Technical Independent Studies Proposal

"A Study of The Optimization of Weeding Blades: Material & Model"

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I. Abstract

Weeding is a laborious and costly agricultural task that can cause numerous health problems, particularly for those who engage in it regularly. After conducting interviews with farmers and agricultural enthusiasts, it is also found that the frequent motion of bending down and squatting during weeding has caused lower back pain and knee pain [1]. In addition, improper weeding can also negatively impact crop quality by depriving them of nutrients, water, space, and sunlight. This insufficient supply leads to interference or competition between crops and weeds [2]. Therefore, weeding tools have been widely used during agricultural activities. This study aims to analyse the requirements of weeding tools materials, by taking into account the environmental factors and comparing different weeding tool materials, in order to develop the optimal blade materials and model for the weeding tool created by GreeFarm. The GreeFarm project intends to generate a mechanical device to alleviate the physical burden of gardeners and agricultural enthusiasts by lowering the frequency of bending over while removing weeds from their roots during weeding.

II. Research Context

Weeding tools that exist in the market are differentiated based on their power source, which includes manual, animal-drawn, and power or tractor operated tools. This study will focus on manual weeding tools, such as trowel or small shovel, spade or chopping hoe, long handle hoe, and star weeder [3]. These tools all feature metal blades and are commonly made of two materials: metal for the blade and wood or plastics for the handle. Currently, there are several emerging materials that have not yet been implemented in these tools as they are not yet widely used.

III. Research Questions

The study aims to discover the following aspects related to weeding tool materials:

1. The requirements of weeding tool materials
2. The comparison of various types of materials for weeding tools
3. The identification of the most suitable material for the blade
4. The determination of the optimal model and placement of the blade

Hypothesis:

1. The weeding tool's blade material should be made of a metal
2. Steel is the best metal to use for the blade
3. The optimal blade position is 45-degree

IV. Research Method

The research will commence with a literature review of materials commonly used in weeding tools worldwide, specifically focusing on materials used in similar environmental conditions to Hong Kong. From this review, a set of general requirements, such as material durability, will be derived. Subsequently, a short analysis of various material categories will be conducted, followed by a comparison to determine the optimal material for the blade. Once the material is identified, further research will be conducted to determine the ideal blade shape and placement.

V. Research Findings

The research findings and analysis about the requirement of weeding tool materials, materials types and comparisons, and the ideal blade shape and placement are as followed:

i. Overall requirement of weeding tool materials

As weeding tools are used in open-space crop fields, there are many factors that need to be put into consideration while selecting a material for a weeding tool, including the environmental conditions in which the tool will be used. It is important to consider the following factors:

1. Weight – the weight of the material should be appropriate for the users, typically ranging from 0.45 to 1.8 kilogram for short-handle weeding tools and 2.2 to 4.5 kilogram for long-handle weeding tools reducing strain and fatigue on the user's hands and arms during prolonged use
2. Durability – the material should be able to withstand wear and tear from daily use, as well as exposure to harsh outdoor conditions such as rain, wind, moisture, sunlight, and extreme temperatures
3. Hardness – the material should be able to withstand sudden force or impact without being deformed ensuring its longevity and reliability in tough farming conditions
4. Flexibility – the material should be able to flex without breaking, allowing the tool to adapt to the contours of the soil and plants being weeded
5. Sharpness retention – the material should be able to hold its sharpness to cut through roots, sod, and tough materials that can be found in soil efficiently and effectively
6. Heat resistance – the material should be able to withstand temperatures of at least 90 degrees Celsius to avoid damage during use
7. Conductivity – the material should be able to conduct heat, allowing for efficient use in hot weather conditions and reducing the risk of overheating or damage
8. Rust and corrosion resistance – the material should resist rusting and corrosion over time, maintaining its shape and performance throughout the tool's lifespan thus reducing the need for frequent repairs or replacements
9. Cost – the material should be affordable for farmers in Hong Kong, considering their average monthly salary of HKD 10,700, with the lowest being HKD 5,700 and the highest being HKD 16,300
10. Availability – the material should be easily accessible for farmers in Hong Kong

Taking into account these universal factors [4] [5] [6] will help ensure the chosen material is appropriate for the intended use of the weeding tool and provides a comfortable and comprehensive experience for the user while also being sustainable to the environment.

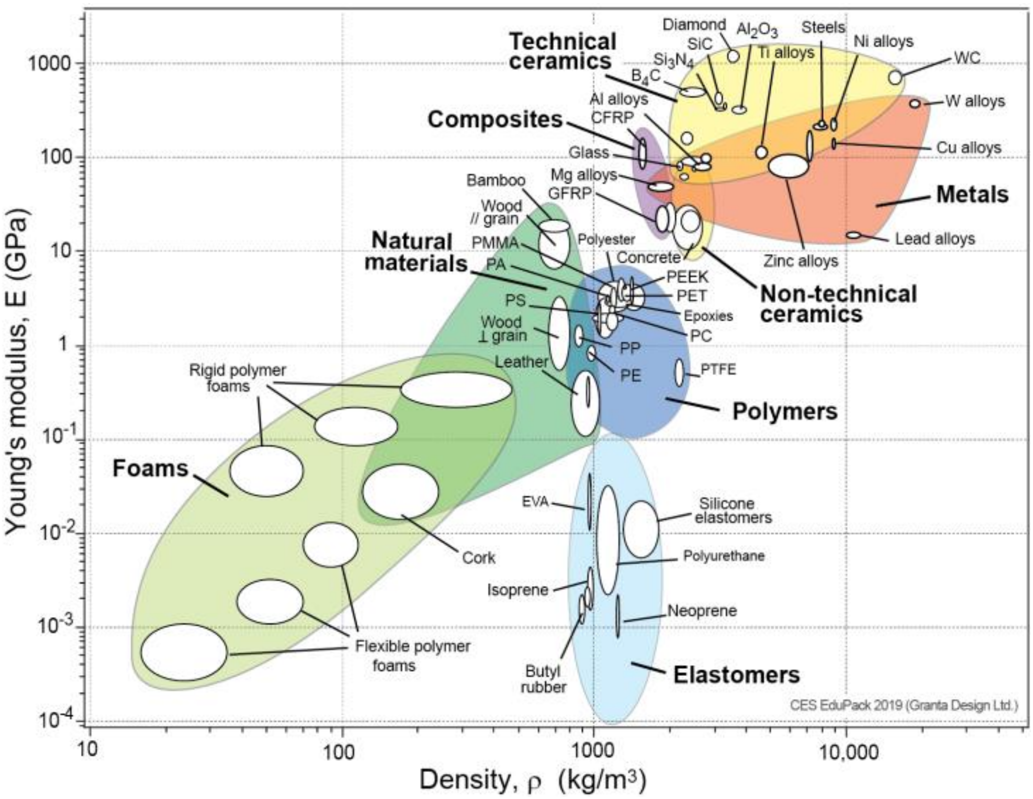
ii. Materials

There are three classes of material based on their atomic bonding forces: metallic, ceramic, and polymeric. This research will primarily focus on metallic materials, which can be further subdivided into ferrous metals (including irons, carbon steels, alloy steels, stainless steels, tool and die steels) and nonferrous metals and alloys (such as aluminium, copper, magnesium, nickel, titanium, precious metals, refractory metals, superalloys). In addition to these, an additional polymeric material will also be covered, which is nylon. The followings are the materials properties data found [7] [8]:

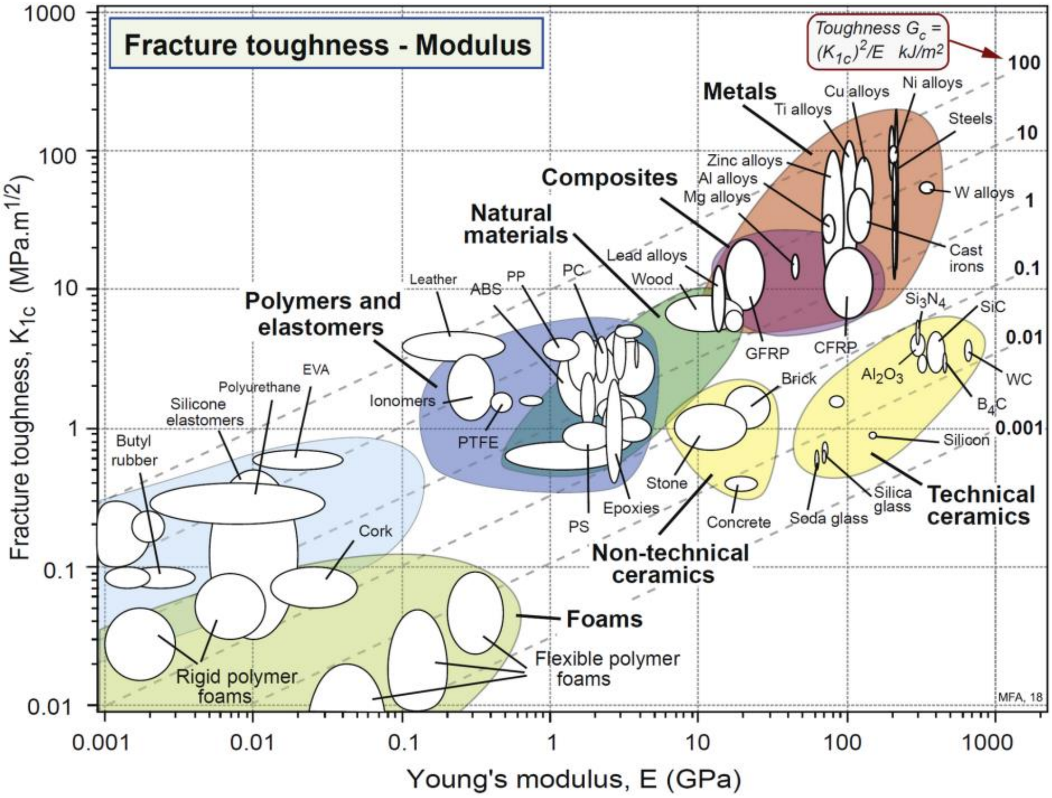
	Cast Iron	Steel	Stainless Steel	Aluminum
Density (Mg/m³)	7.05 - 7.25	7.8 - 7.9	7.6 -8.1	2.5 - 2.9
Young's modulus (GPa)	80 - 180	200 - 215	189 - 210	68 - 89
Tensile strength (MPa)	140 - 830	345 - 580	480 - 2240	58 - 620
Yield strength (MPa)	140 - 680	250 - 395	170 - 1900	30 - 610
Vickers hardness (HV)	90 - 320	107 - 173	130 - 570	30 - 160
Fracture toughness (Mpa M½)	10 - 54	41 - 82	62 - 280	18 - 42
Melting temperature (°C)	1130 - 1377	1480 - 1526	1375 - 1450	475 - 677
Thermal conductivity (W / m.K)	29 - 72	49 - 54	11 - 24	80 - 240
Wear resistance	Very Good	Very Good	Good	Average
Corrosion resistance (Salt water)	Average	Average	Very Good	Good
Corrosion resistance (Acid / Alkali)	Poor / Average	Poor / Average	Good / Very Good	Good / Poor
Average price (USD / kg)	0.26 - 0.75	0.47 - 0.84	2.8 - 11.3	1.4 - 2.3

	Titanium	Copper	Nickel	Plastic - Nylon
Density (Mg/m³)	4.4 - 4.8	7.9 - 9.0	8.3 - 9.5	1.14
Young's modulus (GPa)	90 - 120	70 - 148	190 - 220	2.7
Tensile strength (MPa)	300 - 1625	100 - 960	345 - 1300	38.6 - 170
Yield strength (MPa)	270 - 1200	30 - 500	70 - 1000	25 - 90
Vickers hardness (HV)	155 - 380	44 - 240	80 - 300	31 - 33
Fracture toughness (Mpa M½)	14 - 120	30 - 90	80 - 110	12
Melting temperature (°C)	1477 - 1682	982 - 1082	1435 - 1466	450
Thermal conductivity (W / m.K)	5 - 12	50 - 390	67 - 91	0.24 - 0.3
Wear resistance	Average	Very Good	Good	Good
Corrosion resistance (Salt water)	Very Good	Very Good	Very Good	Very Good
Corrosion resistance (Acid / Alkali)	Good / Good	Poor / Good	Good / Very Good	Very good / Poor
Average price (USD / kg)	28 - 56	1.8 - 10.1	5 - 15	2.7

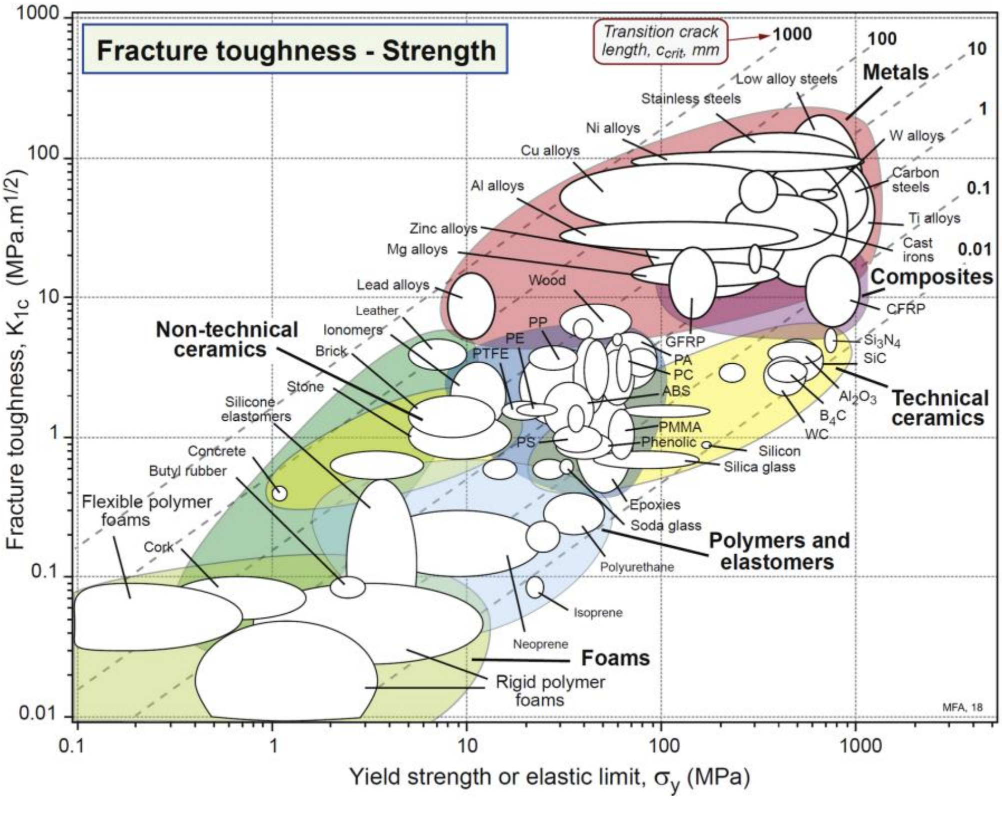
Table 1.1 Mechanical Properties of The Material



Graph 1.1 Young’s modulus - Density



Graph 1.2 Fracture toughness – Young's modulus



Graph 1.3 Fracture toughness – Yield strength or elastic limit

In conclusion from the Table 1.2 and Graph 1.1 to 1.3, the materials fulfilled the factors:

Materials	Factors Number									
	1	2	3	4	5	6	7	8	9	10
Cast Iron	–	–		✓		✓	–		✓	✓
Steel		✓	✓			✓	✓		✓	✓
Stainless steel	–	✓	✓	–	✓	✓	–	✓	✓	✓
Aluminium	✓		–	✓	–	✓	✓	–	✓	✓
Titanium	✓	✓			✓	✓		✓		
Copper		–	✓	✓	–	✓	✓	✓	✓	✓
Nickel		✓	✓	✓	✓	✓	✓	✓	–	–
Plastic – Nylon	✓			✓	✓	–		✓	✓	✓

Table 1.1 Materials – Factors fulfilment

Note:

1 Weight
2 Durability
3 Hardness
4 Flexibility
5 Sharpness retention
6 Heat resistance
7 Conductivity
8 Rust and corrosion resistance
9 Cost
10 Availability

✓ = highly fulfil the factor's requirement

– = acceptably fulfil the factor's requirement

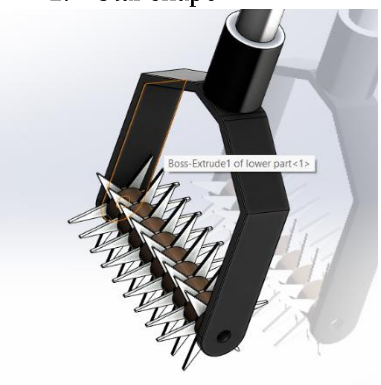
iii. Common materials and recommendation

The blade material for a weeding tool is an important consideration for farmers and gardeners. While materials like aluminium, medium carbon steel, and stainless steel are commonly used due to their durability, strength, and cost-effectiveness, Table 1.1 suggests that copper is the most suitable material for a weeding tool blade, followed by stainless steel and nickel. However, copper has certain disadvantages, including its heavy weight and inability to maintain a sharp edge or hold its shape when struck against tough objects. To address these limitations, copper is often combined with other metals, such as tin, aluminium, or manganese to create bronze, which is stronger, tougher, and more hard-wearing than copper alone. Moreover, bronze does not rust and holds sharp edges well compared to steel. Therefore, bronze is a recommended blade material for a weeding tool, given its practical advantages, aesthetics, and material properties.

iv. Blade shape

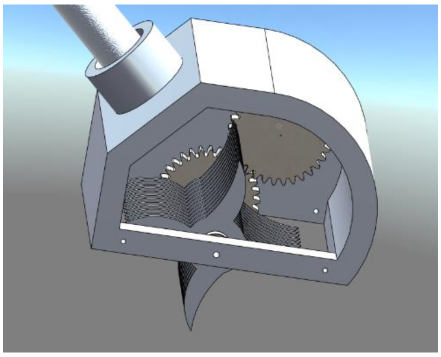
The purpose of the blades is to kill and pull out some of the weeds. Therefore, there are three designs are proposed:

1. Star shape



The aim of the model is to kill the weeds and cut through tough materials in the soil

2. Crescent moon shape



The aim of the model is to kill the weeds and hook the small size weeds onto the blades

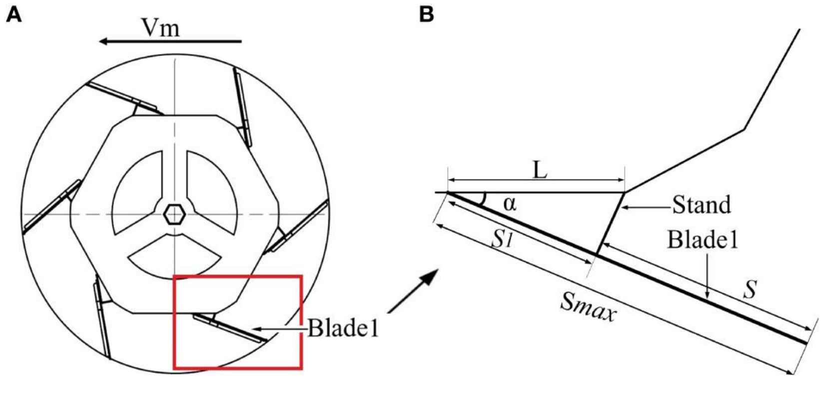
3. V shape

The model is similar to a slingshot shape with the aim to kill the weeds and hook small to middle size weeds onto the blades.

v. Optimisation range analysis of blade parameters

The position of the same blades in a row should be diversified to prevent the build-up of soil and debris on the blades. When multiple blades of the same size and shape are placed in a row, they tend to create a "dead zone" in the center of the row where the blades do not effectively cut through the soil or remove weeds. By positioning the blades in a row at different angles, each blade can effectively cut through the soil and remove weeds without being impeded by the soil and debris that may have accumulated on the adjacent blades. Furthermore, the weeding tool can better adapt to the contours of the soil and more effectively remove weeds from different areas of the field [9].

In a study conducted by Frontiers [10], a hexagonal wheel with six blades installed at a fixed angle α was tested. Stands were also employed between the surface of the wheel and the blades to maintain stability, resulting in a constant value of α and preventing the blades from being buried during wheel rotation. The angle (α) of the blade affects the actual penetration length of the blade and, in turn, the resistance experienced by the weeding wheel during operation. Figure B illustrates the relationship between α and the actual penetration length of the blade, providing valuable insights into the behaviour of the weeding tool and enabling users to adjust α to optimize its performance.



Picture A **Picture B**

$$S_1 = L\cos\alpha, \quad \textbf{Eq. (1)}$$

$$S = S_{max} - S_1 = S_{max} - L\cos\alpha, \quad \textbf{Eq. (2)}$$

S_1 is the length of the unburied blade, L is the length of the blade-installation side, S_{max} is the total length of the blade. All are measured in mm.

In Equation (2), S_{max} and L are fixed, a smaller α corresponds to a smaller S. As per an established formula [11] and Eq. (2), the resistance of the weeding wheel to cut the soil can be expressed as

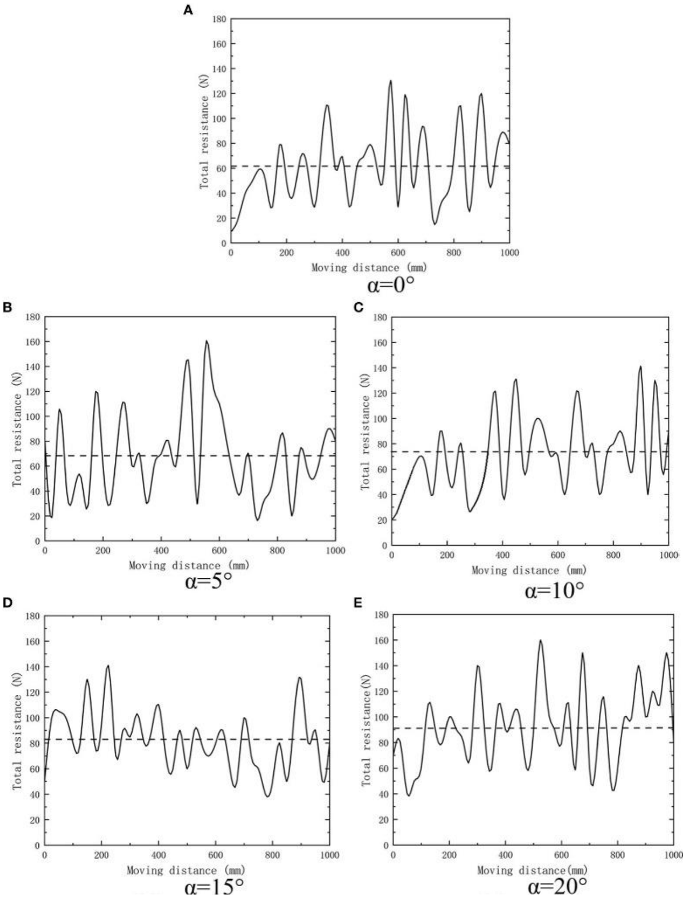
$$P_c = k_c \frac{3Sv_m}{9.55\pi} = (S_{max} - L\cos\alpha)\frac{3v_m k_c}{9.55\pi}, \textbf{ Eq. (3)}$$

P_c is the resistance of the weeding wheel in N, k_c is the specific energy consumption while cutting the weeds in N·m/mm^3, and v_m is the forward speed of the weeding wheel as it cuts the soil in m/s. In Equation (3), α is the only variable. It can be seen that P_c parallel to α. When α = 0°, the resistance of the blade to cutting the soil is the smallest [12].

The statement is proven in accordance to the simulation done by Frontiers [10]:

A. When α=0°, the resistance fluctuated in the range of 40–130 N, and the average resistance was approximately 61 N.
B. When α=5°, the resistance fluctuated in the range of 10–150 N, and the average resistance was approximately 68 N.
C. When α=10°, the resistance fluctuated in the range of 20–150 N, and the average resistance was approximately 73 N.
D. When α=15°, the resistance fluctuated in the range of 40–150 N, and the average resistance was approximately 82 N.
E. When α=20°, the resistance fluctuated in the range of 40–160 N, and the average resistance was approximately 91 N.

In conclusion, the optimal degrees of the blades from the center of the wheel should be 360°/6, which is 60°.



Graph 2.1 Total resistance – angle

VI. Significance of Research

Currently, weeding tools on the market primarily use steel and aluminium. This study aims to discover the most suitable materials and blade models to increase the efficiency and effectiveness of weeding. The research will provide valuable insights for the GreeFarm team's project to reduce the physical burden of weeding on farmers and agricultural enthusiasts. By identifying the most suitable materials and blade model and placement, the team will be able to determine the blade specifications, thus improving the device's effectiveness in providing a more efficient way for users to remove weeds down to their roots with less bending hence alleviating the physical burden of gardeners and agricultural enthusiasts.

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