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# Design and Fabrication of IOT Based Flame Weeding Machine

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**ABSTRACT**

Weeding is a crucial practice in agriculture, aimed at removing unwanted plants from cultivated areas. It can be done using mechanical, chemical, or non-chemical methods. Flame weeding is a modern and efficient non-chemical method that is particularly effective at killing weeds in their early growth stages. The main purpose of flame weeding is to remove weeds from agricultural land before sowing. Traditional flame weeding machines available commercially require manual effort. However, this paper describes an automated flame weeder. The interface between the weeder and the operator is controlled by a mobile application called Blynk, which allows for controlling movement and flame activation. This technology enables the eradication of weeds without the need for manual entry into the fields. The automated flame weeder quickly eliminates weeds by subjecting them to intense heat. It is powered by LPG (Liquefied Petroleum Gas) due to its easy accessibility. The process involves the curling and subsequent death of the weeds after flaming.

**Keywords:** Weeding, Mechanical weeding, Chemical weeding, Non-chemical weeding, Flame weeding, Blynk Mobile application, LPG (Liquefied Petroleum Gas), Weed eradication, Weed control, Intense heat, Curling.

## INTRODUCTION

Flame weeding, a method developed in the late 19th and early 20th centuries, involves passing flames over weed-infested areas to kill weeds without harming crops. It saw a resurgence in the 1980s and 1990s, especially among organic farmers and those seeking alternatives to chemical weed control. The technique directs a flame at weeds, causing them to wilt and die, offering a natural and eco-friendly alternative to chemical weed killers. Advancements in technology have led to various models of flame weeders, from hand-held to battery-powered, catering to different farming operations and scales. While historically more prevalent in regions like North America and Europe, flame weeding's adoption is increasing worldwide. The flame weeder is fueled by LPG gas and ignited using a spark or pilot light. Operators direct the flame toward the weeds, moving the wand back and forth to ensure all weeds are exposed to the heat, effectively dehydrating the plants. Flame weeding is effective against a wide variety of weeds and can be used in various settings such as lawns, gardens, and agricultural fields. Safety guidelines should be followed to prevent fires, and results obtained from using a flame weeder can be compared with other research in discussions.
Mike Collins has done an experiment on thermal weed control. The paper states that in recent years have seen a resurgence in "flame weeding" and the emergence of other heat-based weed control methods. This paper examines the impact of heat on plants and reviews various techniques for applying heat to weeds, such as hot water, steam, hot air, hot foam, and enhanced flame weeders. It concludes by assessing the potential of these methods in Australia (1999).
Steve Diver upon conducting an experiment on flame weeding for vegetable crops concluded that pre-emergent flaming, like the stale seedbed and peak emergence techniques, targets weeds before crop emergence, while post-emergent methods direct flames away from crops to target weeds selectively. Techniques such as cross flaming, parallel flaming, and middle flaming are used for post-emergent weed control, often in combination with mechanical cultivation. Other thermal weed control methods include infra-red weeders, steam, and hot water weed control. Infra-red weeders heat ceramic elements or steel plates to high temperatures, causing wilting and death in weeds. Steam and hot-water weed control offer flame-free alternatives, particularly in

regions with fire hazards. However, affordability and availability of small-scale equipment remain challenges, leading farmers to explore innovative solutions or collective ownership arrangements for access (2002).
Johan Ascard experimented on effects of the angle of burner during weed control. This study investigated the impact of flame outlet angles on small weed control in the field. Burners were angled at 45° and 67° forward, backward, and then 90° straight down. The 67° angle directed backward resulted in the highest reduction of weeds, but overall, there were no notable differences between burner angles. Weeds with the protected growing points were more tolerant to flames, while those with sensitive leaves and exposed growing points were more susceptible. In the laboratory, temperatures in the flame were measured 1 cm above the ground with the same burner angles and speed used in the field. Although there were noticeable temperature differences between angles of the flame outlet, there was no correlation between these thermal parameters and control of weeds in the field. This suggests that evaluating thermal weeders based on measurements including temperature may not be reliable (2008).
Charles N Merfield *et al…,* conducted experiment on direct-fired steam weeder. The study states that flame weeders are valuable for organic and non-organic growers, especially as herbicide options decrease. However, they have drawbacks like low energy efficiency, reduced performance in wind, and fire risk. Steam weeders are considered superior, but it has been a challenge producing enough steam on tractor-mounted equipment. A solution is the 'direct-fired steam' weeder, which sprays water into hot exhaust gases, creating steam without needing a pressurized system. This design can use diesel or renewable fuels like vegetable oil, addressing environmental concerns. Commercial production of these steam weeders has started in New Zealand (2009).
Miroslav Mojzis *et al…,* experimented on weed control effectiveness. This paper addresses the challenges and factors influencing the effectiveness of flame weeding mechanism as a non-chemical weed control method. It highlights the importance of precise parameter settings influenced by factors like weed species, growth stage, weather, crop type, and heat absorption by plants. Field trials confirm the need for precise parameter settings to achieve optimal weed control (2013).
Reihaneh Loni inferred *et al* that weed management is a significant challenge in producing organic crop. This study is aimed to design, and evaluate a targeted-distinct flame weeder in the laboratory and compare continuous flame weeding with targeted flaming of inter-row weeds in an organic maize field.
In laboratory tests, the optimal height and angle of burners, including the precision and accuracy of the targeted flamer, were evaluated at three ground speed levels (0.5, 0.7, and 0.9 m/s). Field experiments investigated the effects of the similar ground speed levels at three maize growth stages (V4, V6, and V8) on fuel consumption and weed eradication. The lab tests determined that the optimal position for flame outs was 25 cm above the ground level and inclined at 30° for accurate targeted flaming. During field trials, both targeted and uniform flaming showed same results in eradication of weeds, but targeted flaming had significantly lower fuel consumption. Additionally, weed control one day after flaming was significantly lower than three days after flaming, and the first flaming was more effective than successive flaming. This study suggests that targeted-distinct flame weeding with machine-vision technology is a potential alternative to flaming uniformly, offering lower fuel consumption and air pollution (2014).
Steven Z Knezevic states that flaming for vegetation control dates to the mid-1800s, using heat to damage or kill plants. The critical temperature for mortality of leaf is between 55°C to 70°C. Heat injures plants by disrupting membrane permeability, breaking down the cuticle (leading to desiccation), denaturing proteins, boiling water inside tissues, and causing chemical decomposition. Flaming can effectively control weeds in organic crop production for several agronomic crops if done correctly at the most tolerant growth stage. However, it shouldn't be the only method for weed control but rather part of integrated approach. Still other measures are necessary to manage weeds throughout the season (2016).
Mohamed Abdelaziz balah in his study evaluated a locally made flaming weeder machine, assessing its performance across different gas pressures, flame heights, and travel speeds in terms of field capacity and efficiency for weed control in organic olive and apple agriculture. The most effective parameters were found to be double burner rows, a travel speed of 0.6 km/h, 2 bar gas pressure, and a flaming height of 15cm, with gas consumption of 40kg/fed. Flaming demonstrated favorable outcomes in both narrow and broad-leaved weeds when contrasted with perennial weeds. The efficacy of weed control was observed to escalate with reduced travel speed, increased gas pressure, and elevated burner height. Future research is recommended for designing suitable burners and sensors to ensure regularity of fire and avoid harm to economic plants (2016).
Electra kanellou *et al* on his experiment on flame weeding at archeological sites of mediterranean regions concluded that at Mediterranean ancient sites, flame weeding was investigated as a potential substitute for the application of herbicides in the control of weeds. Two propane doses (99 kg $ha^{-1}$ and 129 kg $ha^{-1}$) administered twice, thrice, or thrice were tested at three Greek sites: Early Christian Amfipolis, Ancient Messene, and Kolona. Both weed heights and the percentage of weed suppression were greatly impacted by flame treatments. According to the study, a four-time application of 129 kg $ha^{-1}$ of propane resulted in good weed control (>90%) for more than two months. Compared to grasses and permanent broadleaf plants, fire was a more effective way to control annual broadleaf weeds. Flame weeding may be an effective method of controlling weeds in Mediterranean archeological sites, as evidenced by the fact that the archeological site managers wanted the average vegetation height to be around 10 cm, which was achieved by applying a high dose of propane four times (2017).

M.Mojzis *et al* inferred that physical weed control methods like solarization, mulching, electricity, steam, and flame weeding are gaining popularity in organic crop production. Flame weeding, particularly in vegetable cultivation without chemical treatment, is widely used. Although more expensive than chemical spraying, the added value of bioproducts can offset the costs. However, cost remains a factor hindering wider adoption. Optimizing flame weeder parameters such as burner angle, height, gas pressure, speed, weed growth stage, species, and climate conditions can enhance weed control efficiency. Field and laboratory tests in Canada and Slovakia aimed to confirm the influence of these parameters on flame weeding effectiveness (2017).

Steven ZK has done an experiment of flame weeding in agronomic crops. Flame weeding utilizes heat to boil water inside plant tissues, causing plant death. Machines called "weed flamers" deliver propane-fueled heat to achieve this. Various systems are available, from handheld for home gardens to tractor-pulled for larger areas. It's effective in several crops when done at the right growth stage (2017).

Lara Abou Chehade *et al* in their study aimed to develop a weed control strategy for organic garlic production in Liguria, Italy, using flaming as an additional tool. Different flaming doses and timings were tested, with one flaming treatment at BBCH 13 stage showing effective weed control. Frequent flaming didn't significantly reduce weed biomass. Flaming at doses higher than 16 kg·ha−1 LPG resulted in better garlic production compared to the weedy control, with similar yields to hand weeding. Garlic tolerated up to three flaming treatments without yield decline. Integrating flaming with other mechanical tools could provide economic savings in weed management (2018).

AlonHoresh *et al* investigated the efficacy of liquefied petroleum gas (LPG) flaming as a weed control technique for both direct-seeded onion seedlings and transplanted onion bulbs, both before and after emergence. They compared cross-row flaming, which targets the intra-row area from both sides of the row, with broadcast flaming for bulb onion. The findings revealed that cross-row flaming conducted twelve days after planting did not significantly impact onion dry weight, whereas broadcast flaming resulted in a 36% reduction in plant dry weight compared to the control group. The angle and inter-burner distances of the tested burners had no impact on weed control efficacy for the cross-row technique. Similar control levels (55% to 45%) were observed 15 cm from both sides of the row center. Direct-seeded onion cultivars showed varying tolerance levels to flaming treatment across different growth stages, with the pre-crop-emergence stage being completely safe for the crop. The study demonstrated the potential of flaming as a post-emergence weed control tool for onions, suggesting cost savings and potential benefits for organic farming. Future research should explore sequential applications and complementary control methods for the initial growth stages (2019).

Mehrdad Hassani *et al* inferred that weed control is crucial for maintaining crop yields, but traditional chemical methods can have negative environmental impacts. Thermal control, such as flame weeding, is a more environmentally friendly option. A study evaluated the efficiency of a flame weeding method for eliminating weeds near the row at different driving speeds and liquid gas consumption levels. The flame weeder was attached to the rear end of an offset tractor and had a sidewall to prevent direct contact with crop plants. The study used split-plots and a controlled movement speed experiment (low, medium, high) and liquid gas consumption (low, medium, high). Results showed interactive effects between speed and gas consumption on weed control in sugar beet and corn. Weed control rates varied significantly with different speeds and gas consumption levels, with weed control decreasing as speed increased and gas consumption decreased. Broadleaf weeds were more effectively controlled than needle leaf weeds. The study suggests an negative correlation between gas and speed consumption, with lower speeds and higher gas consumption leading to better weed control (2020).

Milos Rajkovic *et al* did an experiment on corn production using flame weeding. This inferred that flame weeding is a cost-effective supplement to traditional weed control methods in maize production using organic methods. A study compared inter-row cultivation, hand hoeing, and flame weeding using both prototype and commercial flame-weeding machinery. While hand hoeing yielded higher (8.3 t/ha) but costly results, flame weeding reduced costs per hectare. The flame weeder showed better economic returns (€489.39/ha) compared to the Red Dragon flame weeder (€456.47/ha). Additional hand hoeing to enhance flame weeding efficacy wasn't justified economically, as the costs didn't match the yield increase. Flame weeding's economic benefits would be more significant in larger fields (2021).

Andrzej Borowy in his study aimed to assess glufosinate-ammonium spraying, flame weeding, and nighttime soil tillage for weed control in summer savory. After soil cultivation and application of treatments, including flaming and glufosinate-ammonium, weed emergence was suppressed but new weeds appeared afterward. Three weeks later, plots treated with flame weeding and glufosinate-ammonium had significantly fewer weeds compared to the control, irrespective of nighttime tillage. However, weed infestation, plant height, and herb yield were unaffected by the methods. Oil content in the herb varied annually but wasn't influenced by weeding. Control plant oil contained primarily carvacrol and gamma-terpinene (2022).

A Upadhyay *et al* summer season experiment at Junagadh Agricultural University in India, flame weeding, mechanical weeding, and hand weeding were compared. Flame weeding showed higher weed control efficiency (91.10%) compared to mechanical (78.26%) and hand weeding (98.06%). Operational time was lowest for flame weeding (13.24 man-h/ha), followed by mechanical (80.56 man-h/ha) and hand weeding (255.75 man-h/ha). Energy consumption was highest for hand weeding (501.27 MJ/ha), followed by flame (2500.24 MJ/ha) and mechanical weeding (157.89 MJ/ha). Flame weeding also had the lowest operational cost (4754.62 ₹/ha), followed by mechanical (3180.01 ₹/ha) and hand weeding (9590.79 ₹/ha). Considering labor requirement and operational cost, flame weeding outperformed mechanical anhand weeding methods (2021).

The use of heat-based weed control methods, such as flame weeding, provides alternatives to chemical herbicides by enabling precise targeting and integration with other techniques. Optimization of parameters including burner angles and fuel usage enhances effectiveness while lowering environmental impact. Though economically feasible, affordability of equipment and crop tolerance present challenges.
Upon review, thermal weed control offers promising solutions for sustainable agriculture. Methods such as flame weeding allow for targeted treatment of weeds without broad application of chemicals. Continued refinement of technology and operating parameters can improve control and reduce costs. While crop safety requires further evaluation, heat-based approaches present opportunities to minimize herbicide use. Overall, additional research and technological advancement may help address remaining issues to realize the potential of these thermal control methods.

## MATERIALS AND METHODS

### Basic components of machine

IoT based flame weeding machine consists of the following components to full fill the requirement of complete operations of the machine.

### 2.1 PNEUMATIC TYRES

The use of pneumatic tires in a flame weeder enhances mobility, stability, adjustability, versatility, and transportability, making it a valuable tool for weed control in agricultural settings. Pneumatic tires offer excellent mobility and manoeuvrability, allowing the flame weeder to navigate various terrains, including uneven or rough surfaces commonly found in agricultural fields. The tires absorb shocks and bumps, providing a smoother ride and reducing operator fatigue during weed control operations.

### 2.2 CYLINDER

The cylinder's design, with a capacity typically around 5kg, facilitates portability, enabling easy transportation and installation of the flame weeder across various locations within agricultural fields. Connected to the combustion system, it supplies fuel to the burners via hoses and regulators, ensuring a consistent flame. This setup allows for continuous operation during extended weed control sessions, minimizing downtime and maximizing efficiency.

### 2.3 LPG GAS

LPG serves as the primary fuel source for generating the flame in a flame weeder. LPG is a mixture of propane and butane, and its composition makes it suitable for combustion in agricultural applications. LPG cylinders provide autonomy to the flame weeder, allowing it to operate for extended periods before needing a refill. When the LPG in the cylinder is depleted, it can be easily refilled or exchanged for a full cylinder

### 2.4 FUEL TUBES

The fuel tube in a flame weeder serves as a conduit for delivering fuel, typically liquefied petroleum gas (LPG). Once the fuel reaches the burners or nozzles, it mixes with air in the correct proportion to support combustion.

### 2.5 DRIVE GEARS

Drive gears are mechanisms that transmit power from the engine or motor to the wheels or other moving parts of the flame weeder. Drive gears contribute to the precision of flame weeding operations by ensuring consistent application of heat to targeted weed-infested areas.

### 2.6 ADJUSTMENT ROD

The adjustment rod in a flame weeder is a component that allows operators to fine-tune the height or angle of the burner assembly relative to the ground. This adjustment capability is essential for optimizing the effectiveness of flame weeding while minimizing the risk of crop damage or incomplete weed control.

### 2.7 Y SHAPED BRASS CONNECTOR:

The Y-shaped connector is likely used to split the fuel flow into two branches. This allows the distribution of fuel to multiple burners or flame delivery points. By dividing the fuel flow using a Y-shaped connector, the flame weeder aims to achieve uniform heat application. This design ensures that each burner receives an equal and controlled supply of fuel, contributing to even weed control.

### 2.8 MICROCONTROLLER

This is ESP WROOM 32 MCU Module. These Microcontrollers can be programmed to control the ignition process of the flame weeder. They can manage the timing and duration of the spark generation, ensuring precise ignition of the fuel-air mixture at the burners or nozzles. This helps optimize combustion efficiency and reduce fuel consumption.

### 2.9 DC Motor

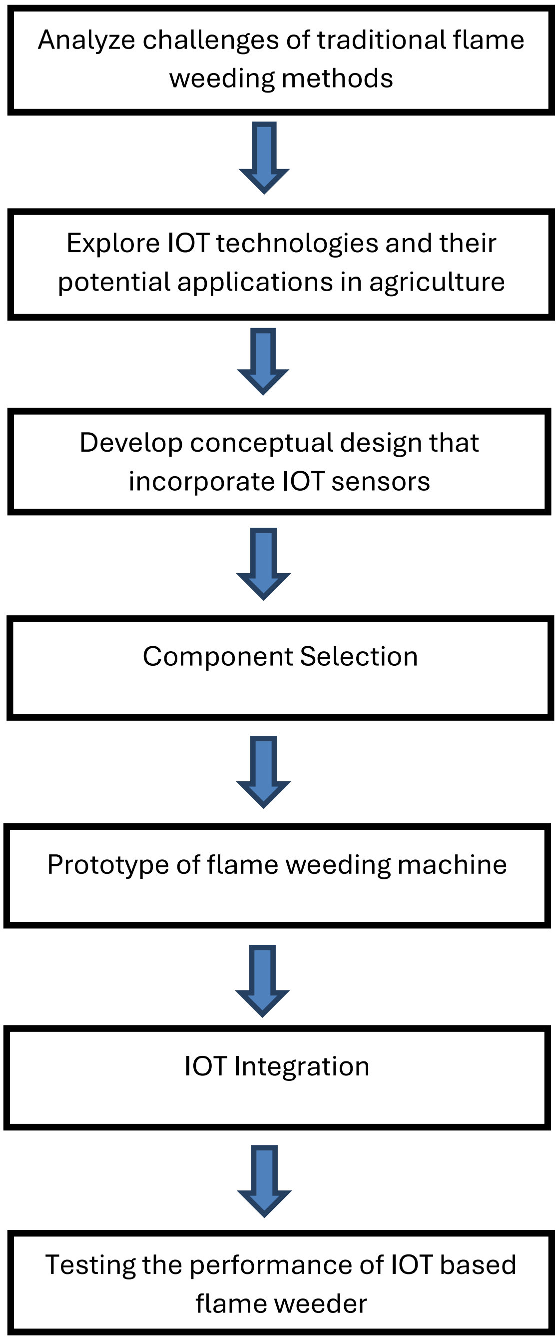
DC motors offer variable speed control, allowing operators to adjust the speed of the flame weeder according to the requirements of weed control operations. This flexibility enables precise positioning and movement of the equipment, optimizing weed eradication while minimizing damage to crops.

### 2.10 BATTERY

The battery powers the wireless communication modules, such as Wi-Fi, Bluetooth, or cellular modems, allowing the flame weeder to connect to the internet or local networks. This enables remote monitoring, control, and data exchange between the flame weeder and centralized servers, mobile application.

## METHODOLOGY

The methodology for fabricating the agriculture soil testing and nutrient spraying machine is described below. As shown in Figure 3.1, the flowchart outlines the methodology for fabricating the machine.



## RESULT AND DISSCUSION

A recent study was conducted for testing of flame weeder on an open level area of the both plain and rough area. The purpose was to assess the performance of the weeder under controlled conditions. The flame weeder was operated across the test surface and recorded various parameter values. The results of testing are presented below.

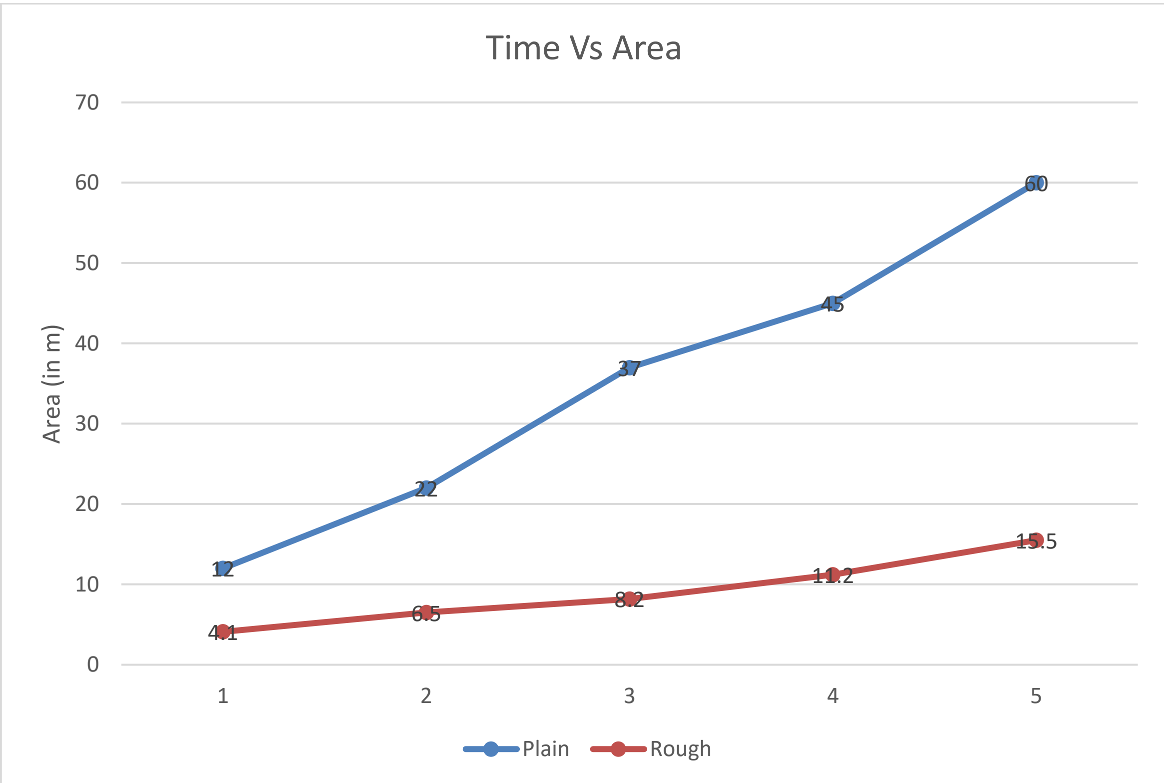
**Table 1.1 Data Obtained from Plain surface**

| Time (in mins) | Area (in metre) |
|---|---|
| 1 | 12 |
| 2 | 22 |
| 3 | 37 |
| 4 | 45 |
| 5 | 60 |

**Table 1.2 Data Obtained from Rough surface**

| Time (in mins) | Area (in metre) |
|---|---|
| 1 | 4.1 |
| 2 | 6.5 |
| 3 | 8.2 |
| 4 | 11.2 |
| 5 | 15.5 |

A Comparison of Work Efficiency on Smooth and Rough Surfaces from above table values:

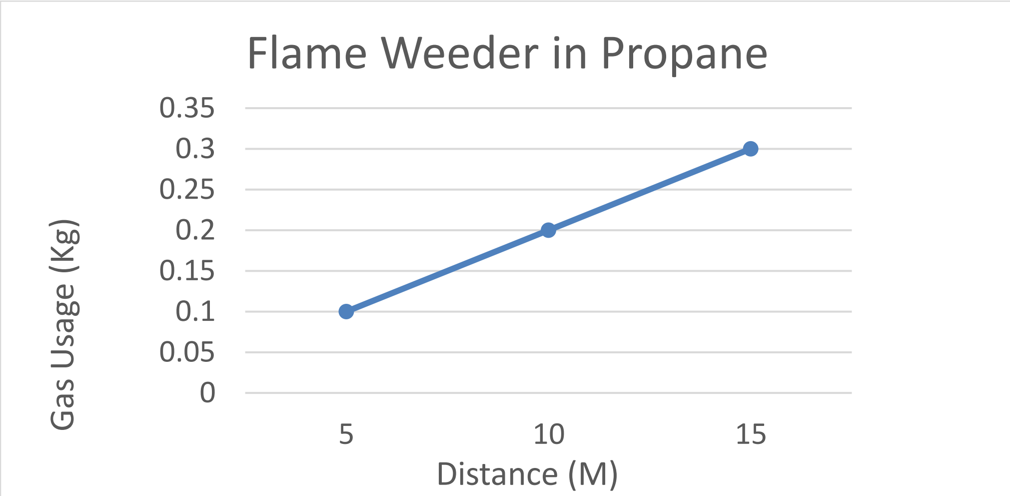



A Comparison of Work Efficiency on Smooth and Rough Surfaces
An analysis was conducted to compare work efficiency when performing the same task on both the rough surface and smooth surface. The task involved covering a specified area within a one minute timeframe. On the smooth surface area, 12 square meters were able to be covered within one minute. In contrast, on the rough surface only 4.1 square meters were able to be covered in the same one minute period.
A graphical representation of these results clearly illustrates the significant difference in work efficiency based on the type of surface. As depicted in the chart, working on a smooth surface allows for over 3.2 times more

area to be covered in the allotted time compared to working on a rough surface. This comparison demonstrates the advantages of a level, uniform surface for maximizing productivity during a task.

TEST 1:
An Analysis of Propane Gas Efficiency in Flame Weeding Applications

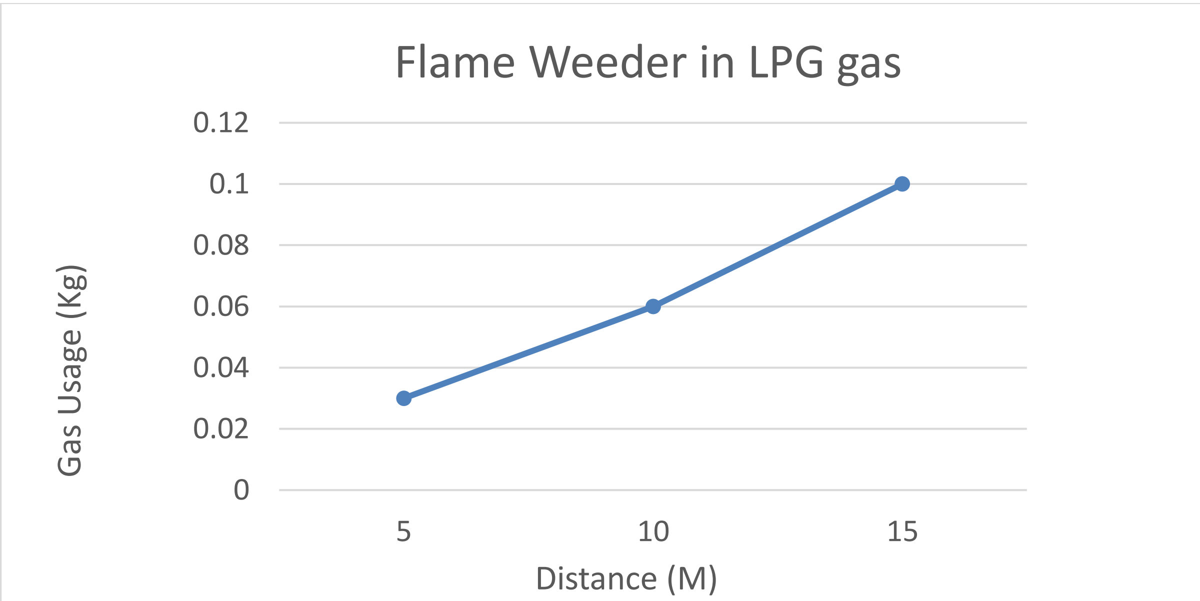
| Gas Usage (KG) | Distance (M) |
|---|---|
| 0.1 | 5 |
| 0.2 | 10 |
| 0.3 | 15 |




An analysis was conducted to assess the efficiency of propane gas usage in flame weeding applications. Gas usage, measured in kilograms, was analyzed in correlation to the corresponding distance covered, measured in meters. The results of the analysis showed: 0.1 kg of propane gas was used to cover 5 meters, 0.2 kg was used to cover 10 meters, and 0.3 kg was used to cover 15 meters.

TEST 2:
An Analysis of LPG Gas Efficiency in Flame Weeding Applications

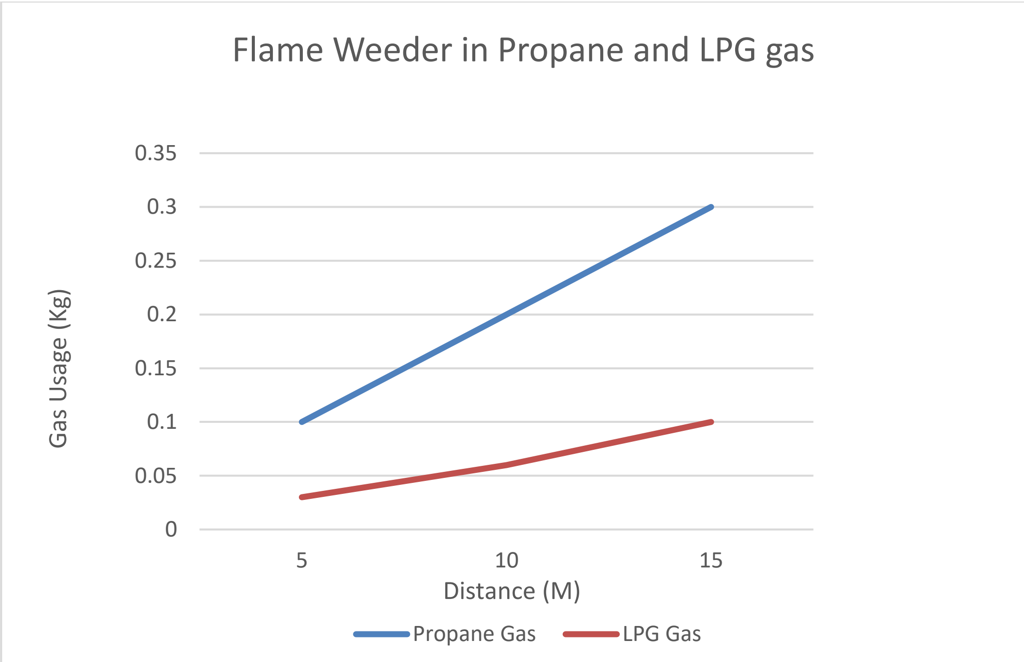
| Gas Usage (KG) | Distance (M) |
|---|---|
| 0.03 | 5 |
| 0.06 | 10 |
| 0.1 | 15 |



An investigation was conducted to analyze the efficiency of liquefied petroleum gas (LPG) in flame weeding applications. The study found a direct relationship between gas usage, measured in kilograms, and the distance traveled in meters during weeding. Specifically, results showed gas consumption of 0.03 kg at 5 meters, 0.06 kg at 10 meters, and 0.1 kg when covering a distance of 15 meters. This correlation provides useful insights for agricultural operators utilizing LPG flame weeding to estimate gas requirements based on intended acreage.

TEST 3:
By comparing the two tests the efficiency of Propane gas and LPG in flame weeder is

| Gas Usage in Propane gas(kg) | Gas Usage in LPG (kg) | Distance (m) |
|---|---|---|
| 0.1 | 0.03 | 5 |
| 0.2 | 0.06 | 10 |
| 0.3 | 0.1 | 15 |




A comparative assessment of propane gas and liquefied petroleum gas (LPG) in the context of flame weeding applications reveals notable differences in efficiency. Through meticulous examination of gas usage and corresponding distances covered, distinct consumption patterns emerge. Propane gas exhibits a linear increase in consumption, with 0.1 kg expended to treat 5 meters, escalating to 0.2 kg for 10 meters, and further reaching 0.3 kg for 15 meters. In contrast, LPG demonstrates a more economical consumption pattern, requiring merely 0.03 kg to treat 5 meters, followed by 0.06 kg for 10 meters, and a modest 0.1 kg for 15 meters.

This comparison underscores the potential for LPG to offer a more resource-efficient solution for flame weeding practices, as it achieves comparable results with notably lower gas consumption. Such findings not only hold significance for practitioners seeking to optimize resource utilization but also prompt further inquiry into the underlying mechanisms driving these consumption disparities. Consequently, this comparative analysis serves as a foundation for informed decision-making in selecting the most efficient fuel for flame weeding operations, ultimately contributing to enhanced sustainability and effectiveness in agricultural weed control strategies.

Calculation

Plain surface calculation:
Machine takes 12 meters/min
Therefore for 1hour it travels 720 meters
Hence 0.72Km/hr
1hr = 12×60
= 720 meters
= (720)/1000
= 0.72km
Therefore 0.72km/hr

Rough surface calculation
Machine takes 4.1 meter/min
Therefore foe 1hour it travels 246 meters
Hence 0.24 km/hr
1hr = 4.1×60
= 246 meters
= (246)/1000
= 0.24km
Therefore 0.24km/hr

In the field of agricultural mechanization, understanding machinery performance across diverse terrain types is essential for efficient operations management. Assessing machine traversal capabilities on both level and rough surfaces provides critical insights for resource planning and operational scheduling. On level surfaces, where the machine maintains a steady pace of 12 meters per minute, it covers a considerable distance of 720 meters within an hour, reflecting an impressive speed of 0.72 kilometers per hour. This underscores the machine's effectiveness in traversing uniform landscapes efficiently. Conversely, on terrain characterized by uneven surfaces, the machine's pace decreases to 4.1 meters per minute. Consequently, its hourly travel distance diminishes to 246 meters, resulting in a slower speed of 0.24 kilometers per hour. This nuanced evaluation highlights the significance of adapting machinery performance expectations to varying environmental conditions, facilitating informed decision-making aimed at optimizing productivity and efficient resource allocation in agricultural operations.

In conclusion, the comparative analyzes conducted in this study provide valuable insights to optimize efficiency and resource utilization in agricultural practices. The evaluation of flame weeding performance on both plain and rough surfaces underscores the importance of surface characteristics in determining productivity levels. Moreover, the assessment of propane gas and LPG efficiency in flame weeding applications highlights the potential to optimize fuel selection to achieve desired outcomes while minimizing resource expenditure. These findings contribute to a broader understanding of agricultural mechanization and provide actionable insights for practitioners aiming to enhance sustainability and effectiveness in weed control strategies. Ultimately, informed decision-making based on empirical data is pivotal for driving improvements and innovation in agricultural operations.

## CONCLUSION AND FUTURE SCOPE

Flame weeding is an agricultural technique that originated in the 19th-20th centuries and has grown in popularity among organic farmers and those seeking chemical-free herbicides. It involves applying flame to eliminate weeds while sparing crops. Fueled by gas and ignited, flame weeders offer a natural solution to weed control. Technological advances have led to different models for various operations and scales. Adoption is increasing worldwide due to efficacy and versatility across landscapes.

This study examined the relationship between surface conditions and machinery performance on different terrains. Significant disparities in productivity between smooth and rough surfaces were found. On smooth terrain, impressive 12 square meters per minute coverage showed efficacy. Conversely, on rough surfaces, performance was impaired at only 4.1 square meters in the same time. Findings underscore the role of surfaces in dictating productivity, with smoother surfaces facilitating greater output.

The investigation also assessed operational capacities on varying terrains, elucidating surface characteristics' tangible effects. On smooth surfaces, the swift 0.72 km/hr speed enabled efficient distances. In contrast, on rough terrain, the pace significantly decelerated to 0.24 km/hr, emphasizing challenges. Findings underscore efficiency gains from smoother surfaces and their critical role in maintaining optimal speeds.

In conclusion, this study underscores the importance of surface conditions in shaping operational efficiency, particularly in agriculture. Smooth surfaces emerge as pivotal facilitators of productivity and faster speeds compared to rough terrain. These insights hold implications for machinery-reliant industries, emphasizing surface assessment and management to enhance performance and drive excellence. By optimizing surface conditions, industries can unlock substantial productivity gains, fostering competitiveness and sustainability.

The forthcoming research initiative aims to advance agricultural practices by enhancing the efficacy and versatility of flame weeding technology. Central to this endeavour is the incorporation of electronic ignition systems within the flame weeder apparatus, facilitating seamless and automatic ignition of propane or gas fuel upon activation. Complementing this innovation is the development of a sophisticated control system, designed to dynamically adjust the position and angle of flame outlets in response to various agronomic factors, including weed density, crop type, and field conditions. By leveraging cutting-edge technology, this control system will optimize flame weeding operations, maximizing weed eradication while minimizing fuel consumption and environmental impact.

Furthermore, the project seeks to revolutionize agricultural machinery by integrating fertilizer application functionalities alongside flame weeding capabilities within a single, multifunctional platform. This integrated approach promises to streamline farming operations, offering farmers unprecedented efficiency gains, reduced labor costs, and enhanced crop health. Through the design and implementation of separate compartments or mechanisms for fertilizer application and flame weeding, the machine will provide farmers with unparalleled flexibility and precision in managing their fields. Moreover, efforts will be directed towards downsizing the machine to enhance its portability, thereby catering to the diverse needs of farmers across various scales of agricultural operations. In sum, this interdisciplinary research endeavour holds great promise for advancing sustainable and efficient farming practices, ultimately contributing to the global effort towards food security and environmental stewardship.

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