https://doi.org/10.17221/23/2024-RAE

Geometrical analysis of the 3-point linkage of tractors for the measurement and display of the working depth

Prabhanjan Kumar Pranav[1]*, *Anmol Kumar*[2], *Abhishek Kumar Ansh*[3], *Sanjay Kumar*[1]

[1]*College of Agricultural Engineering and Technology, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur (Bihar), India*
[2]*Bihar Agricultural University, Sabaur (Bihar) India*
[3]*Indian Agricultural Research Institute, New Delhi, India*

**Corresponding author: pkjha78@gmail.com*

Citation: Pranav P.K., Kumar A., Ansh A.K., Kumar S. (2024): Geometrical analysis of 3-point linkage of tractors for measurement and display of working depth. Res. Agr. Eng., 70: 237–244.

Abstract: The display of the depth of operation on tractors' dashboards facilitates the operator in achieving precise operation. In this study, the depth of operation of a mounted implement was measured and digitally displayed on a tractor's dashboard. The change in depth of operation was sensed by measuring the rotation of the rocker arm of the tractor's hydraulic system. The measured angle of rotation was multiplied by a calibration factor to convert it into the actual depth of operation in centimetres. For the calibration factor, a geometrical analysis of the three-point linkage was carried out, and a mathematical relationship was established based on the length of various linkages and their locations. A computer program was also developed to solve these equations to calculate the calibration factor. The program was validated with six different sizes of three-point linkages and found the maximum root mean square error was within 5%. The developed digital display was evaluated in the laboratory with three different implements and found a maximum error of ± 1 cm. A further evaluation was also carried out in an actual field with implements at three different depth levels, and a deviation of up to ± 13% was found with respect to the manual depth measurement.

Keywords: computer program; depth of operation; microcontroller; precise operation

Tractors are a well accepted power source in the field of agricultural and mounted implements are very commonly used in the field. Mounted implements are controlled by a tractor's hydraulic system which has an automatic position and draught control system. It has been well evaluated that the existing automatic position and draught control of hydraulic system is not sufficient for precise operation due to its slow response time (Dwyer 1969; Dwyer et al. 1974; Crolla and Pearson 1975; Cowell and Milne 1977). The precise operation in agriculture is a prime need for the overall improvement in agricultural productivity. The precise application reduces the input cost and enhances the crop yield. The depth of operation is one of the important parameters of precision agriculture. Placing the seed at the correct depth is critical for maximising a crop's yield. The tillage and weeding depth are also recommended according to the crop and season. In absence of any depth indication on a tractor's dashboard, it is very difficult for the operator to set the required depth of operation.

Studies on three-point linkages offer new hope in improving the tractor's drawbar performance (Ambike and Schmiedeler 2007; Kumar 2012, 2015; Molari et al. 2014; Bauer et al. 2017; Dhruw et al.

https://doi.org/10.17221/23/2024-RAE

2018; Kumar et al. 2018; Avello Fernández et al. 2022). However, the measurement of the depth of operation has also been the concern of many researchers for evaluation purposes of tractors or their implements. In recent past, various efforts have been conducted on depth measurement systems for mounted implements on tractor dashboards (Mouazen et al. 2004; Mouazen and Ramon 2006; Reina and Milella 2012; Suomi and Oksanen 2015; Roeber et al. 2016; Milella et al. 2017; Wang et al. 2018; Kamgar et al. 2019; Li et al. 2019; Kim et al. 2020), but none of the tractor manufacturers have adopted them so far because the suggested methodology is either costlier, more complicated or tractor specific. Based on these points, it was concluded that a simple and universal technology is needed for the depth measurement. Therefore, the objectives of this study were to measure the rotation of the rocker arm of a tractor's hydraulic through sensor and to develop the easiest method to calculate the calibration factor to be multiplied in the detected change in the rocker arm to predict the actual depth of operation.

MATERIAL AND METHODS

This section is divided into three sub-sections, namely (*i*) the geometrical relationship (*ii*) computer program and (*iii*) sensing and display. Under the first sub-section, 3-point linkages of a tractor were analysed geometrically and a mathematical relationship for the vertical change in the hitch point height with respect to the rocker arm rotation of the tractor's hydraulics was established. Under the computer program, the developed relationship was used to calculate the depth constant (d_k) for various tractor makes and models with the help of a computer program. The depth constant was used as a calibration factor for multiplying it with the degree of rotation of the rocker arm to get the desired depth of operation. In the last sub-section, the sensing of the depth of operation and its digital display on the dashboard using a microcontroller is discussed.

A geometrical relationship for the change in the vertical height of the hitch point with respect to the rotation of the rocker arm was established by a geometrical analysis of 3-point linkages. A simple line diagram of the 3-point linkage geometry in the XZ plane is shown in Figure 1. Here, the lower line shows position 1 and the upper line shows position 2 by lifting θ^0 of the lift arm. The dotted lines are used to draw the perpendicular lines and *HH*' represents the vertical change in the hitch height due to the change in position from 1 to 2.

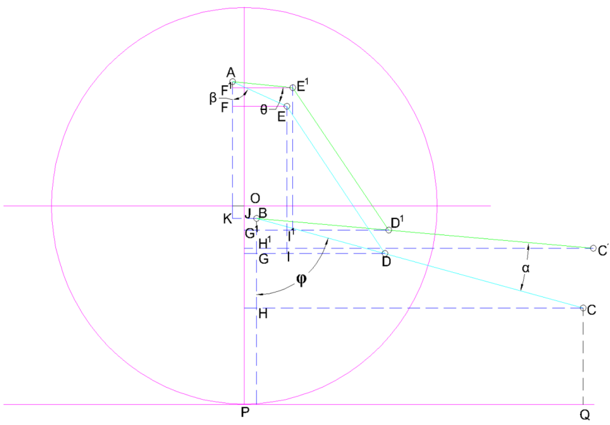

Figure 1. Three-point hitch geometry in the XZ plane

From Figure 1:

BC = *BC*' = length of the lower link;
AE = *AE*' = length of the lift arm;
DE = *D'E*' = length of the lift rod;
BD = *BD*' = distance of the lift rod connection point from the link point of the lower link;
<*FAE* = angle of the lift arm with vertical (β);
<*HBC* = angle of the lower link with vertical (ϕ);
AK = vertical distance between the link points of the lower link and fixed point of the lift arm;
BK = horizontal distance between the link point of the lower link and fixed point of the lift arm;
CQ = llower link point height from the ground;
OP = centre point of the wheel from the ground;
OJ = vertical distance of the link point lower arm from the centre: <*EAE*' = θ; <*CBC*' = α

In the right angle triangle *BCH*

$$\cos\varphi = \frac{Bh}{BC} = \frac{OP - OJ - QC}{BC} \tag{1}$$

In the right angle triangle *AEF*

$$AF = AE\ \cos\beta; \rightarrow EF = AE\ sin\beta \tag{2}$$

In the right angle triangle *BDG*

$$BG = BD\ \cos\varphi; \rightarrow DG = BD\ sin\varphi \tag{3}$$

From the geometry,

$$EI = AK - AF + BG = AK - AE\cos\beta + BD\cos\varphi \tag{4}$$

https://doi.org/10.17221/23/2024-RAE

$$ID = KB + GD - EF = KB - BD \sin\varphi - AE \sin\beta \quad (5)$$

In the right angle triangle *DEI:*

$$DE^2 = EI^2 + ID^2 \quad (6)$$

Using Equations 4 and 5:

$$DE^2 = (AK - AE\cos\beta + BD\cos\varphi)^2 + (KB - BD\sin\varphi - AE\sin\beta)^2 \quad (7)$$

Similarly, in triangle *D'E'I'*:

$$(D'E')^2 = \left\{AK - AE\cos(\beta+\theta) + BD\cos(\varphi+\alpha)\right\}^2 + \left\{KB - BD(\sin + \alpha) - AE\sin(\beta+\theta)\right\}^2 \quad (8)$$

Since, $DE = D'E'$, α can be calculated by knowing the value of θ using Equation (8)

From the geometry, the change in the vertical height at the lower hitch point $HH' = HB - H'B$

In the triangle, *BHC*:

$$HB = BC\cos\varphi \quad (9)$$

In the triangle, *BH'C'*:

$$H'B = BC'\cos(\varphi+\alpha) \quad (10)$$

$$HH' = HB - H'B = BC\cos\varphi - BC\cos(\varphi+\alpha) = BC\left\{\cos\varphi - \cos(\varphi+\alpha)\right\} \quad (11)$$

A computer program was written in the Visual Basic 6 programming environment to calculate the depth constant (d_k) of the different tractor models. The input parameters for the program are associated with the 3-point linkage geometry of tractors.

The input parameters to run the program are the 3-point linkage geometry, which is available in the tractor test report released by the Central Farm Machinery Training and Testing Institute, Budni, India. The input parameters can also be called from the database based on the tractor's make and model. The flow chart of the developed program is presented in Figure 2. The program calculates the change in the vertical height of the hitch point for every 5 ° of rotation of the rocker arm of the tractor hydraulics. The change in hitch height with respect to the change in the angle of rotation is displayed on the output window. The input and output window of the developed program is shown in Figure 3. These values can be plotted

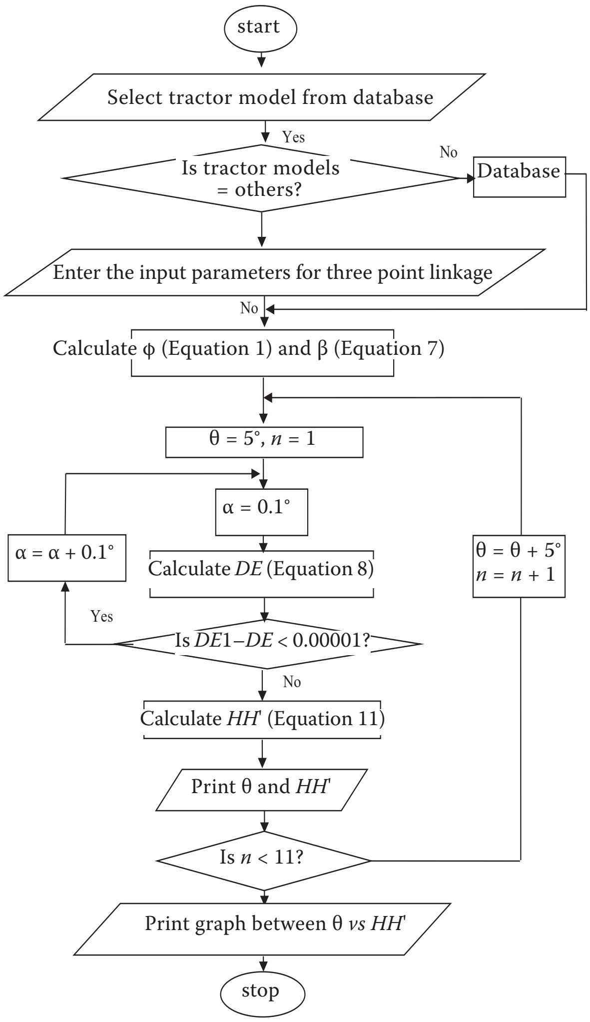

Figure 2. Flow chart of the development program

n – a computer variable restrict the calculation more than 11 time for the plotting the result

between the lift arm angle and the change in the hitch height on the same output window using Microsoft Excel (software version 10).

The developed program was validated using the measured data in the laboratory for six different tractor models. The validation was carried out by measuring the vertical change in the lower hitch point with respect to the change in the rocker arm of the tractor hydraulics. The angle of rotation of the rocker arm was measured with the help of a protractor which was fixed in line with the centre of the rocker arm when the lower link was lifted/lowered with the help of a mechanical jack. The lower links was lifted slowly and the change in the vertical height of the lower hitch point was noted for each 5° of rotation of the lift arm using a scale. The lifting was continued up to the maximum height of the

https://doi.org/10.17221/23/2024-RAE

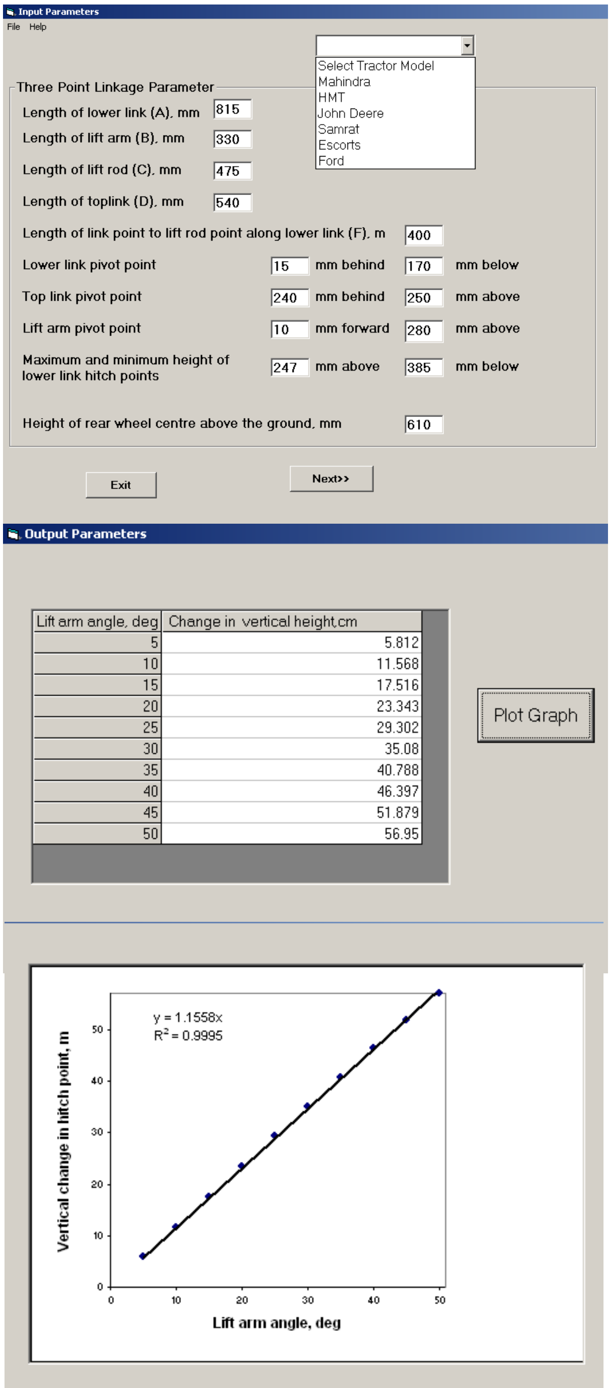

Figure 3. Input and output window of the developed program

hitch point. The reading was noted when lowering the hitch point also. Three replications were taken to verify the accuracy and consistency of the readings. Similar procedures were adopted for all the tractor models.

The depth of operation was sensed by a rotary potentiometer which was fixed on the rocker arm of the tractor hydraulics. The depth of operation was calculated by multiplying the d_k to the measured angle of the rocker arm. The multiplication was carried out using Arduino Uno with the required coding. A 16 × 2 LCD screen was used to display the depth (Figure 4). An electrical switch was also provided to nullify the display of the rocker arm angle when the implement just touches the ground (zero depth).

The off-field evaluation was the method validating the digital display of the depth of operation by simulating the desired condition. A suitable place was developed where the mounted implement can be lowered from a horizontal position in the stationary condition of the tractor. The validation was performed with three implements, namely a cultivator, a mound board plough and a zero till drill. In all the cases, the zero depth was considered when the implement was kept on a level surface. At this condition, the digital display was first made to be "zero" by pressing the reset button. After this, the implement was allowed to lower through the tractor's hydraulics in small steps and the depth was measured by a scale with reference to the level position. A minimum of three replications were taken during lowering and lifting. A comparison between the measured data from the

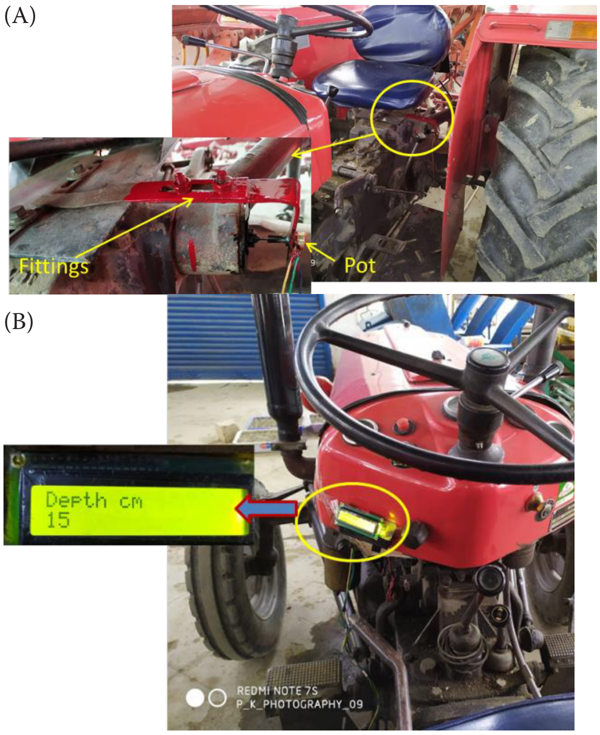

Figure 4. (A) Mounting of the potentiometer on the rocker arm and (B) display on the dashboard

https://doi.org/10.17221/23/2024-RAE

scale and the digitally displayed value was made and is presented under the results.

In the field evaluation, a laptop was used for transferring the display value of the depth of operation through a USB port. The refreshing interval of the display was set at an interval of 3 s and, hence, the data were transferred at a three second interval. The tractor with an implement was operated for about 20 m at a certain depth and the data were recorded. On the other hand, the depth of operation was measured by cleaning the furrow using a scale as per the set manual procedure at 5–8 places. The experiment was conducted with three implements namely a cultivator, an MB plough and a zero till drill at three depths. In each case, three replication measurements were taken. During these experiments, the depth indicated was recorded and measured manually using a scale. The average value of both methods was compared in terms of the correlation coefficient and the root mean square error was calculated. Furthermore, a *t*-test was also performed to determine the significance of the deviation from the measured value.

RESULTS AND DISCUSSION

The first part of this section deals with the validation results of the computer program. The second and third parts deal with the evaluation of the depth measurement system in laboratory and field conditions.

Computer program validation. The measured and predicted values of the change in the vertical hitch point with regard to the rocker arm rotation for different tractors are shown in Figure 5. It was noticed that the predicted values were very close to the measured values as indicated by the percentage root mean square error (RMSE; %) for all the tractor models. Statistically, there was no significant difference between the measured and the predicted values in any of the tractor models. Hence, it was concluded that the developed computer program computes the depth constant (d_k) efficiently.

Off-farm depth measurement. The comparison of the digitally and manually measured depths of operation is plotted on a 1:1 line for a cultivator, an MB plough and a zero till drill, which is presented in Figure 6. These curves clearly indicate the closeness between the manually and digitally measured values with the maximum RMSE of 0.7 in the zero till drill. Further, the deviation was not recorded in either direction under or over the indication. In the simulated situation, the depth was compared during the lowering and lifting of the implement to the known hysteresis effect of the sensor. No hysteresis effect was observed, as around 30 ° of the

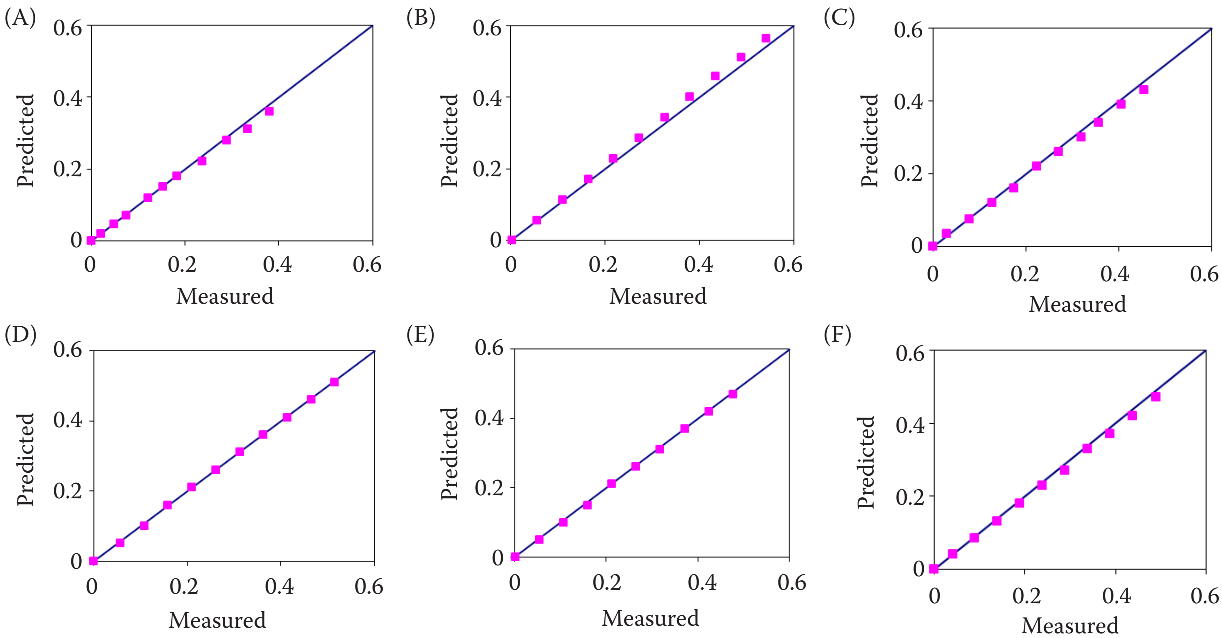

Figure 5. Measured and predicted change in the vertical hitch point on a 1 : 1 line
(A) tractor 1 (RMSE = 5.45%); (B) tractor 2 (RMSE = 5.22%); (C) tractor 3 (RMSE = 5.7%); (D) tractor 4 (RMSE = 1.7%); (E) tractor 5 (RMSE = 5.07%); (F) tractor 6 (RMSE =1.27%); RMSE = root mean square error

https://doi.org/10.17221/23/2024-RAE

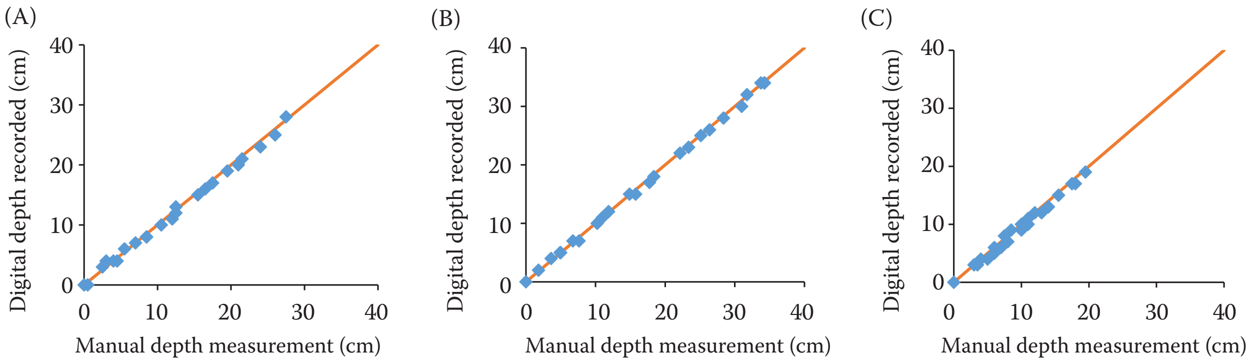

Figure 6. 1 : 1 curve between the manual and digital depth: (A) cultivator, (B) MB plough, and (C) zero till drill

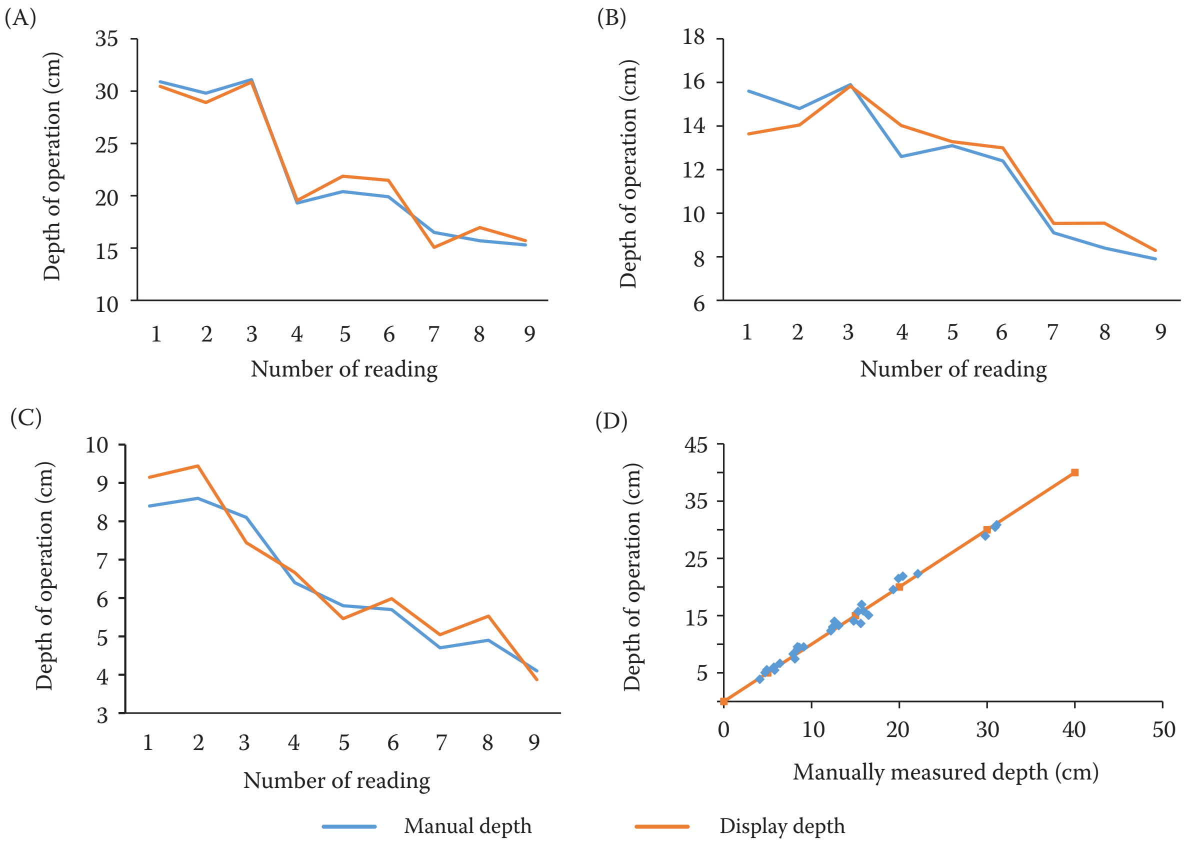

Figure 7. Comparison between the manually and digitally measured depths in the field: (A) MB plough, (B) cultivator, (C) zero till drill, and (D) 1 : 1 plot

rotary potentiometer is used for the lowest point to the zero depth. Furthermore, it can evidenced that the errors are due to either human error in the manual depth measurement or rounding up issues in the digitally measured depth of operation. Therefore, it can be concluded that digital display, independent of the types of implements, performed equally for all implement types.

For a statistical comparison, a *t*-test was performed in SPSS tools (software version 20) and it was found that there is no significant difference between the manually measured and digitally observed value as, in all cases, the *t*-value was more than 0.05. The statistical analysis is presented in Table 1.

On-farm performance. From the data recorded during field test, it was observed that there was a variation in the depth of operation for all depth levels. In the case of the MB plough, the average depth of operation was 30.5 cm with a minimum and maximum value of 26 and 34 cm, respectively.

https://doi.org/10.17221/23/2024-RAE

Table 1. Comparison of two means for the different implements

Implement	No. of data	Mean depth (cm)		Correlation coefficient	t-value
		manual	digital		
Cultivator	23	12.19	11.91	0.998	2.4
MB Plough	24	17.51	17.33	1.0	2.4
Zero till drill	23	9.74	9.26	0.995	4.3

MB – mold board

This variation is due to the point-to-point variation in the soil properties and, accordingly, due to the existing automatic depth and draught control of the tractor's hydraulics. This result is supported by Pranav (2011), Pranav et al. (2012) and Kim et al. (2020).

The average deviation was found to be –2.4 mm with a variation from –13.6 to +12.6 mm. The negative deviation refers to the higher value of the digital measurement than the manual measurement and *vice-versa*. The percentage deviation clearly indicates that the maximum frequency of the percentage deviation is below ± 5%. The chance of error in the manual depth measurement is more as it requires cleaning of the furrow and the identification of a reference point. Therefore, it presumes that the observed variation was due to an error in the manual depth measurement as it was less in the case of the off-farm performance.

Furthermore, the comparison is presented in a graphical form for ease of understanding for the MB plough, cultivator and zero till drill, as seen in Figure 7. The curves clearly overlap each other and, hence, it can be resolved that there is no consistency in the over/under measurement by the digital display. The presentation is also made on 1 : 1 graph between the manually and digitally measured depths of operation as shown in the figure. Statistically, there is no significant variation between the manually and digitally measured values per the t-value (0.11) of more than 0.05 and the correlation coefficient of 0.994.

CONCLUSION

A mathematical relationship was established using a geometrical analysis to calculate the change in the hitch point height of the lower links with respect to the rotation of the rocker arm of the tractor's hydraulics. Furthermore, a computer program was successfully developed to predict the calibration factor for the depth measurement for any size of linkage geometry for three-point linkages. The depth of operation was also measured and digitally displayed on the tractor's dashboard by sensing the rocker arm rotation through a rotary potentiometer. The laboratory and field evaluation showed that the displayed depth of operation was well within the accepted range. Hence, such a depth display will facilitate the precise operation of the tractor.

Acknowledgement. We thank to the Dean, CAET, Pusa for extending the support and providing the facility to conduct this project.

REFERENCES

Ambike S.S., Schmiedeler J.P. (2007): Application of geometric constraint programming to the kinematic design of 3-point hitches. Applied Engineering in Agriculture, 23: 13–21.

Avello Fernández L., Maraldi M., Mattetti M., Varani M. (2022): A Computational tool for three-point hitch geometry optimisation based on weight-transfer minimisation. Agriculture, 12: 460.

Bauer F., Porteš P., Slimařík D., Cupera J., Fajman M. (2017): Observation of load transfer from fully mounted plough to tractor wheels by analysis of three point hitch forces during ploughing. Soil Tillage Research, 172: 69–78.

Cowell P.A., Milne M.J. (1977): An implement control system using pure draught sensing and modified linkage geometry. Journal of Agricultural Engineering Research, 22: 353–371.

Crolla D.A., Pearson G. (1975): The response of tractor draught controls to random variations in draught. Journal of Agricultural Engineering Research, 20: 181–l97.

Dhruw L.K., Pareek C.M., Singh N. (2018): A visual basic programme for performance evaluation of three-point linkage hitch system of agricultural tractors. Current Journal of Applied Science and Technology, 28: 1–12.

Dwyer M.J. (1969): The effect of draught control response on the performance of agricultural tractors. Journal of Agricultural Engineering Research, 14: 295–312.

Dwyer M.J., Crolla D.A., Pearson G. (1974): An investigation of the potential for improvement of tractor draught controls. Journal of Agricultural Engineering Research, 19: 147–165.

https://doi.org/10.17221/23/2024-RAE

Kamgar S.M., Loghavi M., Shafaei S. (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: 11–23.

Kim Y.S., Kim T.J., Kim Y.J., Lee S.D., Park S.U., Kim W.S. (2020): Development of a real-time tillage depth measurement system for agricultural tractors: Application to the effect analysis of tillage depth on draft force during plow tillage. Sensors, 20: 912.

Kumar A., Pranav, P.K., Kumar S. (2018): Computer simulation of three-point linkage parameters for virtual hitch point and optimum depth of operation. Engineering in Agriculture Environment and Food, 11(3): 114–121.

Kumar G.V.P. (2012): Development of a computer program for the path generation of tractor hitch points. Biosystems Engineering, 113: 272–283.

Kumar G.V.P. (2015): Geometric performance parameters of three-point hitch linkage system of a 2WD Indian tractor. Research in Agricultural Engineering, 61: 47–53.

Li C., He Y., Feng Q., Jiang K., Wang X., Zhang C. (2019): Design and test of tilling depth measurement device based on angle sensor. IOP Conference Series: Earth Environmental Science, 346: 012011.

Milella1 A., Nielsen M., Reina G. (2017): Sensing in the visible spectrum and beyond for terrain estimation in precision agriculture. Advances in Animal Biosciences: Precision Agriculture, 8: 423–429.

Molari G., Mattetti M., Guarnieri A. (2014): Optimal three-point hitch design to maximize lifting performance. Transactions of the American Society of Agricultural and Biological Engineers, 57: 371–379.

Mouazen A.M., Ramon H. (2006): Development of on-line measurement system of bulk density based on on-line measured draught, depth and soil moisture content. Soil & Tillage Research, 86: 218–229.

Mouazen A.M., Anthonis J., Saeys W., Ramon H. (2004): An automatic depth control system for online measurement of spatial variation in soil compaction, Part 1: Sensor design for measurement of frame height variation from soil surface. Biosystems Engineering, 89: 139–150.

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.

Reina G., Milella A. (2012): Towards autonomous agriculture: Automatic ground detection using trinocular stereovision. Sensors, 12: 12405–12423.

Roeber J.B.W., Pitla S.K., Kocher, M.F., Luck, J.D., Hoy R.M. (2016): Tractor hydraulic power data acquisition system, Computers and Electronics in Agriculture, 127: 1–14.

Suomi P., Oksanen T. (2015): Automatic working depth control for seed drill using ISO 11783 remote control messages. Computers and Electronics in Agriculture, 116: 30–35.

Wang X., Peng B., Bogdan M., Hu B., Xu M. (2018): Detection of the trench depth based on a differential inertial sensor technology. Elektronika Ir Elektrotechnika, 24: 8–14.

Received: March 1, 2024
Accepted: October 17, 2024
Published online: December 20, 2024