

Geometric performance parameters of three-point hitch linkage system of a 2WD Indian tractor

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Abstract

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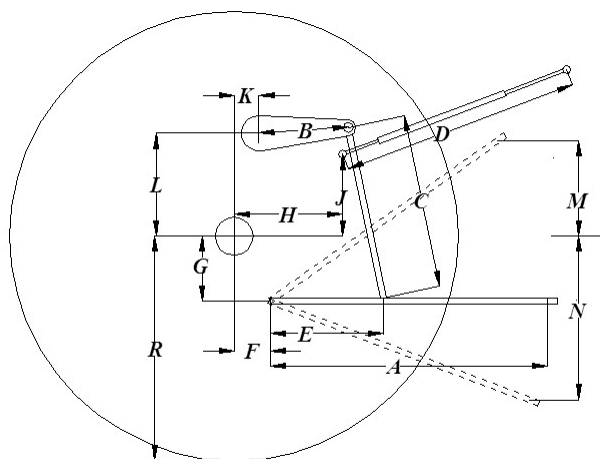
Geometric performance parameters of three-point hitch system of a most sold model of a 2-wheel drive Indian tractor were determined by generating the path of upper and lower hitch points by kinematic linkage analysis. At various locations of pivot point of upper link and adjustments in the length of lift rods, hitch linkage system of the tractor fulfilled all the requirements specified by the standards for category-I and II hitches. An insight into the kinematic linkage analysis revealed that the hitch linkage of the selected tractor is the most suitable for operations with soil working implements. Attachment of upper link to the topmost pivot point reduced the change in orientation of implement during lifting and ensured better weight transfer from implement to the rear axle of tractor. The kinematic linkage analysis has the potential to identify the best settings of the hitch linkage system for the effective utilization of tractor power during various farm operations.

Keywords: kinematic linkage analysis; Newton-Raphson solution; virtual hitch point; vertical convergence distance; mechanical advantage

Three-point hitch linkage system for farm tractors is a fundamental device for the agricultural works. Design of three-point hitch linkage system is governed by the American Society of Agricultural and Biological Engineers (2006.S217.12 DEC01). The Bureau of Indian Standards (Indian Standards: IS 12953:1990 – Drawbar for agricultural tractors-link type and IS 4468-(Part-I):1997 – Agricultural wheeled tractors – Rear mounted 3-point linkage: Part 1 Categories 1, 2, 3 and 4) has given the specifications for the Indian tractors. According to these standards, design of three-point hitch linkage system has to fulfil certain requirements related to lift, movement range and levelling adjustments, and dimensions concerning tractor hitch points and implement hitch attachments specified by the stand-

ards. The lift, movement range and levelling adjustments refer to geometric performance parameters of the hitch (AMBIKE, SCHMIEDELER 2007). They include transport height, lower hitch point height, movement range, mast adjustment height positions, transport pitch, lower hitch point clearance, convergence distances and levelling adjustment. These parameters vary with link lengths, link pivot locations and other adjustments provided in the hitch system.

Among the various geometric performance parameters, transport height, lower hitch point height, movement range, lower hitch point clearance and levelling adjustments are reported in the Indian tractor test reports. Further, these parameters are measured manually in tractor test centres. Geometric performance parameters of the hitch can be determined



	Dimension (mm)	Setting during the test (mm)
A	730	730
B	235	235
C	415 to 465	465
D	533 to 630	630
E	300	300
F	95	95
G	170	170
H	280, 285, 270	285
J	215, 245, 285	245
K	65	65
L	270	270
M	250 to 350	250
N	290 to 430	430
R	590	590

Fig. 1. Details of 3-point hitch linkage system from test report of tractor

A – length of lower link; B – length of lift arm; C – length of lift rod; D – length of upper link; E – distance of lift rod connection point from the pivot point of lower link; F – horizontal distance of pivot point of lower link from the rear wheel axle centre; G – vertical distance of pivot point of lower link from the rear wheel axle centre; H – horizontal distance of pivot point of upper link from the rear wheel axle centre; J – vertical distance of pivot point of upper link from the rear wheel axle centre; K – horizontal distance of pivot point of lift arm from the rear wheel axle centre; L – vertical distance of pivot point of lift arm from the rear wheel axle centre; M – max. height from rear wheel axle centre to which lower hitch point can reach when the implement is lifted; N – min. height from rear wheel axle centre to which lower hitch point can reach when the implement is lowered; R – Dynamic radius of rear wheel of tractor

analytically if the length of lift arm, its power travel and kinematic configuration of the complete hitch linkage system are known. In a vertical longitudinal plane, three-point hitch linkage system is a six-bar mechanism that can be modelled as two distinct four-bar linkages sharing two links (AMBIKE, SCHMIEDELER 2007; PENNOCK 2010; KUMAR 2012). AMBIKE and SCHMIEDELER (2007) used graphical method whereas NASTASOIU et al. (2010) and VASILACHE et al. (2010) used geometrical relations to study the effect of varying link dimensions and spatial location of their pivot points on the path generated by the lower and upper hitch points. PENNOCK (2007) and KUMAR (2012) developed analytical methods that could be used for the kinematic synthesis of three-point hitch linkage system of any tractor.

The present work consists of the following:

- Generation of the coordinates of the path of upper and lower hitch points in the power travel of the lift arm of a tractor using computer-aided kinematic linkage analysis.
- Determination of geometric performance parameters of the hitch linkage based on the coordinates of the generated path of hitch points.
- Analysis of relative merits of adjustments in the hitch linkage system.

MATERIAL AND METHODS

Selection of tractor and details of its hitch linkage system. A most sold model of a two-wheel drive (2WD) tractor (John Deere 5036C) manufactured by one of the renowned tractor manufacturers (John Deere India Private Ltd., Pune, India) in India was selected. Brake horse power (BHP) of the tractor engine was 23.4 kW. It had a wheel base of 1,875 mm. The commercial test report of the tractor was collected from the Central Farm Machinery Training and Testing Centre, Budni, Madhya Pradesh, India. It indicates that the hitch linkage system of the tractor belongs to both category-I and II hitches. Dimensions of the linkage geometry corresponding to projected lengths (in vertical longitudinal plane) of lift arm (B); lift rod (C) and lower link (A), distance of lift rod connection point from pivot point of lower link (E), distances of pivot point of lift arm (K, L); lower link (F, G) and upper link (H, J) from the centre of rear wheel axis, and heights reached by the lower hitch points relative to the centre of rear wheel axis (M, N) as shown in Fig. 1 were collected from the test report. Settings of these parameters during the test (at the test centre) were noted down for the determina-

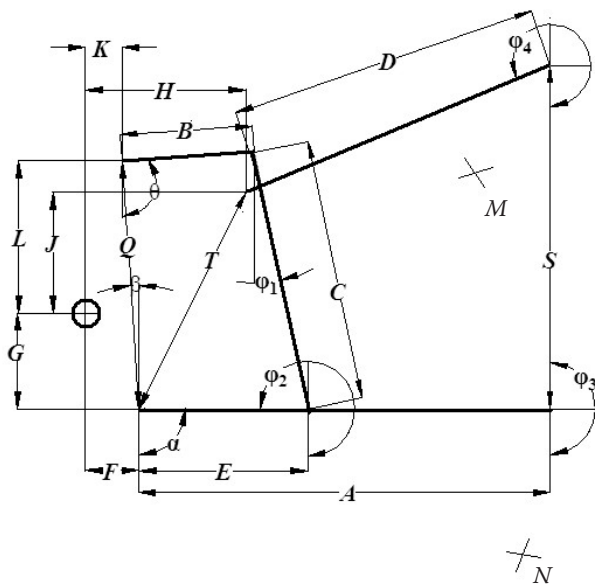


Fig. 2. Tractor three-point hitch linkage
 A – length of lower link, B – length of lift arm; C – length of lift rod; D – length of upper link; E – distance of lift rod connection point from the pivot point of lower link; F – horizontal distance of pivot point of lower link from the rear wheel axle centre; G – vertical distance of pivot point of lower link from the rear wheel axle centre; H – horizontal distance of pivot point of upper link from the rear wheel axle centre; J – vertical distance of pivot point of upper link from the rear wheel axle centre; K – horizontal distance of pivot point of lift arm from the rear wheel axle centre; L – vertical distance of pivot point of lift arm from the rear wheel axle centre; M – max. height to which lower hitch point can reach when the implement is lifted; N – min. height to which lower hitch point can reach when the implement is lowered; S – implement mast; T – distance between lower link pivot point and upper link pivot point; α – angle made by the lower link with vertical reference line; β – angle made by line joining the pivot points of lower link and lift arm with vertical; θ – angle made by the lift arm with vertical reference line; φ_1 – angle made by the lift rod with vertical reference line; φ_2 – angle made by the lower link with vertical reference line; φ_3 – angle made by the implement mast with vertical reference line; φ_4 – angle made by the upper link with vertical reference line

tion of power travel of the lift arm. Length of both lift rods of the selected tractor can be varied in the range from 415 to 465 mm. Variations in dimensions corresponding to H and J were noted down to study the variations in geometric performance parameters.

Determination of power travel of the lift arm. Throughout the kinematic analysis of the hitch linkage system, centre of the rear axle of the tractor

was taken as origin. For the full power travel of the lift arm, lower hitch point moves through a vertical distance equal to $M + N$ as shown in Figs 1 and 2. When the lower link is horizontal and implement mast is vertical as in Fig. 2, $\varphi_2 = 3\pi/2$ radians, $\varphi_3 = \pi$ radians and $\alpha = \pi/2$ radians. The values of θ and φ_1 can be determined using the geometric relationships. The coordinates of lower hitch points can be determined as follows:

$$x_A = K + B\sin\theta + C\sin\varphi_1 + (A - E)\sin(\varphi_2 - \pi) \quad (1)$$

$$y_A = L - B\cos\theta - C\cos\varphi_1 - (A - E)\cos(\varphi_2 - \pi) \quad (2)$$

The value of θ was noted as θ_{level} . The value of θ is now increased (for lifting of implement) by a small value. Summing horizontal and vertical components of link vectors for the first four-bar linkage (Fig. 2) consisting of B, C, E and Q, and defining functions f_1 and f_2 as:

$$f_1 = B\cos\theta + C\cos\varphi_1 + E\cos\varphi_2 + Q\cos(\pi + \beta) \quad (3)$$

$$f_2 = B\sin\theta + C\sin\varphi_1 + E\sin\varphi_2 + Q\sin(\pi + \beta) \quad (4)$$

For a given value of θ , this is a set of two non-linear equations with two unknowns, φ_1 and φ_2 . Therefore, the iterative equations for its solution can be developed using the Newton–Raphson method (NORTON 1999; KUMAR 2012) with values of φ_1 and φ_2 calculated earlier as initial solution. The procedure was continued till the y-coordinate of the lower hitch point became equal to M. The value of θ was noted as θ_{up} . From the position of horizontal lower links and vertical mast, the entire procedure was again repeated by decrementing the value of θ till the y-coordinate of the lower hitch point became equal to N. The value of θ was noted as θ_{down} . The values of θ_{up} and θ_{down} indicate the power travel of the lift arm.

Generation of path of upper and lower hitch points. For the position of horizontal lower links and vertical mast ($\theta = \theta_{\text{level}}$), length of upper link required was determined. Values of $\varphi_1, \varphi_2, \alpha, \varphi_3$ and φ_4 were calculated using the geometric relationships. The value of θ was incremented and the values of φ_1 and φ_2 for the new value of θ were determined. The coordinates of lower hitch points were determined using Eqs. (1) and (2). Considering the second four-bar linkage (Fig. 1) consisting A, S, D and T at this instance and putting $\alpha = \varphi_2 - \pi$, values of φ_3 and φ_4 were determined for the new value of α (or θ) using the Newton-Raphson method. The

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coordinates of upper hitch points were determined using Eqs. (5) and (6):

$$x_D = F + A \sin \alpha + S \sin \phi_3 \quad (5)$$

$$y_D = G - A \cos \alpha - S \cos \phi_3 \quad (6)$$

The procedure was continued till the value of θ became equal to θ_{up} . From the position of horizontal lower links and vertical mast, the entire procedure was again repeated by decrementing the value of θ till the value of θ became equal to θ_{down} .

The coordinates of the path of upper and lower hitch points (x_A, y_A and x_D, y_D) at each value of θ throughout the power travel of the lift arm were stored. Path of hitch points was plotted for various locations of pivot point of upper link (H, J in Figs 1 and 2), and implement mast (S in Fig. 2) of 460 mm (category-I implement) and 610 mm (category-II implement).

Determination of geometric performance parameters of hitch linkage. The values of various geometric performance parameters were determined from the coordinates of the path of upper and lower hitch points (Fig. 3) as follows:

Lower hitch point height = radius of rear wheel – (y_A at $\theta = \theta_{down}$).

Transport height = radius of rear wheel + (y_A at $\theta = \theta_{up}$).

Movement range = transport height – lower hitch point height.

Lower hitch point clearance – (distance between the centre of rear axle and (x_A, y_A) when $\theta = \theta_{up}$) – radius of the rear wheel.

Lowest position of mast adjustment height = radius of rear wheel – {value of y_5 at which ($5^\circ +$ angle made by the line drawn between (x_A, y_A) and (x_D, y_D) with vertical while decrementing the value of θ from θ_{level} became equal to zero)}. The height is measured from the ground surface.

The highest position of mast adjustment height = radius of rear wheel – {value of y_5 at which ($5^\circ -$ angle made by the line drawn between (x_A, y_A) and (x_D, y_D) with vertical while incrementing the value of θ from θ_{level} became equal to zero)}. The height is measured from the ground surface.

Vertical convergence distance = distance from (x_A, y_A) to the point of intersection of lines drawn through (x_A, y_A), (F, G) and (x_D, y_D), (H, J) meet when $\theta = \theta_{level}$.

Transport pitch is angle made by the line drawn between (x_A, y_A) and (x_D, y_D) with vertical when $\theta = \theta_{up}$.

Levelling adjustment was determined by varying the length of one of the lift rods from maximum to minimum length while keeping the other lift rod at the test setting. Coordinates of the vertical convergence distance throughout the power travel of lift arm were used to plot the locus of virtual hitch point (instantaneous centre of rotation of mast).

The magnitude of the geometric performance parameters determined through the kinematic linkage analysis was compared with the limits specified in the standards. Quality of motion and force transmitted to lower links at various adjustments of the linkages were analysed in terms of angular velocity ratio and mechanical advantage (NORTON 1999).

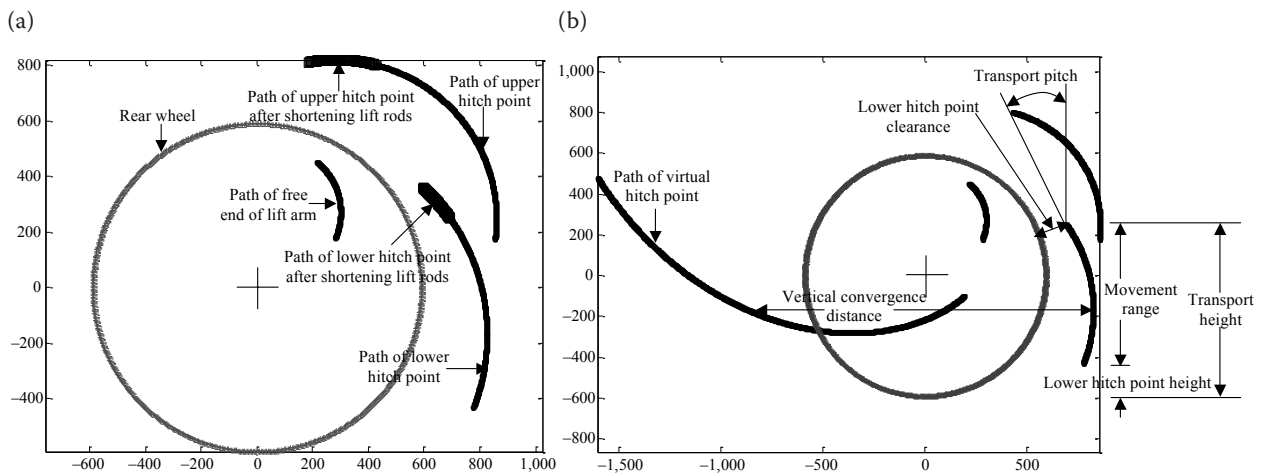


Fig. 3. Path generated by the hitch points with mast height of 610 mm

(a) path of upper and lower hitch points at the test settings and after shortening the lift rods; (b) determination of various geometric performance parameters of hitch linkage system

RESULTS AND DISCUSSION

Power travel of lift arm and path of lower and upper hitch points

The values of θ_{level} , θ_{up} and θ_{down} were found to be 93.68°, 140.19° and 67.11°, respectively. The full power travel of lift arm was 73.08°. Paths of lower and upper hitch points throughout the power travel of lift arm and determination of various geometric performance parameters of the hitch linkage system are shown in Fig. 3.

Geometric performance parameters of hitch

Movement range, lower hitch point clearance and levelling adjustment. The lower hitch point height and transport height were found to be 160 and 840 mm, respectively. The movement range was 680 mm. Shortening the length of lift rods from 465 mm to 415 mm increased the transport height to 950 mm and lower hitch point height to 300 mm.

Lower hitch point clearance and levelling adjustment were 145 and 122 mm, respectively. The hitch linkages of the selected tractor fulfilled the standard specified requirement of max. lower hitch point height (200 mm), min. transport height (820 mm) and min. movement range (610 mm) for the category-I hitch. However, it required shortening of the length of lift rods to meet the standard specified requirement of minimum transport height (950 mm) for the category-II hitch. The lower hitch point clearance was found to be more than the min. recommended by the standards (100 mm) for category-I and II hitches. At the horizontal lower link and vertical mast position, when one of the lift rods was shortened from 465 to 415 mm, the lower hitch

point raised by 122 mm. The standards recommend min. levelling adjustment of 100 mm for category-I and II hitches.

In the test report of the selected tractor, the lower hitch point height and transport height was reported as 160 and 840 mm, respectively when the length of lift rods was 465, 300 and 940 mm, respectively when the length of lift rods was 415 mm. The movement range was reported as 680 and 640 mm when the length of lift rods was 465 and 415 mm, respectively. Lower hitch point clearance was reported as 195 mm and levelling adjustment was reported as 210 mm.

Vertical convergence distance, mast adjustment heights and transport pitch. The vertical convergence distance and transport pitch varied from 1,478 to 2,184 mm and –20 to –28° for mast height of 610 mm, and from 3,343 to 51,060 mm and –8 to –17° for mast height of 460 mm (Table 1). The standards recommend the vertical convergence distance to be not less than 0.9 times the tractor wheel base (1,875 mm) for stable working conditions. Hence, the tractor is recommended to use category-I hitch implements with upper link attached to all three pivot points, whereas category-II hitch implements should be used with upper link attached to the 3rd or topmost pivot point only. The lowest position of mast adjustment height for the mast height of 460 mm was well below the lower hitch point height, and for the mast height of 610 mm it varied from 190 to 278 mm (Table 1). The standards recommend the lowest position of mast adjustment height to be max. 200 mm for category-I and II hitches. The highest position of mast adjustment height was well above the min. specified by the standards for the category-I hitch (508 mm), whereas for the category-II hitch it was below the min. specified by the standards (610 mm).

Table 1. Vertical convergence distance, mast adjustment heights and transport pitch at various spatial locations of upper link pivot point and mast height of 460 mm and 610 mm

Upper link pivot point*	Vertical convergence distance (mm)		Lowest position of mast adjustment height (mm)		Highest position of mast adjustment height (mm)		Transport pitch (°)	
	460	610	460	610	460	610	460	610
(280, 215)	3,343	1,478	OMR	278	622	536	–17.00	–27.67
(285, 245)	5,520	1,689	OMR	252	670	549	–13.63	–25.50
(270, 285)	51,060	2,184	OMR	190	779	580	–7.55	–20.40

*coordinates measured from the centre of the rear axle (mm); OMR – out of movement range

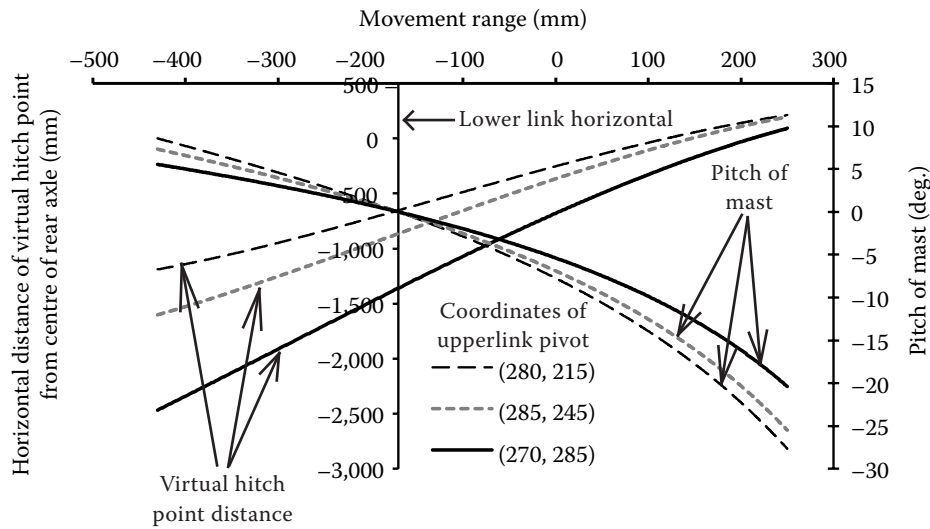


Fig. 4. Variations in horizontal distance of virtual hitch point and pitch of the mast with motion of lower hitch point in the movement range at different locations of pivot point of upper link when mast height is 610 mm

Virtual hitch point and pitch of the mast. Variations in horizontal distance of virtual hitch point from the rear axle centre and pitch of mast in the movement range are shown in Fig. 4. When the lower links were raised above their horizontal position, virtual hitch point moved nearer to the rear axle. Variation in the lift of the implement did not change the location of virtual hitch point widely when the virtual hitch point was nearer to the rear axle. However, as the implement was lowered, virtual hitch point moved faster far in front of the rear axle. The rate of shift of virtual hitch point was faster when the upper link was attached to 3rd pivot point (270 mm, 285 mm). This indicates that during the operation of heavy tillage implements in field,

upper link has to be attached to 3rd pivot point to ensure better weight transfer from implement to the rear axle. Further, pitch of the mast varied through a narrow range when the upper link was attached to the 3rd pivot point. This reveals that for the implements whose pitch of the mast should not change significantly in the movement range (implements like seed drill, planters, sprayers, levellers etc.), upper link has to be attached to the 3rd pivot point.

Variation in angular velocity ratio and mechanical advantage in the movement range. Max. value of mechanical advantage (0.79) and min. value of angular velocity ratio (0.41) were observed at -204 mm and it is just below the horizontal lower link position (Fig. 5). Though variation in mechanical advantage and angular velocity ratio in the movement range are low, the lowest value of mechanical advantage and the highest value of angular velocity ratio were observed at the transport height. This indicates that the hitch linkage of tractor has the better transmission of force to the implement from the hydraulic system of tractor during tillage operations rather than during lifting and transportation tasks. Therefore, tractor is the most suited for operations using soil working implements like plows, cultivator, harrows, seed drill etc.

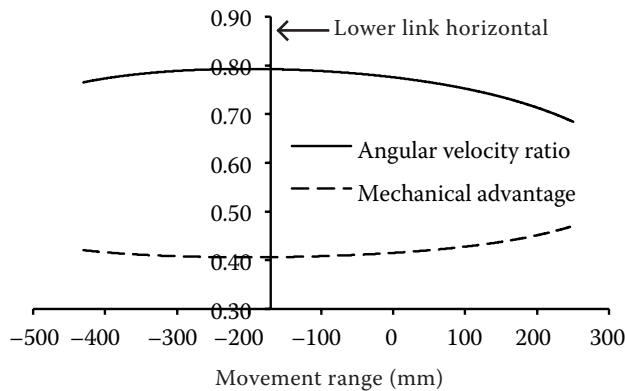


Fig. 5. Variation in angular velocity ratio and mechanical advantage in the movement range

In retrospect, kinematic linkage analysis has the ability to identify the best adjustment in the three-point hitch linkage system of tractor for various farm operations.

CONCLUSIONS

The kinematic analysis of the three-point hitch linkage system indicated that the implements with mast height of 460 mm can be operated by the selected tractor by attaching the upper link to all three pivot points. The upper link has to be attached to the 3rd pivot point only for the operation of implement with mast height of 610 mm. Further, attaching the upper link to 3rd pivot point ensures the higher weight transfer from implement to the rear axle of tractor. In addition, orientation of implement will not change significantly during lifting of implement when the upper link is attached to the 3rd pivot point. The kinematic linkage analysis revealed that the hitch system of tractor is the most suitable for tillage, sowing and intercultivation operations.

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