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Development of Visual Basic Program to Design Front Mounted Three-Point Linkage for Higher Power Tractors

Naseeb Singh[1*] and K. P. Pandey[1]

[1]Department of AgFE, IIT Kharagpur, West Bengal, 721 302, India.

Authors' contributions

This work was carried out in collaboration between both authors. Author NS calculated the forces on front-three point linkage and developed a program in visual basic for design of front-three point linkage. Author KPP managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

In higher power tractors, to fully utilize the available power and for timeliness of tillage operations, front mounted three-point linkage is another option. With this view, a user friendly computer program is developed in Visual Basic environment to design of front mounted three-point linkage. The input parameters of the developed program are mainly speed of operation, type of implement, mast height, PTO power, angle of links, hydraulic pressure, yield strength of materials etc. The program is capable to compute draft, forces on linkage, links dimensions, link points, design of hydraulic cylinder, minimum hydraulic lift capacity etc. ASAE draft equation is used to calculate draft and horizontal and vertical forces on links are calculated to determine safety against bending of links. A front three-point linkage is fabricated as per dimensions provided by developed program. Developed visual basic program is simple, cheap and practically useful to design front mounted linkage.

Keywords: Visual basic; tractor; front three-point linkage; hydraulic cylinder.

**Corresponding author: E-mail: naseeb501@gmail.com;*

NOMENCLATURE

Sym.	: Description	Sym.	: Description
2WD	: Two wheel drive	l_l	: Distance between LLP and point where cylinder is attached to lower link
b	: Thickness of lower link	M_B	: Bending moment
d	: Rod diameter, Width of lower link	PTO	: Power take off
F_c	: Force applied by each cylinder	S	: Speed of operation
$F_l^{'}$	: Force on each lower link along its length	V	: Vertical component of soil reaction force
F_h	: Force in lower link in horizontal direction along the direction of motion	W_i	: Weight of implement in condition i
F_t	: Force in top link	x_f	: Distance between implement center of gravity and front axle
F_v	:Vertical force on lower link	σ	: Allowable stress of material
h	: Mast height	θ_c	: Angle between lower link and axis of cylinder
LLP	: Lower link point	θ_h	: Angle of lower link with horizontal
LHP	: Lower hitch point	θ_t	: Angle of top link with horizontal
L_l	: Length of lower link	θ_v	: Angle of lower link with direction of motion in horizontal plane
x	: Moment arm of resultant vertical soil and gravitational force on the implement about the cross shaft	y	: Height of cross-shaft from center of resistance

1. INTRODUCTION

Agriculture is the most important sector of Indian economy. The biggest challenge before the agricultural sector of India is to meet the growing demands of food for its increasing population from 1.22 billion in the year 2010 to 1.46 billion by the year 2030 [1]. Since the cultivated area has remained nearly constant (within 138 to 142 Mha) over the years, the only option to increase food production is to increase the productivity of land [2]. One way to increase productivity is through farm mechanization. Higher productivity and greater output are the two major contributions of farm mechanization [3]. Tractors are an integral part of mechanization and have a crucial role to play to enhance agriculture productivity. In search of higher productivity, farmers are taking more than two crops in a year. In this farming pattern, they don't have much time for field preparation. Timeliness in farm operations helps in increasing production, productivity and profitability in agriculture. But, as per recent trends, workers are migrating from agriculture to other sectors which lead to unavailability of sufficient manpower in farm and also enhancing labor wages during peak time. Therefore, farmers want to complete various farm operations as soon as possible. Front-mounted implements make it possible to perform two operations in a single pass, using both a front and a rear mounted implements. So, there is a need for design of front mounted linkage.

To design a front three-point linkage for a tractor many calculations are involved for each parameter. For example, draft will vary with speed of operation, type of implement, number of working tool etc. ASAE draft equation constants changes with soil type, and minimum lift capacity for tractor hydraulic depends upon PTO power, tractor type, tractive efficiency which ultimately decide the links width and thickness. Top link and lower links angles also affect linkage forces. In designing the hydraulic cylinder, stroke length, retract length, link points, rod diameter etc. are calculated which depend upon length of lower link, angle of lower link, transport height and ground clearance. So, any change in these parameters will change the overall design of hydraulic cylinder. So, in designing of front three-point linkage many calculations are involved and lots of iterations are necessary with each parameter to obtain the output parameters in recommended range. Due to so many calculations and iterations, designing process required considerable time and possibility of errors also present. But, by using developed VB program, time required to design front linkage and possibility of error get reduced. So, this program is simple and user friendly.

In past, a computer program was developed using Visual Basic for cost estimation of agricultural machines [4]. For predicting haulage and field performance of 2WD tractors also, a computer program was developed in Visual Basic [5]. Another Visual Basic program was developed to find out ballasting on front and rear axles to optimize ballasting in order to reduce soil compaction without decrease in tractive efficiency [6]. These programs have been proven to be user friendly and efficient in their performances. Hence, Visual Basic environment is chosen for development of computer program.

This program is developed to keep in mind the requirement of tractor industries. Before fabrication, it is necessary to find out link points, links length, hydraulic cylinder dimensions, hydraulic lift capacity, transport height etc. This program will provide all these parameters to designer in less time. Program operator can change input parameters according to requirement easily and get the output design parameters with accuracy. This program will help in increase the speed of front three-point linkage design and fabrication in tractor industry. Research students can also use this program to find out the theoretical forces acting on linkage by providing input parameters of tractor, implements and soil type like implement width, forward speed of tractor, type of soil, mast height etc.

So, by keeping the above facts in mind present study was undertaken with the objective of developing a user friendly computer program in Visual Basic for designing of front mounted linkage.

2. MATERIALS AND METHODS

Front three-point linkage consists of lower links, top link, hydraulic cylinders and upper torsion arm. Designs of these parts are discussed in following sections.

2.1 Forces on Linkage

For structural strength design of front linkage, forces on links must be known. Effects of forces during tillage operations on tractor, three-point linkage and on driving wheels are analyzed by measuring as well as by computing to develop a mathematical model [7]. Forces on links acts due to tillage operation or, when three-point linkage lifts a specified load. Higher force among these two was considered for design.

2.1.1 Forces on linkage due to implements

Various implements are attached to tractor for different operations like tillage, sowing, inter-cultivation etc. Out of these, primary tillage used the maximum power. Therefore, forces on linkage are calculated by considering primary tillage implements on front. As tractor move forward, pushing force applied on implement mounted on front and pulling force on implement mounting on rear. Due to this, for front linkage, top link comes under tension and lower links comes under compression, while the reverse is true in case of rear mounted implements. For measuring draft forces acting on three-point linkage during tillage operation, a three-point hitch device was design and developed [8]. But, for theoretical determination of draft during tillage operation ASAE (American Society of Agricultural Engineers) [9] draft Eq. (1) used widely.

By using ASAE (American Society of Agricultural Engineers) draft Eq. (1), the draft for implements was predicted,

$$D = F_j\,[A + BS + CS^2]\,WT \qquad (1)$$

Where, D = Draft (N); F = dimensionless soil texture adjustment parameter; j =1 for fine, 2 for medium and 3 for coarse textured soils; A, B and C = machine-specific parameters; S = field speed, (km/h); W = machine width, (m); T = tillage depth, (cm). Values of co-efficient are provided in ASAE D497.4.

While tractor moves forward, it pushes the implement through soil and forces acting on linkage during this are shown in Fig. 1.

By taking moment about upper hitch point and lower hitch point on implement, we get Eqs. (2)-(5).

$$F_h = D\left(1 + \frac{y}{h}\right) + \frac{(W_i + V)x}{h} \qquad (2)$$

$$F_{t\cos\theta_t} = \frac{Dy}{h} + \frac{(W_i + V)x}{h} \qquad (3)$$

$$F_V = W_i + V + F_t \sin\theta_t \qquad (4)$$

$$F_h = D + F_t \cos\theta_t \qquad (5)$$

Compressive and bending forces on lower link are determined by resolving horizontal force along the direction of motion and vertical force on each of lower link as shown in Fig. 2.

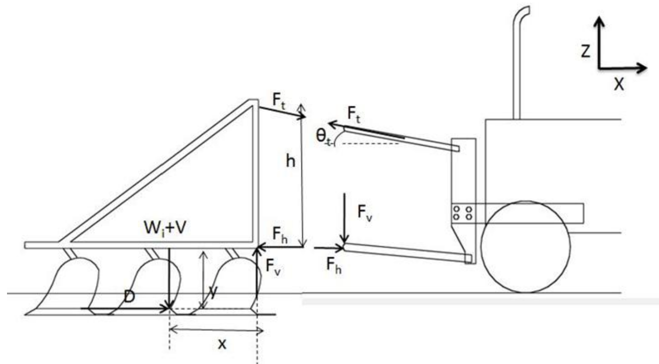

Fig. 1. Forces on front linkage

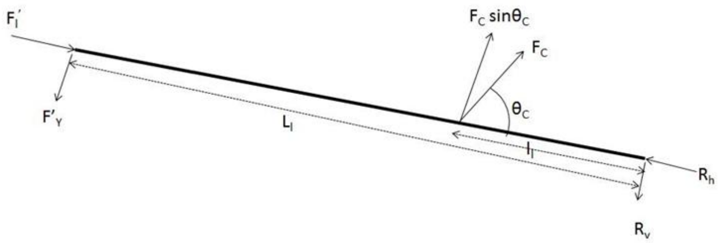

Fig. 2. Forces on front lower link

Eqs. (6) and (7) are used to express the compressive and bending forces in lower links and Eq. (8) is used to calculate the force in hydraulic cylinder rod.

$$F_l = \frac{F_h \cos\theta_h + F_V \sin\theta_h}{\cos\theta_V} \quad (6)$$

$$F_y = \frac{F_V \cos\theta_h - F_h \sin\theta_h}{\cos\theta_v} \quad (7)$$

$$F_c = \frac{F_y'}{sin\theta_c} \times \frac{L_l}{l_l} \quad (8)$$

2.1.2 Forces acting on front linkage while lifting a specified load

Fig. 3 shows forces acting on front links while lifting a specified load. W_{LF} be the lift capacity at 610 mm away from hitch point.

Eqs. (9) - (12) were used to calculate the forces on each linkage,

$$F_t = \frac{W_{LF}}{COS\theta_t} \quad (9)$$

$$F_V = W_{LF} + F_t \times sin\theta_t \quad (10)$$

$$F_h = F_t \times cos\theta_t \quad (11)$$

$$F_c = \frac{F_V}{l_l} \times \frac{L_l}{sin\theta_c} \quad (12)$$

After calculating the forces on linkage assuming both cases, maximum force was considered for designing front three-point linkage.

2.2 Design of Bent Lower Link

Forces acting on bent lower link are shown in Fig. 4.

Let M_{B1} and M_{B2} are the bending moment due to force F_y and F_l as given in Eqs. (13) and (14).

$$M_{B1} = F_y \times (L_l - l_l) \quad (13)$$

$$M_{B2} = F_l \times x \quad (14)$$

So, resultant bending moment is given by Eq. (15).

$$M_B = \sqrt{M_{B1}^2 + M_{B2}^2} \quad (15)$$

Maximum stress produced in lower link is expressed as in Eqs. (16) and (17).

$$\sigma_{max} = \sigma_{compressive} + \sigma_{bending} \quad (16)$$

$$\sigma_{max} = \frac{M_B \times 6}{bd^2} + \frac{F_c \times cos\theta_c}{bd} \quad (17)$$

Where, b and d are the thickness and width of lower link respectively.

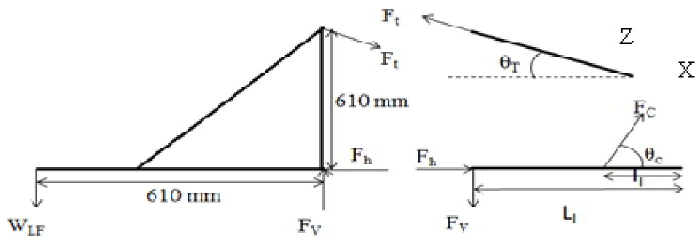

Fig. 3. Forces in front linkage while lifting a specified load

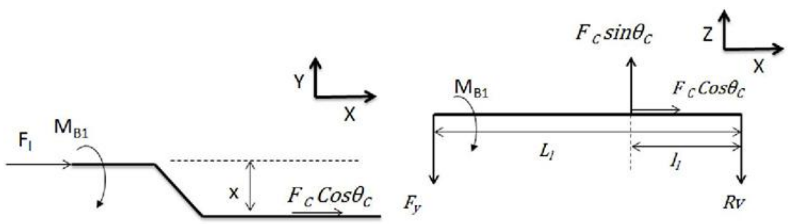

Fig. 4. Forces acting on bent lower link

2.3 Design of Top Link

Top link always be in hollow cylindrical shape to adjust the length of top link according to attached implement. Therefore, two dimensions, outer diameter and inner diameter of hollow cylinder is decided for top link design. If D and d, are the outer and inner diameters of adjusting tube of top link and σ_t is the allowable stress then, using Eq. (18), the value of D and d can be calculated.

$$\sigma_t = \frac{F_t}{\frac{\pi}{4}\times(D^2-d^2)} \quad (18)$$

2.4 Design of Actuator

If F_c is the force applied by each cylinder, then rod diameter (d) and bore diameter (D) of hydraulic cylinder is expressed as in Eqs. (19) and (20).

$$d = \sqrt{\frac{2\times F_c}{\pi\times\sigma}} \quad (19)$$

$$D = \sqrt{\frac{2\times F_c}{\pi\times P} + d^2} \quad (20)$$

Where, P is the hydraulic pressure of system.

2.5 Determination of Link Points and Length of Various Links

Two points are named in linkage namely link point and hitch point. The point at which linkage is attached with tractor body is called *link point* and the point at which implement is attach with linkage is called *hitch point*. Locations of link points are important because it decided the weight transfer and thus affect tractive performance of tractor. The distance, L, from the front end of the PTO to the center of the lower hitch points (with the lower link horizontal) should be between 550 mm to 625 mm [10]. Also, the top link angle should be 10°- 15° when the lower link is horizontal [11]. By keeping these in view, the links geometry at different positions is drawn to find link points and links length as shown in Figs. 5-7.

From Figs. 6-8, link points and length of links can be calculated by using Eqs. (21) – (23).

$$y_1 = TH - (x_1 + L) \times sin\theta \quad (21)$$

$$y_1 = GH + (x_1 + L) \times sin\varphi \quad (22)$$

$$T_l = \frac{(L-z)}{cos15°} \quad (23)$$

Links point of top link = (x_1+z) from LLP (front)

Where,

z = distance between top link point and end of front PTO
T_l = length of top link
GH = maximum distance of LHP from ground
TH = transport height

By solving Eqs. (21) and (22), the values of x_1 and y_1 will be obtained. So, using x_1 and y_1, the link points and length of all linkage can be calculated.

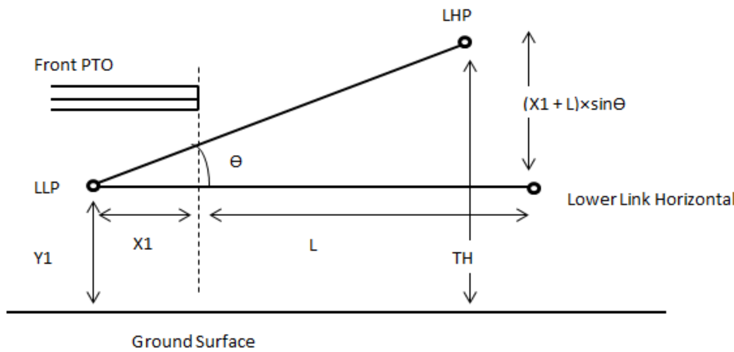

Fig. 5. Geometry of lower link at maximum height

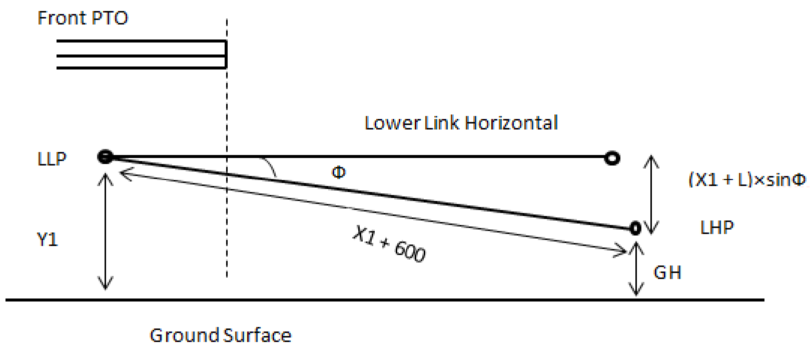

Fig. 6. Geometry of lower link at minimum height

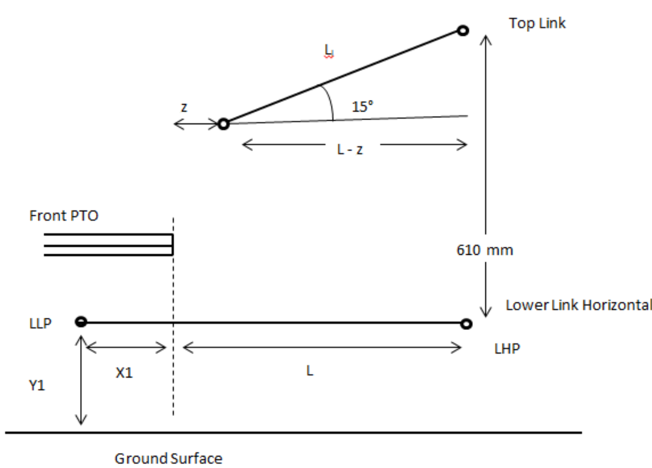

Fig. 7. Geometry of top link with lower link horizontal

3. RESULTS AND DISCUSSION

Fig. 8 shows the opening screen in which draft and suction force is calculated. From 'implement type' drop down button, selection of any implement like mould board plough, cultivator etc. must be made. After filling all other information required in ASAE draft equation, draft and vertical suction is calculated which will help to find the forces on links. Vertical suction considered as 0.25 times of draft [12].

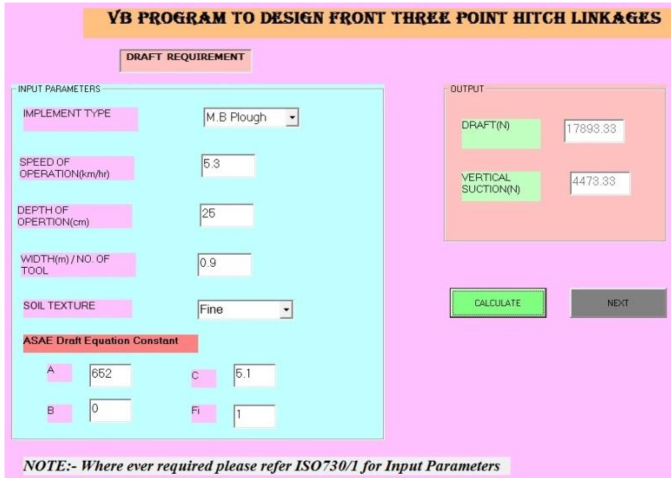

Fig. 8. Draft requirement by implement

Fig. 9 shows the 2nd screen in which link points and length of links are calculated. By clicking help button, information about required data will pop up, which will help to fill the required input parameters. Distance between end of front PTO and top link point should be entered according to tractor geometry. Increase in this dimension will increase length of all links. Output parameters of this screen includes length of top and lower link, links points, swap width etc.

Fig. 10 shows the 3rd screen in which force on linkage were calculated when front mounted hitch linkage lift the specified load. Minimum hydraulic lift capacity of tractor, having PTO power less than 65 kW, should be 310 N per kW of drawbar power of tractor measured at 610 mm away from hitch point [8]. Therefore, minimum required hydraulic lift capacity depends upon PTO power, tractor type and tractive condition. Output parameters will be minimum lift capacity, force on top link, horizontal and vertical force on lower link. Lift capacity considered for design is 1.5 times the minimum lift capacity required.

Fig. 11 shows the 4th screen in which forces on linkage due to implement is calculated. Top link force and horizontal as well as vertical forces on lower links are the output parameters. As we know the link lengths and links points using 2nd screen, so by drawing line diagram in Pro-E, Solidworks etc. software, angles can be measured which asked in 4th screen.

Fig. 12 shows the 5th screen which includes the design of hydraulic cylinder. Input parameters will be angle between cylinder rod and lower link, yield strength, working pressure and factor of safety. Output parameters will be stroke length requirement for cylinder, retract length, extended length, hitch points of cylinder, rod diameter, bore diameter and force on cylinder rod.

Fig. 9. Screen showing length of links and links point

Fig. 13 shows the 6th screen which shows the dimensions of top link and lower link. Input parameters will be yields strength of materials and factor of safety. Output parameters will be inner and outer diameter of top link, width and thickness of lower link etc.

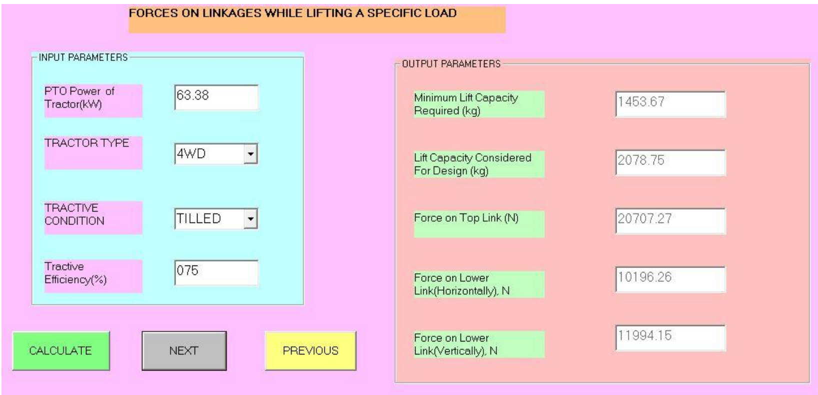

Fig. 10. Forces on linkage while lifting a specified load

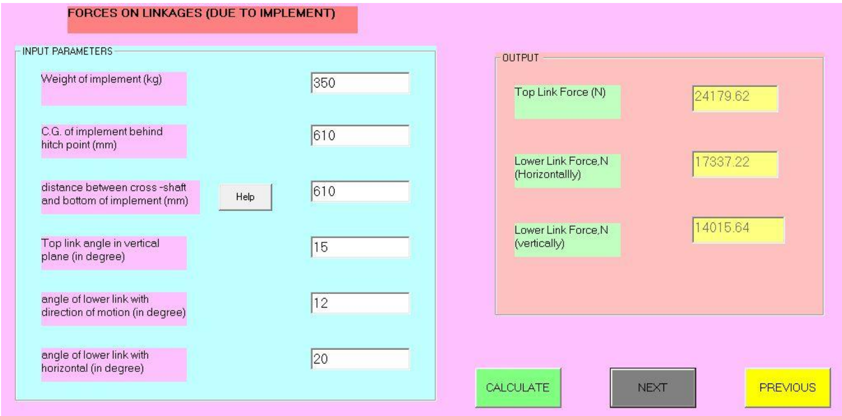

Fig. 11. Forces on linkage due to implement

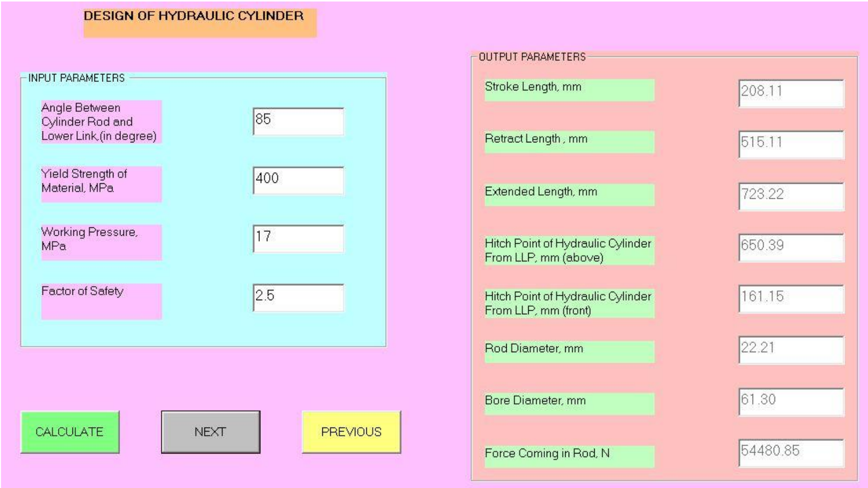

Fig. 12. Design of hydraulic cylinder

Fig. 13. Dimensions of top and lower links

By using presented software, output parameters front mounted three-point linkage were fabricated and mounted on tractor of 63.38 kW power. Fig. 14 shows the fabricated front mounted linkage.

Fig. 14. Fabricated front mounted linkage

4. CONCLUSIONS

Based on the results of present study, it can be concluded that developed visual basic program is useful:

1. To predict draft and vertical suction using ASAE draft equation to find the forces on linkage.
2. To find out the link points, length of links, different dimensions of links and hydraulic lift capacity of tractor.
3. To design the hydraulic cylinder for front mounted linkage which includes stroke length, retract length, rod diameter, bore diameter, link points of cylinder on tractor body, position of rod on lower link from link point.

Hence, developed visual basic program is simple, cheap and practically useful to design front mounted linkage.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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