Design of a rice transplanter for Zimbabwean farmers

Tawanda Mushiri
Department of Mechanical Engineering
University of Johannesburg
P.O Box APK 524
Johannesburg
South Africa
tawandanda.mushiri@gmail.com, tawandamushiri123@hotmail.com

Brighton Gutsa
Department of Mechanical Engineering
University of Zimbabwe
P.O Box MP167
Mt Pleasant
Harare
Zimbabwe
brightontapiwagts@live.co.uk

Charles Mbohwa
Faculty of Engineering and the Built Environment
University of Johannesburg
P.O Box APK 524
Johannesburg
South Africa
cmbohwa@uj.ac.za

Abstract

Rice is a crop of growing importance in Zimbabwe but with a production of only 700 metric tonnes. This is because in wetlands it is largely grown by broadcasting of seeds and seedlings; and manual transplanting of seedlings. In practicing the said method however, farmers are exposed to musculosketal disorders as well as back problems due to the repetitive bending as well as the awkward posture needed in performing the task. Though manual transplanting gives uniform crop stand it is quite expensive and requires lot of labour besides involving lot of drudgery. Singh et al., 1985 reported that transplanting takes about 250-300 man hours/ha which is roughly 25 per cent of the total labour requirement of the crop. The rice production in Zimbabwe has also been very low because the common rice types were affected by the local climatic conditions however in 2014 businessman and farmer struck a deal with renowned Chinese agricultural scientist for National Hybrid Rice Research and Development Centre in Changsha in Hunan Province to start a pilot hybrid rice production exercise that could easily transform Zimbabwe into a major rice growing hub in the SADC region using varieties suitable to local conditions. This paper aims to design an ergonomic rice transplanter suited for the Zimbabwean climate and terrain. The mechanical transplanting of rice has been considered the most promising option, as it saves labour, ensures timely transplanting and attains optimum plant density that contributes to high productivity. Mechanization of rice sector will lead to higher productivity with releasing of work force to other sectors.

Keywords
Rice transplanter, musculosketal disorders, Design, mechanization.

1. Introduction

Zimbabwe has the capacity to produce rice owing to its vast water bodies and good soils. But agriculture consultant Mr Tapuwa Mashangwa says the country is importing over 90 percent of rice from Asia to meet its yearly consumption. To transplant is to replant (a plant) in another place (Oxford Dictionary, 2001). A transplanter is an agricultural machine used for transplanting seedlings to the field. Transplanted rice had 10 to 20% higher yield than broadcasted rice (Garg et al., 1997).

2. Literature review

Manual transplanting of rice seedling is causing musculoskeletal disorders, back problems, drudgery and it proving costly because of the labour required. This further leads to reduced profits to rice farmers in Zimbabwe. Also broadcasting seedlings or rice seed reduces the yield by 2 to 3 times.

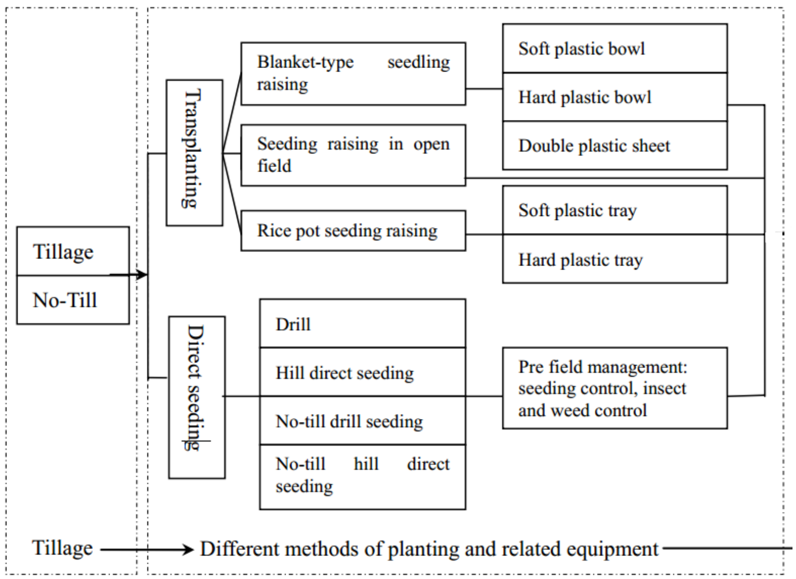

Figure 1: Rice Production Processes

Transplanted rice had 10 to 20 % higher yield than broadcasted rice (Garg et al., 1997). Transplanting of paddy seedlings can be categorized into three groups as follows:

1. By hand (manual)

2. Manually operated machines (work by man power)

3. Mechanically operated machines (work by engine power)

This method is good for small fields and to fill patches.

Figure 2: Rice Transplanting By Hand.

3. Methodology

The design solution is found by first reviewing the relevant literature on existing transplanters and doing a case study on Zimbabwean rice farming to determine important parameters like soil type and hardness to be considered in the design. Natural Farming Region 1 of Zimbabwe (areas in dark green below) is where rice and other cereal crops like wheat and coffee are grown. It receives rainfall above 1000mm and consists of variations of clay soil from deep red clay soils formed from mafic rocks to greyish brown and yellowish red clays formed on granitic rocks all of which are very fertile. These area include Chimanimani, Muzarabani, Nyanga and Chipinge covering an area of 613 000 hectares which is 1.56% of the total land area.

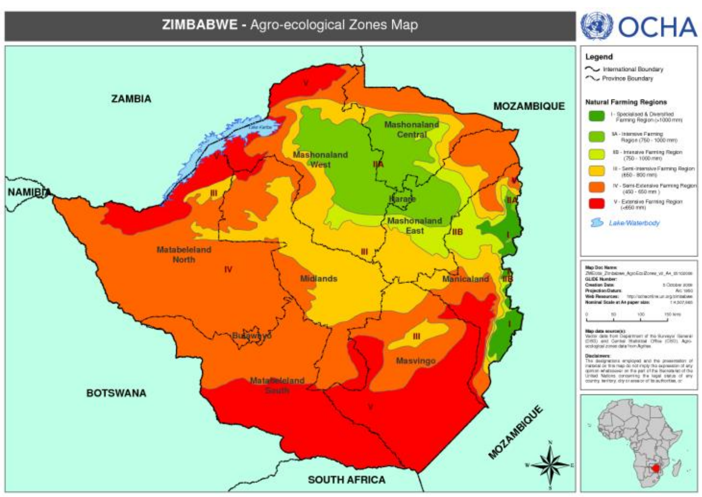

Figure 3: Natural regions of Zimbabwe

4. Results and discussion

4.1 Design

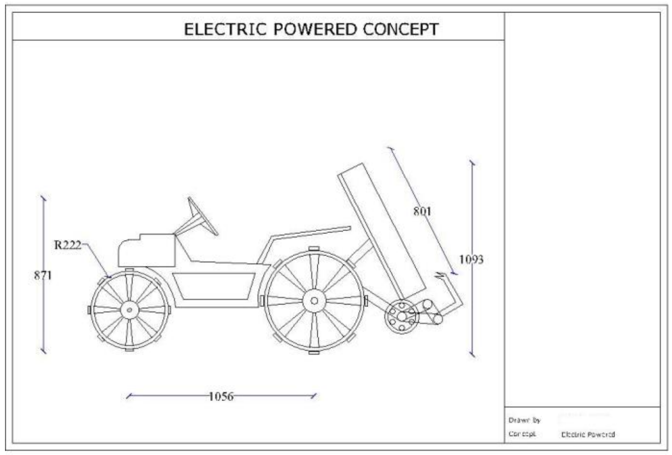

Figure 4: Electric powered rice transplanter

This four wheel concept which uses a dc electric motor powered by Lithium-ion (Li-ion) batteries. The traction D.C. electric motor is located between the two back wheels and the battery array is fitted in the chassis of the machine. It is a riding type and transplants eight rows in a single pass; and can carry more seedlings to replenish the seedling tray intermittently. The transplanting mechanism is driven by sprockets on the rear axle. The D.C. motor is the solitary source of the torque to drive the machine forward while also driving the transplanting mechanism. The general mechanism that is going to be adopted is the use of the transplanting arm.

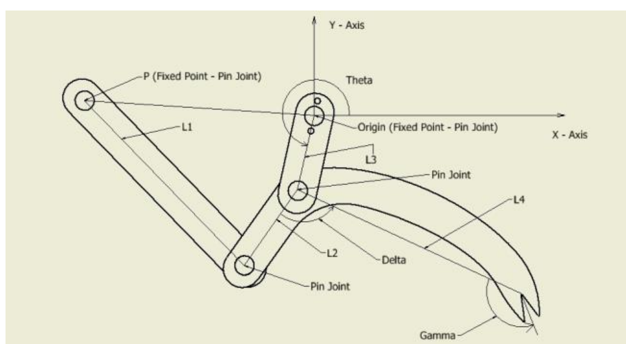

Figure 5: Rice transplanting arm

It is a four bar linkage mechanism that picks and plants the rice seedlings. It is used to determine the degrees of freedom of a mechanism. It looks at the number of links, type and number of kinematic pairs. The mechanism above was analysed with MATLAB r2014a software to obtain the optimum plot shown below and thus determine the length of links L1 to L4.

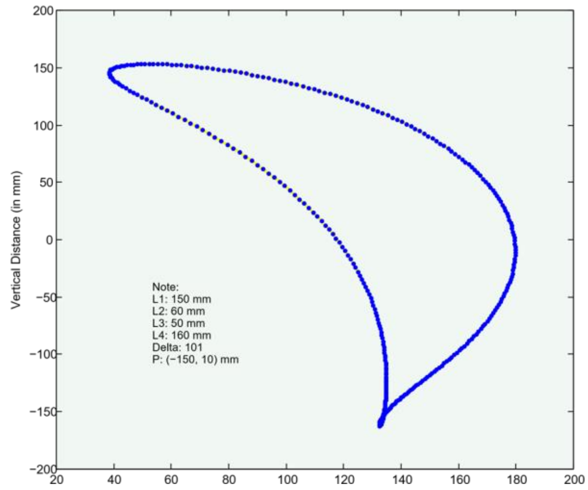

Figure 6: Trajectory of the picking mechanism

$P{:}\,(-150, 10)\ mm$, $L1 = 150\ mm$, $L2 = 60\ mm$, $L3 = 50\ mm$, $L4 = 160\ mm$, $Delta = 101\ degrees$

$Thickness\ of\ each\ link = 5\ mm$

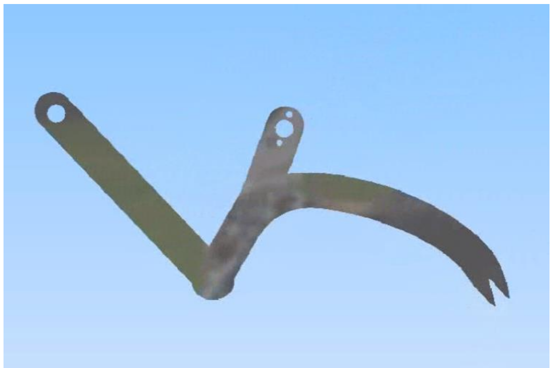

Figure 7: Transplanting arm

The chain link obeys Grashof's condition

4.2 Design of power transmission and attachments

It was found from existing self-propelled rice transplanters that: Power required to drive the mechanism and machine forward $= \boldsymbol{3kW}$, Optimum transplanting speed $= \mathbf{1.5}\boldsymbol{ms^{-1}}$, For 6 hours of transplanting, energy required $= 6 * 3 = \boldsymbol{18kW}$, Setting losses due to aerodynamic and viscous drag at **10%.**

$$\text{Total Energy Required} = \mathbf{18 + 0.1(18)}$$

$$= \mathbf{19.8}$$

$$\approx \mathbf{20}\ \boldsymbol{kWh}$$

4.3 Sprockets

No. of teeth of each sprocket at wheel = **42** *(double sprocket)*, No. of teeth of sprocket at planting mechanism = **11** *(double sprocket)*, $Centre\ distance = \mathbf{568}\ \boldsymbol{mm}$, $Length\ of\ the\ chain, \boldsymbol{L} = \mathbf{2.54}\ \boldsymbol{m}$

4.4 Motor configuration

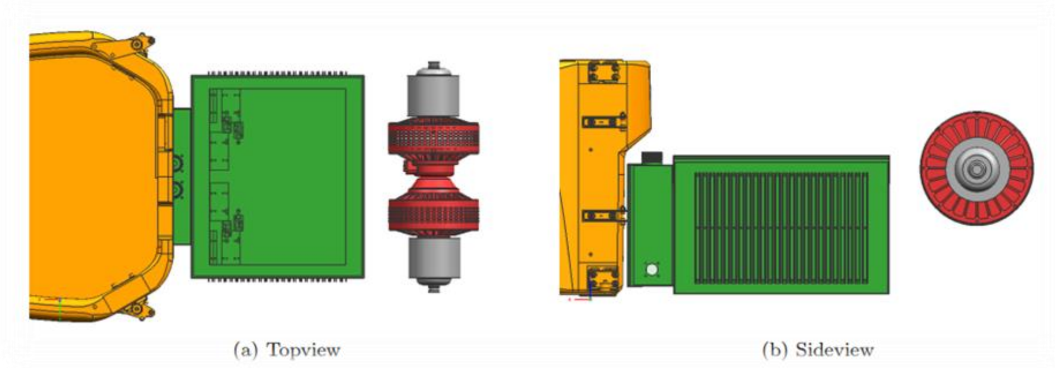

Figure 8: The motors are located next to the drivetrain and connected with a planetary set. These form the rear axle. The battery box is lying on its back

This configuration with the planetary set and the battery box lying on its back was selected to be applied in this design project.

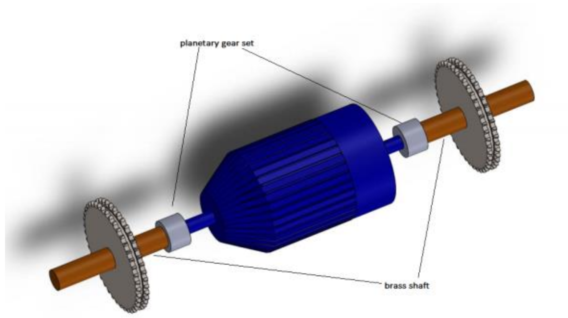

Figure 9: Rear axle comprising of motor connected to two brass shafts with sprockets.

4.5 Motor selection

All power to propel the machine forward and drive the mechanism is supplied by the electric motor. Chain and sprocket mechanism is used to transmit power to the planting unit. A double shafted D.C. War P9 motor was selected because it does not need an inverter as compared to the A.C. induction motor which decreases the overall cost of the machine.

Figure 8: War P9 D.C motor (www.electriccarparts.com, 2016)

It comes equipped with extra-large brushes which are designed for the high voltages and currents of electrical vehicles of today.

4.6 Full mechanism

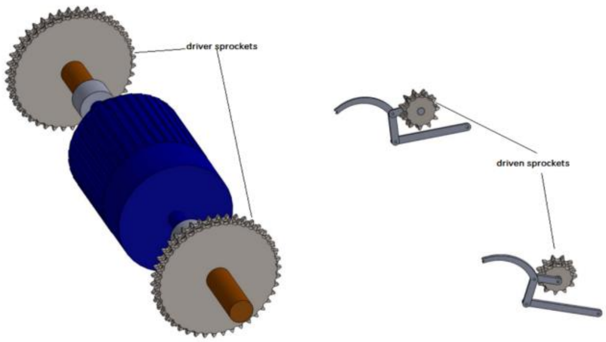

Figure 9: Power transmission and Transplanting mechanism.

4.7 Planetary gear

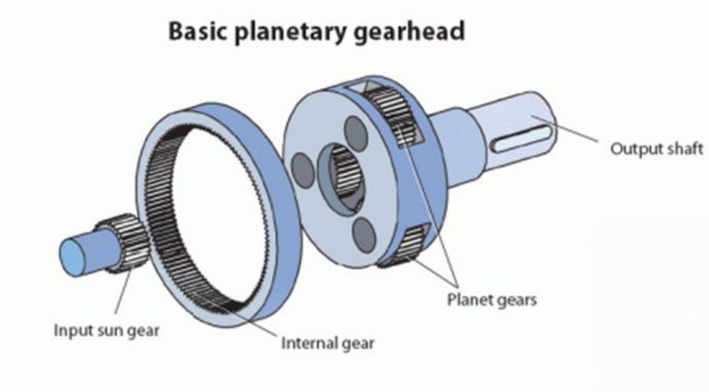

Figure 10: Basic Planetary Gear Exploded View

$$Sun\ gear = 30\ teeth$$

$$Planetary\ set = 120\ teeth$$

$$Ring\ gear = 90\ teeth$$

The motor shafts will be connected to the planetary carriers and the axle shafts to the sun gear and thus the planetary gear is the driver. With this configuration, the ring gear will be stationary.

$$the\ gear\ ratio\ between\ the\ planetary\ gear\ and\ sun = \frac{120}{30} = 4{:}1$$

This means that the planetary carrier has to turn 4 times to produce one revolution of the sun gear. This means that the motor will rotate at speed four times that of the wheels i.e. $(300 * 4 = 1200\ r.p.m.)$

4.8 Battery sizing

Specifications

Rated capacity[(1)]	Min. 2700mAh
Capacity[(2)]	Min. 2750mAh Typ. 2900mAh
Nominal voltage	3.6V
Charging	CC-CV, Std. 1925mA, 4.20V, 3.0 hrs
Weight (max.)	46.5 g
Temperature	Charge*: 0 to +45°C Discharge: -20 to +60°C Storage: -20 to +50°C
Energy density[(3)]	Volumetric: 577 Wh/l Gravimetric: 214 Wh/kg

[(1)] At 20°C [(2)] At 25°C [(3)] Energy density based on bare cell dimensions

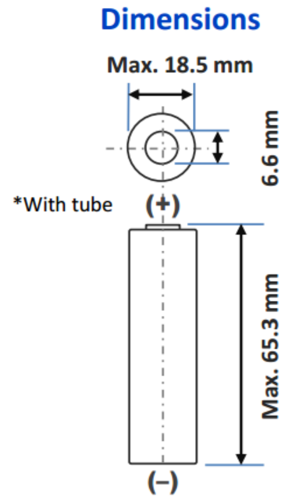

Figure 11: Battery specifications (www.panasonic.com, 2016)

$Number\ of\ batteries\ required = \mathbf{2070\ batteries}$. These will be on $\boldsymbol{three\ rows\ of\ 35 \times 20}$ batteries ($\mathbf{2100}$) on top of each other which is $\mathbf{0.651m}$ long and $\mathbf{0.372m}$ wide. The height will be that of 3 batteries = $\mathbf{0.1959m}$. Total weight of battery array $= 46.5 * 2100 = 97\ 650g = \mathbf{97.65kg} \approx \mathbf{100kg}(including\ casing\ of\ management\ system)$. The battery box will be inside the space chassis frame.

4.9 Chassis

It is made of $33.7 * 4\ mm$ hollow circular bars of Aluminium alloy 6063 and Finite Element Analysis was used to analyse the space frame chassis with all other loads treated as dead weights acting through their centres of gravities.

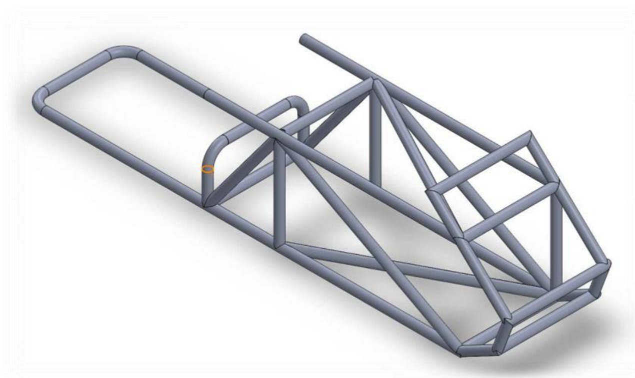

Figure 22: First Look at Chassis

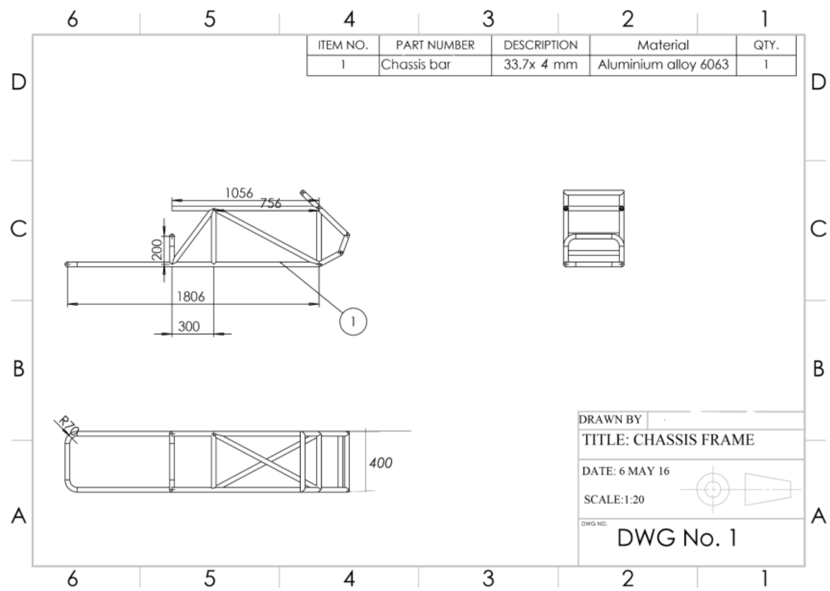

Figure 13: Orthographic views of the rice planter

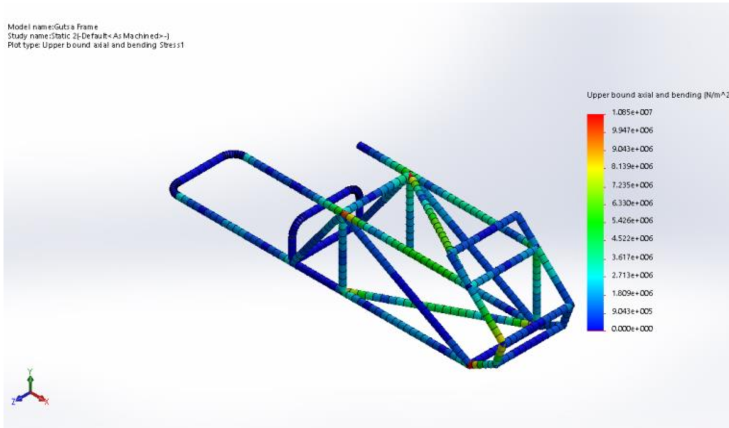

Figure 14: Results of Static Bending Simulation

On the legend, it can be seen that the maximum von-Misses stress $\mathbf{1.08 \times 10^7 \, N/m^2}$ which is less than the yield stress of $\mathbf{21.5 \times 10^7} Nm^{-2}$ and gives a minimum factor of safety of $\mathbf{20}$, thus the design is safe. All the other chassis frame elements will bear a load less that that supported by this bar, hence the rest of the chassis will be relatively safe.

Figure 15: First Look at the Seedling Tray

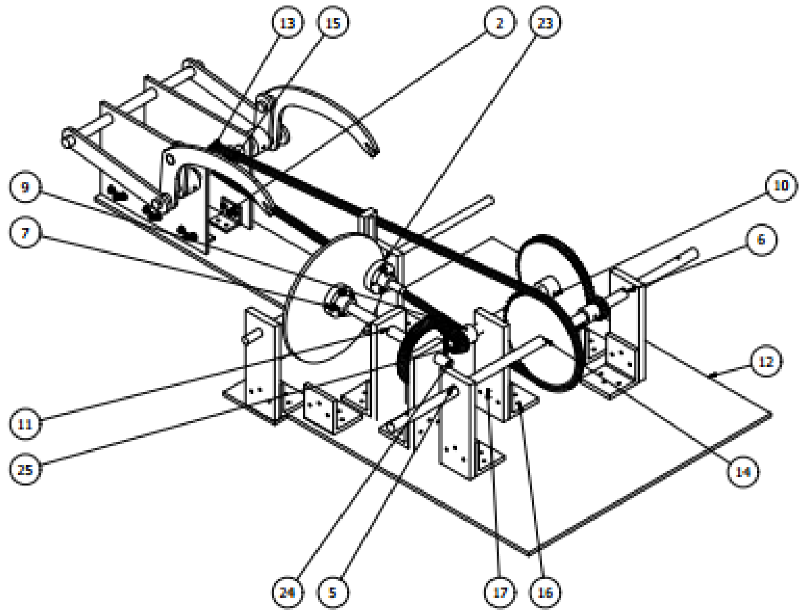

Figure 16: All the transmission mechanisms: i. Power transmission, ii. Tray Whitworth Slide Mechanism and iii. Transplanting Mechanism.

5. Recommendations and Conclusions

A manual lever mechanism should be incorporated which can be used to adjust the plant spacing and planting depth during operation. Lighter material like graphite or carbon fibre can be used to replace the alloy steel of the transplanting fingers. Redesign of the transplanting arm so that it can accommodate a variety of crops such as tobacco which are dominant in Zimbabwe. A better range of the transplanter can be achieved by using a larger battery bank. Rice paddy transplanter is highly recommended to the local farmers in Zimbabwe though beforehand the farmers need to be educated regarding its proper use since mechanized transplanter requires mat – type nursery. It would also decrease the high dependence of farmers on labourers for transplantation. Mechanical Transplanting is more efficient than Manual Transplanting.

References

1. Singh, G. ;Ravinder P.S., 2010. Design and Development of rice planter machine. Design Clinic Scheme, National Institute of Design.
2. Anon, 2014. Zimbabwe : Mutsvangwa Signs Hybrid Rice Production MoU Zimbabwe : Mutsvangwa Signs Hybrid Rice Production MoU. , (2), p.65961114.
3. Anon, Cereal yield (kg per hectare) in Zimbabwe.pdf.
4. Density, H.E. & Operation, S., 2000. Lithium Ion Batteries (Li-Ion) | Panasonic Industrial Devices Lithium Ion Batteries (Li-Ion) | Panasonic Industrial Devices Page 2 of 2, pp.2–3.
5. Eurenius, C.A. & Wass, J., 2013. Analysis of Composite Chassis Bachelor Thesis in Applied Mechanics.
6. Gordon-bloomfield, N., 2010. Why EV Battery Packs Might Just Believe in LIfe After Death Why EV Battery Packs Might Just Believe in LIfe After Death. , pp.1–4.
7. In-hybrid-electric, P., 2012. Automotive Battery | Panasonic Automotive & Industrial Systems Company Europe Automotive Battery | Panasonic Automotive & Industrial Systems Company Europe Page 2 of 2. , pp.1–2.
8. Turner, S., School of Engineering Chassis Design Analysis for Formula Student Car by Author's Self Assessment.
9. Ericsson, A., 2000. A model for predicting digging forces when working in gravel or other granulated material. , pp.1–9.
10. Supplier, C., 2015. Hot sale tobacco transplanter in America hot sale tobacco transplanter in America. , pp.1–7.
11. Anon, 2014. Zimbabwe : Mutsvangwa Signs Hybrid Rice Production MoU Zimbabwe : Mutsvangwa Signs Hybrid Rice Production MoU. , (2), p.65961114.

Acknowledgements

I would like to thank the company that I worked with for data gathering.

Biography

Tawanda Mushiri is a PhD student at the University of Johannesburg in the field of fuzzy logic systems and maintenance, is a Lecturer at the University of Zimbabwe teaching Machine Dynamics, Solid Mechanics and Machine Design. His research activities and interests are in Artificial intelligence, Automation, Design and Maintenance engineering Contacted at tawanda.mushiri@gmail.com / tawandamushiri123@hotmail.com

Brighton Gutsa is a Mechanical Engineering Graduate at the University of Zimbabwe (2016). Contacted at: brightontapiwagts@live.co.uk

Charles Mbohwa is currently a Full Professor of Sustainability Engineering and Engineering Management at the University of Johannesburg, South Africa. Contacted at cmbohwa@uj.ac.za