not powered and only move when power is transmitted from the rear tires, their movement can be considered as the speed of the tractor during the process. To measure the practical speed, another encoder sensor was installed on the front axle of the tractor (as shown in Figure 4). The encoder sensor included a small gear with 8 teeth attached to its axis. A large gear with 135 teeth was installed on the front tire axle. This created a gear ratio of 16.87. Consequently, the encoder generated 6075 pulses for one revolution of the front tire's movement. By calibrating the system based on the diameter of the front tire, the accuracy of the device reaches 0.58 mm per pulse. This means that each pulse represents a movement of the front tire by 0.58 mm. This allows for precise measurement and calculation of the practical speed of the tractor based on the pulse count from the front axle encoder sensor.

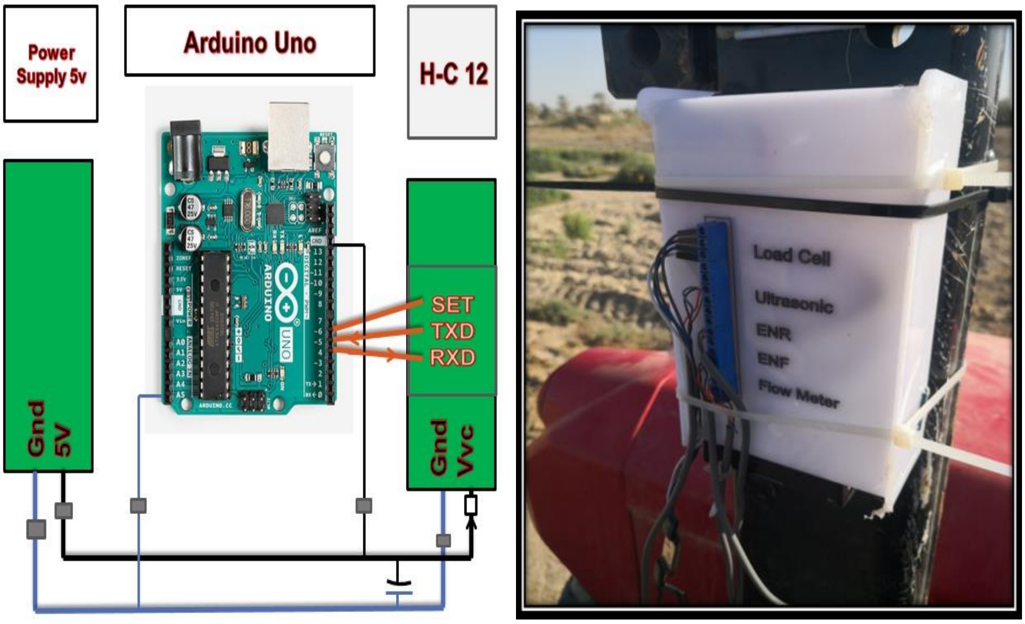

Figure 1 Transmitter system

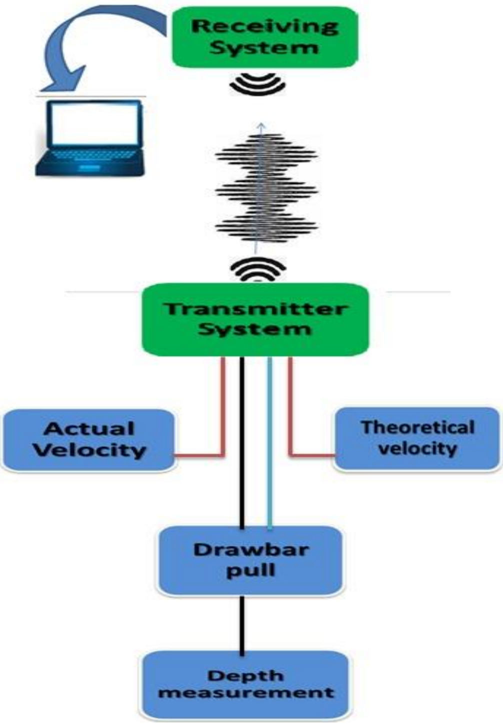

Figure 2 Diagram of data transmission between the transmitting system and the receiving system

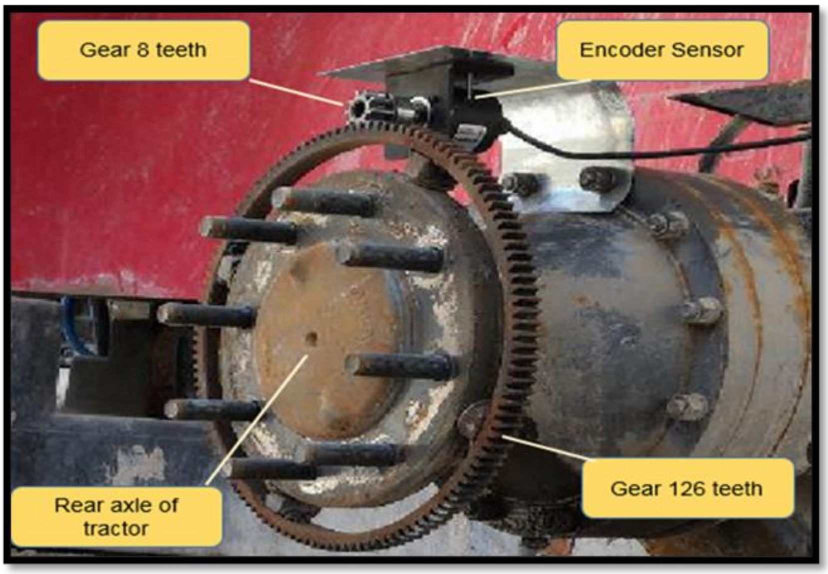

Figure 3 Installed encoder sensor and gears on rear wheel

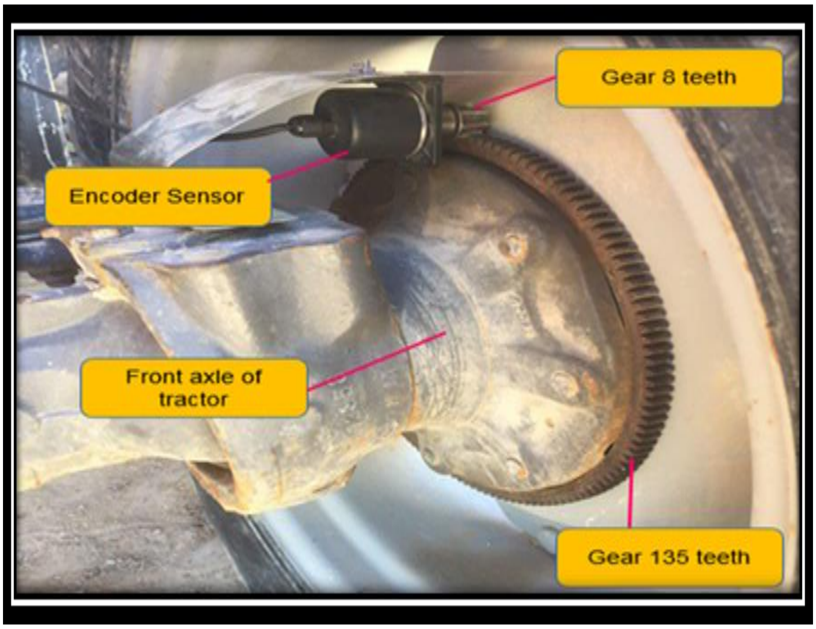

Figure 4 Installed encoder and gears on front wheel

2.6 Measurement of tillage depth

To measure the tillage depth, an ultrasonic sensor (HY-SRF05) is utilized. The sensor is mounted on the plow, positioned on the side facing the uncultivated soil. The plow is placed on a flat, paved ground surface for reference. The sensor measures the distance from its installation point to the flat ground by emitting sound waves. These sound waves are then reflected back to the sensor upon striking the ground. By calculating the time it takes for the waves to travel and return, and considering the speed of sound, the sensor determines the distance between the installation point and the ground. This calculation is performed by the Arduino electronic controller. Following the initial distance measurement on the flat ground, the plow is then engaged in the field at a desired depth. As the plow enters the soil, a new distance measurement is taken between the sensor position and the ground. This new distance is expected to be smaller than the one measured on the flat ground, as the plow has penetrated the soil. The tillage depth is determined as the difference between the distance measured on the flat ground and the distance measured in the field. This calculation is represented by the equation shown in Figure 5.

$$\text{Tillage depth} = DG - DF \tag{3}$$

Where:

DG= distance measured on flat ground by ultrasonic sensor (cm).

DF= the measured distance when the plow is working in the field at a certain depth (cm).

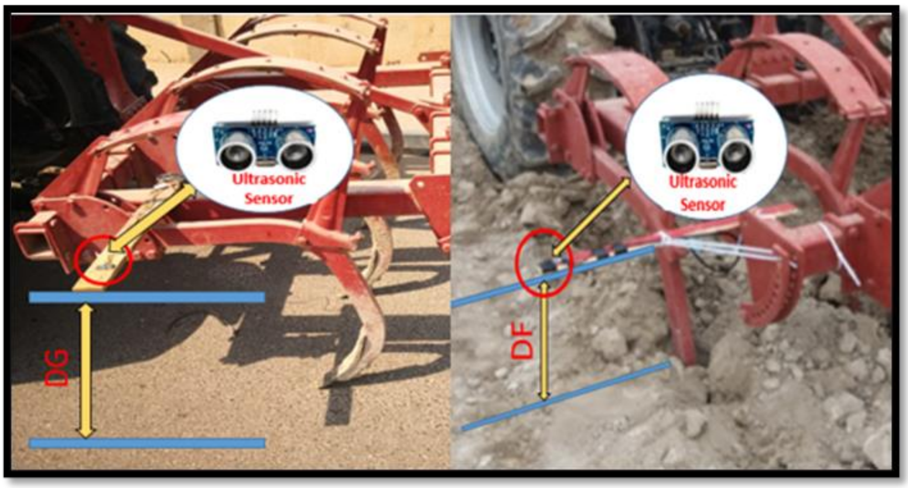

Figure 5 The process of measuring tillage depth using an ultrasonic sensor

2.7 Drawbar pull measurement

The traction force during the towing process was measured using the RNAM (1995) system. A specially designed S-shaped load cell was utilized for this purpose. The load cell was installed between the two tractors involved in the towing operation. The first tractor used in the towing process is the MASSEY FERGUSON / XTRA-440, which is equipped with the electronic system for data collection and measurement. The second tractor, a CASE JX75T, serves as an auxiliary tractor to which the plows are attached. The gearbox of the auxiliary tractor is positioned in neutral during the measurement.

By installing the load cell between the two tractors, the traction force exerted by the MASSEY FERGUSON / XTRA-440 tractor during the towing process can be accurately measured. This provides valuable information about the force required to tow the auxiliary tractor and the attached plows.

2.8 Slip measurement

To measure slip, both the theoretical velocity (calculated based on the gear ratios and encoder pulses) and the actual velocity (measured using the front axle encoder sensor) were measured. The Arduino was programmed with a specific equation to calculate the slip within the programming code. The slip can be calculated using the following equation:

$$S = \left(1 - \frac{v_a}{v_t}\right) \times 100 \qquad (4)$$

Where,

S=slippage (%),

Va=actual velocity (m s^{-1}),

Vt=theoretical velocity (m s^{-1}).

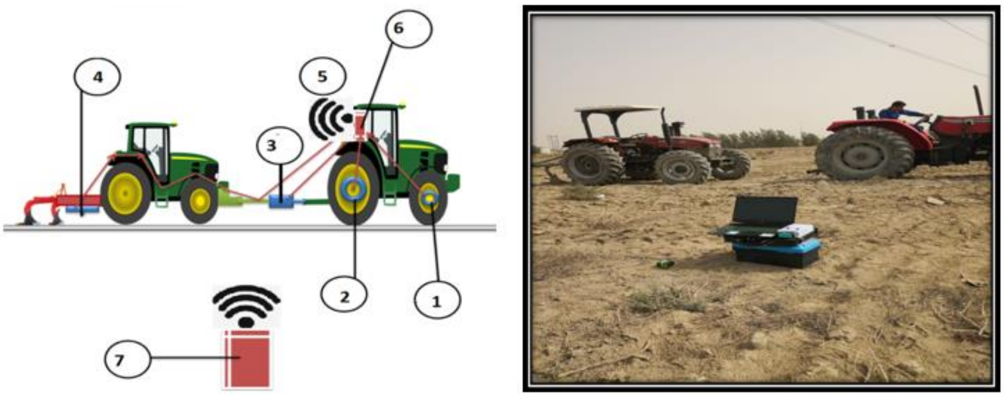

Figure 6 Scheme of the electronic system for measuring tractor performance indicators

Labels: 1-Actual velocity sensor, 2-Theoretical velocity sensor, 3-Load cell, 4-Ultrasonic sensor, 5-Wireless communication 6-Transmitter system, 7-Receiving system

2.9 Data analysis

To assess the significance of the study factors on the characteristics of traction force and slipping, the Design Expert software (version: 8.0.6.1) was employed. This software was utilized for evaluating, analyzing, and generating mathematical models to predict the parameters of traction force and slip based on the experimental data. A total of 81 field experiments were conducted as part of the study.

3 Result and discussion

3.1 Tillage depth

In Figure 7, the relationship between the actual plowing depth and the measured depth using the ultrasonic sensor is depicted. The test was conducted using three different types of plows: moldboard plow, chisel, and disk plow. The objective was to assess the accuracy of the ultrasonic sensor in measuring the depth of plowing. The test results demonstrated a strong correlation between the plowing depth values obtained from the ultrasonic sensor and those obtained through traditional measurement methods. The high accuracy and reliability of the ultrasonic sensor were confirmed by the R-squared value of 0.9978. This indicates a significant level of agreement between the measured depths and the actual depths of plowing. These findings highlight the effectiveness and precision of the ultrasonic sensor in accurately measuring the depth of plowing. The device's ability to provide reliable depth measurements can contribute to enhancing the precision and efficiency of plowing operations in agricultural practices.

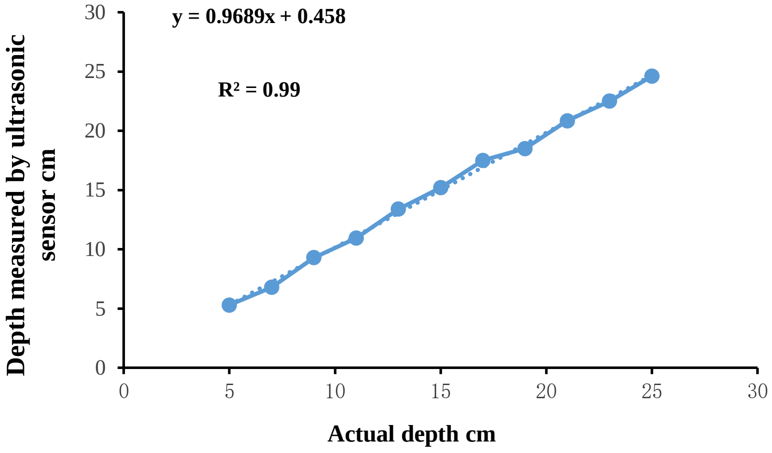

Figure 7 The relationship between actual depth and depth measured by ultrasonic sensor

3.2 Theoretical and actual speeds

As shown in Figure 8, the relationship between the real theoretical velocity and the theoretical velocity measured by the encoder sensor is illustrated. The real theoretical velocities were obtained by adjusting the gearbox of the agricultural tractor and include values such as 0.51 m s^{-1}, 0.85 m s^{-1}, 1.45 m s^{-1}, 2.02 m s^{-1}, 2.83 m s^{-1}, 3.35 m s^{-1}, 4.1 m s^{-1}, and 6.06 m s^{-1}. The results of the experiment revealed a strong agreement between the data obtained from the encoder sensor and the real values of the theoretical velocities. This is demonstrated by the coefficient of determination (R-squared value) of 0.9986, which indicates a high level of accuracy and reliability in measuring the theoretical velocity using the encoder sensor. Figure 9 shows the relationship between the actual speed and the actual speed measured by the encoder sensor. The experiment involved varying the actual speeds by applying different tractive forces to the tractor engine. The real actual speeds were determined by calculating the time required to cover a distance of twenty meters based on tractor movement. The values used for the real actual speeds were 0.43 m s^{-1}, 0.55 m s^{-1}, 0.70 m s^{-1}, 0.82 m s^{-1}, 0.95 m s^{-1}, and 1.05 m s^{-1}. The results indicated minimal discrepancies between the real actual speed values and those measured by the encoder sensor. This is evidenced by the R-squared value of 0.9986, signifying the high accuracy of the encoder sensor in determining actual speeds under varying field conditions, including different traction forces.

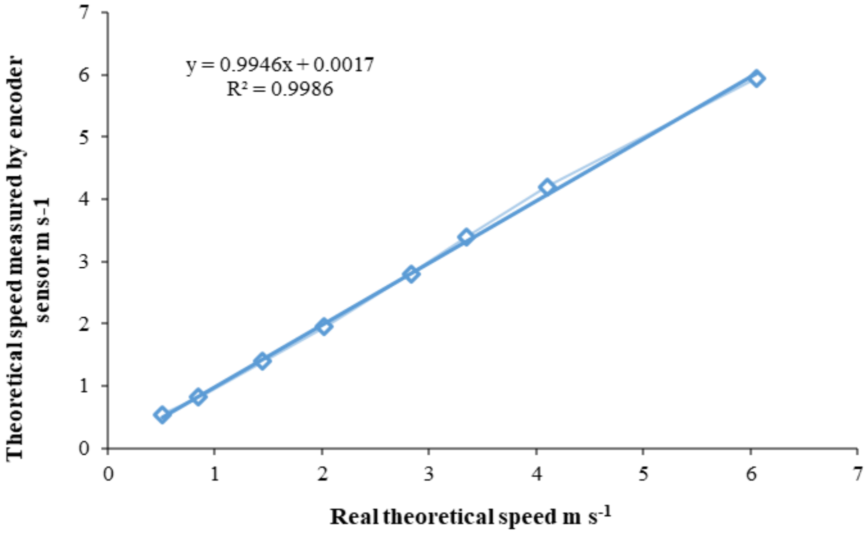

Figure 8 The relationship between real theoretical speed and theoretical measured by encoder sensor

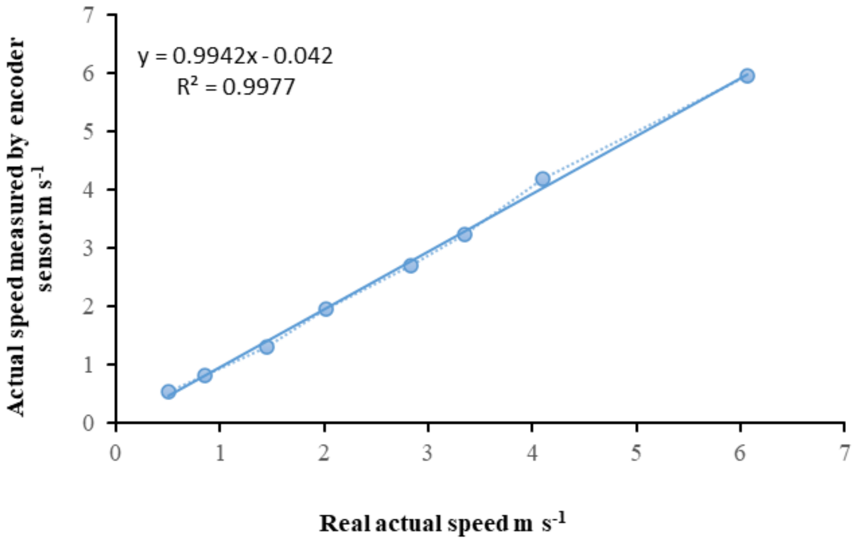

Figure 9 The relationship between real actual speed and actual speed measured by encoder sensor

Table 1 Analysis of variance for draft force

Source	Sum of squares	*df*	F value	*p*-value prob > F
Model	594.27	6	169.20	< 0.0001
A-type of plow	100.34	1	257.11	< 0.0001
B-tillage depth	368.35	1	943.86	< 0.0001
C-speed	109.97	1	281.78	< 0.0001
AB	4.11	1	10.54	0.0362
AC	3.53	1	4.93	0.0413
BC	5.99	1	6.03	0.0314
Residual	27.7	75		
Cor Total	621.98	81		

3.3 Draft Force

Table 1 indicates that all the studied parameters, including plow type, tillage depth, and forward speed, as well as their interactions, had a significant effect on draft force.

Figure 10 demonstrates the impact of different plow types (moldboard, chisel, and disc plow) on draft force at various plowing depths (15 cm, 20 cm, and 25 cm). The findings revealed that, at a forward speed of 0.51 m s^{-1} and a plowing depth of 25 cm, the draft force requirements for moldboard, chisel, and disc plows were 14.3 kN, 11.25 kN, and 10.35 kN, respectively. These results align with previous studies conducted by Almaliki (2018) and Al-Suhaibani et al. (2010), which also indicated that moldboard plows require more pulling force compared to chisel plows, and chisel plows require more force than disc plows. Additionally, the results indicated an increase in traction force as the plowing depth was increased from 15 cm to 25 cm. This increase ranged from 72% to 75% for all plow types at a forward speed of 0.51 m s^{-1}. This can be attributed to the larger volume of soil being disturbed during plowing at greater depths, resulting in increased pulling force requirements. Moreover, deeper plowing leads to greater soil rupture, size, and mass, necessitating more energy to cut through the soil. These observations are consistent with the findings of other researchers, such as Karmakar (2005), Abbaspour-Gilandeh et al. (2006), Rashidi et al. (2013), and Almaliki (2018). Overall, the results from Figure 10 provide valuable insights into the relationship between plow type, plowing depth, and draft force, highlighting the significant impact of these factors on the traction requirements during the plowing process

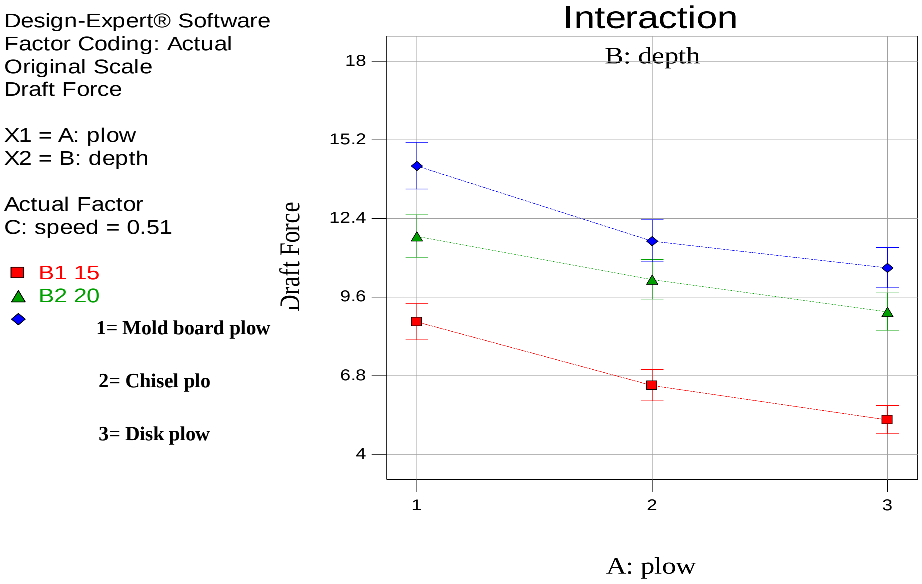

Figure 10 The effect of plow type on draft force at different tillage depth

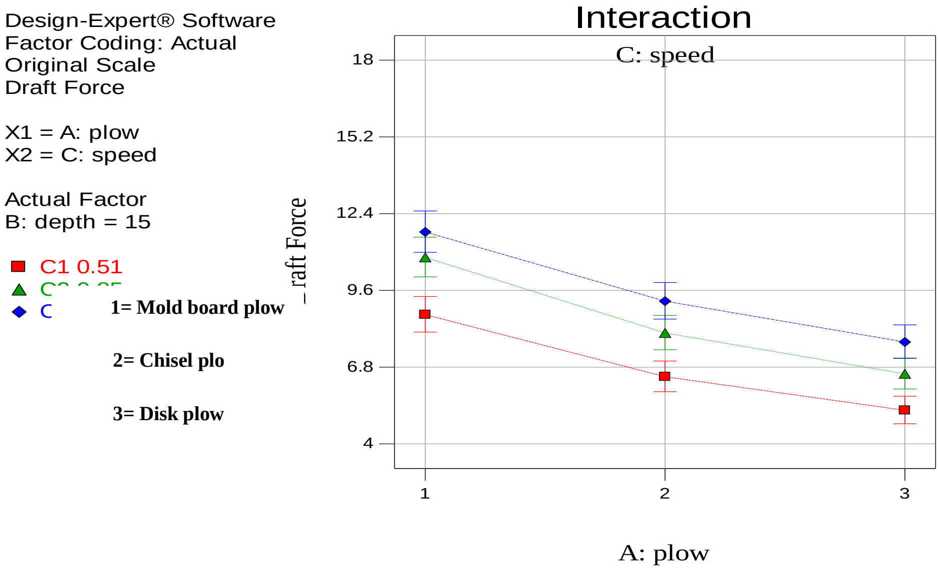

Figure 11 The effect of plow type on draft force at different forward speed

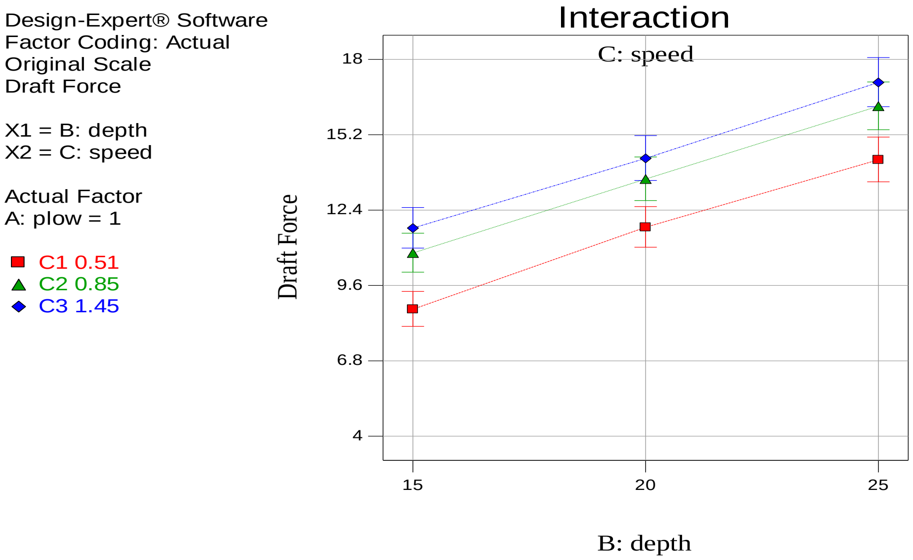

Figure 12 The effect of tillage depth on draft force at different forward speeds

Figure 11 depicts the influence of different plow types at various forward speeds. The findings indicate that increasing the forward speed from 0.51 m s^{-1} to 1.45 m s^{-1} resulted in a 45%-50% increase in traction requirements for all plows used at a plowing depth of 15 cm. Furthermore, the results highlight that the interaction between the moldboard plow and forward speed had a more substantial effect compared to other interactions, with the highest recorded pulling force reaching 11.56 kN. Figure 11 also demonstrates the impact of the interaction between forward speed and tillage depth on traction requirements. The results indicate that the highest pulling force recorded was 16.88 kN when utilizing the moldboard plow under different operating conditions, specifically a forward speed of 1.45 m s^{-1} and a plowing depth of 25 cm. These findings align with a study conducted by Naderloo et al. (2009).

2.4 SLIP

Table 2 demonstrates that the type of plow, plowing depth, and forward speed had a significant impact on slippage. Furthermore, the results indicate that the interactions between these factors also had a significant effect on slippage.

Table 2 Analysis of variance for slip

Source	Sum of squares	Df	F value	*p*-value prob > F
Model	0.48	6	124.69	< 0.0001
A-type of plow	0.041	1	94.71	< 0.0001
B-tillage depth	0.28	1	656.13	< 0.0001
C-speed	0.15	1	355.33	< 0.0001
AB	0.065	1	0.084	0.0332
AC	0.024	1	3.31	0.04594
BC	0.014	1	31.99	< 0.0001
Residual	0.031	75		
Cor Total	0.51	81		

Figure 13 illustrates the impact of plow type (moldboard, chisel, and disc plow) on slip percentage at different plowing depths (15 cm, 20 cm, and 25 cm). The results indicate that the moldboard plow exhibited the highest slip values across all plowing depths, with slip percentages of 7%, 12%, and 15% at depths of 15 cm, 20 cm, and 25 cm, respectively, at a forward speed of 0.51 m s^{-1}. This can be attributed to the higher traction requirements of the moldboard plow compared to the chisel and disc plows, resulting in increased soil displacement and subsequently higher slip. Conversely, the disc plow demonstrated the lowest slip values for all tillage depths, with slip percentages of 5%, 8%, and 9% for the respective depths mentioned above. This can be attributed to the smaller working width of the disc plow (90 cm) compared to the chisel plow (1.65 cm). Additionally, the mechanical action of the disc plow, which involves rotation around the center when in contact with the soil, reduces the traction requirements and consequently minimizes slip. These results contradict the findings of García-Rivera et al. (2021), who observed that the disc plow exhibited higher slip compared to the chisel plow. García-Rivera et al. (2021) attributed this discrepancy to the larger working width and weight of the disc plow used in their study compared to the chisel plow.

Furthermore, the results indicate that increasing the plowing depth led to an increase in slippage for all plow types. Specifically, increasing the plowing depth from 15 cm to 25 cm resulted in a 114% increase in slip percentage for the moldboard plow, a 100% increase for the chisel plow, and an 80% increase for the disc plow at a tractor speed of 0.51 m s^{-1}. This relationship between plowing depth and slip percentage aligns with the findings of other researchers, such as Zoz and Grisso (2003), Çarman and Taner (2012), and Almaliki et al. (2021).

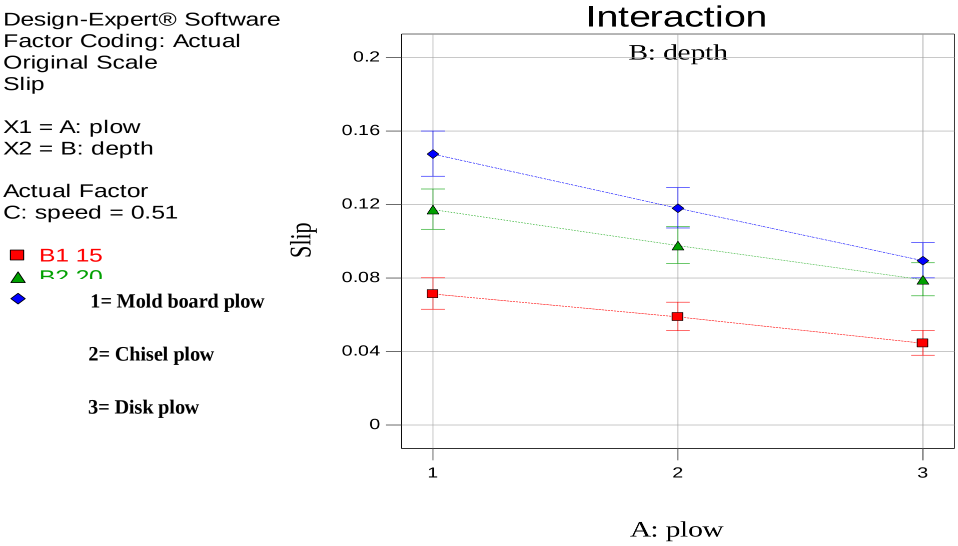

Figure 13 The effect of plow type on slip at different tillage depth

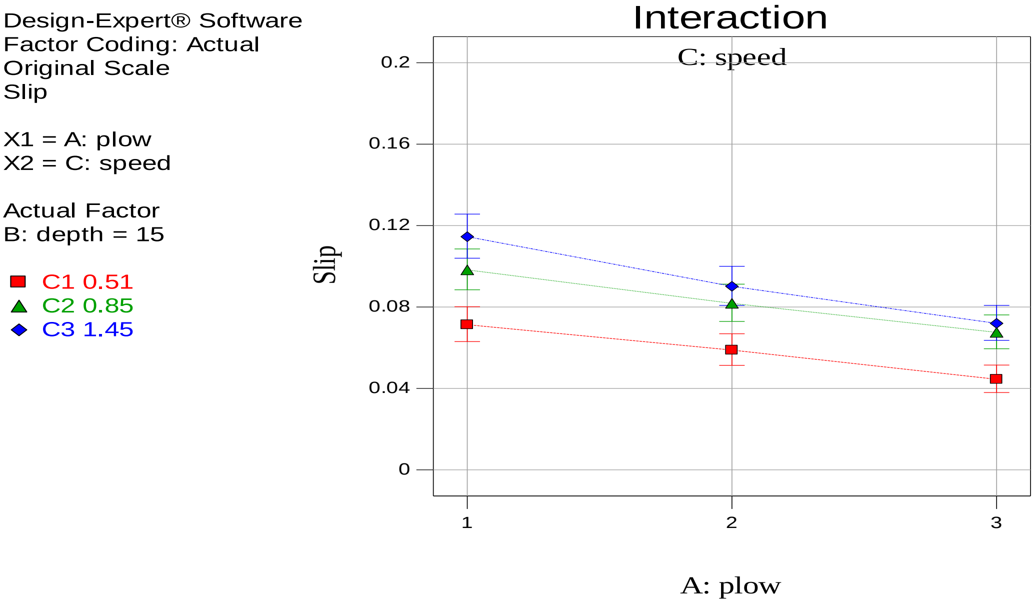

Figure 14 The effect of plow type on slip at different forward speeds

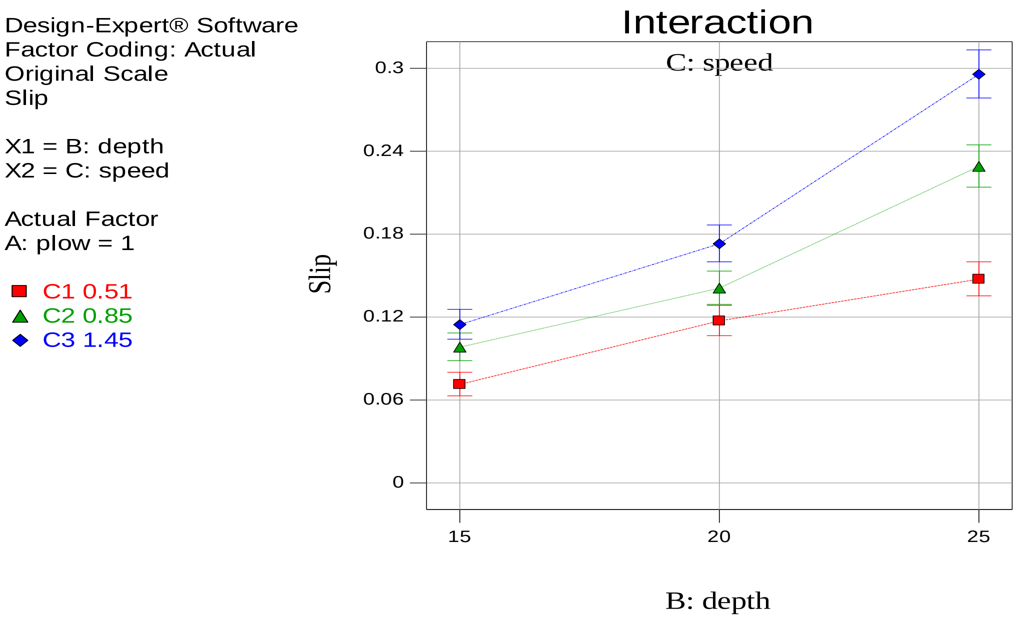

Figure 15 The effect of tillage depth on slip at different forward speeds

Figure 14 depicts the influence of different plow types on slipping at various forward speeds. The results indicate that the moldboard plow exhibited the highest slip when increasing the forward speed from 0.51 m s^{-1} to 1.45 m s^{-1}. The slip increased by 57% for the moldboard plow, while it was 50% for the chisel plow and 40% for the disc plow. This can be attributed to the acceleration of soil cutting and cracking particles that occurs with higher speeds. The increased speed leads to higher traction requirements, resulting in greater soil displacement and subsequently increased slip. Figure 15 demonstrates the effect of the interaction between plowing depths and forward speeds on slip when using the moldboard plow. The results indicate that the highest slip occurred at a forward speed of 1.45 m s^{-1} and a plowing depth of 25 cm, reaching 29%. Conversely, the minimum slip of 7% was observed at a plowing depth of 15 cm and a forward speed of 0.51 m s^{-1}.

4 Conclusion

An electronic system was developed and produced to measure key performance indicators of the tractor-implement system during field operations. The system demonstrated effectiveness and reliability in measuring parameters such as plowing depth, actual and theoretical forward speeds, traction force, and slip for three types of plows: moldboard, chisel, and disc plows. The results of the study revealed that the moldboard plow required the highest traction force among the three plow types, followed by the chisel plow and the disc plow. Moreover, both plowing depth and forward speed were found to have significant impacts on traction force. Increasing the plowing depth and forward speed resulted in higher traction force requirements. Notably, the effect of plowing depth was more pronounced than that of forward speed in increasing traction force. In terms of slip, the disc plow exhibited lower levels of slippage compared to the chisel and moldboard plows across various operational conditions. Additionally, the results indicated that slip increased with higher plowing depths and forward speeds.

References

Abbaspour-Gilandeh, Y., A. Khalilian, R. Alimardani, A. R. Keyhani, and S. H. Sadati. 2006. A comparison of energy requirements of uniform-depth and variable-depth tillage as affected by travel speed and soil moisture. *Iranian Journal of Agricultural Sciences*, 37(4): 573-583.

Almaliki, S. 2017. Development and Evaluation of Models for MF-285 Tractor Performance Parameters Using Computational Intelligence Techniques. Ph.D. diss., University of Tehran, Iran.

Almaliki, S. 2018. Simulation of draft force for three types of plow using response surface method under various field conditions. *Iraqi Journal of Agricultural Sciences*, 49(6): 1123-1131.

Almaliki, S. A., M. S. Himoud, and S. J. Muhsin. 2021. Mathematical Model for Evaluating Slippage of Tractor under Various Field Conditions. *Basrah Journal of Agricultural Sciences*, 34(1): 49-59.

Almaliki, S., R. Alimardani, and M. Omid. 2016. Fuel consumption models of MF285 tractor under various field conditions. *CIGR Journal*, 18(3):147-158.

Al-Suhaibani, S. A., A. A. Al-Janobi, and Y. N. AlMajhadi. 2010. Development and evaluation of tractor and tillage implements instrumentation system. *American Journal of Engineering and Applied Sciences*, 3(2): 363-371.

Al-Suhaibani, S. A., and A. E. Ghaly. 2010. Effect of Plowing Depth of Tillage and Forward Speed on the Performance of a Medium Size Chisel Plow Operating in a Sandy Soil. *American Journal of Agricultural and Biological Sciences*, 5(3): 247-255.

ASABE Standard. 2009. ASAE D497.6 Agricultural Machinery Management Data. ASAE. St. Joseph. MI: 49085. 1-8.

Black, C. A. 1965. *Methods of Soil Analysis: Part 1 Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling*. Madison, Wis: American Society of Agronomy.

Çarman, K., and A. Taner. 2012. Prediction of tire tractive performance by using artificial neural networks. *Mathematical and Computational Applications*, 17(3): 182-192.

Das, A., M. K. Ghosal, and D. K. Das. 2020. Development and performance studies of electronic wheel slip control device for two wheel drive agricultural tractor. *International Journal of Current Science (IJCS)*, 8(2): 1575-1579**.**

David, A. M., M. Banzi, D. Cuartielles, and T. Lgoe. 2007. Arduino: an open electronics prototyping platform. In *Conference on Human Factors in Computing Systems*, (pp. 3449–3454) . San Jose, California, USA, 28April - 3 May.

Devika, S. V., S. K. Khamuruddeen, S. K. Khamurunnisa, J. Thota, and K. Shaik. 2014. Arduino Based Automatic Plant Watering System. *International Journal of Advanced Research in Computer Science and Software Engineering*, 4(10): 449-456.

Fisher, D. K., and H. Kebede, 2010. A low-cost microcontroller-based system to monitor crop temperature and water status. *Computers and Electronics in Agriculture*, 74(1): 168-173.

Fisher, D. K., and P. J. Gould. 2012. Open-source hardware is a low-cost alternative for scientific instrumentation and research. *Modern Instrument*, 1: 8-20.

García-Rivera, G., M. Cadena-Zapata, J. A. López-López, G. F. López, S. G. Campo-Magaña, A. Zermeño-González, and H. Gutiérrez-Flores. 2021. Agricultural tractor slippage measurement system using encoders. *Ingeniería Agrícola y Biosistemas*, 13(2): 261-271**.**

Gupta, C., V. K. Tewari, A. A. Kumar, and P. Shrivastava. 2019. Automatic tractor slip-draft embedded control system. *Computers and Electronics in Agriculture*, 165: 104947.

Jithender, B., D. M. Vyas, S. Abhisha, and P. J. Rathod. 2017. Determination of Physical and Mechanical Properties of Pomegranate (*Var. bhagwa*) Fruit and Aril. *International Journal of Current Microbiology and Applied Sciences*, 6(10): 879-885.

Kadimi, J., and R. J. Dheeraj. 2014. The TRACALTOR: automated farm area calculator and direction monitoring. *International Journal of Computer Applications*, 106(5): 29 -32.

Karmakar, S. 2005. Numerical Modelling of Soil Flow and Pressure Distribution on a Simple Tillage Tool Using Computational Fluid Dynamics. Ph.D. diss., Department of Agricultural and Bioresource Engineering, University of Saskatchewan, Canada**.**

Lu, Z., X. Bai, Y. Liu, J. Chang, and Y. Lu. 2013. Wheel slip measurement in 4WD tractor based on LABVIEW. *International Journal of Automation and Control Engineering*, 2(3): 113-119.

Manoj, H. G., and N. G. S. Udupa. 2015. Application of Soil Moisture Sensor in Mixed Farming. *International Research Journal of Engineering and Technology*, 2(4): 311–314.

Naderloo, L., R. Alimadani, A. Akram, P. Javadikia, and H. Z. Khanghah. 2009. Tillage depth and forward speed effects on draft of three primary tillage implements in clay loam soil. *Journal of Food, Agriculture and Environment*, 7(6): 382- 385.

Nataraj, E., P. Sarkar, H. Raheman, and G. Upadhyay. 2021. Embedded digital display and warning system of velocity ratio and wheel slip for tractor operated active tillage implements. *Journal of Terramechanics*, 97: 35-43. 1

Rashidi, M., I. Najjarzadeh, S. T. Namin, F**.** Naserzaeim, S. H. Mirzaki, and M. S. Beni**.** 2013. Prediction of moldboard plow draft force based on soil moisture content, tillage depth and operation speed. *American-Eurasian Journal of Agricultural and Environmental Science*, 13(8): 1057–1062.

RNAM. 1995. RNAM Test Codes and Procedures for Farm Machinery/Economic and Social Commission for Asia and the Pacific, Regional Network for Agricultural Machinery. Bangkok, Thailand: RNAM technical publications.

Shafaei, S. M., M. Loghavi, and S. Kamgar. 2019. Development and implementation of a human machine interface-assisted digital instrumentation system for high precision measurement of tractor performance parameters. *Engineering in Agriculture, Environment and Food*, 12(1): 11-23.

Shin, J., S. Kim, and K. U. Kim. 2022. Performance Evaluation of Agricultural Machinery Considering Fuel Consumption and Work Efficiency. *Agronomy*, 12(2): 345.

Shrivastava, P., V. K. Tewari, C. Gupta, and A. Chouriya. 2024. HMI-assisted visual interface-cum-embedded system for measurement of tractor–implement performance parameters. *Journal of Field Robotics*, 41(7): 2147–2168.

Singh, T., A. Verma, M. Singh, and P. Kaur. 2023. Multi-sensor data fusion for precise measurement of a tractor implement performance in the field. *Current Science*, 124(9): 1082**.**

Soylu, S., and K. Çarman. 2020. Automatic control of wheel slip in soil tillage. *Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi*, 9(2): 848-858.

Tatović, M., A. Milovanović, and I. Karapandžić. 2016. Device for the remote measurement of meteorological data based on Arduino platform. *Serbian Journal of Electrical Engineering*, 13(1): 133-144.

Teli, S., and C. Mani. 2015. Smart real time embedded Arduino based data acquisition system. *International Journal of Research in Engineering and Technology*, 4(8): 258-262.

Thalheimer, M. 2013. A low-cost electronic tensiometer system for continuous monitoring of soil water potential. *Journal of Agricultural Engineering*, 44(3): e16.

Zoz, F. M., and R. D. Grisso. 2003. *Traction and Tractor Performance*. ASAE distinguished lecture series No. 27. ST Joseph, MI, USA: ASAE.