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DESIGNING AN ELECTRONIC SYSTEM TO MEASURE THE PERFORMANCE INDICATORS OF THE TRACTOR-IMPLEMENT SYSTEM

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Abstract
The objective of this study is to design an electronic system using the Arduino electronic controller is a low-cost, accurate, and easy-to-install system to measure and record the effective parameters of the tractor-implement system. In addition to field testing of this system using three plows: moldboard, chisel, and disc plow. Experiments were carried out in the fields of the College of Agriculture - University of Basra, Karma Ali site, in silty clay soil. The basic design of the system generally consists of two systems, the first is the transmitter and the second is the receiver. The transmitting system consists of three sensors (Encoder Sensor, Ultrasonic sensor, and Load Cell). This system sends the signal wirelessly via (H-C 12) to the other receiving electronic system. The receiving system's function is to receive the transmitted signal from the sending system. This system saves data automatically via a (Micro SD Card) with a memory card specified by the designer with a capacity of no less than (2GB). The results of the tests showed a high match in the values of the depth of plowing measured by the ultrasonic sensor and the depth of plowing measured by traditional methods (R-Squared is 0.9978). The results also indicated that the actual and theoretical forward speed values measured using the encoder sensor were identical to the traditional methods R-Squared = 0.9941 and 0.9986, respectively. Which proves the device's accuracy and high reliability. The results showed that the traction requirements at a forward speed of 0.51 m/sec and plowing depth of 25 cm, were (14.3, 11.25, and 10.35 kN) for moldboard, chisel, and disc plow, respectively. The results also showed that the traction force increased by (72-75%) and (45-50%) when the plowing depth and forward speed were increased, respectively. The disc plow showed less slip compared to the moldboard and the chisel plow. The results also indicated that the effect of tillage depth is greater than the effect of forwarding speed on the slip percentage.
Keyword: Data acquisition system, Encoder sensor, Arduino, Draft force, Slip

1. Introduction

The beginning of the process in the cultivation of any crop includes a set of necessary operations that often begin with the plowing process. Tillage is the process of creating soil conditions for seed germination and crop growth (Ghaly and Al-Suhaibani, 2010). It is considered one of the most extensive agricultural operations as the tillage process requires the most energy on the farm (Jithender et al., 2017). These operations are carried out using tractors and various plowing equipment, which represents the treatment of soil with mechanical forces, so it is necessary to know the energy requirements of the tractor-implement system. Many types of research and studies are conducted on various agricultural equipment to study their performance and efficiency to reach the optimal state of the best use of the agricultural machine. When the measurement of performance indicators such as slip, traction force, tillage depth, etc. is not accurate, the recorded data are incorrect and will therefore give a different criterion from the performance of the agricultural machine. Therefore, many researchers focused their studies on developing different measurement systems to obtain high accuracy and reliability.

Jha and Rahman (2006) conducted a study on wheel slip measurement on a two-wheel tractor using a microcontroller-based slip sensor. The measuring system consists of 4 components: throttle position sensing (a rotary potentiometer is installed on the tractor), gear position and wheel rpm (proximity switch is installed); Data collection and display processing, power source (power is taken from the tractor battery itself). The evaluation of this system showed that its accuracy is not less than 95%. Pranav et al. (2010) used an optical aperture sensor to measure the actual and theoretical speed of the tractor by measuring the front and rear wheel revolutions per minute (RPM) and used these speeds to calculate the tractor's slip. In another study, wheel slip was calculated using the actual and theoretical speed of the tractor, as in the method of Pranav et al. (2010). An automatic wheel slip control system based on a microcontroller has also been established for the two-wheel drive tractor (Pandey et al., 2012). Zhixiong et al. (2013) developed an electronic system for measuring slip in agricultural tractors using the lab view software. The system consists of the fifth wheel, a primary sensor, and hardware and software to measure wheel slip. Fifth wheel slip is considered a zero slip condition. The front and rear wheel slip is then compared to the zero slip condition to determine the front and rear wheel slip separately. Tewari et al. (2016) experimented to develop a digital wheel slip meter based on mechatronics. It contains a load cell-based dynamometer to measure traction. A Hall sensor to measure wheel slip by calculating the magnetic pin installed on the disc, an amplifier to amplify readings taken by a dynamometer and a microcontroller to manipulate the received load cell, and a sensor database to calculate drawbar pull and wheel slip. Measurements are displayed on the LCD screen as well as data is recorded on the SD card unit. To compare the access to the accuracy degree of the developed measuring system, the degree of accuracy of the developed traction measurement system, and the wheel slip measurement system, a system with 3 linked points to measure the traction force simultaneously was developed, and a non-contact type radar sensor was used to validate the wheel slip measurement system. A maximum discrepancy of +2.1% to -2.1% wheel slip is observed between the manually developed and manually measured values. Ashok Kumar et al. (2016) developed an electronic wheel slip measurement system using a Hall sensor. The measuring system has been tested in the condition of the controlled soil box. Wheel slip is displayed in an integrated digital microcontroller-based system on a display panel. The system is also equipped with an operator warning system with an audio and visual warning if the optimum limits are exceeded. To know the accuracy of this system, it was compared to the commercial radar system. The development in the field of electronics has led to the development of inexpensive components that can be assembled into sensor systems, control, and data storage, unlike commercially available electronic systems, which are expensive and complex to operate (Fisher and Kebede, 2010; Fisher and Gould, 2012; Thalheimer, 2013; Teli and Mani, 2015; Tatović et al., 2016). Arduino is one of the most inexpensive open-source electronic model control systems based on flexible and easy-to-use hardware and software (David et al., 2007). Therefore, it has been focused on by researchers to make many applications in the agricultural field. The ATMEGA328 microcontroller (Arduino) was used to build an efficient and inexpensive microcomputer system for calculating the area plowed by a tractor. It consists of a Hall sensor and a digital compass (Dheeraj Kadimi, 2014). Almaliki et al. (2016) also used Arduino to create a low-cost and high-accuracy electronic system to measure the performance of the tractor. The measuring system consists of a data logging system and flowmeters sensor for measuring fuel consumption, actual speed, theoretical speed, drawbar pull, and plow depth. Devika et al. (2014) use Arduino (ATmega328) in developing an automated plant watering system. The system is programmed to water the plants twice a day, depending on the moisture content of the soil. The system can report the status of current conditions as well as remind the user to refill the water tank. Manoj et al. (2015) developed a device that detects the moisture level in the soil when the device is placed in the field using the Arduino electronic controller. It works under three conditions: wet, normal, and dry. The paper aims to design an electronic system using the Arduino electronic controller is a low-cost, accurate, and easy-to-install system to measure and record the effective parameters, which include: drawbar pull, theoretical velocity, actual velocity, slip, and plowing depth. In addition to field testing of this system using three plows: moldboard plow, chisel plow, and disc plow.

2. Materials and Methods

2.1. Tractor-plow unite

Two tractors were used, the first of the MASSEY FERGUSON /XTRA-440 type, and the second of the CASE JX75T type. The sensors used to measure theoretical speed, actual speed, slip and traction force were installed on the first tractor. The first tractor is responsible for the towing process, as the load cell device connects the two tractors through a flexible cable. The second tractor is in the operation position, the gearbox is in the neutral position, and the used plow is fixed to the second tractor. Three types of plows (moldboard plow, chisel plow and disc plow) were used to test the measurement system on them. The plow depth sensor (ultrasonic sensor) is installed on the plow used.

2.2. Field test site

Experiments were carried out in the fields of the College of Agriculture - University of Basra, Karma Ali site, in silty clay soil. The field was divided into three sections to conduct the process of testing the locally manufactured electronic system on three types of plows (Mouldboard, chisel, and disc plow). Soil samples were taken to measure the initial properties before conducting the experiments on soil texture, moisture content, bulk density, and soil resistance to penetration. Soil texture was estimated by measuring the soil particulate content by the pipetting method mentioned in Black (1965). Soil moisture was measured by the gravimetric method and calculated as a percentage on the basis of dry weight and according to the method described in Black (1965). Samples were weighed before and after being placed in the oven at 105˚ for 24 hours. The humidity was calculated according to equation (1). The bulk density was measured using the Core Sample method mentioned in Black (1965) and calculated according to Equation 2. The soil resistance to penetration was estimated using a digital soil penetration meter (Penetroloagger) according to ASAE S313.2 standards (ASAE, 2009).

$$P_W = \frac{M_W}{M_S} * 100 \qquad (1)$$

Where

P_W = Soil moisture content (%)

M_W = water weight (gm)

M_S = dry weight of soil (gm)

$$\boldsymbol{\rho_b} = \frac{\mathbf{M_S}}{\mathbf{V_S}} \qquad (2)$$

Where

ρ_b= Soil bulk density $Mg.m^{-3}$

M_S= Dry soil weight Mg

V_S= Dry soil volume m^{-3}

2.3. Data acquisition system

The basic design of the system generally consists of two systems, the first is the transmitter and the second is the receiver. The transmitting system consists of three sensors (Encoder Sensor, Ultrasonic sensor, and Load Cell). This system takes the signal from the sensors and works on programming it according to the commands issued by the Arduino electronic controller and according to what is required of it. The system is equipped with power through external rechargeable and replaceable batteries, Battery Li 3.7V /3800ma. The system is equipped with a Power Supply 5v that converts the AC input into DC. This system sends the signal wirelessly via (H-C 12) to the other receiving electronic system (Figure 1). The transmitter system is equipped with a signal detector that can predict the progress of the process. It is an LED that gives a light indicating that the process is taking place correctly or not so that the worker does not fall into a problem by not sending the signal, such as if there is a cut in the wires, a low battery, or a defect in one of the sensors.

The receiving system's function is to receive the transmitted signal from the sending system (Figure 2). The signal can be transferred from the transmitting system to the receiving system at a distance of not less than (about 1 kilometer). This system consists of a receiver (H-C 12), a Micro SD card, an electronic controller of the Adriano Uno type, a Power Supply 5v, and rechargeable and replaceable external batteries (Battery Li 3.7V/3800ma). This system saves data automatically via a (Micro SD Card) with a memory card specified by the designer with a capacity of no less than (2GB).

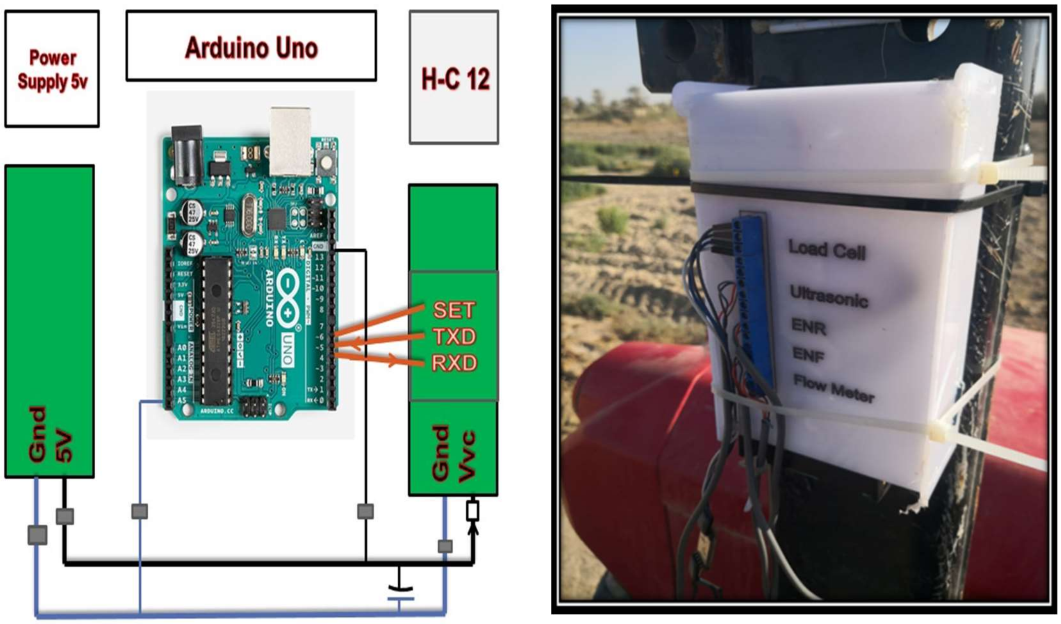

Figure (1) Transmitter system

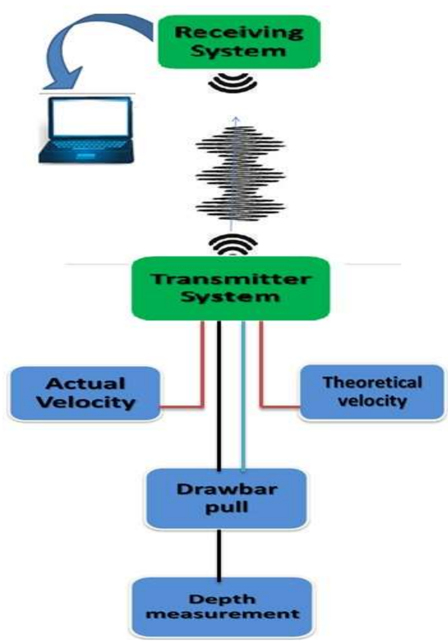

Figure (2) Diagram of data transmission between the transmitting system and the receiving system

2.4. Measurement of the theoretical speed

The theoretical speed of the tractor was measured by installing the gear sensor system on the rear axle of the tractor. The speed sensing unit consists of the encoder sensor and two gears, the small gear (8 teeth) is connected to the encoder axis. The large gear (126 teeth) is fixed to the inner side of the tractor's rear axle (Figure 3). The gears are engaged with each other making a 15.75 gear ratio. The encoder generates 360 pulses for each revolution of its movement, and when the gear ratio is taken with the large gear (15.75), the encoder will generate 5760 pulses for each revolution of the movement of the rear tires of the tractor. Depending on the diameter of the rear tire and after being calibrated on it, the accuracy of this device reaches 0.84 mm/pulse. That is, each pulse indicates a movement of the rear tire by 0.84 mm.

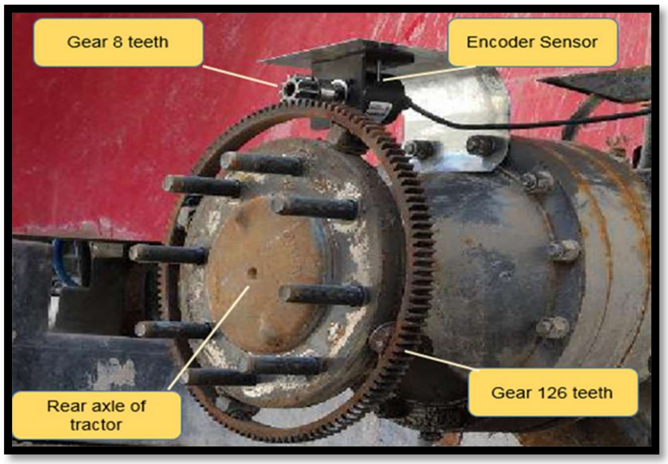

Figure (3) Installed encoder sensor and gears on rear wheel

2.5. Measurement of the actual speed

It is the speed at which the tractor (two-wheel drive tractors) moves forward, taking into account the slippage in the tires. Since the front tires are free to move, that is, they move when power comes to the rear tires and do not move forward when slippage occurs in the movement of the tractor, so the speed of movement of the front tires can be considered as the speed of the process. The practical speed was measured using another encoder sensor, which was installed on the front axle of the tractor as shown in the figure (4). The small gear (8 teeth) was attached to the axis of the encoder. As for the large gear, which was installed on the axle of the front tire, the number of teeth was 135. The gear ratio was 16.87. Thus, the number of pulses generated by the encoder for one cycle of the movement of the front tire is 6075. After calibration based on the diameter of the front tire, the accuracy of the device reaches 0.58mm/pulse. That is, every single pulse indicates 0.58 mm of movement of the front tire.

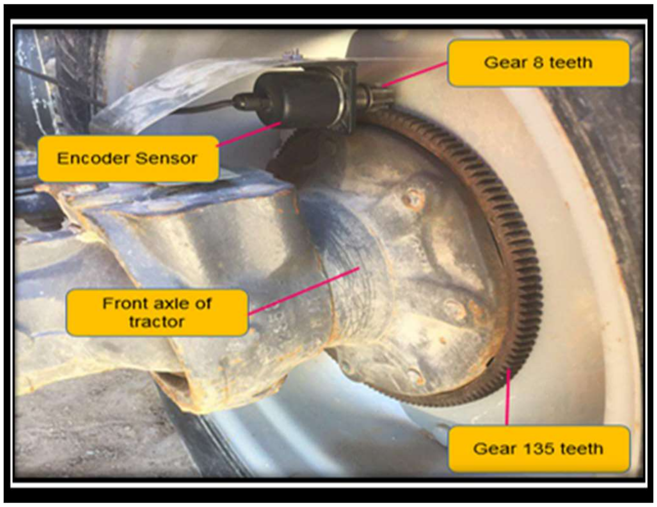

Figure (4) Installed encoder and gears on front wheel

2.6. Measurement of tillage depth

Tillage depth is measured using an ultrasonic sensor (HY-SRF05). The sensor is installed on the plow on the side of the uncultivated soil. The used plow is placed on flat ground (paved land). The distance is measured from the location of the sensor installation to the flat ground by sending sound waves. When they strike the ground, the waves are reflected and returned to the sensor, which in turn measures the distance depending on the speed of sound and the time of sending and receiving sound waves. This calculation is done by the Arduino electronic controller. Then the plow is worked in the field at a certain depth. The new distance is measured after the plow enters the soil between the sensor position and the ground, which is less than the distance measured at the flat ground. The plowing depth is the difference between the distance measured on flat ground and the distance measured in the field according to the following equation (Figure 5).

$$\boldsymbol{Tillage\ depth = DG - DF} \qquad (3)$$

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).

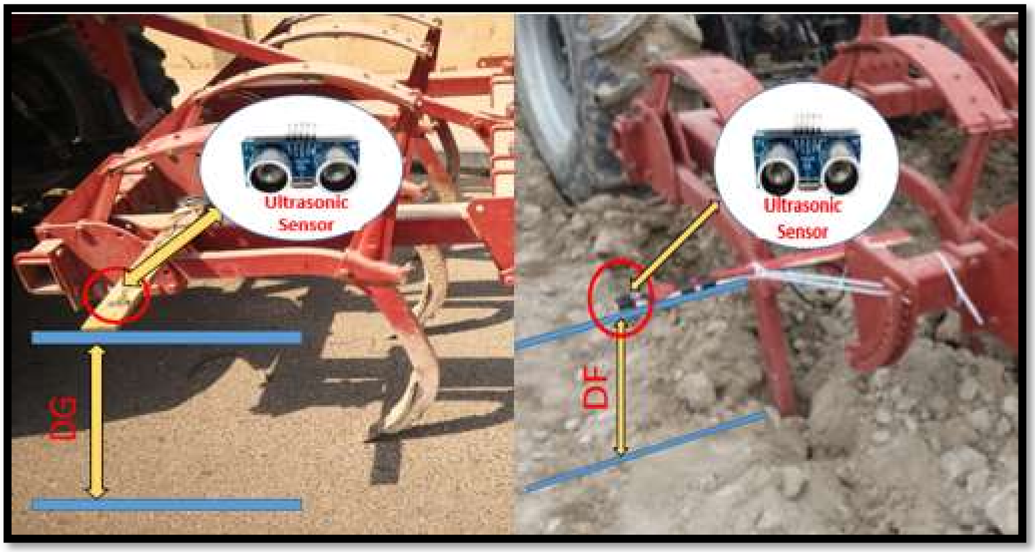

Figure (5) The process of measuring tillage depth using an ultrasonic sensor

2.7. Drawbar pull measurement

The traction force was measured based on the RNAM (1995) system. An S-shaped load cell was used to measure the traction force. The load cell is installed between the two tractors. The first tractor is MASSEY FERGUSON /XTRA-440, which is used in the towing process, and on which the electronic system has been installed. The second tractor (CASE JX75T) is an auxiliary to which the used plows are attached, and its gearbox is in the neutral position.

2.8. Slip measurement

Slip was measured indirectly after measuring both theoretical and actual velocity. The Arduino was programmed and the special equation was written to calculate the slip within the programming code. The slip was calculated according to the following equation:

$$S = (1 - \frac{Va}{Vt}) \times 100 \qquad (4)$$

S: Slippage (%)
Va: Actual velocity (m/s)
Vt: Theoretical velocity (m/s)

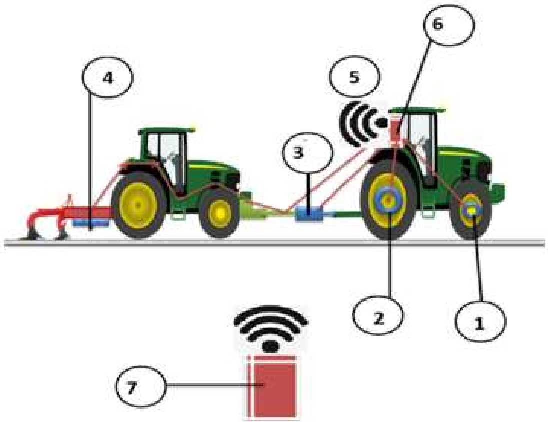

Figure (6) Scheme of the electronic system for measuring tractor performance indicators

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

For the purpose of knowing the significance of the effect of the study factors on the studied characteristics, the Design Expert software (version: 8.0.6.1) was used to evaluate, analyze and produce mathematical models to predict the parameters of traction force and slipping. 81 field experiments were conducted. The study included the use of three different plows (moldoard, chisel and disk plow), three plowing depths (15, 20 and 25cm), three forward speeds (0.51, 0.85 and 1.45 m/sec), and three replications. Data were also analyzed using an ANOVA table to indicate the importance and interaction of independent factors in traction force and slip.

3. RESULT AND DISCUSSION

3.1. Tillage depth

Figure (7) shows the relationship between the actual depth and the measured depth using the ultrasonic sensor. The test was carried out using the three plows (moldboard plow, chisel, and disk plow) at different depths for the purpose of knowing the validity of this device in measuring the depth of plowing. The test results showed a great match in the values of the plowing depth measured by the ultrasonic sensor and the plowing depth measured by traditional methods. The R-Squared value is 0.9978, proving the device's high accuracy and reliability.

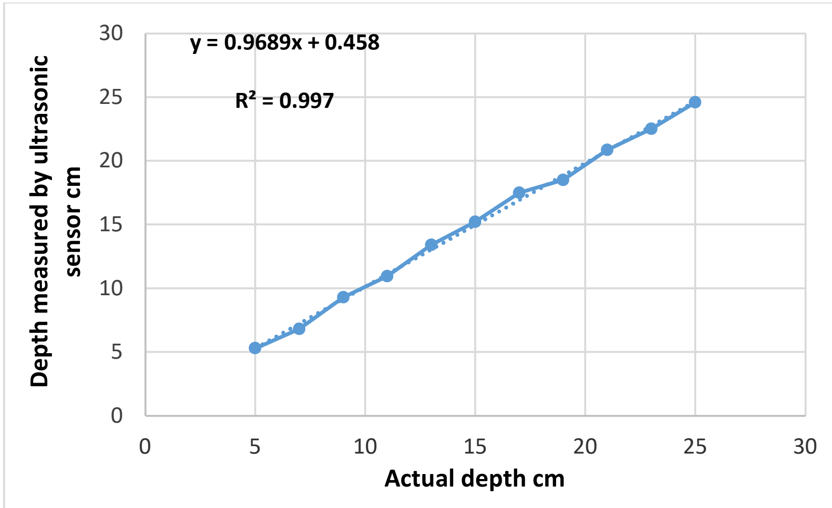

Figure (7) the relationship between actual depth and depth measured by ultrasonic sensor

3.2. Theoretical and actual speeds

Figure 8 shows the relationship between the real theoretical velocity and the theoretical velocity measured by the encoder sensor. The real theoretical velocities used are (0.51, 0.85, 1.45, 2.02, 2.83, 3.35, 4.1, and 6.06 m/sec) and these were obtained by changing the gearbox of the agricultural tractor. The results showed that there is a high match in the data values when using the encoder sensor and the real values of the theoretical velocities, and this can be seen through the value of the coefficient of determination where R-Squared = 0.9986. This confirms the validity and reliability of the theoretical velocity measurement using an encoder sensor. Figure (9) shows the relationship between the real actual speed and the actual speed measured by an encoder sensor. The experiment was conducted using different actual speeds by loading the tractor engine with different tractive forces. The real actual speeds used, which are measured by calculating the time required to travel a distance of twenty meters from the movement of the tractor, are (0.43, 0.55, 0.70, 0.82, 0.95, 1.05 m/s). The results showed that there are very few differences between the real actual speed values and the values measured by the encoder sensor, and this was evident through the value of R-Squared = 0.9941. Thus, the device using an encoder sensor has a high accuracy in determining the actual speeds under different field conditions (different traction forces).

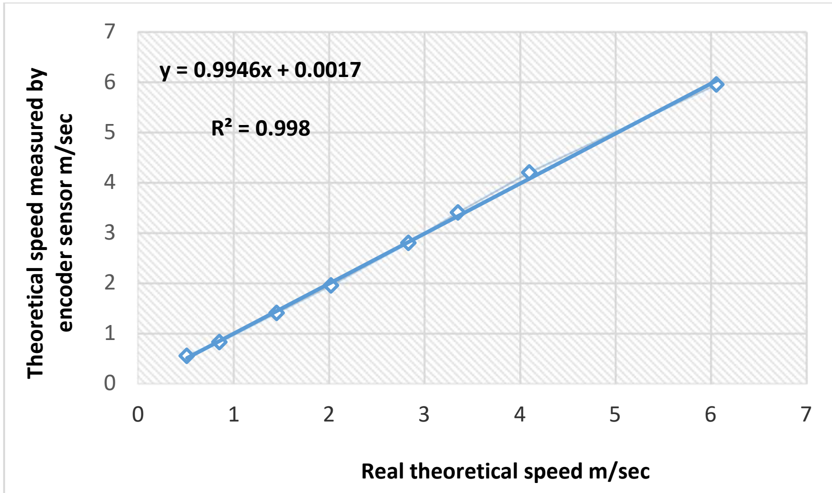

Figure (8) the relationship between real theoretical speed and theoretical measured by encoder sensor

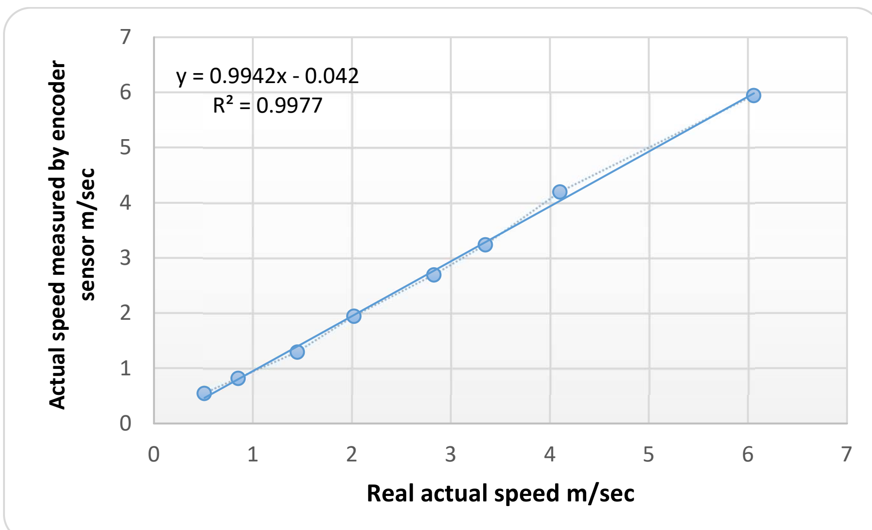

Figure (9) the relationship between real actual speed and actual speed measured by encoder sensor

3.3. Draft Force

It can be intrepreted from Table 1 that all studied parameters (plow type, tillage depth and forward speed) and their interaction between them had significant effect on draft force.

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*		

Figure (10) illustrates the effect of the type of plow (moldboard, chisel and disc plow) on the draft force for different plowing depths (15, 20, 25 cm). The results showed that the traction requirements at a forward speed 0.51 m/sec and plowing depth of 25 cm, were (14.3, 11.25, and 10.35 kN) for moldboard, chisel, and disc plow, respectively. This is consistent with the findings of (Almaliki, 2018; Al-Suhaibani et al., 2010). They reported that the moldboard plow has a higher pulling force than the chisel plow and the chisel is higher than the disc plow. The results also showed an increase in the traction force when increasing the plowing depth from 15 to 25 cm by (72 - 75%) for all used plows at a forward speed of 0.51 m/sec. This is due to the increase in the volume of the soil disturbed by plowing with the increase in the depth of plowing which leads to an increase in the pulling force. In addition, increasing the depth of plowing would result in an increase in soil rupture, size and mass so that more energy would be needed to cut the soil. These results agree with those of other researchers (Karmakar, 2005; Abbaspourgilandeh et al., 2006; Rashidi, et al., 2013; Almaliki, 2018).
Figure 11 shows the effect of different types of plows at different forward speeds. The results illustrated that increasing the forward speed from 0.51 to 1.45 m/sec led to an increase in the traction requirements by 45-50% for all plows used at a depth of 15 cm. The results also showed that the effect of the interference between the moldboard plow and the forward speed was higher than the other interactions, where the highest pulling force was recorded, reaching 11.56 kN. Figure 11 shows the effect of the interaction between forward speed and tillage depth on traction requirements. The results showed that the highest pulling force recorded was 16.88 kN when using the moldboard plow under different operating conditions (forward speed of 1.45 m/sec and plowing depth of 25 cm). These results are similar to those obtained Naderloo et al., 2009.

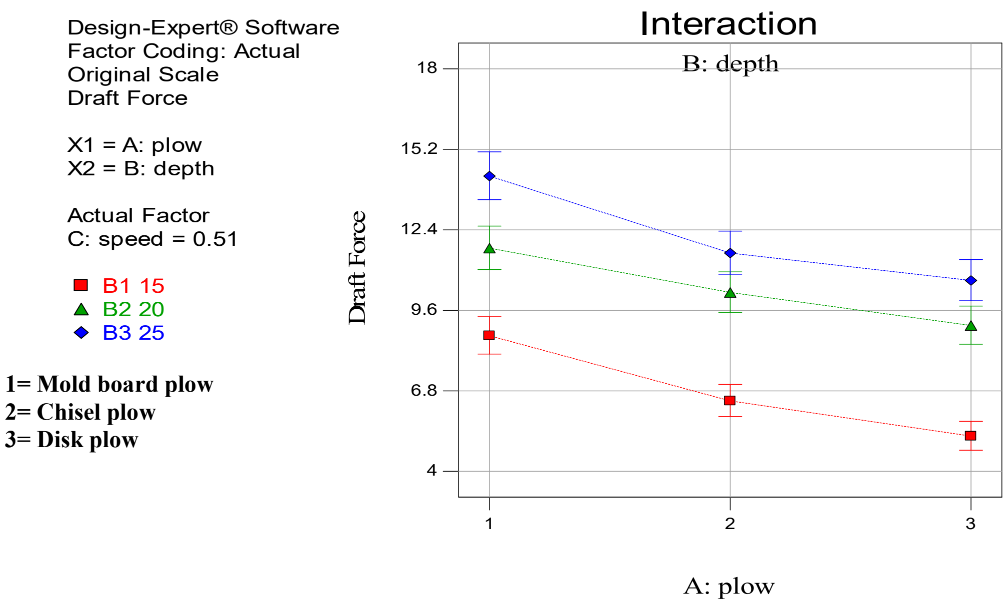

Figure (10) the effect of plow type on draft force at different tillage depth

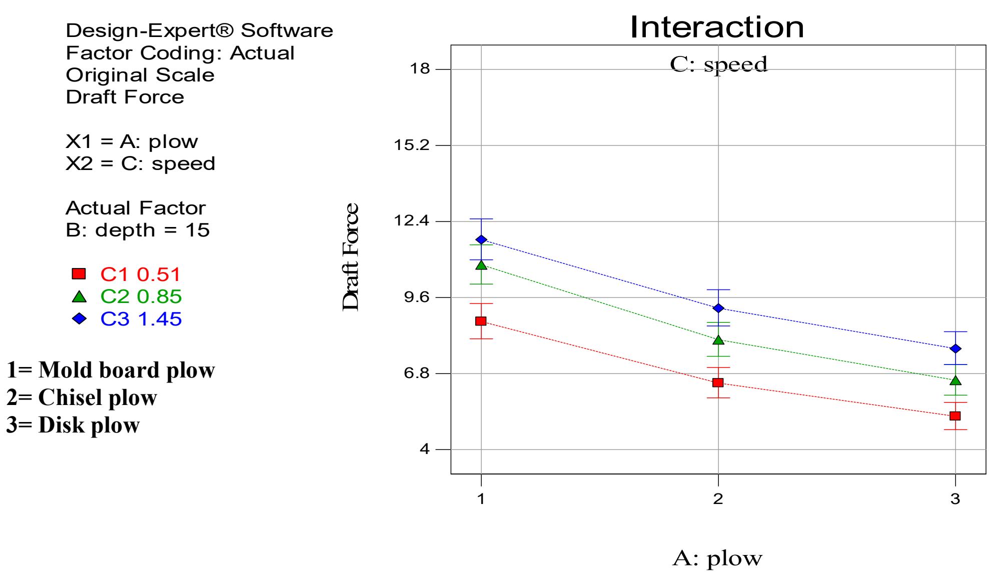

Figure (11) the effect of plow type on draft force at different forward speed

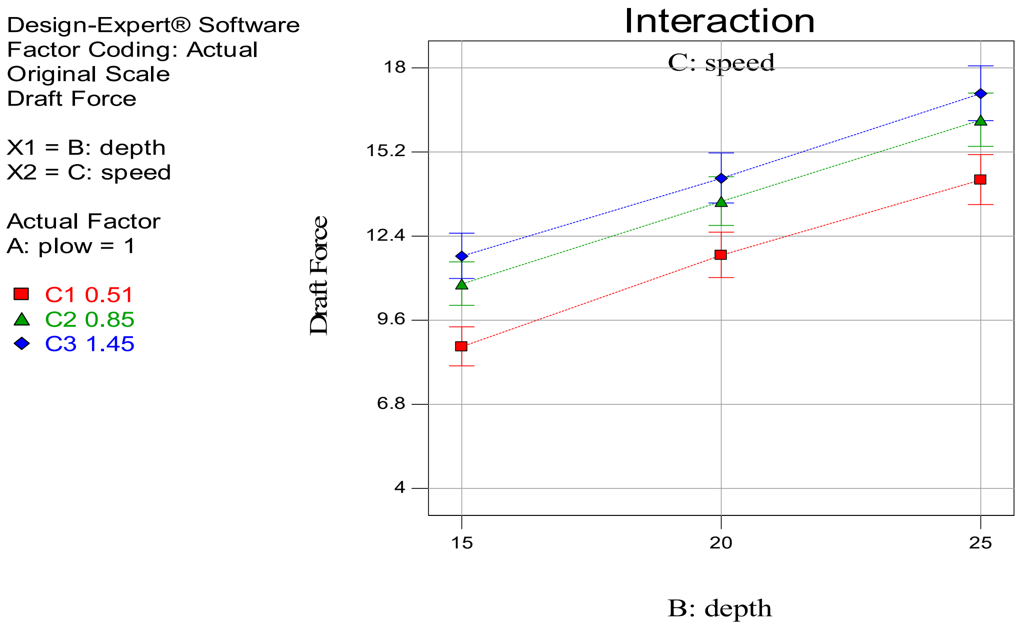

Figure (12) the effect of tillage depth on draft force at different forward speeds

3.4. SLIP

Slippage was significantly affected by the type of plow, plowing depth and forward speed (Table 2). The results also showed that the effect of interactions between the studied factors on slippage was significant

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) shows the effect of the type of plow (moldboard, chisel and disk plow) on the slip percentage for different plowing depths (15, 20, and 25 cm). The results showed that the highest slip was obtained at the moldboard plow and for all plowing depths, where the slip values were (7, 12, 15 %) at 15, 20 and 25 cm depths, respectively, at a forward speed of 0.51 m/sec. This is because the traction requirements of the moldboard plow are greater than that of the chisel and disc plow, which leads to an increase in the displacement of the soil and thus an increase in slip. The results also showed that the disc plow gave the lowest slip values for all tillage depths and were (5, 8 and 9 %) for the above depths. The reason for this is due to the small working width of the disc plow (90 cm) compared to the chisel plow (1.65 cm). The other reason is the mechanical work of the disc plow, which is the rotation around the center when in contact with the soil, which reduces the requirements for traction and thus reduces the slip. These results contradict the findings of the researchers López et al. (2021), who indicated that the disc plow gave the highest slip compared to the chisel plow, and they attributed this to the fact that the working width and weight of the used disc plow were greater than the chisel plow. The results also indicated that increasing the depth of plowing leads to an increase in slippage for all used plows. Increasing the plowing depth from 15 to 25 cm led to an increase in the slip percentage by 114%, 100% and 80% for the moldboard plow, chisel plow and disc plow, respectively, at a tractor speed of 0.51 m/sec. Increase of tillage depth brings out increase of draft force. Increase of draft force increases gross traction which lead to increment of displacement of soil. Similar results have been reported by researchers which confirm the results of the present study (Zoz and Grisso, 2003; Schreiber and Kutzbach, 2007, 2008; Tiwari et al., 2009; C¸arman and Taner, 2012; Almaliki et al., 2021).
Figure (14) shows the effect of different types of plows on slipping with different forward speeds. The results showed that the moldboard plow gave the highest slip when increasing the forward speed from 0.51 to 1.45 m/sec, where the slip increased by 57%, while it was 50% and 40% in the chisel and disc plow, respectively. This is due to the fact that increasing the speed leads to an acceleration of cutting and cracking soil particles. Which leads to an increase in the requirements for traction, which leads to an increase in the displacement of the soil, and thus increases the slip.
Figure (15) shows the effect of the interaction between depths and forward speeds on slip when using the moldboard plow. The results showed that the highest slip occurred was 29% at the forward speed of 1.45 m/sec and at a plowing depth of 25 cm. While the minimum slip was 7% at a plowing depth of 15 cm and a forward speed of 0.51 m/sec.

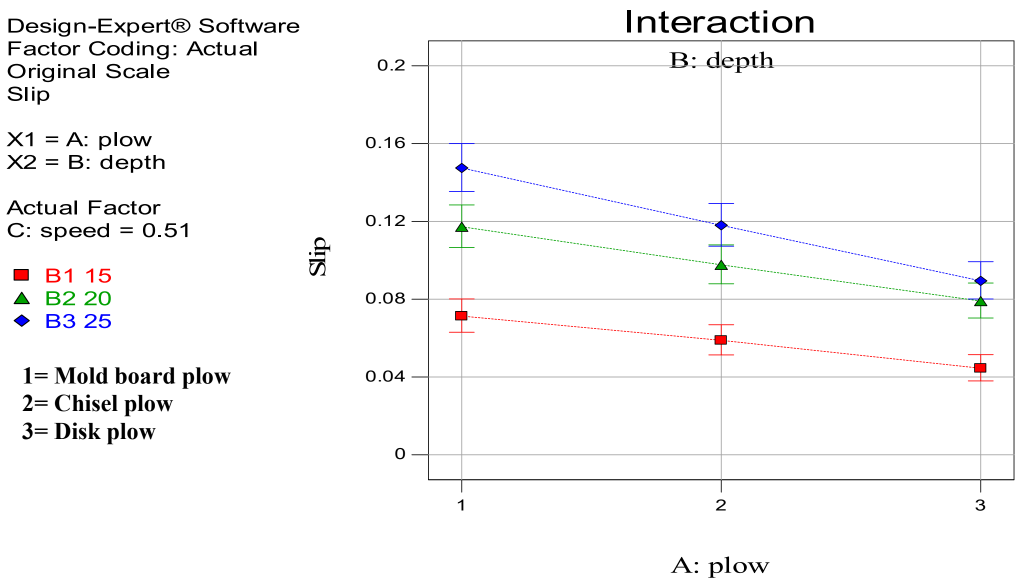

Figure (13) the effect of plow type on slip at different tillage depth

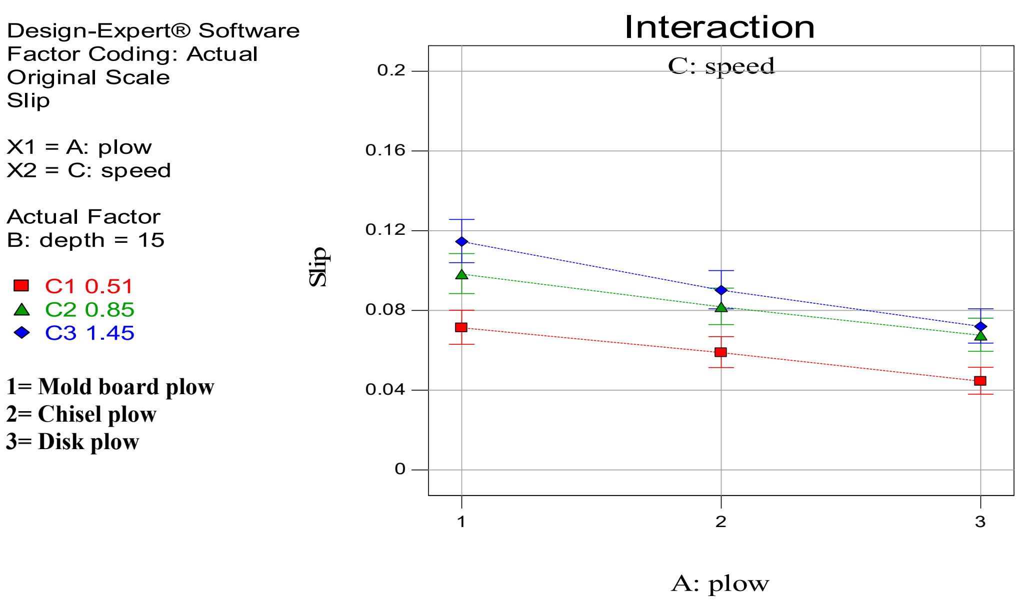

Figure (14) the effect of plow type on slip at different forward speeds

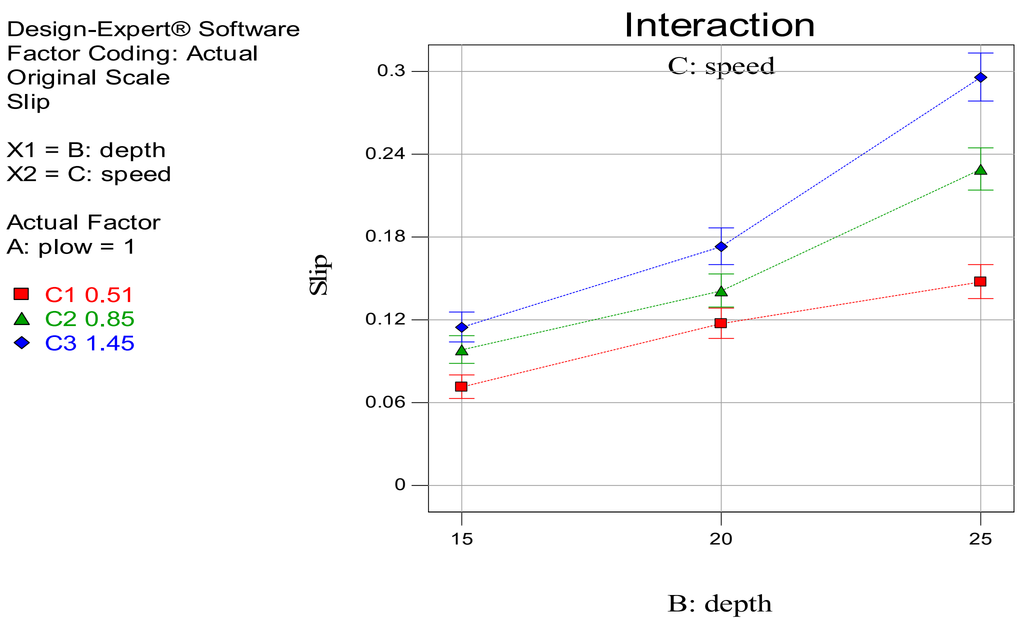

Figure (15) the effect of tillage depth on slip at different forward speeds

Conclusion

An electronic system was designed and manufactured to measure the field performance indicators of the tractor-implement system. The results showed the efficiency and reliability of this system in measuring the depth of plowing, actual forward speed, theoretical forward speed, traction force and slip for three types of plows (moldboard, chisel, and disc plow). The moldboard plow showed the highest traction requirements, followed by the chisel and disc plow. The results also indicated an increase in traction requirements with an increase in plowing depth and forward speed. The effect of tillage depth was greater than the effect of forward speed in increasing traction requirements. The disc plow showed less slippage than the chisel and moldboard plow under different operating conditions. The results also showed an increase in slipping with an increase in plowing depth and forward speed.

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References

Abbaspourgilandeh, 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 http://www. fspublishers.org

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, 1123-1131. https://doi.org/10.36103/ijas.v49i6.151

Almaliki, S., Himoud, M. and Muhsin, S. 2021. Mathematical Model for Evaluating Slippage of Tractor under Various Field Conditions. Basrah J. Agric. Sci., 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. http://www.cigrjournal.org

Al-Suhaibani, S.A., A.A. Al-Janobi and Y.N. AlMajhadi. 2010. Development and evaluation of tractor and tillage implements instrumentation system. American J. Eng. Appl. Sci., 3(2): 363-371

Arvidsson, J., T. Keller and K. Gustafsson. 2004. Specific draught for moldboard plough, chisel plough and disc harrow at different water contents. Soil Tillage Res., 79: 221-231. DOI:10.1016/j.still.2004.07.010

Ashok kumar,A., Brajesh Nare. and Tewari, V. K. 2016. Embedded digital draft force and wheel slip indicator for tillage research. https://doi.org/10.1016/j.compag.2016.05.010

David, A. M., M. Banzi, D. Cuartielles and T. Lgoe (2007). Arduino: an open electronics prototyping platform. Conference on human factors in computing systems San Jose, California, USA. https://explore.researchgate.net/display/support/Stats

Devika, S.V., Khamuruddeen, Khamurunnisa and Jayanth, T.2014. Arduino Based Automatic Plant Watering System. International Journal of Advanced Research in Computer Science and Software Engineering, 4(10), 449-456. http://www.ijarcsse.com/

Fisher D.K. and H. Kebede (2010). A low-cost microcontroller-based system to monitor crop temperature and water status. Comput. Electr. Agric. 74:168-73. http://www.elsevier.com/locate/compag

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. http://dx.doi.org/10.4236/mi.2012.12002

Ghaly, A. and Al-Suhaibani, S. (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, 247-255. http://dx.doi.org/10.3844/ajabssp.2010.247.255
http://www.worldfood. net/scientficjournal/2009/issue3/pdf/agriculture e/34.pdf

Jha, S.K. and Raheman, H. 2006. Wheel slip measurement in 2WD tractor. Journal of Terramechanics 44 (2007) 89-94. https://doi.org/10.1016/j.jterra.2006.03.001

Jithender, B., D.M. Vyas, S. Abhisha and Rathod, P.J. 2017. Determination of Physical and Mechanical Properties of Pomegranate (Var. bhagwa) Fruit and Aril. Int.J.Curr.Microbiol.App.Sci. 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. http://www.ijcaonline.org/

Karmakar, S. 2005. Numerical Modelling of Soil Flow and Pressure Distribution on a Simple Tillage Tool Using Computational Fluid Dynamics. PhD Dissertation, Department of Agricultural and Bioresource Engineering, University of Saskatchewan, Canada, pp: 220.

https://harvest.usask.ca/bitstream/handle/10388/etd-10282005-081153/PhD_Thesis_KARMAKAR_Subrata.pdf?sequence=1&isAllowed=y

kumar, A., Brajesh Nare. and Tewari, V. K. 2016. Embedded digital draft force and wheel slip indicator for tillage research. Comput. Electron. Agric. 127 (1), 38-49, https://doi.org/10.1016/j.compag.2016.05.010

López, G. F., Campo-Magaña, S. G., Zermeño-González, A., & Gutiérrez-Flores, H. (2021). Agricultural tractor slippage measurement system using encoders. Ingeniería Agrícola y Biosistemas, 13(2), 261-271. http://dx.doi.org/10.5154/r.inagbi.2021.07.070

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. J. Food, Agric. Environ., 7:382- 385.

Pranav, P. K., Tewari, V. K., Pandey, K. P., & Jha, K. R. (2012). Automatic wheel slip control system in field operations for 2WD tractors. Computers and electronics in agriculture, 84, 1-6. https://doi.org/10.1016/j.compag.2012.02.002

Pranav, P.K.; Pandey, K.P.; Tewari, V.K. 2010. Digital wheel slipmeter for agricultural 2WD tractors. Comput. Electron. Agric., 73, 188–193, https://doi.org/10.1016/j.compag.2010.05.003.

Rashidi, M., I. Najjarzadeh, S. Namin, F. Naserzaeim, S. Mirzaki and M. SalimiBeni . 2013. Prediction of moldboard plow draft force based on soil moisture content, tillage depth and operation speed. Am.-Eurasian J. Agric. Environ. Sci. 13 (8): 1057–1062. DOI: 10.5829/idosi.aejaes.2013.13.08.11022

RNAM, 1995. RNAM Test Codes and Procedures for Farm Machinery/Economic and Social Commission for Asia and the Pacific, Regional Network for Agricultural Machinery. RNAM technical publications: 12, Bangkok, Thailand. https://www.worldcat.org/title/224884306

Sahu, R.K. and H.A. Raheman (2006). Draught prediction of agricultural implements using reference tillage tools in sandy clay loam soil. Biosystems Engineering, 94:275-284. http://dx.doi.org/10.1016/j.biosystemseng.2006.01.015

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. http://dx.doi.org/10.2298/SJEE1601133T

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. http://www.ijret.org/

Thalheimer, M. (2013). A low-cost electronic tensiometer system for continuous monitoring of soil water potential. Journal of Agricultural Engineering, 44(3), p. e16. http://dx.doi.org/10.4081/jae.2013.e16

Zhixiong, L., Xuefeng, B., Yiguan, L., Jiangxue, C., & Yang, L. (2013). Wheel slip measurement in 4WD tractor based on LABVIEW. International Journal of Automation and Control Engineering, 2(3), 113-119. http://www.seipub.org/ijace