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A PROJECT IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE BSc IN AGRICULTURAL ENGINEERING

Project Tittle: DESIGN AND CONSTRUCTION OF A MODIFIED SEMI-AUTOMATIC TOBACCO TRANS-PLANTER

By:

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DECLARATION

I, **Redemption Zengenene**, **B202485B**, I declare that, with the exception of what is noted in the acknowledgement and references, all of the research and work for this study was done by me. According to my knowledge NO other university has received this project, in whole or in parts.

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DEDICATION

This paper is dedicated to the Zengenene family for raising, nurturing and supporting me from the beginning of my time up to this moment. They provided unending financial and moral support thus strongly motivating me to keep moving towards my goals from my childhood till date.

ACKNOWLEDGEMENTS

This work was made successful by contributions from different sources. I wish to express my profound gratitude to Engineer Zendera and Dr. C. Ever Gongora Leyva whose scientific guidance, suggestions and friendly approach helped me during the time of my research and writing of this project. This milestone was made possible by the interference of various sources. Unwavering support was given to me by Dr. D. Zengenene as well as all family members.

Special thanks goes to Dr. Shonhiwa for her outstanding interference and resourcefulness rendered during my study period at Bindura University. I am impressed with her love and determination in helping those in crisis.

It is a great pleasure to be under the care of my loving mother who always assisted me through prayers and support in this journey.

ABSTRACT

Tobacco farmers are experiencing massive problems in their transplanting process. This has prompted this design which aims at solving the problem by designing and making of a prototype that transplants tobacco and is reasonably affordable. As a result, a field study was conducted so as to ask farmers on their preferences in machine design using random sampling and interviews in obtaining answers. This study was followed by carefully crafted design calculations and prototype manufacturing. The designed prototype functioned well with some improvements needed in the mechanism behind the transplanting part. Some lines were being developed instead of holes. The overall transplanting process was a success as the machine managed to be operated by a single individual.

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LIST OF ACRONYMS AND ABBREVIATION

N: Newtons

M: Meters

s: Seconds

kg: Kilograms

CHAPTER 1

1.1 INTRODUCTION

1.1.1: Background

Agriculture as a sector occupies a significant role in the country's economy, contributing on average around 15 % of Gross Domestic Product (GDP) over the past three decades (Ministry of Agriculture, 2018, p. 9). The country's economy greatly relies on agriculture with an estimation of 70 % of the population deriving their livelihood directly or indirectly from agriculture. One-third of the formal labour force is employed in this sector (Zimbabwe National Statistics Agency, 2017, p. 16). This makes Agriculture the backbone of the country.

Since 1985, the contribution of agriculture to GDP have varied from a low of 6 % to a high of 24 %, with its contribution to Zimbabwe's GDP reaching its zenith at 24.2 % in 2008. This had declined to just over 11 % in 2016 (Ministry of Agriculture, 2018, p. 9). Despite the fluctuation from year to year, in 2018 agriculture accounted for 30 % of export earnings and around 10 % of GDP. Of total agricultural export earnings, tobacco earned 25 %, followed by livestock (24 %), maize (14 %) and cotton (12 %) (Ministry of Agriculture, 2018, p. 2). This brings to light the significance of tobacco. Considering tobacco only, there are roughly 70 000 communal growers, 50 000 small-scale (A1) growers, 9 000 medium- to large-scale A2 growers, and 8 000 small-scale commercial growers of tobacco (TIMB, 2018, p. 18).

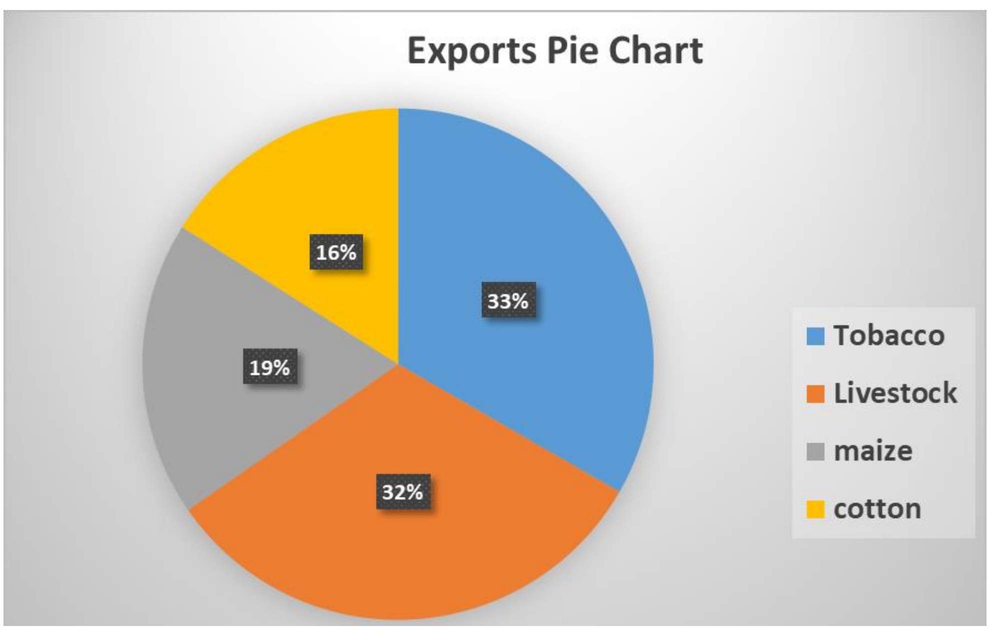


Figure 1: Zimbabwe's current agricultural exports. Source: (Ministry of Agriculture, 2018).

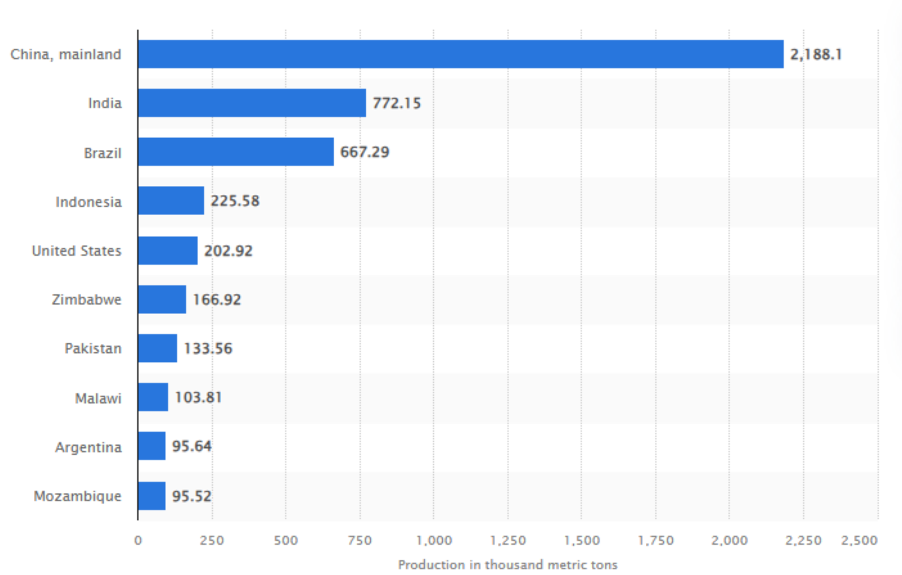


Figure 2: Zimbabwe's tobacco production world ranking in 2022. Source: (Statista, 2024)

Currently Zimbabwe is the fifth largest grower of tobacco on a world scale and happens to be the largest grower of tobacco in Africa.

Three types of tobacco have traditionally been grown in the country: Virginia flue cured, burley and oriental tobacco. Over 95 % of Zimbabwe's tobacco consists of flue-cured tobacco, which is renowned for its flavour (Xinhua, 2018). The cash crop is a major part of Zimbabwe's economy. In 2017, tobacco accounted for 11 % of the country's GDP, and 3 million of the country's 16 million people depended on tobacco farming for their livelihood (Newsday, 2015).

Since tobacco is the leading agricultural export, it has significantly introduced foreign currency into the country and improved lives of thousands for both small scale and commercial farmers. It has created employment and improved the economic quo. Thousands of farmers are depending on it for their sustainable livelihoods. This brings to light the sensitivity and importance of tobacco farming both locally and on the international market.

Despite the economic importance of tobacco and its contribution to GDP, the yield per hectare still remains very low due to several factors. The national average yield is between 1 and 1.3 tonnes per hectare compared to 2.5 and 5 tonnes per hectare potential (TRB, 2012). Studies have shown that the low yield per hectare that is being obtained in the small holder farming sector is particularly a result of the poor agronomic practices employed by the small holder farmers (TRB, 2012). Studies further indicated that these poor agronomic practices have a major bearing on the quality of the produce as well and since tobacco is sold through the auction system, this has a bearing on the profitability of the farmers (TIMB, 2013). Amongst the poor cultural practices are late topping and desuckering due to labour shortages (Mazarura, 2004). In addition to that improper nutrition is also a challenge due to inadequate application of fertilisers as a result of the higher costs of fertilisers on the market therefore affecting quality of the leaves produced, also poor weed control strategies are also employed by small holder farmers and this is critical since weeds have been shown to have potential to reduce yield by up to 50 % (Katahari et a.,l 1999).

One of the most contributing factors in tobacco production reduction is the absence of modern technology in its management, planting and harvesting. This has not only affected small scale farmers but also commercial farmers leading to a serious decrease in production hence derailing the economy.

One of the most worrisome, labour requiring phase in tobacco production is the seedling transplanting phase. Transplanting or replanting is the technique of moving a plant from one location to another (Simon, 2010). Other sources have agreed that transplanting entails transferring seedlings from their original growing medium which can be nursery pots to a new growing medium which is usually the main field to enable them to grow to the desired size for yield production (Diao et al., 2016). For proper transplanting, several trans-planters and tools are used, and their designs depend on the type of seedling crop (Kumar and Rahman, 2011)

In this context, tobacco transplanting serves two primary purposes which are to shield young plants from diseases and pests until they are robustly established and preventing germination issues by opting for seedlings rather than direct seeding. It should also be noted that the tobacco seeds are extremely tiny that transplanting is the only viable option.

According to Access tobacco farming guide, during the transplanting phase, soil conditioners such as viagrow power p+ and viagrow power evolution are required in the planting hole just before the plant itself. These are known to encourage vigorous root development since a quick root system has to be built up for quick adaptation to the new field environments.

Viagrow Power P (7-21-0 with 0.2 % Zinc) is specially engineered as a significantly more mobile, efficient, and available form of soil-applied phosphate. Replicated trials over many years have consistently shown that Viagrow Power P, creates a positive growth response in plants, resulting in increasing yields with less phosphate being applied (Viagrow, 2022).

Viagrow Power Evolution enhances native soil microbial activity and improves calcium exchange capacity (CEC) and water holding capacity to improve the soil health and function for your crop. This in turn brings plant and root stimulation effects to grow more roots, finer root hairs, increases root exudates, and improves mineralization of carbon and nutrients in the root zone (Viagrow, 2022).

During the tobacco transplanting phase, compound C fertilizer is also integrated in the soil at 10 cm away from the planted seedling. Covering is then done so as to cover much of the plant stem as well as the fertilizer and chemicals. These processes are being done by human labour which is causing serious discomforts and demotivation thus subsequently leading to a reduction in the planted hectares. This also leads to a series of problems such as the absence of enough workforce to tackle the hard works.

Another cause for concern is the presence of lower back pains that happen during tobacco tans-planting. United Kingdom estimates have placed low back pains as the largest cause of absence from work and is responsible for about 12.5 % of all sick days (Frank, 1993). This was concluded based on non-tobacco farmers who work in offices under less demanding workspaces. The study by Omokhodion (2004) illustrates that farming activities increase the odds of suffering lower back pains by four, compared to individuals not exposed to farming activities. A study closest to tobacco transplanting was carried out during rice transplanting in India. This study was conducted, demonstrating the prevalence of lower back pains among Thai farmers during rice transplanting process.

The results of the current study showed a very high prevalence (83.14 %) of lower back pains in all farmers. Previous studies showed a higher dominance of lower back pains in occupations with excessive loads, poor working conditions or a combination of both. Within that category were industrial workers, vehicle drivers and farmers (Omokhodion, et al, 2000). In studies taken during the rice transplanting stage, a higher prevalence of lower back pains was noticed among Thai farmers, the prevalence of low back pains was reported to be 99 % (Omokhodion, 2002). This is because in farm working conditions, farmers rarely check their working postures and they work for extended time without resting. These factors are highly likely under the tobacco farming communities because tobacco is a demanding crop that requires undivided time and focus.

The high prevalence of lower back pains among farmers is most likely the result of injury to the spinal structures, which may arise from working postures and movements of the lower back during the working process. The study from India analyzed farming postures and showed that the farmers were working with forward lumbar bending and twisting and were carrying weights of 10 kg or less and that these postures seemed to generate their lower back pains (Omokhodion, 2002)

Researchers have reported that these working postures are associated with lower back pains (Omokhodian, 2000). Similar to tobacco transplanting, the planting postures are repeated, asymmetric, constrained and prolonged. These postures can generate load on the lumbar region, which can overload tissues and exceed their thresholds of tolerable stress, causing injury due to overexertion or imbalance (Prista et al, 2004). Further studies have shown that, the maintenance of static postures for prolonged periods of time compresses the veins and capillaries inside the muscles, causing micro lesions due to the absence of tissue oxygenation and nutrition. In tobacco farming, farmers work in squat postures and reach with their arms to plant seedlings, an activity that increases the load on their lumbar region. All of these factors can contribute to imbalance, fatigue, discomfort, and pain due to disruption of tissues (Jordaan et al, 2005).

Researchers have noted that lower back pains were undeniably high on the African soil among African farmers as compared to other continents because of a lack of legislation to support workers suffering from lower back pains and no legislation to ensure that they receive optimal rehabilitation and support (Frank, 1998). Massive workloads and workers exploitation due to the presence of cheap labor caused by economical instabilities are other causing agents making the issue of lower back pains to be ignored even by the affected communities in Africa.

These muscle strains cause lower back pains thus resulting in labour shortages and a decrease in tobacco production hence leading to land underutilization and economic drawbacks. Mechanization and automation of tobacco transplanting could reduce or completely eliminate this chain of problems this leading to increased production and profits.

Other mechanization attempts have been made to try and reduce the laboriousness of tobacco farming and ease its growing process. These measures include the invention of the ridger with a tyridge marker and chemical applicators. Despite all the gathered knowledge on the ease of tobacco farming, little has been done in the local production of tobacco trans-planters. Their absence makes the process labour-intensive and tedious.

1.2 Statement of the problem:

Most farmers are facing a problem in the tobacco transplantation process due to the unavailability of tobacco trans-planters which makes the process more strenuous and labour intensive. Absence of these trans-planters induces human strain and increased labour force on the transplanting, fertilizer application and chemical application during tobacco transplantation. This, in turn will increase costs as much human interference will increase losses due to mistakes, and reduce productivity for the farmer due to uneven chemical and fertilizer distribution.

The goal of the project is to design a machine that transplants tobacco, applies chemicals and fertilizers during that transplanting phase. The goal also includes creating a prototype of the trans-planter and testing its functionality and performance.

1.3 Objectives

1. Design a tobacco trans-planter that:

- Transplants tobacco
- Facilitates one man usage

2. Make a prototype of the designed tobacco trans-planter.
3. Test the functionality of the trans-planter and compare it to manual transplanting.

1.4 Significance of the Study:

Both the farmer and the worker face challenge due to manual transplanting. It is a slow and exhausting process that limits the planting scale and lowers tobacco output. Labour force often experience serious health issues like back pains and muscle cramps which resultantly reduces their lifespan. The farmer also struggles to find enough labour at peak times. Moreover, human involvement makes it hard to ensure proper spacing and plant density, especially with random transplanting and contract labour. Another problem is the uneven application of fertilizer and chemicals during the transplanting phase resulting in uneven plant growth thus compromising the quality and quantity of the yielded tobacco.

Therefore, it is imperative to design a machine that will eliminate manual transplanting, fertilizer implementation as well as chemical application. Introducing this machine will not only curb human strain but will also boost farm productivity for commercialization. It will nullify the effects of labour shortages and increases farm output thus positively affecting the farms revenue. A higher degree of precision in planting, chemical application, and fertilizer implementation will ensure optimum plant growth and uniformity.

The study is also important to the student as it poses the ultimate challenge in his last semester at Bindura University. It also teaches and exposes him to the practical world associated with engineering designs and requires the application of the learned principles. The project requires the integration of a number of learned principles thus being a good step to learn from.

1.5 Limitations

The design was carried out using the Zimbabwe agreed tobacco transplanting specifications. Different countries use different planting specifications but the design was meant to cater for the 95% who do flue cured tobacco**.**

1.5 Delimitations

Several adjustments were made on the machine so as to cater for the other populace who would favour different planting spots.

1,7 Chapter Summary

This chapter focused on giving the information on what the reader needs to know so as to understand the dissertation. It also gave the relevance and importance of the project to different benefactors. It contextualized the problem by linking already known factors around the problem especially those that arise due to the absence of proper consideration of the researched topic. It described the exact issue of what this project seeks to address and its relevance to society. It covered on who the problem affects and how it affects the individuals and the economy at large. It also highlighted on where and when the problem arises. It also gave an overview of how the problem has affected the African farmer’s populace.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Tobacco transplanting is divided into two main groups and several tools are used in each transplanting process. The different transplanting categories are manual and mechanical transplanting thus different transplanting tools are used.

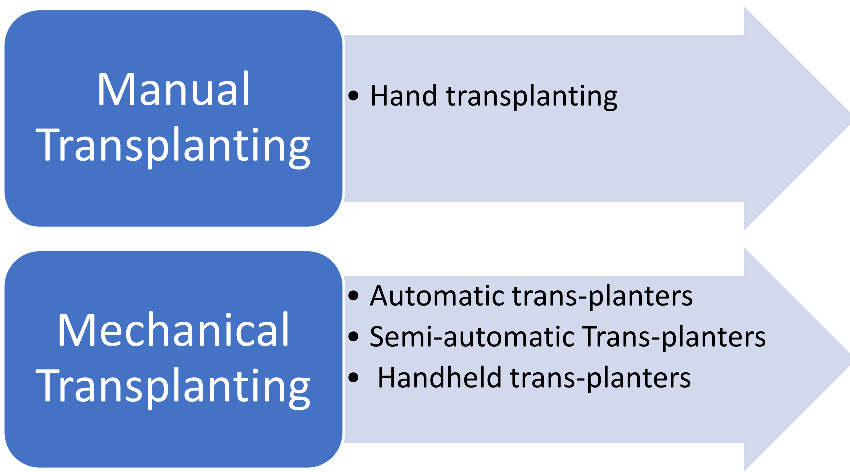


Figure 3: Transplanting categories.

While there has been much research on large scale vegetable transplanting, few researchers have taken tobacco into consideration despite its contribution to world trade. This chapter focuses on the literature review which is related to the different designs of existing seedling trans-planters across the world mainly focusing on their transplanting mechanisms and their main areas of existence. It also focused on the advantages and disadvantages thus establishing the significance of this project. The knowledge gaps identified by the researcher and justifications of the research concluded the chapter.

2.2 Mechanism analysis

Several trans-planting machines have been developed especially in the realm of horticultural produce and much of them have been targeting vegetable transplanting at commercial level. These share similarities with the tobacco transplanting machines since the transplanting mechanism is the same. Different mechanical transplanting mechanisms have been placed and have been classified by level of mechanization as automatic, semi-automatic and handheld. These trans-planters share main structural components and these are seedling nursery trays or tray holders, a picking unit, a conveying unit, and a planting unit for the planted seedling (Kumar and Rahman, 2008).

2.2.1 Automatic trans-planters

A seedling-feeding device, combing device, inserting ejecting-type seedling extraction device, plate-turning device, seedling-conveyor device, seedling-separation device, planting device, empty-tray recovery device, and suppression device are the main components of a fully automated trans-planter. The fully automatic trans-planter moves through the transmission system, driving the seedling-separation device, planting mechanism, air compressor, and generator (Wen et al., 2021).

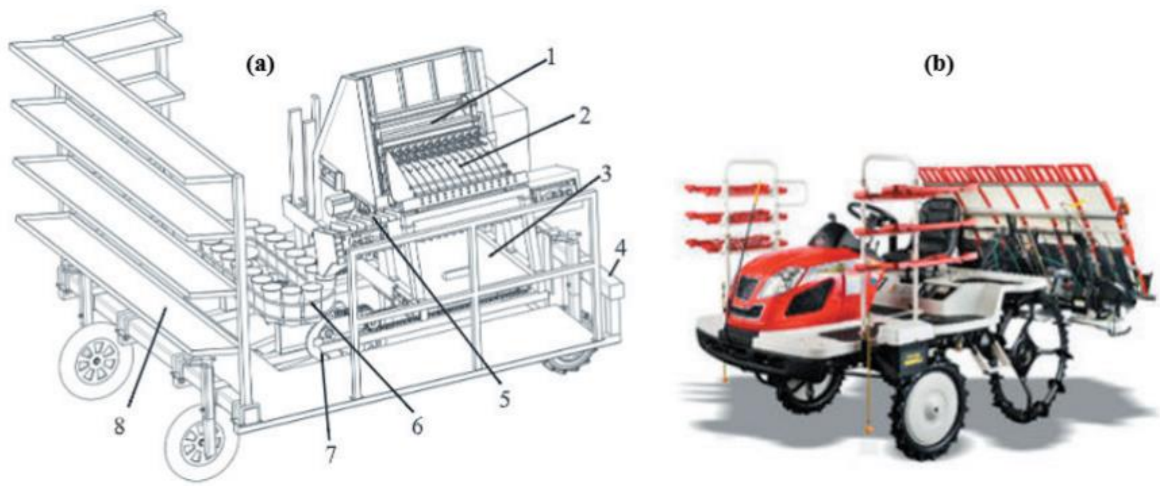


Figure 4: Automatic trans-planter.

Where: major components (a): seedling feeding device (1), combing device (2), empty tray recovery device (3), chassis (4), seedling conveyer device (5), seedling separation device (6), planting device (7), Plug seedlings rack (8), and fully automatic trans-planter (b).

Fully automated trans-planters may be walk-behind or riding-type machines, which substantially reduce the labour requirement for feeding the seedlings (Parish, 2005). The walk-behind-type trans-planters are generally self-propelled whereas riding type are either self-propelled or tractor-operated, where the number of rows is more than four.

A performance evaluation of the fully automatic seedling trans-planter was made using chilli seedlings by Han in 2019. According to Han (2019), the automatic seedling trans-planter had a transplanting efficiency of 92.6% and a field efficiency of 76.12 %. The miss transplanting data of the trans-planter was 4.9 % and multiple transplanting percentage of 1.1. Seedling mortality rate was 0.9 % leading to a high overall efficiency. In addition to its high efficiency, the trans-planter requires minimum labour in its operations. The fully automatic trans-planter has provided opportunities for savings in labour and time required for transplanting operation in open field and controlled environmental structures (Abhijit, 2018).

However, despite the remarkable performance of this fully automated trans-planter, numerous farmers perceive it as unattainable due to its exorbitant costs. Additionally, the prices are further inflated as these machines are not manufactured within Africa, necessitating the burden of shipping and resulting in higher expenses. Consequently, this unavailability on the African continent has led to reduced tobacco production and underutilization of land.

Furthermore, these trans-planters lack fertilizer and chemical application systems that are essential for tobacco production. As a result, they only address the specific challenge of transplanting without considering the other interconnected processes involved in tobacco cultivation. As a result, these trans-planters are predominantly viewed as suitable for vegetable transplanting and have been manufactured in large quantities to cater to the needs of vegetables and other horticultural crops.

In addition, farmers claimed that the existing technologies do not completely serve the farmer's field requirements (Abhijit, 2018). This is because farm environments are often characterized by rugged and rough conditions, which renders the fully automated trans-planter unsuitable for such settings. Acquiring and utilizing the trans-planter in such conditions would inevitably result in accelerated depreciation, reduced lifespan, and higher operating costs. Consequently, this would diminish the ultimate profitability derived from the crop.

It is worth noting that these fully automated trans-planters were primarily intended to serve the needs of large-scale commercial farmers, given their user-friendly operation and cost considerations. Furthermore, research indicates that these machines are not readily accessible within the African community, leaving African farmers grappling with manual transplanting methods. This implies that, as these trans-planters are sourced from international markets, their maintenance costs in Africa could be higher, contributing to an overall increase in expenses and negatively affecting the profitability of African tobacco production.

With all that under consideration, this brings the importance of a native design that is adaptable to local field conditions and is user friendly. This requires the designing and testing of a trans-planter that will be less costly and is available to suite the local market and beyond. This brings to light the significance of this project as it seeks to combine engineering principles in the design, manufacturing and testing of the trans-planter that seeks to cancel all these negatives and combine tobacco oriented results. This project will design, create a prototype and test an easily accessible, affordable and user friendly trans-planter that uses easy to grasp approaches and easy functionality making it usable by everyone.

2.2.2 Semi-automatic Trans-planters

Semi-automatic trans-planters consist of an engine that generates power, a transmission system that distributes the power to the driving wheel and transplanting device, a seedling cylinder where seedlings are manually placed, a transplanting device that plants the seedlings supplied from the seedling cylinder into the soil, a control section that manages the operation of the trans-planter, and a plant-spacing control device (Sri et al., 2022). Semi-automatic trans-planters contain a seat for the worker, who loads the seedlings into the planting unit (Khadatkar and Mathur, 2022).

The seedlings are kept in a seedling holder before being fed into the planting unit. The seedlings are metered at the specified seeding rate, then transferred to the furrow at predetermined intervals and covered with the surrounding soil (Kumar and Rahman, 2008).

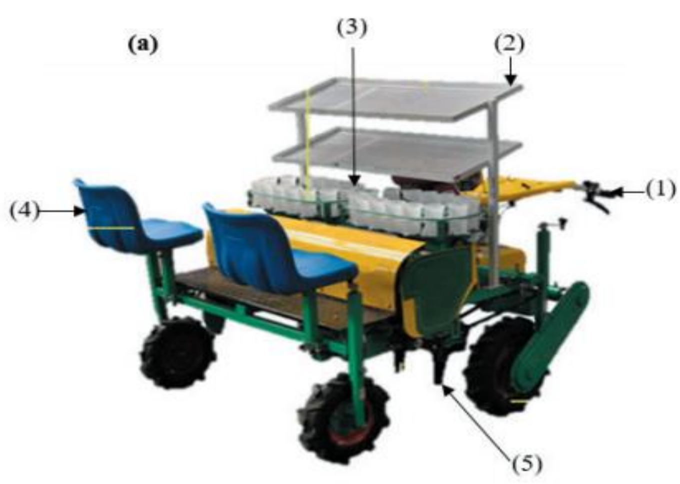


Figure 5: Semi-automatic trans-planter.

Where: steering handle (1), seedling nursery tray (2), seedling cup (3), seedling feeding seat (4), transplanting duckbill (5), and tractor-drawn seedling trans-planter type (Russo, 2012).

Semi-automated trans-planters can be categorized into 2 and these are the walking type and the tractor-drawn type. Walking types are operated by steering handles, while tractor-drawn types must be attached to a tractor and require an operator; all of them require workers to manually feed seedlings into the planting device (Rahul et al., 2019). A performance evaluation comparing a semi-automatic vegetable trans-planter with manual transplanting showed that the effective field efficiency of semi-automatic trans-planters was 0.026 ha·h-1, with 81 % transplanting efficiency proportional to the speed of the trans-planter (Sharma and Khar, 2022)

A comparison was made between the semi-automatic trans-planter and manual transplanting to determine their working capacity and field performance and the results were as shown:

Table 1: Shows the performance analysis of semi-automatic and manual trans-planters.

Criteria	Unit	Semi-automatic	Manual
Plant mortality	%	5.65	8.08
Labour requirement	Man/ ha	55.6	184.7
Transplanting Cost	USD/ha	45.7	42.0
Time requirement	h/ha	9.4	36.9

As backed up by Rickman et al (2015), these trans-planters bring less transplanting shock, early seedling vigor and uniform crop stand. They also contribute to reduced stress, monotony, and health hazards for agricultural workers. Specifically, the semi-automated trans-planter demonstrates a lower rate of plant mortality and requires an intermediate level of labour, which is higher than that of an automated trans-planter but lower than that of a handheld trans-planter. Moreover, these machines offer cost-effective transplantation with minimal time investment.

However, there has been a lack of initiative in the tobacco sector to adopt the semi-automatic trans-planter for tobacco transplantation. Much progress has been made in horticultural produce. In Africa, these trans-planters are completely absent, resulting in underutilization of land and reduced cultivation area across the continent.

Moreover, these trans-planters have a higher maintenance cost and are generally expensive thus adding to be the reason why they are absent in Africa and very few under the Asian markets. Additionally, little has been done to develop these trans-planters with an aim of targeting tobacco transplanting. On the contrary, much emphasis has been given towards the development of vegetable trans-planters.

In addition, the currently available semi-automatic trans-planters are not suitable for small-scale farmers due to various reasons. Not only are they costly, but they are also incompatible with ox-drawn systems or physical pulling using human labour, which is generally preferred by small-scale farmers. This therefore creates a gap in the system thus this project seeks to bridge this existing gap in the tobacco trans-planting world.

2.2.3 Handheld Trans-planters

Handheld trans-planters are powered by human hands and have a handle, hopper, seedling delivery tube or hollow pipe, jaw opening lever, and jaw mouth as major components. (Khadatkar et al., 2018). For transplanting, the jawed mouth penetrates into the soil by applying a force on the clutch while holding a handle with the upside movement of the clutch lever, which conveys the seedling into the furrow and covers it with the surrounding soil to a vertical planting state of 2-cm depth, following the pushing, punching, and earthing mechanisms (Sharma and Khar, 2022)

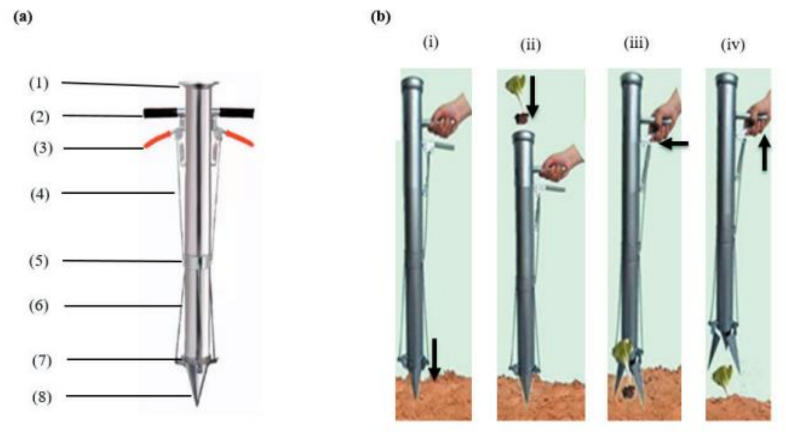


Figure 6: Handheld trans-planter.

Where: On (a): seedling hopper (1), Rubber handle (2), pull handle (3), pull wire (4), sliding tube (5), stainless steel body (6), depth lever (7), triangle cup (8), and seedling transplanting steps (b): insert the trans-planter into the soil by pushing (i), put the seedling into a trans-planter cylinder tube by earthing (ii), hold the handle by punching (iii), and lift the trans-planter (iv).

The handheld trans-planter is one of the most useful tools designed to cater for small-scale farmers. Thus, has been used in tobacco transplanting among other seedlings that need to be transplanted. Patil et al (2015) analysed the performance of this trans-planter and concluded that it has a field capacity of about 0.02 ha h–1 and a field efficiency of 82.3 %. Another test by CIAE news (2017) concluded that this trans-planter has a transplanting rate of 15 to 17 seedlings per minute. This trans-planter has higher performance than manual transplanting thus making it suitable for small-scale transplanting.

Another performance analysis of the handheld trans-planter was tested on several vegetable crops; the findings revealed that it operated properly, with no misplantings, and a negligible rate of tilted planting depending with the operational ability of the operator thus leading to an 82.30 % field efficiency (Kaushik et al., 2022). These analyses proved that the trans-planter is a significant tool for progress since it has great overall efficiency.

The trans-planter has significantly streamlined the transplanting process, alleviating the laboriousness associated with manual transplantation. Moreover, it has effectively diminished the workforce demands while ensuring promptness. After evaluating various trans-planters, a comprehensive cost analysis revealed that the handheld trans-planter stands out as the most economical option, rendering it affordable even for the local small scale community.

However, notwithstanding the advantages mentioned earlier, the handheld trans-planter has exhibited constraints in terms of its flexibility when used in field conditions. It demonstrates limited adaptability to intricate soil conditions. This limitation arises due to the presence of rugged terrains, which often necessitate considerable exertion to penetrate the soil, particularly during stormy weather. Moreover, certain soil types can be sticky, adversely affecting the transplanting process. Additional challenges arise from hard or compacted soil, rocky terrains, or areas where existing vegetation poses significant root competition. In such instances, the utilization of mechanized equipment with enhanced power and capabilities becomes imperative to ensure successful transplantation

In addition, this trans-planter requires the user to be carrying their seedlings which is not suitable for larger farms thus sometimes requiring another person who will be handing the other person those seedlings. This makes the trans-planter unsuitable for medium to large scale transplanting. This also makes the transplanting process more tiresome and less enjoyable thus affecting the planting pace and area coverage

Moreover, the act of transplanting tobacco seedlings using handheld trans-planters can be labour intensive, particularly for larger tobacco farms. The manual nature of the process often necessitates a substantial investment of time and labour resources, which varies depending on the scale of production. Farms with ample labour availability or those operating on a smaller scale may find handheld trans-planters to be a suitable option while larger farms consider mechanized alternatives as a more viable option.

In addition, hand trans-planters typically have a limited capacity, allowing for the transplanting of one or a few seedlings at a time. This can slow down the transplanting process, especially when compared to mechanized or automated transplanting equipment that can handle larger volumes of plant material more quickly

2.2.4 Hand transplanting

Transplantation is the method of shifting a plant from one location where it has been growing, and reseeding it at another location during the planting season. This technique is commonly used by African farmers in tobacco production and among Asian farmers in rice production. Hand transplanting falls under manual transplanting and, it involves transplanting by hand.

Under the African tobacco production, it is done with the assistance of small hoes as shown below:

Figure 7: Hand transplanting.

Manual transplanting of tobacco seedlings is causing musculoskeletal disorders, back problems, drudgery and it proving costly because of the labour required (Garg et al., 1997). In addition, other disadvantages were mentioned by MA Bell, V Balasubramanian, and JF Rickman on IRRI website and they are as follows:

- Transplanting is tedious and time-consuming
- Planting labourers can suffer from back problems which is a health risk.
- Difficult to get enough labour at peak periods to plant on time.
- Difficult to maintain optimum spacing and uniform plant density, especially with random transplanting and contract labour.
- Low plant density with contract transplanting on area basis lowers yields.
- Risk, in rain fed areas, that seedlings (especially of modern varieties) may get too old before rain falls and the field is ready to be planted

This therefore solidifies the need for the introduction of an acceptable machine to alleviate these problems on modern farmers.

2.3 Seedling picking mechanism analysis

Seedling picking mechanisms implores the engineering mechanism used when a plant is supplied to the planting mechanism. The mostly used seedling picking mechanism is the invention by Zhang Fei and Yan YaMin in 2018. As shown below according to Zhang Fei and Yan YaMin, (2018) the design of seedling device is mainly composed of seedling cup of fixed plate 1, 2 3, guide tube seedling cup, bevel gear drive shaft 4, chain drive 5, seedling cup, etc. Its structure characteristics is through screws in seedling cup fixed tray, seedling cup fixed plate are connected to the seedling cup drive shaft through the key, seedling cup drive shaft through the bearing installed on the connected to the side panel of support plate, seedling cup drive shaft are connected to the bevel gear shaft through the chain transmission; Guide tube seedling in seedling cup wheel right behind, seedling cup and guide the tube corresponding to the centre line of the overlap.

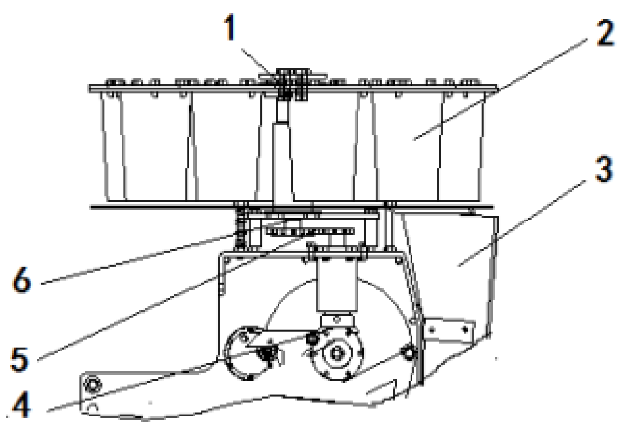


Figure 8: Seedling throwing mechanism.

1. Seedling cup fixing plate 2. Seedling cup 3. Guide tube 4. Bevel gear 5. Chain drive 6. Seedling cup drive shaft

The analysis of the seed throwing device as elucidated by Zhang Fei and Yan YaMin was based on the principle that seedlings are placed in the seedling cup holders which are rotated by the seedling cup drive shaft which will be gaining its kinetic energy from the chain drive. This movement will cause the seedling to be injected into the guide tube where it is led into the soil.

2.4 Conclusion

Most trans-planters in existence seek to reduce the laboriousness on the transplanting process. They enhance the process by reducing the plant mortality rate encountered. This project however, seeks to design and create a prototype of a tobacco trans-planter that is affordable and should be locally manufactured to suit local environmental and climatic conditions. Affordability of this trans-planter is facilitated by its seedling picking mechanism where it is done by human hand thus categorising it as a semi-automated trans-planter.

The trans-planter in this design is meant to increase tobacco trans-planters accessibility within the continent and is designed to suits local terrains and farming practices. The trans-planter in this design is going to be user friendly with reduced drudgery and a reduced risk of being injured while in operation. The trans-planter is going to be easy to operate and repair using local resources. It will also reduce laboriousness of the transplanting process and will have low seedling mortality rate.

2.5 Justification

Many researchers have focused on different vegetable trans-planters and little has been done on tobacco trans-planting. More so, present designs and machinery are being used in other continents excluding the African soil despite its contribution to tobacco world trade. This study however seeks to bridge the gap on African tobacco trans-planters that target small to medium scale tobacco farmers. The trans-planter should be affordable and ought to have an acceptable seedling mortality rate as well as an easy going ease of operation.

2.6 Summary

This chapter dealt with the different seedling handling mechanisms and planting mechanisms for already existing trans-planters. It also nailed on their advantages and disadvantages this establishing the research gap and the importance of carrying out the study, design and prototype of the trans-planter. It also described the justification of the research. The next chapter therefore focuses on the research methodology which are the design solutions, analysis and solutions.

CHAPTER 3

DESIGN METHODOLOGY: REQUIREMENTS AND DESIGN SPECIFICATIONS

3.0 Introduction

Leedy (1997:195) defines research design as a plan for a study, providing the overall framework for collecting data. MacMillan and Schumacher (2001:166) define it as a plan for selecting subjects, research sites, and data collection procedures to answer the research question(s). Their further analysis pointed out that, the main aim of a profound research design is to provide results that are judged to be credible. For Durrheim (2004:29), research design is a strategic framework for action that serves as a bridge between research questions and the execution, or implementation of the research strategy.

Schwardt (2007:195) defines research methodology as a theory of how an inquiry should proceed. It involves analysis of the assumptions, principles and procedures in a particular approach to inquiry. According to Schwardt (2007), Creswell and Tashakkori (2007), and Teddlie and Tashakkori (2007), methodologies explicate and define the kinds of problems that are worth investigating; what constitutes a researchable problem; testable hypotheses; how to frame a problem in such a way that it can be investigated using particular designs and procedures; and how to select and develop appropriate means of collecting data.

For the purpose of this research, this design methodology is going to give a detailed analysis towards creating a tobacco trans-planter suited for small to medium scale farmers. It is going to give the block diagram, a detailed system description and the specified design calculations. The bridge between the objectives and the practicality of the machine to be constructed is going to be brought to light in this chapter. It is also going to cater for the selection of the materials that are going to be used and the reasons why they have been chosen as well as give different theories and an AutoCAD generated pictorial sketches that support the design calculations. A detailed system development, which includes the different steps for the manufacture and assembly of components or assembly guidelines and the summary are going to conclude the chapter.

3.1 User requirements

To identify the proper user requirements of the tobacco trans-planter, interviews on 12 tobacco farmers were carried out. These were used to determine hardware requirements of the trans-planter and determine its operational principle. These farmers were selected using random sampling method. 7 of the chosen farmers were from Madziwa, 3 were from Matepatepa and 1 was from Marondera and the other one from Macheke. Questions asked were as follows:

- What type of tobacco were they farming?
- What transplanting method do they use?
- Are they comfortable with their current transplanting methods?
- What are some of the challenges faced during tobacco transplanting?
- Are mechanical trans-planters available or easily accessible?
- Are they interested in the development of an affordable tobacco trans-planter?
- Are they willing to buy a trans-planter to replace their current transplanting methods?
- What are the requirements they would want on the mechanical trans-planter?

Interview responses highlighted the following:

- All the farmers were planting flue cured tobacco.
- They used manual transplanting method specifically hand transplanting.
- They were not comfortable with their transplanting method.
- Challenges faced included:

1. Drudgery.
2. Inconsistent planting spaces.
3. Back pain hazards.
4. Slowness of the process.
5. Shortages of labour.
6. Poor work performance.
7. Engaging a larger crowd meant increased thieves.

- Mechanical trans-planters were never heard of by the farmers.
- They were thrilled to here of the possibility of mechanical trans-planters.
- They were willing to buy a mechanical trans-planter but most of them suggested for it to be affordable.
- They wanted the following requirements.
    1. It should require less effort to use the device.
    2. Easy usage of the device even under amateur expertise.
    3. It should maintain a constant in row spacing.
    4. It must be affordable.
    5. It must require minimum operators.
    6. Durability.
    7. Easy maintenance.

8. More time between maintenance intervals.

This therefore concluded that the following hardware requirements were required to meet the mentioned challenges.

3.2 Hardware Requirements

- The trans-planter easily propels on rough terrain
- Automatic transplanting mechanism
- The device requires minimum manual effort to operate
- Durability.
- Readily available manufacturing materials.
- Easy maintenance.
- Adjustable in-row spacing**.**

To aid to the decision on the various engineering prospects in the designing and manufacturing of the trans-planter, other factors are to be considered. This follows bearing in mind the recipients or end users of the proposed device, their working conditions, health hazards, user comfort among others. Resultantly, the above highlighted interview responses are to be used in decision making on the engineering prospectus of the device. Also, other unmentioned factors are to be considered in the designing and manufacturing of the proposed design. This brings into consideration factors like the lack of reliable electricity despite the ongoing rural electrification program. Factors such as the inadequacy of solar technology in rural areas. Unavailability of maintenance centres on most small to medium scale farms. Taking into consideration the cost of fuel and its unavailability in rural areas among other factors, it raises the need to make the trans-planter entirely manual. In the same sense, the system should require minimum manual labour to reduce drudgery and improve comfort in its usage.

Therefore, in addition to the above factors, the following were considered as well:

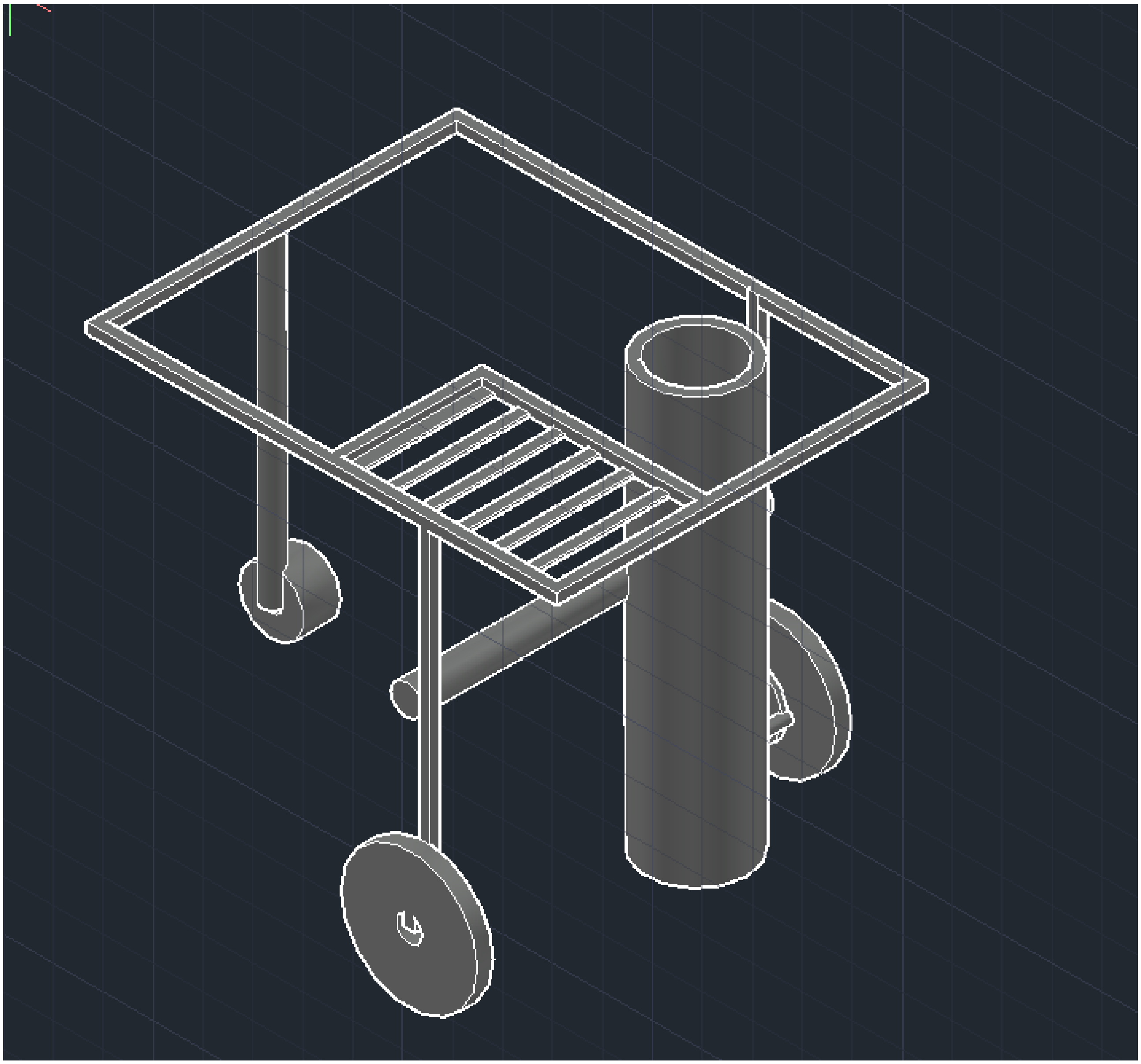
- Strength
- Stiffness
- Weight
- Environmental impact
- Aesthetics
- Convenience
- Lubrication

These affected the choice of materials, fabrication, load determination, its effects and other factors.

3.3 Conceptual Designs

Two designs of the proposed tobacco trans-planter were developed in accordance to the design requirements generated from above. Each design is explained at length to highlight its capabilities and shortcomings.

3.3.1 Three wheel tobacco trans-planter



The above figure shows a three wheel tobacco trans-planter. It puts into practice the principle is that, rotational motion is provided to the wheel through a push or a pull. Since the wheel close to the cylinder is mounted to the shaft, this will turn the cylinder plate mounted to the wheel shaft. This will activate the scotch yoke mechanism. If the hollow cylinder is engaged, this converts the rotational motion from the wheel into vertical linear motion of the hollow cylindrical pipe. These cylinder movements create a line of holes to the ground which are simultaneously used as planting spots. As the holes are created, they are simultaneously fed a tobacco seedling and is transferred to the ground through the transplanting cylindrical pipe. The trans-planter moves from the transplanted seedling and continuously repeats the process. The third wheel on this design, will act as a pressing wheel that does some cover up operations for the planted seedlings.

Considering this design an analysis was made and I ended up understanding that considering the irregularities of the field conditions that the trans-planter was going to operate in, a cover up wheel will end up destroying the plants. These semi-automatic trans-planters are made using lighter material so as to facilitate their easy manoeuvre in field conditions. This means that they will be subjected to instability in maintaining planting positions unless the soil is made to a fine tilth. With this instability, introducing pressing wheels will destroy the plants thus disregarding this design. This therefore leads to the proposal of the following design.

3.4 Working principle of the proposed design

3.4.1 Block Diagram

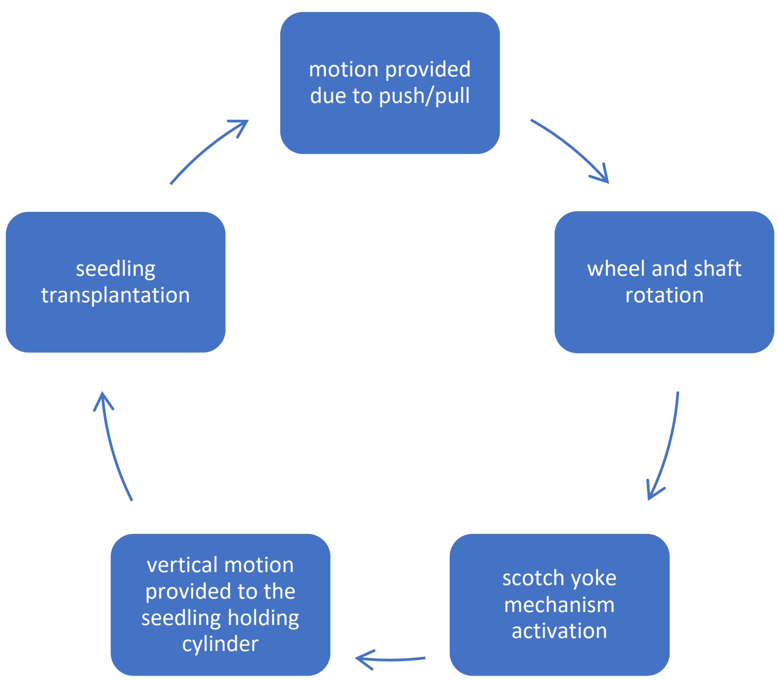


Figure 9: Block Diagram

From the block diagram the system uses human effort through a push or pull. This push or pull will provide motion to the wheels. One of the wheels is interconnected to the shaft causing a rotation of the shaft as well. This in turn, activates a quick return scotch yoke mechanism mounted on the shaft thus converting the rotational motion of the shaft into linier motion of the receiving cylinder or the cylindrical pipe that holds the seedling. The movement of the cylindrical pipe will trigger a spring to open and leave the seedling in the ground. The spring will be mounted on the receiving cylinder and will be controlling the opening gap of the cylinder.

3.5 AutoCAD representation of the system

3.5.1 AutoCAD 2D Display

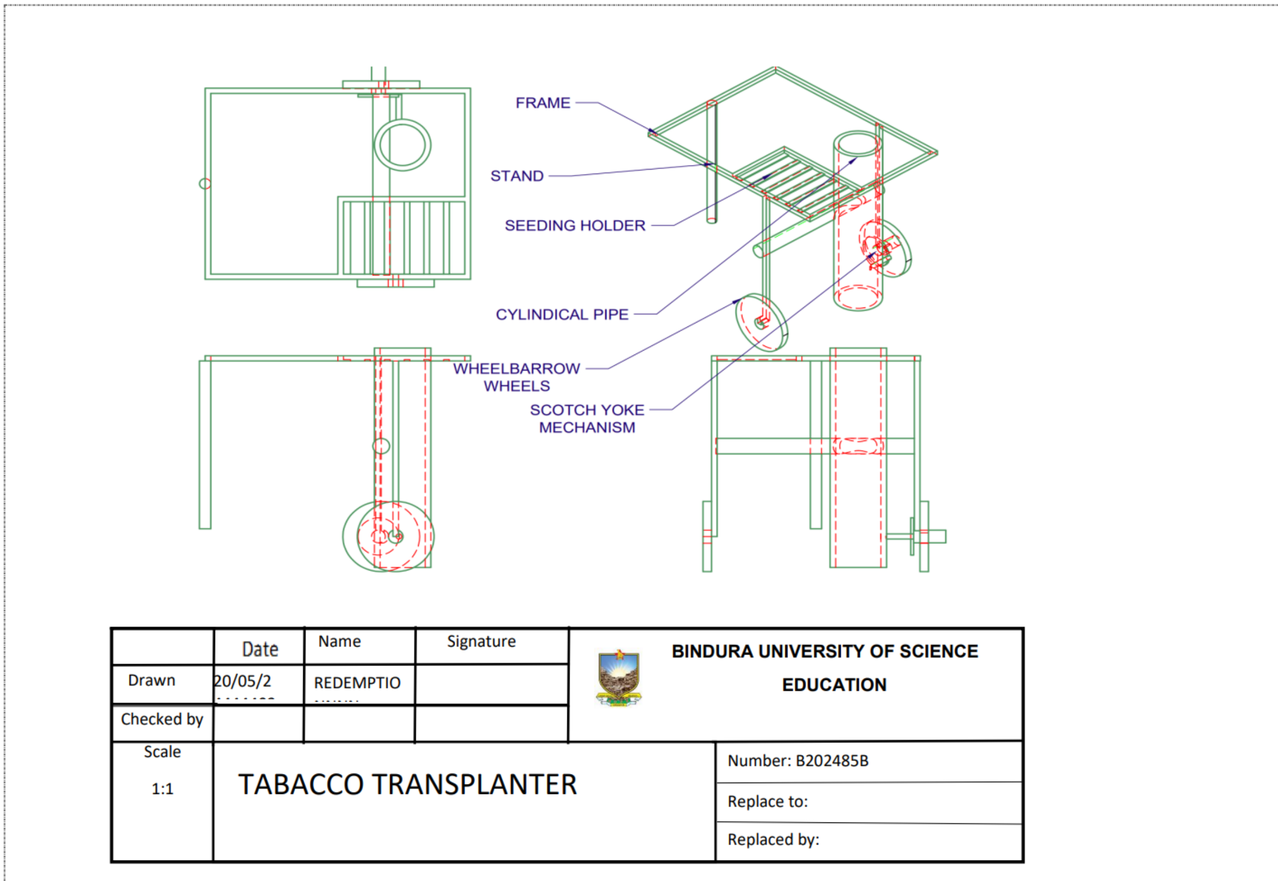


Figure 10: AutoCAD 2D display of system.

The figure above shows the 2D design of the proposed trans-planter. The trans-planter consist of a frame which integrates other machine elements. It shows the main body were other elements are mounted on. It also consist of the cylindrical pipe which opens holes and also injects the plant to the ground. The cylindrical pipe has a bottom opening that facilitate for it to perfectly penetrate the ground so as to allow the plant to be injected into the soil.

A scotch yoke is mounted to one of the wheel. Its function is to convert rotational motion of the wheel and make it linier motion of the cylindrical pipe. On the same diagram, a seedling holder is mounted on the frame and serves the purpose of holding the seeds as the trans-planter is in use. A stand is part of the system and its function is to allow stability when the machine is not in use. A cylindrical supporter is added. Its function is to allow the cylindrical pipe to move through it as it provides guidance to the moving cylindrical pipe so as to maintain linier motion. A clearer display is shown below:

3.5.2 AutoCAD 3D display of the system

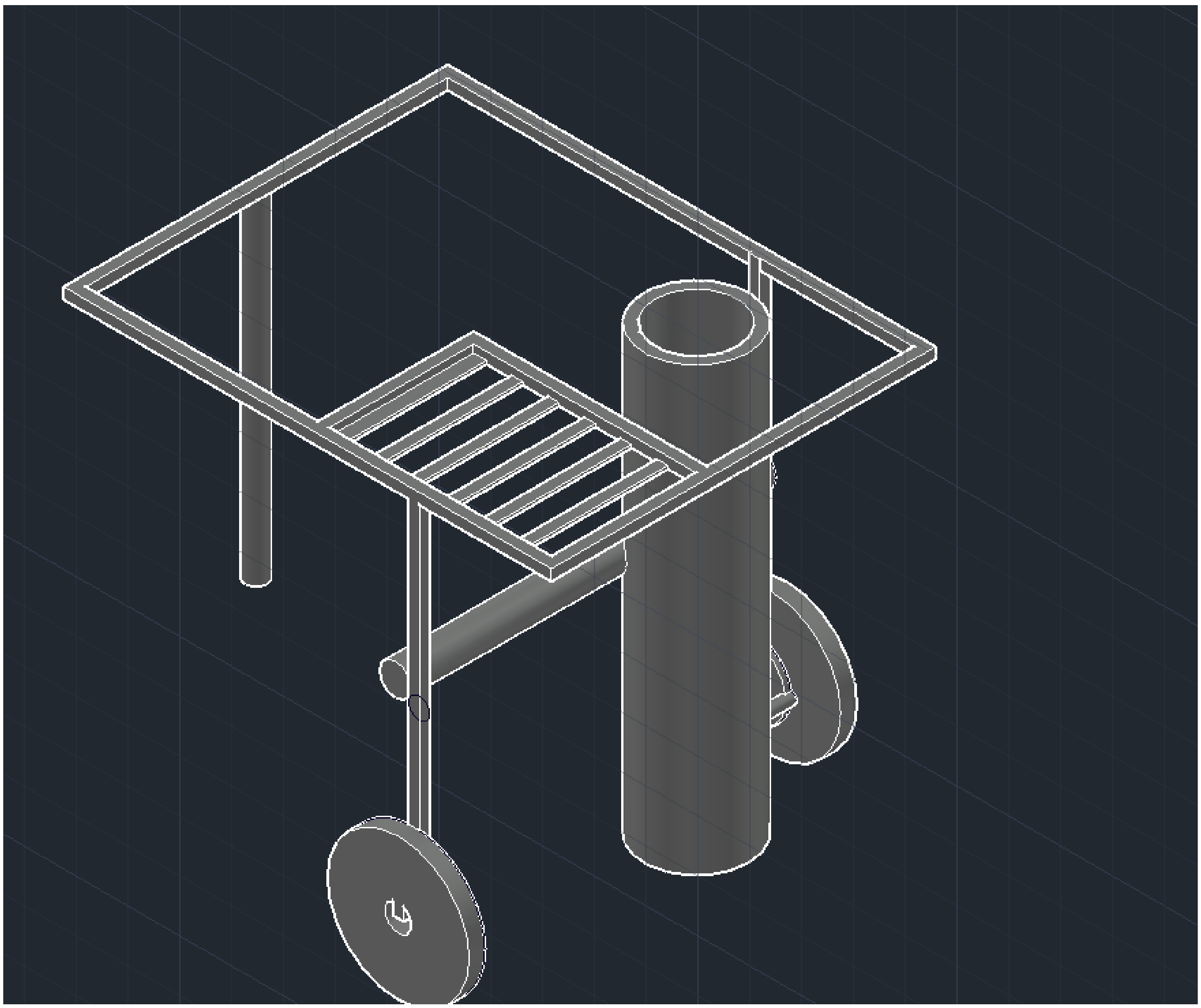


Figure 11: AutoCAD 3D display of System

3.6 Operational framework analysis

The operation of this trans-planter relies on the motion of the wheel. A scotch yoke mechanism is activated by the movement of the wheel. It the transfers rotational motion into linier motion of the cylindrical hollow pipe. Due to the way the pipe is sharpened at the end, it then penetrates the soil hence creating transplanting holes into the ground. These holes are simultaneously planted in the same time. Seed placement in the soil solely depends on the machine operator. This therefore completes the transplanting process.

Scotch yoke Mechanism

Figure 12: scotch yoke mechanism

This scotch yoke mechanism unites the shaft from the wheel with the planting tube via a cylindrical plate. The cylindrical plate acts as a motion convertor thus changing rotational motion into linier motion of the hollow cylindrical tube. This up and down movement of the cylindrical tube opens holes on the ground.

3.6.1 Frame width determination

To establish a well-founded flue cured tobacco trans-planter it is necessary to have a detailed understanding of the requirements and characteristics of its plant species. It is necessary to have a profound understanding of what sets tobacco apart from other plant species thus considering its growth habits, environmental needs and physical attributes. In precision, this means I will bring to book their light requirements, watering needs, temperature range, soil preferences, space requirements, maintaining requirements and propagation methods. Understanding these precise details on tobacco, will determine factors like the machine length, height above the ground, working conditions of the trans-planter, its yield strength thus making it specifically made to suite tobacco production.

Since over 95 % of the local grown tobacco is flue cured, it has been established by different researchers on the recommended in row and inter-row spacing also known as plant spacing. In this context, plant spacing refers to distances between tobacco plants within rows and between rows in the field, but it can also be interpreted as total number of plants and leaves produced within a defined area (Tso, 1990).

In Northern Italy, the recommended number of flue-cured tobacco plants per ha is 24,000 (Cristanini, 2006). This comes as a result of having 115 to 120 cm between rows and approximately 35 cm within rows. Others scholars have argued that such spacing enhances leaf growth towards the row and eases mechanical harvesting. Another study was conducted in the United States of America and it led most American tobacco farmers to have an average of 14 700 plants per hector emanating from a row spacing of 122 cm with approximately 56 cm between plants (Campbell et al., 1980)

Different studies in different areas have brought about different planting specifications. In Croatia flue-cured tobacco is commonly grown at plant spacing of 100 cm between and 45 cm within rows which transcends to a planting density of about 22,000 plants per ha. Closer spacing of plants generally results in a reduction of size, body, thickness, and weight per unit area of the leaf (Tso, 1990). At higher planting densities an increase of yield has been reported by several authors (Chaplin et al., 1968; Collins et al., 1969; Campbell et al., 1982; Collins and Hawks, 1993). However, quality of such leaves was usually lower due to decreased nicotine content (Chaplin et al., 1968; Campbell et al., 1982; Collins and Hawks, 1993). Price of tobacco grown at higher plant densities was also lower, resulting in lower income from such production (Chaplin et al., 1968; Collins et al., 1969; Collins and Hawks, 1993). Collins et al. (1969) and Wu et al. (1971) observed a decrease in total leaf area per plant with increased plant population.

Locally, a study was also carried out to determine the effects of in row and interow spacing by O. Mlambo of Midlands state university and it concluded that nicotine levels in leaves increased sharply at the expense of sugars as spacing increased which increased the recommended tobacco quality. Further research analysed that Nicotine is an alkaloid and it is synthesised in the root tip and transported through the xylem vessels and then deposited in the leaves (Mudzengerere, 2013). The root tip is the source of nicotine while the leaf is the sink for nicotine. So due to closer intra row spacing competition might have occurred for soil water, light, and nutrients and this affected the availability of nitrogen such that nicotine might have been produced in lower or inadequate amounts in the soil (O Mlambo, 2015)

The above analysis further solidifies the importance of inrow and inerrow spacing in tobacco farming. This therefore directly contribute to the design of the machine and poses potential amendments to introduce an adjustable planting device that suits the requirements of different farmers in terms of inrow and inerrow spacing to suit their knowledge.

However, despite all the researchers, a Zimbabwean company Access tobacco farming guide stipulates an interrow spacing of 1.2m and an in-row spacing of 55cm which results into 15000 to 15100 plants per hectare. This therefore establishes the notion that in this project, a higher in row spacing of 55 cm and an interow spacing of 1,2m is going to be used. This will directly affect the machine design, its shaft size, and planting spots thus impacting its functionality.

This company hand-out further stipulated that, ploughing is carried out at a time from 30 to 60 days before transplantation. Ridging is then carried out according to ridge height of 38-42 cm and ridge top width of 30 to 45 cm; ridge bodies are full in plate tile shape or trapezoid, the ridge spacing is 120 m. Healthy strong seedlings are transplanted according to row spacing of 50 cm. The seedling planting depth is 12 to 15 cm and the seedling stalks are 3-5cm higher than the ground from the surface soil to the tobacco seedling growing point after transplantation. Collins and Hawks (2013) have suggested that a high, wide row ridge promotes water drainage away from sensitive tobacco roots, reduces fertilizer losses, and increases soil temperature all of which are beneficial to tobacco growth

Considering the above information, this further establishes the idea that ideally a functional trans-planter should have its wheels spaced by 1.2 m. However, for the purpose of fabrication with the aim of testing and concept checking, a frame width of 70 cm was used. A frame length of 90 cm was also used. Considering usage comfort a height of 1.90 m was used.

Materials used

In the fabrication process, several materials were used and their pictures are displayed below.

Figure 13: 20 mm Square Tube.

Figure 14: 34 mm steel pipe.

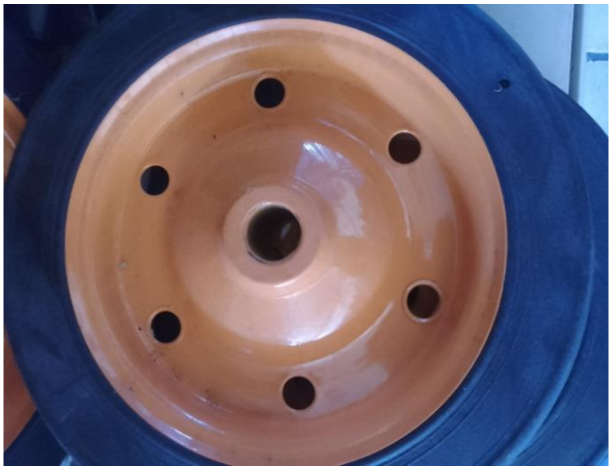


Figure 15: Wheelbarrow wheel.

Figure 16: Wheel and cylindrical plate.

3.6.2 Frame

The frame is the larger part of the machine with the purpose of integrating other machine components and provide support against the weight of other components of the tobacco trans-planter. Mild steel was selected for the fabrication of the machine so as to make use of its hardness, toughness, rigidity, machining characteristics, accessibility as well as affordability. This went well with the functionality because it is readily available within the country and most African countries. Its rigidity also managed to counter the various loads generated due to the machine functionality.

3.7 Fabrication

Figure 17: Fabrication Process

For the sake of this particular publication and resource mobilization during this project, a tubular square tube was cut and welded together to form the frame of the prototype. The frame was made with a width of 70 cm and a length of 90 cm .

A 50 by 30 cm tobacco holder was framed on the frame. The generated load was considered and thus contributing to the wheel placement leg stands and wheels were finally mounted to the frame.

Figure 18: Final Prototype.

3.8 Design Calculations

To come up with the prototype above, the following design calculations were considered:

3.8.1 Weight distribution

3.8.1.1 Seedling weight

Tobacco seedlings are typically transplanted to the field when they reach 4 to 6 weeks of age after seeding (Pearce, 2018). At this stage, the seedlings are around 10-15 cm tall and have developed 4-6 true leaves (Flue-Cured Tobacco Production, 2020). The root system is well-established, allowing the seedlings to better withstand the transplanting process (Miner, 2015).

Proper timing of transplanting is crucial, as transplanting too early can lead to higher transplant shock and reduced survival rates, while waiting too long can result in overgrown, leggy seedlings that are more difficult to handle (Tobacco Production Guide, 2022). The optimal transplanting window is generally considered to be when the seedlings are 4-6 weeks old (Pearce, 2018).

Factors such as tobacco variety, growing conditions, and local climate can influence the specific timing of transplanting (Flue-Cured Tobacco Production, 2020). In some regions, growers may transplant a bit earlier or later than the 4 to 6 week timeframe, but this general stage is considered the optimal window for transplanting healthy, well-developed tobacco seedlings (Tobacco Production Guide, 2022). At this stage, the average weight of the seedlings are 2g to 4g. This means that for the purpose of this publication I will use 4g in weight determination for the trans-planter.

Since the seedling holder can carry 300 seedlings then the weight if the seedlings become:

$$300 \times 4 = 1200\ g\ = \mathbf{1.2\ kg}$$

Converting to Newtons

$$1.2 \times 9.81 = \mathbf{11.772\ N}$$

The seedling holder will be exerting a downward force of 11.772 N. Another downward force will be exerted to the system by the frame and the transplanting cylinder.

3.8.1.2 Cylinder weight

Hollow cylindrical pipe

To calculate the weight per meter of a 50 mm mild steel pipe, we can use the following formula:

Weight per meter = π × (Outer Diameter^2 – Inner Diameter^2) × Density/4

Since:

- Outer Diameter (OD) = 50 mm
- Wall Thickness = 3.2 mm
- Inner Diameter (ID) = OD – 2 × Wall Thickness = 50 mm – 2 × 3.2 mm = 43.6 mm
- Density of Mild Steel = 7 850 kg/m^3

Plugging these values into the formula:

Weight per meter = π × ((0.05)^2 – (0.0436)^2) × 7 850 / 4

Thus:

$$\pi \times (0.05^2 - 0.0436^2) \times \frac{7850}{4} = 3.66 kg/m$$

Therefore, the weight per meter of a 50 mm mild steel pipe is approximately 3.66 kg/m .

To convert the weight per meter of the 50 mm mild steel pipe from kilograms to Newtons, we use the formula:

Force (N) = Mass (kg) × Acceleration due to gravity (m/s^2)

Assuming the standard acceleration due to gravity (g) is 9.81 m/s^2, we can calculate the weight in Newtons as follows:

Weight per meter in Newtons = Weight per meter in kilograms × 9.81 m/s^2

From the previous calculation, we found that the weight per meter of the 50 mm mild steel pipe is 3.66 kg/m.

Plugging this value into the formula:

Weight per meter in Newtons:

$$3.66 \times 9.81 = 35.9\, N/m$$

Therefore, the weight per meter of a 50 mm mild steel pipe is approximately 35.9 Newtons per meter (N/m).

Since the cylindrical pipe is 90 cm then the weight is $0.90 \times 35.9 = 32.3\ N$

3.8.1.3 Frame weight

The standard weight of the 20 mm square tube that I used is 5.364kgs per 6meters therefore:

Outer frame length: $90 \times 2 = 180\ cm$

Outer frame width:$70 \times 2 = 140\ cm$

Inner frame width: $30\ cm$

Inner frame length: $50\ cm$

Legs length: $90 \times 2 = 180\ cm$

Total length of square tube used: 580 cm

Total weight: $\frac{5.8}{6} \times 5.364 = 5{,}185\ kg$

Therefore, total mass: 5.2 kg

Total weight: $9.81 \times 5.2 = 50.8\ N$

Total weight acting on wheels: $50.8 + 32.3 + 11.772 = 94.9\ N$

3.8.2 Bending Moment Diagram

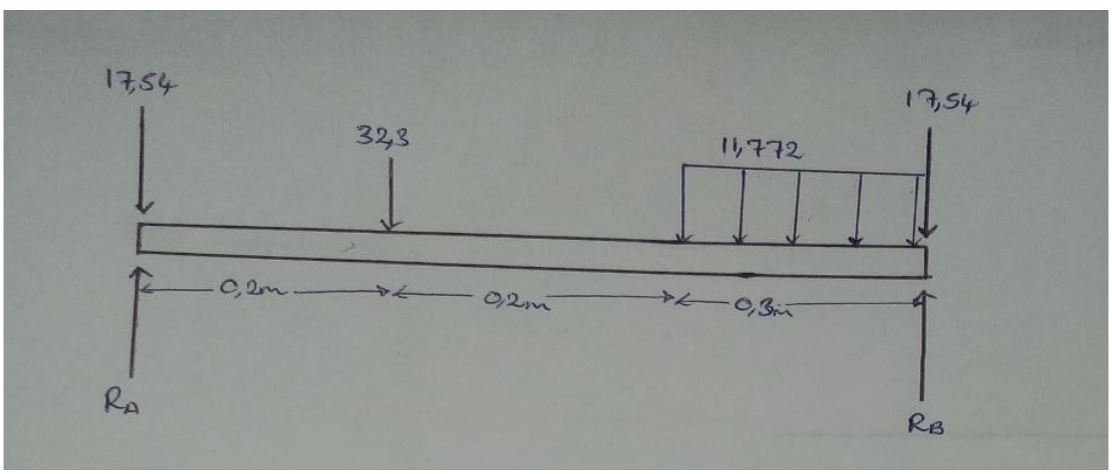


Figure 19: Free body diagram

Neglecting legs length, total frame length =400cm which is 4m

Total mass

$$\frac{4}{6} \times 5.364 = \mathbf{3.576}\boldsymbol{kgs}$$

Total weight

$$3.576 \times 9.81 = \mathbf{35,08}\boldsymbol{N}$$

Total forces on frame including the frame itself:

$$17.54(2) + 32.3 + 11.772(0.3) = \mathbf{70.911}\boldsymbol{N}$$

Calculating Rb:

$$(Rb \times 0.7) = 17.54(0.7) + 11.772(0.3)\left(\frac{0.3}{2} + 0.4\right) + 32.3(0.2)$$

$$= \frac{20.68}{0.7}$$

Therefore: $\boldsymbol{Rb} = \mathbf{29.54}$

Calculating Ra

$$Ra + Rb = 17.54(2) + 32.3 + 11.772$$

$$= 70.912$$

But Rb=29.54:

$$70.912 - 29.54 = \mathbf{41.37}\boldsymbol{N}$$

Therefore, the bending moment diagram becomes:

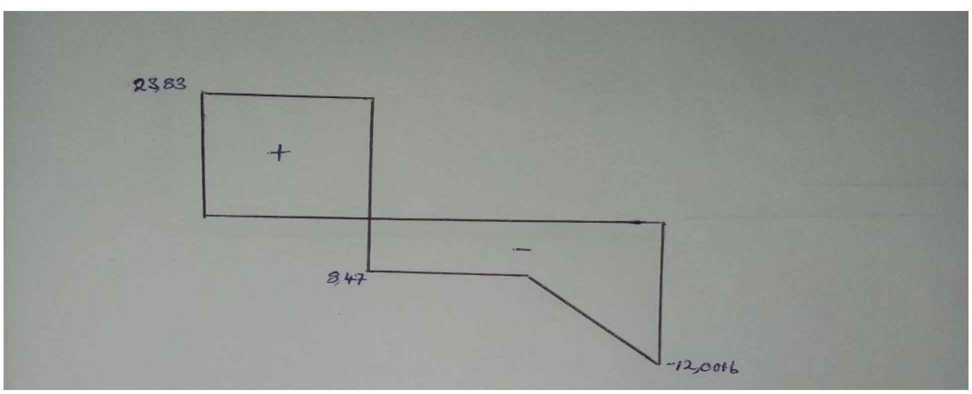


Figure 20: Bending moment diagram.

3.8.3. Determining lifting force required

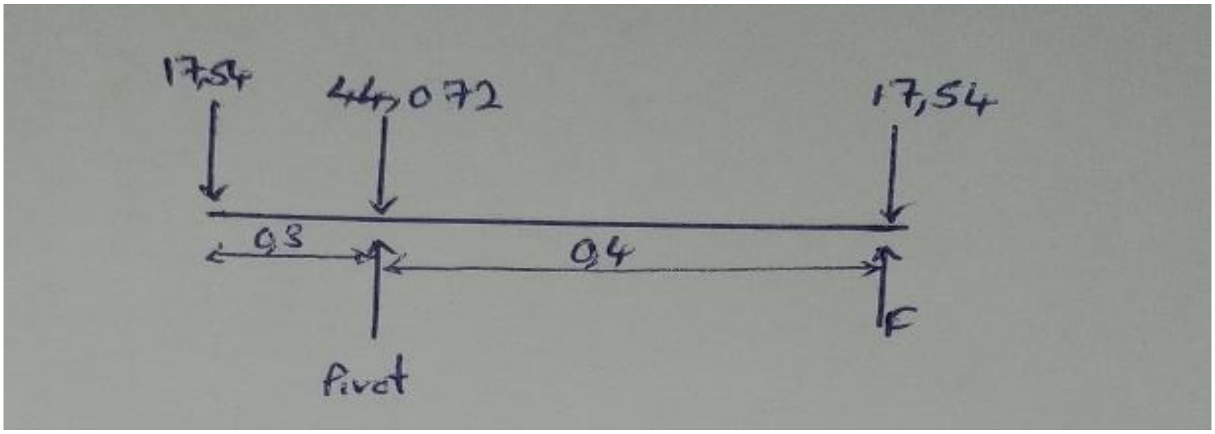


Figure 21: Side view of the system

Taking clockwise moments as positive:

$$17.54(0.4) - F(0.4) - 17.54(0.3) = 0$$

$$\gg 1.754 - 0.4F = 0$$

$$\boldsymbol{F = 4.385N}$$

Therefore, the force required in lifting the trans-planter is **4.385N**

Determining in-row separation

Required in-row separation for tobacco is 55cm therefore the pin that connects the cylindrical plate and the cylindrical tube must be attached at a distance as calculated below

$$\frac{55}{2} = \boldsymbol{27.5cm}$$

This shows that the connecting pin has to be located at a distance of 27.5cm from the centre of the cylindrical plate. As a result, the prototype cylinder plate considered the calculation thus the significance of the holes as shown below. The holes were the ones in which the connecting pin was connected. The holes were placed different distances from the centre of the cylindrical plate so as to facilitate a change in the planting depth depending on what might suit the user. This therefore means that, the depth of the planting holes is adjustable.

Figure 22: Connecting pin holes

3.9 Gantt chart

This displays how events occurred along the manufacturing of the machine and when different tasks were completed.

Table 2: Gantt Chart

Task	March	April	May	June
Quotation of materials				
Purchasing of materials				
Manufacture of machine parts				
Assembly of machine parts				
Machine testing				

4.0 Bill of Quantities

Table 3: Bill of Quantities

Material Make	Specifications	Quantity	Cost $USD	
			Unit	**Total**
Square tube	20 mm	6 m	7.00	7.00
Wheels	Wheelbarrow	2	5.00	10.00
Light flat metal	10 mm	3 m	3.00	3.00
Steel pipe	34 mm	1 m	2.00	2.00
Cylindrical blade	34 mm diameter	1	2.00	2.00
Welding rods	10 guage	20	2.00	2.00
Paint	400 ml	1	2.00	2.00
10 % contingencies				2.80
Total cost				**30.80**

CHAPTER 4

DESIGN ANALYSIS

4.1 Introduction

This chapter entails the considerations that were taken in the manufacturing of the machine design and making of the prototype. It also gives the summary of expected results, the experimental procedure, safety instructions taken prior to machine operation, testing observations and analyses the results obtained. It is concluded by comments on the results obtained and explicitly details the reasons behind the observations.

4.2 General Design Considerations

As entailed in chapter three, the obtained prototype considered various considerations that suit human needs and usage. The following factors were successfully accomplished in the machine design.

4.2.1Safety Consideration of the machine

The machine was designed in a way that enables usage by people of different age range. It was designed in a way that requires minimum effort in its usage and a considerable distance was placed between the cranking mechanism and the operation position. This was done to reduce potential accidents by increasing reaction time in case of a detachment on the planting mechanism. An elongated frame length was made in an effort to reduce feet interference with the vertically moving planting cylinder thus ensuring safe mobility.

4.2.2 Ergonomics

This is the science of the designing of equipment, especially so as to reduce operator fatigue, discomfort and injury. The machine was designed to reduce drudgery encountered in using a handheld trans-planter or doing the actual manual transplanting. In handheld trans-planters users tend to carry seedlings around their necks which is highly uncomfortable and causes high level discomforts especially when working over long fields. Likewise, in the manual hand transplanting, people transplant in an uncomfortable position using small holes that cause massive back pains as explained in chapter 2. Curbing that planting technique where a bad posture was maintained for a longer time was considered in this machine design**.**

4.2.3 Technological Considerations

Accessibility of advanced technology in rural areas was considered. The unavailability and unreliability of electricity in most rural areas across the African continent was considered. The limited availability of internet related systems was considered as well, thus prompting a technologically independent system. That birthed a machine that does not rely on electricity or any other high technology but sorely on human push or pull. This means that the machine can be manufactured under the Zimbabwean technology levels.

4.2.4 Operating conditions

Since tobacco is planted in wet environments, the operation of the machine was made in a way that suits the wet environment. The machine obeys a principle of operation where the wetter the environment, the easier the operation.

4.2.5 Environmental considerations

Environmental considerations were also taken into account. This led to the development of a machine that is non-polluting machine. The machine is a simplified version and does not produce any soot or other environmentally unfriendly components.

4.2.6 Labour requirements

This production took account of the labour requirements that are associated with manual transplanting and the use of handheld trans-planters. As a result, this machine can be used comfortably by 2 operatives. The design also made it feasible for the machine to be used well by one person but in this case, drudgery is experienced after a long usage time.

4.2.7 User specifications / Adjustability

The machine was made in a way to allow adjustments to be made on the circular plate. This changes the in row spacing which suits the variety of tobacco being planted. This gives the machine a provision to be involved in horticultural vegetable transplanting.

4.2.8 Ease of maintenance, cleaning and repairs

Designing this machine considered the ease of maintenance, manufacturing and repairing. The design was made using locally abundant material and can be maintained easily. This machine was easy to assemble and is easy to clean and repair.

4.3 Expected results:

- The trans-planter is to provide an upgraded planting speed and productivity as compared to manual transplanting.
- The trans-planter is to provide improved accuracy and consistency
- Higher plant survival and establishment
- Reduced fatigue in its usage as compared to manual transplanting
- One man usage of the trans-planter

4.4 Performance evaluation of the machine

After carefully considering various aspects in the design of the machine, a performance evaluation was conducted. The evaluated components included the planting ability of the machine and results were obtained from its operation. Additionally, the planting speed of the machine was compared to manual transplanting to determine if there were any advantages in using the machine over the traditional manual method. Manual transplanting was chosen as the comparative aspect because it is the predominant transplanting technique currently used in Zimbabwe. This performance evaluation followed established procedures, and the results were carefully documented.

The first experiment (Experiment 1) conducted involved checking the transplanting performance and checking its functionality. Another experiment was then done so as to determine the planting speed performance of the manually operated trans-planter as compared to manual hand transplanting. The latter experiment was labelled experiment 2. These were conducted to completely fulfil the objectives of this design. The performance evaluation was done in anticipation of the results mentioned below.

4.4 Experimental procedures

4.4.1 Experiment 1

The experiment started by preparing the transplanting area. The area was selected based on its capacity to best emulate or replicate field conditions. The considerations that were taken into account included reduced compaction or loose, friable soil structure, well-aerated soil surface with a slightly uneven appearance, incorporation of organic matter, reduced weed presence, and potentially variable soil moisture conditions. Since the experiment was conducted at a school facility, the best available area that closely matched these conditions is presented below.

Figure 23: Experiment 1.

The trans-planter was brought to the selected experimental sight and was operated at the planting area. Vegetable seedlings were used in place of tobacco since the experiment was done post tobacco seedling time. Planting depth, spacing and the operation ability of the trans-planter were considered and results were documented. Seed damage was also taken into account. A series of tests were done so as to critically analyse the functionality of the trans-planter and the end result.

4.4.2 Experiment 2

Prior to seeing the results after caring out experiment 1, I proceeded to organise another set of tests and the procedure was as follows:

Objective:

To compare the planting speed performance of my manually operated semi-automatic trans-planter against manual hand transplanting.

Experimental Design:

A field trial was conducted. An experimental area was set up. As in experiment 1, the chosen area also emulated actual field conditions**.**

Transplanting Procedure

Manual hand transplanting

- An experienced farm worker in tobacco transplanting was taken to perform the manual hand transplanting.
- The worker followed standard techniques, including creating planting holes, placing seedlings, and firming the soil around each plant.
- The number of transplanted plants in a minute were recorded.

Manually operated Semi-Automated trans-planter

- A single operator used the trans-planter to plant
- Operation for the trans-planter was being done by one operator thus meaning, the placing of the seedlings into the planting mechanism and the pushing of the trans-planter
- Number of plants per minute were recorded.

Data collection:

- A series of trials were done so as to average the values in order to increase results accuracy**.**

Table 4: Results Obtained

Trial	MHT (plants/min)	MOSA (plants/min)
1	52	85
2	48	82
3	55	80
4	50	87
5	53	90

MHT: Manual Hand Transplanting

MOSA: Manually Operated Semi-Automated Trans-planter

4.5 Results:

4.5.1 For Experiment 1

Results obtained on the functionality of the trans-planter showed that the trans-planter transplants very well. The trans-planter managed to transplant all the seedlings well and properly imbedded them into the ground.

Figure 24: Transplanting results

This trans-planter had a transplanting depth of 7 cm. Seedlings were firmly placed into the soil. Further analysis showed that the transplanted positions did not have holes but rather a line where the trans-planter had passed through. This can be considered an advantage since the created line catches moisture.

4.5.2 Experiment 2

For the 5 trials that were tried, the results obtained were tabulated and are as shown below:

Table 5: Experiment 2 Results

Trial	MHT (plants/min)	MOSA (plants/min)
1	52	85
2	48	82
3	55	80
4	50	87
5	53	90
Total	258	424
Average	51.6	84.8

MHT: Manual Hand Transplanting

MOSA: Manually Operated Semi-Automated Trans-planter

4.6 Results Evaluation and analysis

4.6.1 Experiment 1

Due to the mechanism used, noticeable lines were produced on the planting spots and these were created due to the extended drag of the transplanting cylinder as it comes into contact with the ground.

Figure 25: Results Display.

The way the bottom of the transplanting cylinder was cut transplanted in a way that created a void or a low pressure area as it makes contact with the ground. This low pressure area created, forced the side soil to close the plant as soil tries to cover and return itself to its original position. This was made possible by the design of the end of the transplanting cylinder that engages in the soil.

This particular trans-planter required more pushing power. This was because of a lack of bearings thus relying on greasing the pushing power. Due to financial constraints, this prototype required a higher operating power. In actual field conditions this will cause massive frictions because there is a higher dust generation and soil engagement which will cause soil to be imbedded between the wheel and the shaft. If not managed, this will strongly affect the operation of the trans-planter since the planting capacity depends on the rotational motion of the wheel.

4.6.2 Experiment 2

From the result table presented in experiment 2, the following graph was generated

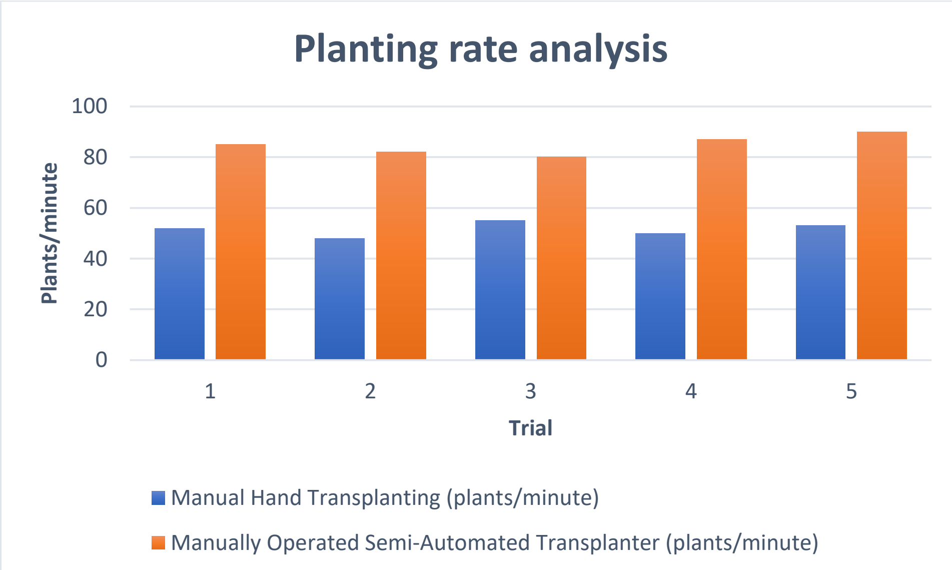


Figure 26: Planting rate analysis.

The trans-planter dominated in all aspects of the transplanting trials. Despite the rate and expertise displayed by the hired trans-planter who was transplanting by hand, the trans-planter was dependent on the speed of the operator. In these trials, the transplanting pace of the manual labourer was still high because he was not yet tired, this means that with a number of trials the manual labourer would have been more tired as compare to the person using the semi-automatic trans-planter. This would suggest a reduction in the operations of the manual labourer thus an increase in the transplanting margin between the two.

Subtracting the average plant different per minute:

$$\mathbf{84.1 - 51.6 = 33.2}$$

This shows that, in every minute the semi-automatic trans-planter transplants 33 more seedlings than manual transplanting. This then leads to a transplanting advantage of 33plants in one minute. Mathematically, this means that in a period of 1 hour under strict working without resting for both the worker and the trans-planter operator the, trans-planter would have planted:

$$\mathbf{33.2 \times 60 = 1992}$$

1992 are the plants that would have been planted by the trans-planter more than using manual labour. 1992 tobacco seedlings justifies a length of 55 cm.

$$\frac{number\ of\ plants}{inrow\ spacing} = \frac{1992}{55} = 36.21\ m$$

This means that, given the same starting time between the manual trans-planter and the semi-automated trans-planter, after an hour operating time, the person with the semi-automatic trans-planter will be ahead by approximately 36.21 m .

4.7 Variables likely to affect the machine

A rocky field will affect the operations of the trans-planter. This is due to the idea that, wheel motion is affected in rocky areas which will highly affect in-row spacing of the tobacco. Rocks may even side-line the machine which will affect the linearity of transplanted tobacco display.

The texture, moisture content, and compaction level of the soil in the transplanting area can significantly impact the performance and efficiency of the transplanting process. Soil Texture, refers to the relative proportions of sand, silt, and clay particles in the soil.

A well-balanced, loamy soil texture is generally ideal for transplanting as was used in this experiment, as it provides a good balance of drainage, water-holding capacity, and aeration. Excessively sandy or heavy clay soils can present challenges, such as difficulty in maintaining proper planting depth or seedling establishment.

In the same context, the optimal soil moisture content for transplanting is typically within the range of 50-80 % of the soil's water-holding capacity. If the soil is too dry, it can be difficult for the trans-planter to create the necessary furrows or openings for the seedlings, and the seedlings may struggle to establish roots. If the soil is too wet, it can become compacted and sticky, leading to problems with the planting mechanism and uneven planting depth.

Another factor to consider is the soil compaction. Compacted soils can present significant challenges for transplanting, as the planting mechanism may struggle to penetrate the dense soil and create the necessary openings for the seedlings. These soils are likely to harm the trans-planter as they impede the movement of the engaged seedling cylinder.

Loose, well-aerated soils are preferred, as they allow the trans-planter to create uniform planting furrows and ensure proper seedling placement and root development. These factors impact the planting depth, seedling placement and seedling establishment. By carefully considering and managing the soil conditions in the transplanting area, the efficiency and effectiveness of the transplanting process can be optimized, leading to better plant growth and overall productivity.

Chapter 5

5.1 Introduction

This chapter entails the conclusion derived from the various findings detailed in the previous chapter. It gives the recommendations for other members of academia to explore and also the areas of further study then the references.

This chapter entails the conclusions drawn from the findings detailed in the previous chapter. It offers recommendations for other academics to explore, as well as areas for further study. Finally, the chapter is then followed by the reference list.

5.2 Conclusion

The trans-planter that facilitates one man usage was developed, a prototype was made and the functionality of the trans-planter was tested. The data and experimental comparison indicate several noteworthy conclusions regarding the semi-automatic trans-planter. The results demonstrate that the trans-planter achieves higher efficiency and labour savings compared to manual transplanting methods. This is evidenced by the fact that the trans-planter only requires a single operator, whereas manual transplanting necessitates a team of workers.

The increased efficiency and reduced labour requirements of the semi-automated transplanting approach can translate to significant cost savings and improved productivity for agricultural operations. By minimizing the human resources needed while maintaining high output, the semi-automatic trans-planter offers an economically viable alternative to traditional manual transplanting practices.

Overall, the data analysis supports the conclusion that the semi-automatic trans-planter represents a technologically advanced and operationally superior option for farmers and agricultural producers. The demonstrated advantages in efficiency, labour reduction, and cost-effectiveness underscore the value that this innovative transplanting system can provide to improve the productivity and profitability of crop cultivation.

In uniform field conditions the trans-planter offers uniform transplanting accuracy and has very low plant mortality rates. The tested trans-planter removed all mortality expectations because of the way the transplanting cylinder is shaped.

Despite the abundance in advantages, it should be noted that the trans-planter requires further research and optimization. Additional research and field trials are necessary to fully evaluate the performance and suitability of this semi-automated trans-planter. Environmental conditions, and farming practices need to be considered as well. Continuous improvements to the semi-automated technology, such as enhanced automation, precision controls, and maintenance considerations, could further enhance its benefits over manual transplanting.

Overally, the development and use of a semi-automated trans-planter technology appears to offer significant advantages in terms of improving planting accuracy, reducing plant mortality, and increasing operational efficiency compared to traditional manual hand transplanting methods. These benefits can contribute to enhanced crop yields, productivity, and cost-effectiveness for agricultural operations

Recommendations

It is imperative that based on the conclusions drawn from the comparison between the manual hand transplanting and the semi-automated trans-planter, here are some key recommendations that could be made and these include the optimization of the semi-automated trans-planter design. This means that other developers should take out the design and continue to refine and enhance the technology based on feedback and field performance. Improvements can be made in areas such as introducing automation and precision control features, expanding its compatibility with wider range of crop types and field conditions. Other enhancements may include the development of tractor drawn tobacco trans-planters so that the technology advances to commercial farmers as well.

Provide training in semi- automated trans-planters and support for adoption must be made. Comprehensive training programs need to be done so as to equip farmers with the technology in-order to enhance productivity by increasing land utilization. This includes going global with the tested designs and establishing a network of service and support centres to assist with maintenance, and any technical issues that may arise. Encourage the development of user manuals, tutorials, and technical documentation to facilitate the smooth adoption of the new technology.

I recommend that further conduct further research and evaluation. This includes encouraging field trials and comparative studies be conducted to assess the long-term performance and suitability of the semi-automated trans-planter across diverse crop types, environmental conditions, and farming practices. Considering the importance of the development of this trans-planter, it is beneficial to explore opportunities for collaboration between researchers, manufacturers, and farmers to continuously improve the technology and its integration into agricultural operations. This should be done while promoting environmental productivity and not disintegration.

Areas of further study

The integration of electrical energy in the advancement of the trans-planter. This will encompass all large scale farmers as more work tends to be done in a short time. Based on the comparative analysis and conclusions drawn from the semi-automated trans-planter project, here are some key areas that could be recommended for further study and research. By pursuing these areas of further study, researchers and stakeholders can continue to enhance the performance, efficiency, and adoption of the semi-automated trans-planter technology, ultimately contributing to the advancement of sustainable and productive agricultural practices.

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