Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Volume 13, Issue 01 January 2024

Design of A Two-wheel Tractor-Based Weeder Incorporated on An Existing Precision Planter Under Minimum Tillage

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Abstract— Weed infestation poses a significant threat to agricultural productivity, especially among smallholder farmers practicing conservation agriculture (CA) in Southern Africa. Current weed control methods employed by these farmers are deemed inefficient. To address this, a 14 HP diesel engine-powered, mechanical disc-type weeder mounted on a two-wheel tractor (2WT) was designed, fabricated, and field-tested under minimum tillage conditions. Integration of an existing precision planter into the weeder aimed to streamline planting and weeding operations for improved timeliness.

Prior to technical development, a structured interview with a selected group of farmers identified key design themes. Utilizing the quality function deployment (QFD) technique, qualitative interview data were translated into definitive technical specifications, considering general farmer requirements. Respondent inputs guided the determination of expected minimum work rates, weeding depth, working width, and the final weeder cost.

Performance assessment of the weeder, under various disc angle combinations, focused on field capacity and weeding quality, encompassing crop damage and weeding efficiency. The weeder, when combined with a precision planter, underwent parallel evaluation using the same performance indicators. This integrated system facilitated simultaneous weed clearing and planting, offering a considerable improvement over the traditional two-step process.

Comparative analysis revealed a remarkable enhancement in the timeliness of operations and field capacity by 93%, coupled with an 88% reduction in fuel consumption per hectare when using the weeder cum planter. This integration not only bolstered agricultural productivity during peak labour demand but also enabled early planting within a short window under rain-fed systems. Furthermore, the reduction in fuel consumption per hectare suggested potential environmental benefits through decreased carbon emissions.

Thus, the amalgamation of a 2WT weeder with a precision planter emerged as a promising strategy to elevate agricultural productivity while promoting sustainability and resilience among smallholder farmers in Southern Africa.

Keywords:—Weeding; mechanical weeder; minimum tillage; two-wheel tractor; precision planter

I.INTRODUCTION

The agricultural landscape in developing nations exhibits a dualistic framework, distinguishing a low-input/ low-productivity sector and a high-input/high-productivity sector among smallholder farmers. One of the significant challenges for smallholders lies in the reliance of farm power, predominantly on manual labour and animal draught power. This dependence leads to extensive labor requirements, toil, and imprecise crop establishment, thereby contributing to diminished productivity. Notably, mechanization strides have significantly advanced in large-scale commercial agriculture, primarily employing four-wheel tractors (4WTs) as the primary source of farm power [1]. The adoption of 2WTs presents a potential transition for smallholder farmers, enabling them to shift from manual labour and animal-powered methods toward mechanised solutions. This evolution requires tailored development of 2WT-based implements, crucial for enhancing small-scale farming productivity. Concerns surrounding food security escalate due to diminished productivity and escalating soil depletion, stemming from inadequate soil nutrient and health management.

Conservation agriculture (CA) emerges as a beacon of hope, advocating for its multifaceted advantages: mitigating soil erosion, increasing soil moisture retention, improving soil structure, fostering long-term soil fertility, gradual augmentation of soil carbon, and comparable or augmented yields vis-à-vis conventional tillage systems [2]. CA is a resource and environmental conscious agricultural practice that ensures sustainable crop production and has been promoted for over three decades [3]. On the contrary, intensive tillage negatively impacts the ecosystem, as it causes environmental degradation [4].

Conflicting findings on the impact of conventional tillage on weed management contribute to variable results of how weed pressure is affected by CA practices. Tillage can both promote and impede weed seed banks: it may surface dormant seeds for germination while burying others deeper [5; 6]. Weeds adapted to germinate within the top 5cm of soil dominate in minimum tillage systems [7; 8; 9; 10]. Unlike conventional tillage, minimum tillage restricts the transfer of weed seeds to the upper 5 cm of soil [11], where seeds face greater risks of desiccation and predation [12]. There are several weed control strategies which include: mechanical, thermal, chemical and cultural. For each strategy, benefits and challenges are assessed and contextualized with the circumstances of smallholder farmers in southern Africa. Thermal weeding include weed flaming, soil solarisation and weed steaming are not commonly used in southern Africa but present an unexplored option for smallholder farmers [2]. Therefore, it is difficult to promote its use to smallholder farming systems in the region. Chemical weed control methods can reduce labour demands by up to 90% as a result of herbicide use [13]. However, negative environmental impacts and herbicide-resistant weed species [14], highlight the essence of responsible use of chemical means to sustainably control weeds. Cultural weed control methods uses cropping systems to reduce weed pressure, which include enhanced crop competition and fertilisation calendars; crop residue retention; intercropping systems and crop rotations. In addition, cultural control method improves the soil, by addition of organic matter and biologically fixed nitrogen [14]. Mechanical and manual weed controls are the most common weed management strategies for smallholder farmers in sub-Saharan Africa [13]. Use of manual hand hoes is associated with drudgery and low work rates, resulting in delayed weeding. The use of animal-drawn cultivators can be an effective form of weed management [15], however, Erenstein [16] reported its poor mulch handling in high plant residue fields as the main drawback in CA systems.

Farmers must have accessible, effective, and timely weed management strategies to combat weed pressure and prevent weeds from seeding in a sustainable and cost-effective way. Weed control is currently identified as the main drawback in southern Africa to adoption of reduced tillage which is key to CA practices [17]. Without effective weed management and control strategies, successful adoption of CA in smallholder farming systems in semi-arid southern Africa is rather unlikely [2]. Most smallholder farmers rely on manual labour using hoes which is drudgerous and labour intensive, delaying weed removal resulting in potential yield drop. Low yields affect food security and income for farmers. A few smallholder farmers uses herbicides which have drawbacks of toxicity, resistance and high production cost. Recent preoccupation with the toxicity of glyphosate [18; 19; 20], the main herbicide associated with reduced tillage [21], requires new solutions to reduce its use and appearance of resistances [22]. The use of mechanical weeding can alleviate the problems of environmental pollution caused by chemical weeding and the high labour intensity of manual weeding [23]. If weed control management is not done efficiently in a cost-effective way, expected yields and profits may not be realised. This study proposed to develop a mechanical weeder as a weed control strategy under minimum tillage for the smallholder farmers powered by a 14 HP two-wheel tractor guided by the following objectives: (1) To design a 2-WT based weeding implement focused on minimum tillage for improved CA requirements, (2) To incorporate a precision planter to the weeding implement to allow for improved timeliness of operations, (3) To fabricate the weeding implement with an adapter to incorporate a precision planter and (4) To determine the performance of the weeding implement incorporated with a precision planter through both laboratory and field test.

II. METHODOLOGY

In this study both qualitative and quantitative methods were used for data collection. Under qualitative, a structured questionnaire was used to interview smallholder farmers on their current farming practices on weed control management, tillage practice and farm power. The results obtained from the interview was used to create thematic areas for the weeder development. The obtained themes were used as the basis for weeder design and fabrication through a quality function deployment (QFD) concept.

A. *Study Site*

The study was conducted in two districts of Southern province of Zambia namely Monze (Namakube and Kazungula camp) and Mazabuka (Dumba and Pimpa camp), located at -16°16'59.99" S 27° 28' 59.99`` E and -15° 51 '21.64`` S 27° 44' 52.80`` E, respectively. The two districts are in the Natural Region IIA receiving an average annual rainfall of 700mm, ranging between 400mm to 1100mm. In these regions, the growing season usually begins in November and lasts until April or May. In this study, we report the results of trials conducted during the 2022/2023 growing season. The soil texture is predominantly sandy loam. Topography is generally flat, with slopes less than 2%.

B. *Study population and sampling*

A structured interview was conducted with farmers, who are referred to as service providers (SPs) that own 2WTs and their attachments. The service providers offer mechanisation services to farmers in their communities which includes ploughing, planting, transport, shelling and threshing. The interview was conducted to gather information on their crop production methods, including farm power, tillage practices and weed management. A total of seven 2WT service providers were interviewed, in Mazabuka and Monze districts.

C. *Quality function deployment (QFD)*

Quality function deployment (QFD) is a concept that translate subjective customer requirements to appropriate technical requirements [24] which was conceived in Japan in the late 1960's [25]. A QFD process was used in this study to convert the voice of the farmer **(Fig. 1a)** to more specific technical requirements. Farmer requirements were obtained from the farmers and translated into appropriate technical requirements.

D. *Product development process*

Product development process is the sequence of activities that is employed to conceive, design and commercialize a product [26]. This process followed after QFD was completed as presented in **Fig. 1b**. Product development process is broken down into planning, product design specifications, concept development, system level design, detail design, prototyping, testing and refinement. Planning preceded project approval and commencement of the product development process. Planning began with opportunity identification, assessment of technology developments and farmer needs. The output of the planning phase is the project mission statement, which specifies the target users of the product, aim, key assumptions and constraints. Product design specification is comprised of design specifications (i.e. for fabrication) and product specification (i.e. after fabrication and testing). It involves translation of subjective customer or client needs into precise targets [26]. Customer needs are usually subjective, which leads to the need of establishing specifications to define clear, precise and measurable details of the product. In this study, a structured interview was used to qualitatively obtain farmer views on weed control management among smallholder farmers. In the concept development phase, having the farmer needs identified, alternative product concepts (**Fig. 2**) were generated and evaluated, and one concept was selected, developed and tested. A weeding implement can be developed using various mechanical working principles. A concept in this context is defined as a description of the form, features and function of the weeding implement and is accompanied by specifications, an analysis of competitive alternative products and an economic justification of the project. A selection criterion was developed based on key indicators such as performance, ergonomics of use, power requirements, durability, affordability (procurement and maintenance cost), among others. A selection matrix was used to select the best compromise among competing alternatives. A proposed innovation was appraised from an economic and social viewpoint. If the technology does not fulfil a need felt by the farmers, or if it cannot be justified economically, further evaluation may be sterile. If the technology is economically justified, then a technical evaluation will give information on the performance and ease of operation. Among the three alternatives shown in **Fig. 2**, disc type was selected for economic reasons. The 2WT is usually sold as a package with a disc plough (**Fig. 2b**). The same discs on the plough are now made versatile for use as a disc plough and weeder under CA through second generation engineering. The system-level design phase includes the description of the product architecture, breakdown of the product into subsystems and preliminary design of key components. The output of this phase include (1) geometric layout, (2) functional specification of each of the subsystems and (3) preliminary process flow diagram for the final assembly process. The two subsystems in this study are: weeding subsystem (designed) and planting subsystem (incorporated).

III. DETAIL DESIGN

Detail design stage transitions from the voice of the farmer into the actual development of the product using QFD, following the farmer interviews. It is also looking into the consideration of the power unit and implement design, prototyping and testing. The interview yielded a number of farmer expectations and experiences in weed management. A summary of farmers' key expectations is presented in **Table I** for a two-wheel tractor-based weeder and these were translated into more definitive technical specifications. The technical specifications were then used as entry design specifications for the implement development.

Table I. Quality function deployment (QFD)

Farmer Requirements	**Target Technical Specifications**
Scrapping the top layer of the soil for minimum tillage.	The implement weeding depth is less or equal to 5 cm.
Improved labour productivity.	Labour requirement of at least 2-person-hours per hectare.
Compatible with a two-wheel tractor.	Implement power requirement of not more than 14 horse power.
Ability to weed in-between rows of bean and maize crop.	Working width of 30 cm to 45 cm in a single pass.
Affordable (cheapest possible option).	Value engineering the disc plough (which they already own) into a weeder.

A. *Power Unit*

The power unit under consideration in this study is a single axle tractor known as a two wheel tractor (2WT) or power tiller or walking tractor. 2WTs provide drawbar power through a single point connection (no option for a three-point hitch). Most used 2WTs are diesel powered ranging from 7 to 22 horsepower (HP). The implement design under this study is based on a 14 HP diesel engine tractor, which is the most popular in the region. This is reduced by a factor of 1.2 (assumption) to cater for inefficiencies of the engine and transmission. The total effective tractor power is therefore reduced to 11.67 HP (8.75 kW). **Equation (1)** below shows the relationship between power and draft at a given speed of operation.

$$Power = Draft \times Speed \qquad (1)$$

Assuming a maximum operating speed of 2 m/s, Draft = 8,694/2= 4,347 N. In order to get the maximum implement available pull, frictional resistance ($F_{required}$) must be deducted from the Draft.

$F_{required} = \mu N$,

Where, μ is the coefficient of friction and N is the normal force acting perpendicular to the frictional force. Frictional resistance is denoted as $F_{required}$. Coefficient of friction (μ) is the measure of the amount of interaction between two surfaces related to the friction between the two surfaces as: (1) they slide over one another; (2) one surface rolls over another and (3) the two surfaces in contact (but not moving) are acted upon by forces in opposite directions.

$$\text{Also, } \mu = \frac{F_{required}}{mg},\ 0 \leq \mu \leq 1 \qquad (2)$$

Where, m=mass; g=acceleration due to gravity; $F_{required}$=force required to start move the object at a constant speed. Using a coefficient of friction (μ) of 0.3 for sandy loam (according to the NAVFAC standards [27]), mass of the 2WT as 400kg and g=10;

$F_{required}=\mu N=\mu mg=0.3*400*10=1{,}200N$. The maximum implement available pull = Draft – Frictional force ($F_{required}$) = 4,347 – 1,200 = 3,147 N.

B. *Implement*

The detail design phase include the materials, tolerances of critical parts, complete specification of the geometry and the identification of the standard parts on the market. SOLIDWORKS was used to detail design the weeder alone and weeder incorporated with a precision planter (**Fig. 3**). Material selection was done in SOLIDWORKS and simulated for stress analysis. Material selection, production cost and robust performance were considered throughout the weeder development process. Purchased components (already existing) were:

a) Two discs (from a 2-disc plough which comes with the 2WT) of diameter 40 cm shown in **Fig. 2b**.

b) One single row precision planter (**Fig. 2d)** powered by a 2WT, with a finger-type seed metering and fluted-wheel fertiliser cog metering.

Determining the available draft pull:

Working resistance (R) of the scrapping discs is given in equation (3) below.

$$R = a \times b \times n \times k \text{ [28]} \qquad (3)$$

Where, R = implement working resistance (N); a = depth of cut, in m; b is the width of cut of a disc (m); n = number of scrapping discs; k = soil resistance (N/m^2). In this case, the maximum depth of cut (a) is 5cm (for minimum soil disturbance), a maximum disc width of cut (b) of 15cm and the number of discs (n) is two. The maximum soil resistance (k) of 100kPa is assumed according to Varga *et al.* [28]. Based on these given parameters, the design draft requirement, R for the implement becomes 1,500 N. Therefore, the implement working resistance is 1,500 N. The power unit has enough draft to power the implement given the calculated maximum implement available pull of 3,147 N versus the implement working resistance of 1,500 N.

C. Design in SOLIDWORKS

SOLIDWORKS 2017 software was used to develop computer-aided design (CAD) drawings and finite element method (FEM) for the strength analysis of the implement (**Fig. 3**). The weeder in **Fig. 3a** simply scraps the weeds outward creating a weed-free planting strip (**Fig. 4i**). An adapter was designed to incorporate a precision planter onto the weeder frame. Components of a planter (given in **Fig. 2d**) are incorporated to a weeder in **Fig. 3a** into a weeder cum planter shown in **Fig. 3b**. Components borrowed from the precision planter include hoppers (for both fertiliser and seed), tine (for fertiliser furrow opening), double disc (for seed furrow opening), seed and fertiliser metering devices. After crop emergence, the discs are set facing inwards (**Fig. 3c**), it removes weeds by scrapping the soil towards the crop.

D. Strength analysis of the weeder

The weeder components were subjected under combined tension, shear, bending and torsion loading in SOLIDWORKS simulation. The following seven steps were taken in the process; Step 1: Enabling SOLIDWORKS Simulation by checking the SOLIDWORKS simulation boxes in Add-ins; Step 2: geometry creation of the part to be analysed in FEM. The study was created for each part for static equilibrium of the part under study; Step 3: Material property assignment: This is done to assign material to the component under simulation; Step 4: boundary condition specification to define the restraints and loads (external forces); Step 5: mesh generation to discretise the part into elements; Step 6: running the simulation to obtain the results of the analysis. The detailed simulation report are provided in Appendices.

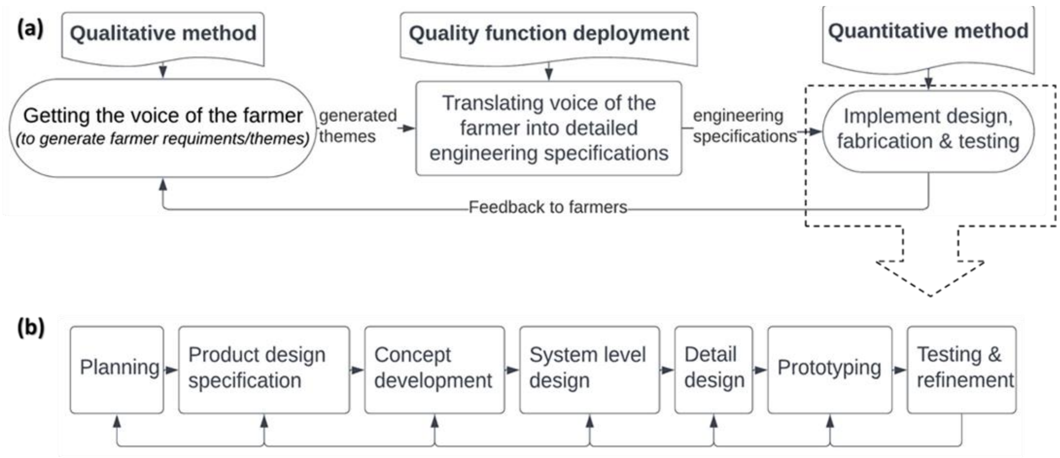

Fig. 1: Research Design Flow chart: Quality Function Deployment (a); Product development process (b).

Fig. 2: Option of soil engaging components: Animal draft cultivator (a) [1]; Disc plough (b); Rotovator (c); Precision planter (d).

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Volume 13, Issue 01 January 2024

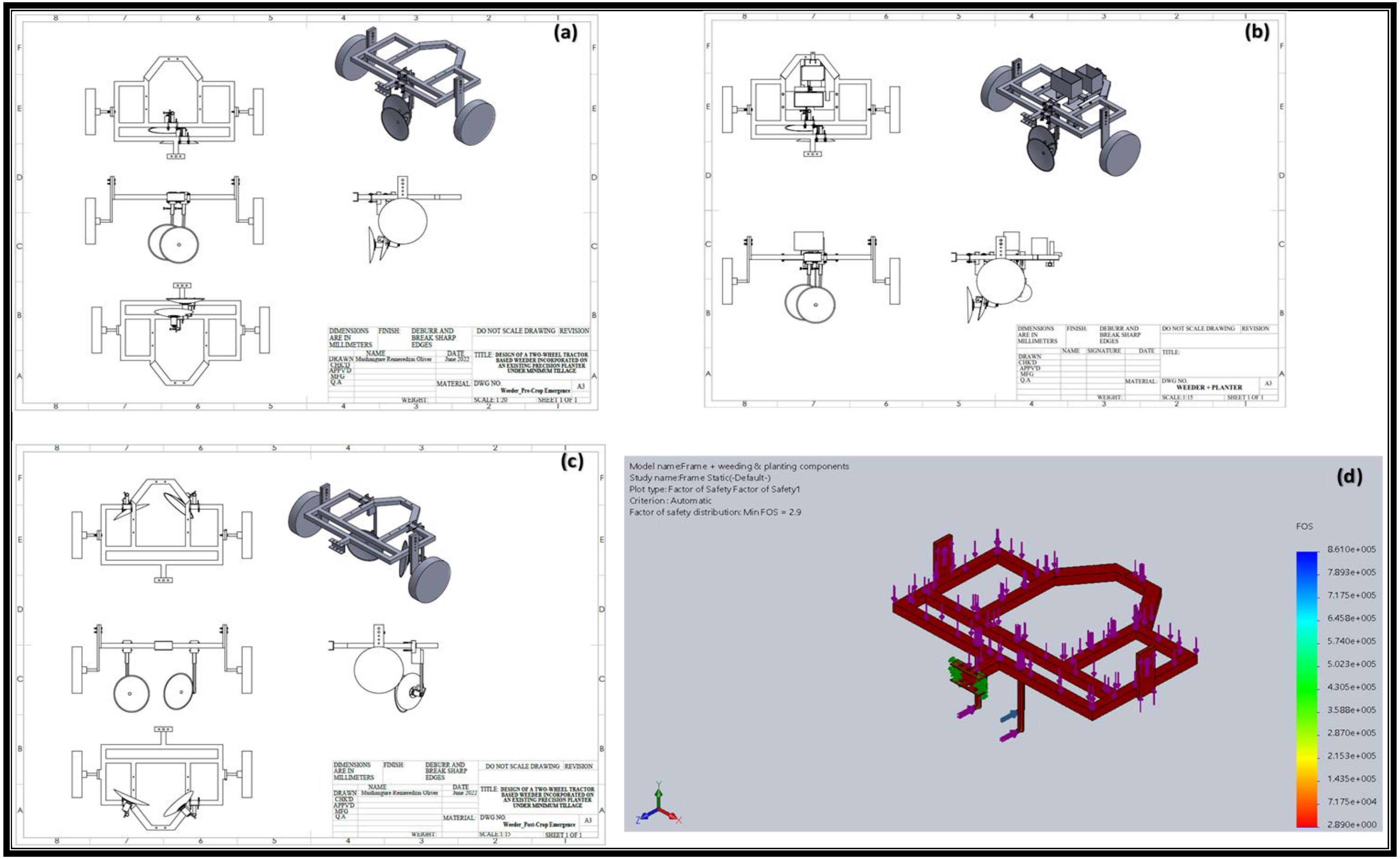

Fig. 3: SOLIDWORKS assembly drawing for (a) weeder before crop emergence; (b) weeder incorporated with a precision planter; (c) weeder after crop emergence and (d) simulation for minimum factor of safety when subjected to all forces.

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Volume 13, Issue 01 January 2024

E. Prototyping

Prototyping was done based on the results from the detail design phase. The developed implement does three main functions, namely, weeding before planting; simultaneous weeding and planting; and weeding after crop emergence. **Fig. 4** shows the stepwise assembling of fabricated components. **Fig. 4a** shows the disc arrangement for scrapping of weeds outward leaving a clean weed-free surface before planting. The tilt and disc angles are adjustable to suite various angle combinations for different weeding requirements as shown **Fig. 4** (**g** and **h**, respectively). Tests were conducted on various tilt and disc angle combination for the best performance of the weeder. **Fig. 4c** shows the mounting of an adapter to the weeder frame for incorporation of planter components so as to combine weed removal and planting into one when introducing a second crop in the case of relay intercropping. Fig. 4d shows mounting of planter components, **Fig. 4e** showing a complete weeder incorporated with a planter. **Fig. 4f** shows the weeder with discs set facing inwards for weeding after crop emergence.

F. Testing of 2WT weeder

1) Laboratory test

Laboratory test was done to determine whether the implement settings are adjustable to meet the desired field test such as angles (tilt and disc angle), cutting depth, width of cut. During the laboratory tests, minimum and maximum attainable setting measurements (for angles, depth and width) were determined. The depth and width were measured using tape a measure, angles were determined by Pythagoras theorem.

2) Field test

The weeder field tests were conducted after laboratory test to observe the performance of the implement if it satisfies the farmer needs. The weeding implement prototype was tested against the design specifications which are: (1) field capacity (hr/Ha), (2) quality of weeding and (3) fuel consumption. The experimental design was comprised of two treatments, which are: T1 = Weeding clearing and planting in two operations, and T2 = Combined weeding clearing and planting in one operation.

The designed weeder has two weeding functions which are (1) before planting and (2) after crop has emerged. These two operations are achieved by setting the weeder differently. Before planting, the weeding discs are set to face outwards The discs are set to superficially scrap the surface to a weeding depth meeting conservation tillage practices of less or equal to 5cm. The scrapping operation moves the soil, weeds and mulch outwards leaving a scrapped surface free of weeds ready for planting. The scrapping is only done where the crop is to be planted, with a scrapping width of not more 45 cm. Weeding operation after crop emergence is achieved by reversing the two discs to face inwards, unlike before planting. With this arrangement, the two discs will be scrapping the soil, weeds and mulch inwards towards the crop (light ridging).

a) Quality of weeding

Quality of weeding was quantified in terms of weeding efficiency and plant damage from the experimental plots. Weeding efficiency is the ratio of the number of weeds removed by the weeding implement to the number of weeds present per unit area expressed as a percentage. The samplings were done by quadrant method, by randomly selecting spots of 1 square meter [29]. Weed control efficiency was determined at various disc angles at a set depth of cut using **equation 4**.

$$\eta\text{weeding } (\%) = \frac{W_1 - W_2}{W_1} \times 100 \qquad (4)$$

Where, W_1 = Number of weeds counted per unit area before weeding operation; W_2 = Number of weeds counted per unit area after weeding operation

Plant Damage represented as PD in **equation (5)** is the ratio of the number of plants damaged after operation in a row to the number of plants present in that row before operation expressed as a percentage.

$$\text{PD } (\%) - \left(\frac{q}{p}\right) \times 100 \qquad (5)$$

Where, p = Number of plants in a 10 m row length of field before weeding; q = Number of plants in a 10 m row length of field after weeding.

b) Fuel consumption

Displacement method was used to measure fuel consumption by replacing the fuel tank with a measuring cylinder. The measuring cylinder is filled to a known measured value (L_1) before running the trial and read off the new value (L_2) after trial run. The fuel displaced (L_1-L_2) is recorded as the fuel consumed for the test duration and weeded area in litres per hour and litres per hectare, respectively.

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Volume 13, Issue 01 January 2024

Fig. 4: Assembly process. (a) discs set facing outward for scrapping weeds before planting; (b) weeder set for weed crapping; (c) mounting of an adapter to incorporate planter components; (d) incorporation of planting components i.e. hoppers, seed metering, tines and discs on the adapter plate; (e) complete weeder incorporated with a planter; (f) discs set facing inwards for weeding after crop emergence; (g) setting of tilt angle; (h) disc angle; (i) weed-free planting strip.

IV. RESULTS

This section reports on qualitative data generated from farmer interviews and quantitative data collected in laboratory and field experiments, and analysed in IBM SPSS 27 statistical software.

A. Qualitative results and Data analysis

A qualitative analysis was conducted to understand how weeding was being done and getting farmers' views and expectations. The interview was conducted to 2WT owners under the SIFAZ project who offer small scale mechanisation services to other farmers using a service provision model. Service provision model is a model whereby one offers a service for a fee, where not every farmer should own a piece of equipment in order to maximise capacity utilisation of equipment. The SIFAZ project has eighteen service providers (SPs) across Zambia, only seven (6 male and 1 female) were sampled from Monze and Mazabuka districts of Southern province. Certain details of the interview are shown in **Table II**.

TABLE II. INTERVIEW RESPONSES

Interview Question	**Response**
Farm power reliance	The 2WT SPs also rely on both ADP and 4WT
Farming practice	85.71% practice CA and 42.86% practice CP
Weeding challenge	All the respondents cited weeding as the main challenging operation for different reasons including limited weeding tools, labour unavailability during peak labour demand.
Weeding methods	All the respondents are still using hand hoe manual weeding methods and only 14% also use herbicides.
Type of labour	About 86% of interviewees use family labour and 43% hire weeding labour.
Appropriateness of 2WT	The participants are satisfied with the appropriateness of the 2WT as an affordable farm power source for the small scale farmers.
Any 2WT weeding implement?	They have a wide range of 2WT implements, except a 2WT powered weeder, which is not currently on the market
Suggested weeding work rate of a 2WT weeder	Respondents also suggested the field capacity for the 2WT weeder to fall between one to 2 days per hectare to replace hand hoe weeding with work rates of about 7 person-days per hectare

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Volume 13, Issue 01 January 2024

B. Two-wheel Tractor Weeder Test Results

1) Implement Laboratory Test

Laboratory test was done to determine the possible implement settings for trial in the field experiments. The laboratory exercise established the minimum and maximum field test measurements and are provided in **Table III.**

Table III: Laboratory measurements

Variable	Magnitude
Width of cut	15 cm to 45 cm
Disc angle	0 cm to 90 cm
Tilt angle	0 cm to 90 cm

2) Angle optimisation

An experiment was conducted to determine the optimum tilt and disc angle with respect to field capacity, fuel consumption, weeding efficiency and plant damage. The data failed to meet the ANOVA assumption, a nonparametric test for two or more independent samples was conducted so as not to violate the outlier, normality and homogeneity assumptions.

a) Nonparametric Independent-Samples Kruskal-Wallis Tests

The Nonparametric Independent-Samples Kruskal-Wallis Test was conducted at 95% confidence interval to determine the effect of tilt and disc angles on the parameters presented in **Table IV**.

The **Fig. 5**, shows plant damage in relation to tilt and disc angle. According to the hypothesis (**Table IV)**, there is no significant difference of plant damage across tilt and disc angle. Tilt and disc angle have a significant effect on the weeding efficiency with the highest efficiency on tilt-30º and disc-31º (**Fig. 5b**). Fuel consumption is significantly affected by tilt and disc angle with tilt-30º and disc-31º, being the most conservative with lowest fuel consumption (**Fig. 5c**). Tilt and disc angle also affect the field capacity significantly with tilt-30º and disc-31º, achieving the best work rates (**Fig. 5d**). The tilt-30 and disc-31 was found to be the optimum combination of angles for the following reasons.

TABLE IV: HYPOTHESIS TEST SUMMARY

#	Null Hypothesis	Test	Sig.[a,b]	Decision
1	The distribution of Plant Damage (%) is the same across categories of Tilt and Disc angle.	Independent-Samples Kruskal-Wallis Test	.374	Retain the null hypothesis.
2	The distribution of Weeding Efficiency (%) is the same across categories of Tilt and Disc angle.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
3	The distribution of Fuel Consumption (L/Ha) is the same across categories of Tilt and Disc angle.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
4	The distribution of Field Capacity (Hrs/Ha) is the same across categories of Tilt and Disc angle.	Independent-Samples Kruskal-Wallis Test	.001	Reject the null hypothesis.
5		Independent-Samples Kruskal-Wallis Test	.002	Reject the null hypothesis.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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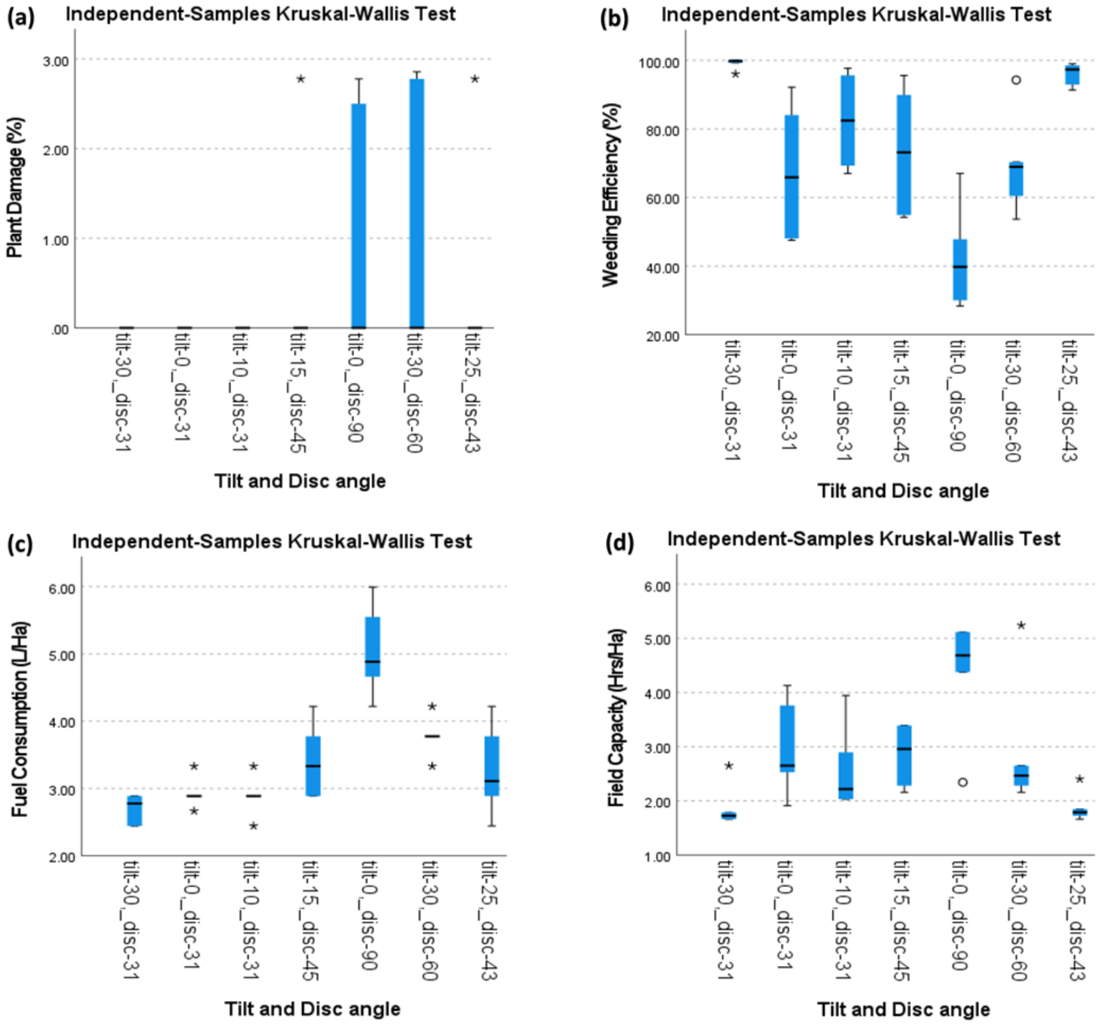

Fig. 5: Two wheel tractor weeder performance. (a) Plant Damage across Tilt and Disc angle; (b) Weeding Efficiency across Tilt and Disc angle; (c) Fuel Consumption across Tilt and Disc angle; (d) Field Capacity across Tilt and Disc angle.

V. DISCUSSION

Weed infestation is one of the top most challenging operation in agriculture with about 62% and 43% of farmers in Zambia and Zimbabwe, respectively, facing labour famine during weeding [30]. In manual CA production systems, the demand for labour for the preparation and weeding of the land is much higher than in conventional production systems [31]. There is a lack of consideration for labour issues emanating from the perception that labour in smallholder systems of Southern Africa is abundant and thus non-limiting [32]. This notion is also fuelled by macroeconomic analyses such as the land : labour ratio [33], which are based on national data that may be too aggregated to reveal farm-level dynamics [34]. Several lines of evidence point to the fact that labour and farm power are increasingly becoming the main limiting factors to the productivity of smallholder systems in Southern Africa [35] and probably a significant constraint to the adoption of sustainable intensification technologies (which are labourious). Most young and middle-aged farmers are migrating to towns resulting in labour famine in rural areas [36]. The most common hand hoe weeding used among smallholders has a mean labour of 13.83 man-days/hectare (110.64 person. Hours/hectare) per weeding operation [37].

Intercropping is a vital practice in the cropping system to sustainably improve land utilisation and increase productivity. However, intercropping systems have many huddles, including labour deficiency [36]. Precision management and close attention to weed control must be solved for cereal and legume intercropping producers [38]. Utilization of agricultural machines that are appropriate for this model would greatly increase labour productivity [36; 39]. There is a need to develop appropriate machinery and tools for mechanical weed control beyond herbicides, cultivators, and hand hoeing to address labour bottlenecks and assess the most cost-effective method to control weeds [30].

VI. CONCLUSION AND RECOMMENDATIONS

A. Conclusions

This study aimed to develop a 2WT-based mechanical weeding implement under minimum tillage agriculture incorporated with a precision planter. The main objective was broken down into more achievable specific objectives. The 2WT weeding implement was designed to meet the reduced tillage requirements of weeds being scraped shallowly to a weeding depth of less than 5 cm. An adapter was developed to attach a precision planter onto the weeder to synchronise weeding and planting operations at the same in a single pass. The weeder cum planter was fabricated and the performance of 2WT weeder was determined through laboratory and field experiments. Combined 2WT weeding and planting operation that was done in a single pass compared to weeding and planting individually in two passes showed an improvement in field capacity and fuel consumption by 93% and 88%, respectively.

B. *Recommendations*

The development of a 2WT weeder from existing plough discs provided with tractors presents promising results. Manufacturers and suppliers of 2WT-based equipment are encouraged to explore this innovation. The simplicity of this development, derived from the 2WT disc plough and precision planter already on the market, allows for versatility as a plough, weeder, and cum planter with minimal additional accessories. Collaboration between the Ministry of Agriculture Extension Services and the manufacturing industry is crucial to generating demand and awareness for reduced tillage innovations. These innovations not only reduce production costs but also enhance operational efficiency. Small-scale farmers, in particular, require more weeding options. Therefore, there is a pressing need to create awareness of available weeding alternatives suitable for adoption by small-scale farmers and service providers. Given that most small-scale equipment, including precision planters and ploughs, are imported, promoting local manufacturing with considerations for appropriate material selection is essential. Local manufacturing not only supports the economy, but also improves access to spare parts, contributing to the sustainability of agricultural practices.

VII. ACKNOWLEDGEMENTS

We express our gratitude to the researchers affiliated with the University of Zambia and the extension officers from the Ministry of Agriculture in Zambia for their unwavering commitment in undertaking this participatory action research alongside us in Zambia. Lastly, we appreciate the farmers we collaborated with for generously providing access to their land and sharing their valuable research insights.

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ISSN: 2278-0181
Volume 13, Issue 01 January 2024

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