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Full Length Research Paper

Development of a greenhouse roof cleaner

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The efficiency of a greenhouse is influenced by the cleanliness of the glazing material through which heat and light penetrate into the enclosure. The common cleaning method for most greenhouses in developing countries is the use of a ladder to climb onto the roof to clean which is labour intensive, time-consuming, imposes severe loads on the roof that could cause failure and is dangerous to the cleaner. Consequently, many greenhouse roofs are rarely cleaned and the accumulated dirts reduce the amount of light and heat penetrating into the house. Experimental studies in such greenhouses may fail to produce valid findings while crop production may not yield the desired produce. There is therefore, the need for appropriate equipment for effective cleaning of greenhouse roofs in order to eliminate the disadvantages of the existing common method. The focus of this study was to develop simple equipments that could be used for the cleaning of a greenhouse roof. A manually operated brush type greenhouse roof cleaner was designed, fabricated and tested. The equipment consisted of a roughly cylindrical brush mounted on a frame attached to a handle made of three concentric and adjustable cylindrical pipes. The equipment was fitted with a wash mix dispenser operated by a1 hp sump pump. The equipment testing involved recording of the illumination within and outside three greenhouses before and after washing with the equipment. Increases of 6.03, 13.19 and 16.36% in transmittances of the roofs following washing with the equipment were recorded. A simple, easy to set-up, operate and maintain equipment for the cleaning of greenhouse roof has been designed and demonstrated great potentials in cleaning. Further studies aimed at reducing the weight, prolonging service life and improving efficiency are required.

Key words: Greenhouse, roof cleaner, transmitted light intensity, transmittance, light transmission efficiency.

INTRODUCTION

Greenhouses are buildings used to create enabling environments for the production of crops either for commercial purposes or for research. The objective is to achieve temperature ranges, relative humidity, light and carbon dioxide (CO_2) levels that are optimal for crop cultivation (Redmond, 2009). Greenhouses were initially designed for commercial crop cultivation during winter in temperate regions where the natural climate could not support the cultivation of crops while in the tropics, the few that existed were exclusively used for research (Mijinyawa and Gbadebo, 2011). There was no need for greenhouses for commercial crop production in the tropics as the natural climate was adequate to support crop production until very recently when the negative effects of climate change on agriculture began to manifest and the hitherto stable climate became unpredictable. The desire to mitigate some of the negative effects of climate change has resulted in an increase in the use of greenhouses in the tropics in recent times. The inherent benefits include extension of cropping period, repeated cropping, efficient water and fertilizer utilization through drip irrigation, qualitative and quantitative food production, reduction of the risks of crop failure, safety of foodstuffs, specialization in crop production and controlled environment for research (Lindley and Whitaker, 1996; Mijinyawa, 2011).

The glazing or roof covering material of a greenhouse is a critical component of the greenhouse, because it is the material that permits the penetration of light and heat

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Figure 1. Manual cleaning procedure at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

into the structure (Gedalyahu et al., 2004). The covering material used on a greenhouse influences the productivity and performance of the structure, greatly impacting on the level and quality of light available to the crop (Giacomelli and Roberts, 2005). Therefore, the greenhouse coverings irrespective of the type must be clean and clear enough to provide optimum light transmission. Light transmitted to crops within the greenhouse is affected by the build-up of internal condensation that forms on the greenhouses' cladding due to temperature gradients, accumulation of birds' droppings which frequently perch and defecate on the roof, carbon deposits, and oil droplets from tractor, algae growth, dust and particles from various agricultural operations in the greenhouse neighbourhood. The accumulation of these dirts on the roof sheets diffuses light rays and prevents about 30% of light energy or photosynthetic radiation from penetrating into the cropping space of the greenhouse (Manor et al., 2004). As a result, the growing rates of the produce and ripening processes of the seeds or fruits are delayed and retarded. In addition, a decrease in amount of light results to about 30% loss of plants' weight and the quality of yield is lower than that of the yields from greenhouses with clean roofs. There are also high risks of plant disease and pest attack, high risk of dormancy, reduction in flowering and tuberization as well as, poor stalks development. Keeping the roof of greenhouses in perfectly clean condition is therefore very important if the maximum benefits of using a greenhouse are to be derived. Regular and thorough cleaning of both the exterior and interior of the greenhouse roof is absolutely essential to maintaining the transmittance of the roof material (Gedalyahu et al., 2004; Mohammad, 2004).

The cleaning of greenhouse roofs could be done manually using ladders or automate using the roof-master (Figures 1 and 2). As a result of cost and high technology involved, the roofmaster is more restricted to advanced countries while the manual method is the one commonly used in many developing countries, especially Nigeria. The manual method does not only endanger the labourers, it is both time consuming and labour intensive, and exposes both the greenhouse glazing and framing to damage arising from imposed live load from the ladders and workmen. For these reasons, many greenhouse roofs are hardly cleaned.

Despite the importance of maintaining the cleanliness of the glazing material, many greenhouse roofs especially, those in Nigeria are rarely washed and this has been partly due to the bottlenecks associated with the manual cleaning method which is the only one available. If accurate research results must be obtained and maximum produce yield, it is necessary that cleaning methods which are easy to use should be developed.

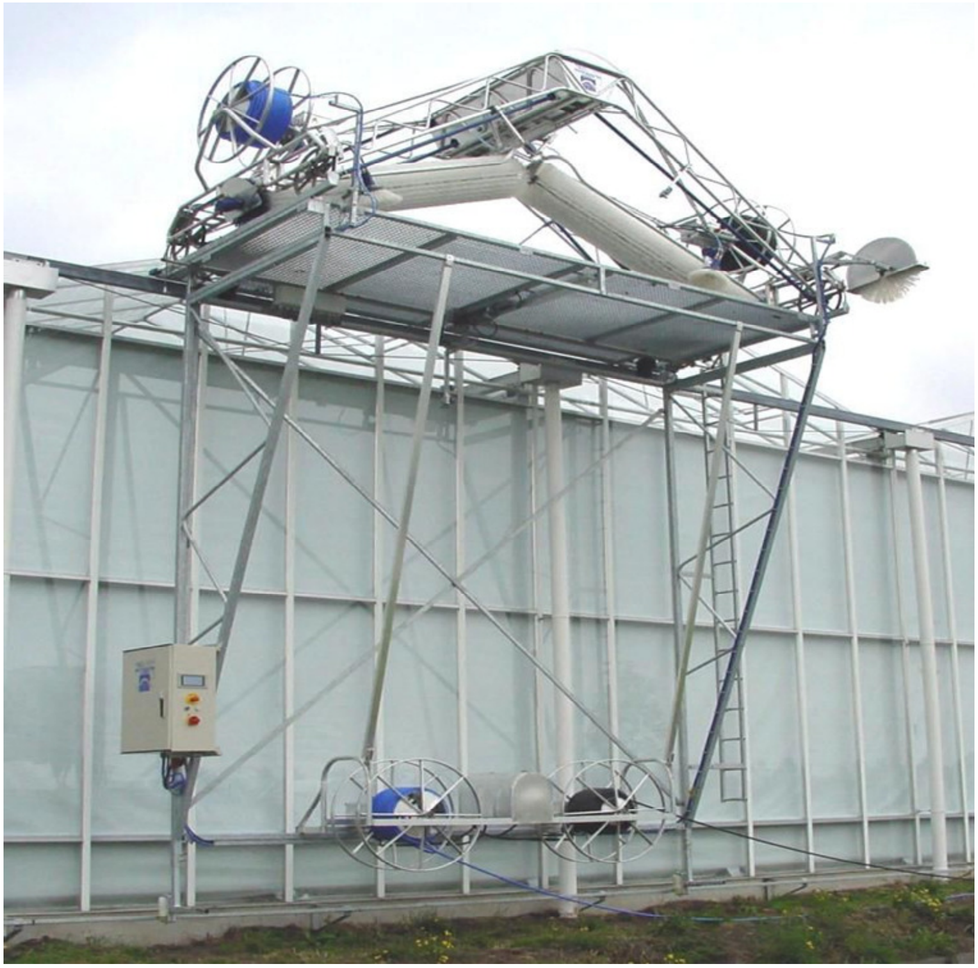

Figure 2. The roofmaster. Brinkman.com (2009).

This is the origin of this study. The primary objective of which is to develop a simple and effective cleaning method for greenhouse roofs.

MATERIALS AND METHODS

Design considerations

In the design of the greenhouse roof cleaning equipment, the following factors were considered.

Adjustability

The equipment to be designed should be usable in cleaning roofs of different slant heights and in order to achieve this, an adjustable handle was considered. A handle of three concentric pipes of the same thicknesses and weights was chosen.

Materials for construction

The choice of materials for construction was based on suitability, availability and cost. This was to ensure that the equipment performs and that if the design is found useful, then, it should be easy to replicate it. It will also be cheap while local artisans would be familiar with its fabrication. The primary materials for construction are stainless and galvanized mild steel, aluminium, wood and fibrous material. These are all materials that are readily available in many Nigerian markets and those used in this work were sourced locally at Mokola and Agodi Gate Construction materials markets in Ibadan, Nigeria.

Weight of components

The washing tool is to be moved by the washer man and hence, it must be as light as possible such that it can easily be lifted during operation. This is why aluminium was recommended for the brush attachment so that the weight could be reduced to the bare minimum.

Material selection

The cleaning brush

The cleaning brush was selected in consultation with painters who use similar tools and the length was chosen to be equal to the

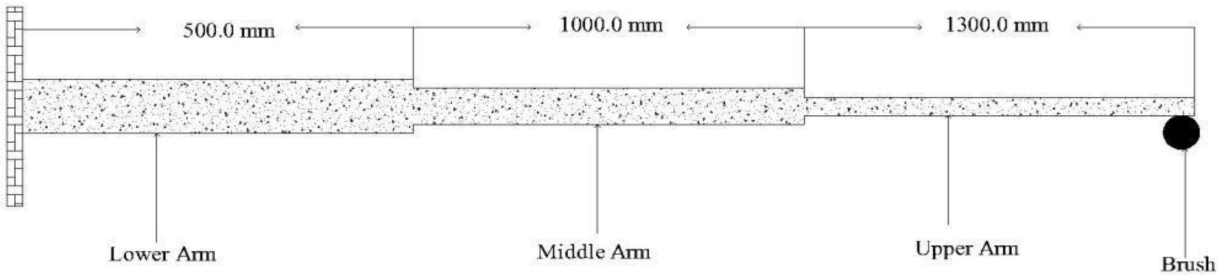

Figure 3. Schematic representation of the brush handle

length of a glass pane to achieve maximum coverage during cleaning. A length of 610 mm was considered adequate. The brush is an assembly of eight 305 mm long brushes mounted on a rectangular frame of 305 and 610 mm made of aluminum using 10 cm bolts and nuts. The shaft is 6.35 mm diameter solid steel rod. Attached to the brush frame is a mix dispenser, which distributes the cleaning mix along the length of the brush during cleaning.

The brush handle

The handle which the brush is attached was made from a 2.5 mm thick cylindrical hollow pipe and was considered necessary to make it three concentric pipes for ease of use in cleaning different heights of the roof. Pipes of internal diameters 55, 50 and 45 mm and of lengths 500, 1000 and 1,300 mm respectively were used for the lower, middle and upper sections of the handle and this was based on the dimensions of the greenhouses expected to be used in testing the equipment while the thickness was to minimize weight. These were tested for bending stress and deflection using the maximum length and least area of cross section in order to confirm their adequacy most especially when the brush is lifted off the roof. Shown in Figure 3 is a schematic representation of the handle as a cantilever. The base of the handle where the operator holds while cleaning is taken to be fixed while the other end where the brush is attached is taken to be the free end with the weight of the brush as the point load.

Design calculations

Bending moment criterion

By the locking system, when assembled, the three concentric pipes behave as a unit and when in operation, it acts as a cantilever with the weight of the brush supported at the free end. The smallest of the three cross sectional areas can be used to evaluate the bending stress as follows:

Bending moment = $$M_b = \frac{W_b \times l}{2} = \frac{50N \times 2{,}800mm}{2} = 70{,}000 Nmm \quad (1)$$

Section modulus = $$Z = \frac{\pi(D^3 - d^3)}{32} = \frac{\pi(45^3 - 40^3)}{32} = 2{,}6633 mm^3 \quad (2)$$

$$Bending stress = \frac{maximum\ bending moment}{section modulus} = \frac{70 \times 1000}{2{,}6633} = 2628 N/mm^2 \quad (3)$$

Where; M_b = moment due to brush; W_b = weight of the brush; l = length of the handle; D = outer pipe diameter; d = inner pipe diameter and Z = section modulus

This value is far less than the permissible bending stress of 500 N/mm^2 for mild steel (Singh, 2005) and from the point of view of bending stresses, the selected dimensions are adequate.

Deflection

Treating the arm as a single beam of length 2,800 mm and using the least cross sectional area, the maximum deflection can be calculated as follows:

$$\Delta = \frac{W_b \times l^3}{3EI} \quad (4)$$

E = 200 × 10^6N/mm^2

$$I = \frac{\pi(45^4 - 40^4)}{64} = 75{,}635.06\ mm^4 \quad (5)$$

$$\Delta = \frac{(W_b)}{3EI} \times l^3 = \frac{500 \times 2{,}800^3}{3 \times 200 \times 10^6 \times 75{,}635{,}06} = 0.024 mm \quad (6)$$

Where Δ is the maximum deflection; E = Young's modulus; I is the moment of inertia and l is the length of handle). The permissible deflection is given as 0.003 l = 0.003 × 2800 = 8.4 mm. This is greater than the calculated maximum deflection and hence the handle is safe.

Sump pump capacity

The capacity of the sump pump to be used to pump the washing mix was based on experience with the pumps used to pump water in domestic houses and offices within the premises of the greenhouses. Taking into account that the height of most greenhouse roofs is less than the height of storey buildings in which 1 hp sump pump is used to pump water; a 1 hp sump pump was recommended for use.

Fabrication

The brush

Aluminum hollow pipe of square dimension was cut to 610 and 305 mm lengths for the fabrication of the brush frame using an arch saw. The brushes were attached to the aluminum frame using 10

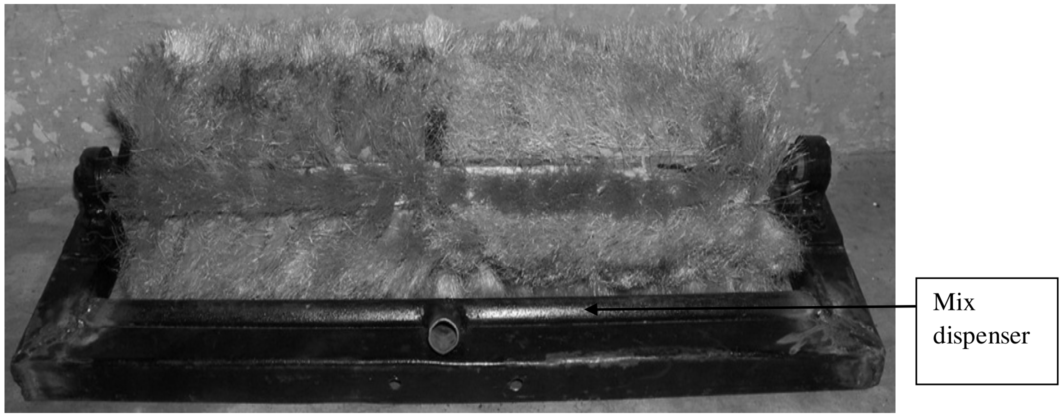

Figure 4. The brush.

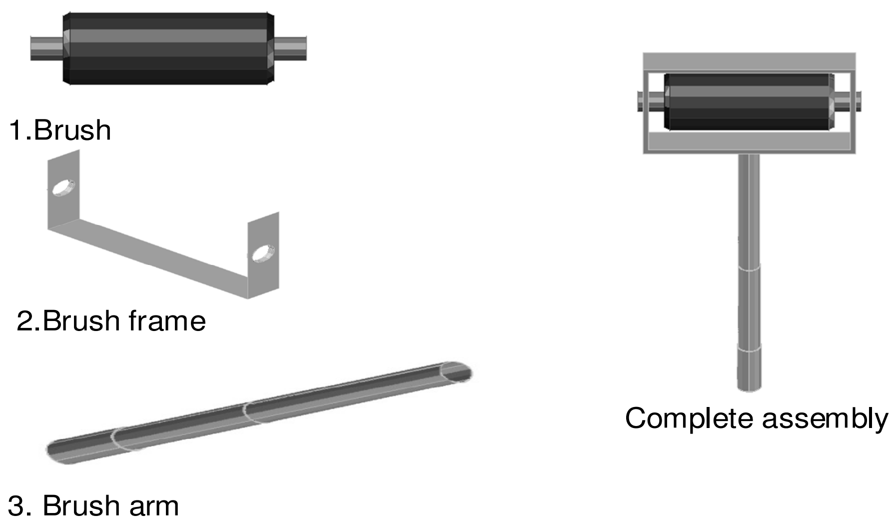

Figure 5. The cleaner components.

cm bolts and nuts. The shaft was fabricated from 6.23 mm diameter solid steel rod and was welded to the frame to provide the revolutional motion of the brush. Because of the initial cutting forces of the arch saw, welding operation and bolting of the brush to the aluminum frame, the brush assembly was balanced on a balancing machine in order to detect the amount of unbalance in the brush. The amount of unbalance detected was corrected by grinding and filing edges and joints. The mix dispenser is a 610 mm long and 19.05 mm diameter pipe with 2.54 mm diameter holes perforated along its length for proper dispensing of the cleaning mix to the brush. The brush is shown in Figure 4.

The handle

The outer diameters of the pipe are 55, 50 and 45 mm. The pipes were cut to 500, 1000 and 1300 mm using an arch saw. The 55 and 50 mm pipes were welded, while bolt holes were drilled through both the 50 and 45 mm pipes making their connection a bolted one. The bolted connection between the 50 and 45 mm pipes makes it possible for the 45 mm pipe to be extruded and retracted into the 50 mm during the cleaning process. The connection between the arm and the brush is also bolted. To ensure durability, the equipment was painted with an oil paint to repel moisture. The components of the cleaner are shown in Figure 5 while the coupled equipment is shown in Figure 6. The materials and cost of construction are presented in Table 2.

Testing

The performance of the cleaner was evaluated based on the comparison between light transmission efficiency of the roof before and after cleaning. The test involved the following four steps:

Experimental set-up

The water tank within the greenhouse was filled with water, the water pump was connected and the solution dispenser was plug to the water source while a stand by generator was available in the event of failure of public power supply. This set-up is shown in

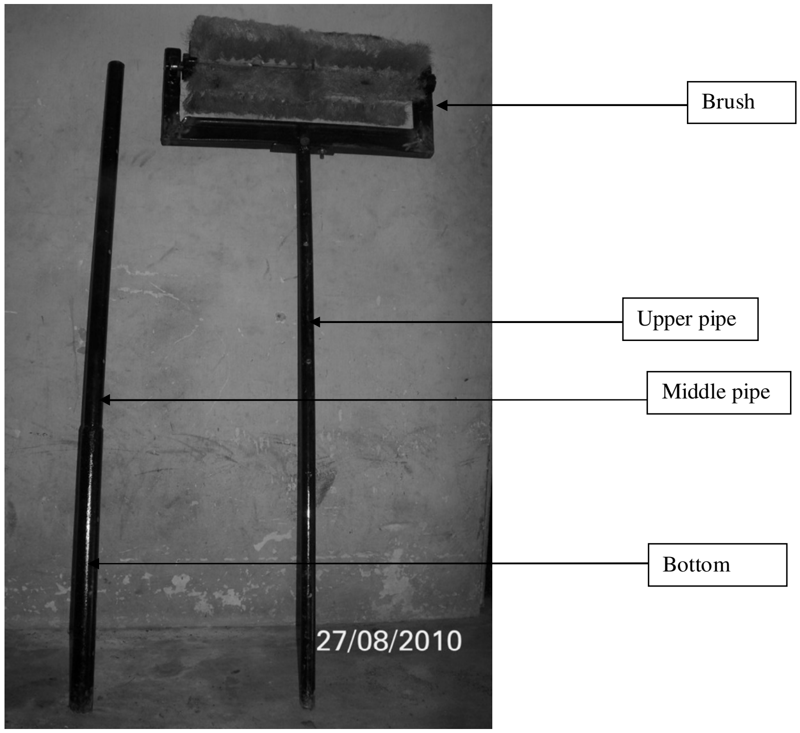

Figure 6. The coupled equipment.

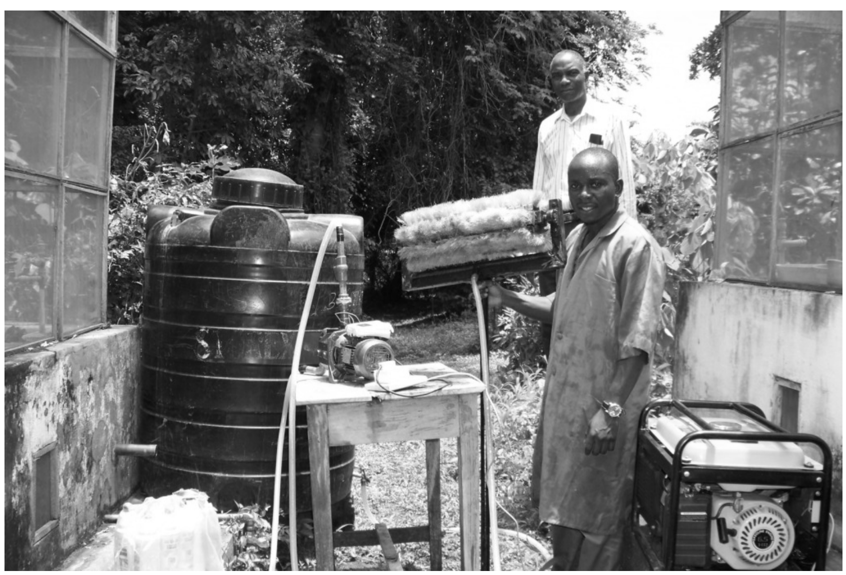

Figure 7. The cleaning set-up.

Figure 7.

Pre- cleaning Illumination

The incident light illumination was taken at various locations around the green house which were then averaged to know the incident light in the environment. The light intensity within the greenhouse was measured at six locations. Repeated readings were taken and later averaged as shown in Figure 8.

Washing

Cleaning was done from the ridge down to the eave while the workman stands on a scaffold. The washing mix was pumped to the

Figure 8. Recording light transmission inside the greenhouse.

Figure 9. Greenhouse roof cleaning using the designed cleaner.

mix dispenser with a dispensing hole of diameter 6.05 mm. Three bays could be washed from one standing position of the scaffold. The set-up was moved to adjacent bays until the entire roof was washed. The washing process is shown in Figure 9.

Post – cleaning illumination

After the cleaning, the roof was allowed to drain and dry after which the illumination was measured again both around and within the greenhouse. The testing procedure reported earlier was carried out in three greenhouses.

Assessment of cleaning efficiency

The primary objective of the claeaning was to improve the transmittance of the glazing mateerial. A reasonable method of assessing the efficiency of the designed equipment is to compare the pre- and post- cleaning transmittances of the glazing material. This was done using Equations 7 (Anonymous, 2011):

$$T_\lambda = \frac{I_1}{I_o} \quad (7)$$

Where, T_λ = Transmittance before cleaning, %;

I_o = Average incident light outside the greenhouse (I_o), lux.
I_1 = Average transmitted light within the greenhouse (I_1), lux.

RESULTS AND DISCUSSION

The results of the equipment tests are presented in Table 1. The average pre- and post- cleaning transmittances for the three greenhouses were 36.62 and 42.65; 43.0 and 56.19; and 38.79 and 55.15% respectively. These data indicate an improvement of 6.03, 13.19 and 16.36% in transmittances of the roofs as a result of the washing. This trend in improvement in transmittance among the greenhouses was not unexpected from the physical observation of the roofs. While the first greenhouse was an abandoned one, the other two that were occasionally used have not been washed since erection close to two decades ago. The best maintenance practice that was done on the roofs of those occasionally used was to remove creeping plants and fallen leaves when the density becomes severe.

Because these roofs have not been cleaned for a long time, the accumulated dirt have stuck into the roof such that a single washing may not completely remove

Table 1. Transmitted light intensity (T_λ) before and after cleaning for greenhouses.

Point of measurement within the greenhouse	Greenhouse I		Greenhouse II		Greenhouse III	
	Before cleaning	After cleaning	Before cleaning	After cleaning	Before cleaning	After cleaning
A	23,500.1	30,132.84	28,734.76	45,890.78	30,456.30	46,325.67
B	22,200.0	29,591.40	31,655.52	41,654.89	30,762.88	42,765.34
C	48,200.00	54,411.00	28,454.87	42,564.23	28,786.65	44,123.56
D	22,082.75	23,686.10	29,500.00	43,259.78	29,125.65	45,321.76
E	24,114.24	25,825.51	29,275.89	43,523.67	28,534.70	43,231,60
F	24,912.6	27,058.82	30,194.005	43,623.56	28,125.30	44,324.60
Total	165,009.69	190,705.67	177,815.05	260,516.91	175,791.48	266,151.93
Average Transmitted Light within the Greenhouse (I_1)	27,501.62	31,784.28	29,635.84	43,419.49	29,298.58	44,357.66
Average Incident Light outside the Greenhouse (I_o)	75,100.0	74,520.70	68,920.56	77,275.75	75,524.56	80,432.12
Transmittance $T_\lambda = \frac{I_1}{I_o}$	36.62%	42.65%	43.00%	56.19	38.79	55.15

Table 2. Estimated materials of construction and specifications.

S/N	Description	Dimensions	Quantity	Cost, N
1	Upper arm pipe	1300 L and 55O D (mm)	1	800.00
2	Middle arm pipe	1000 L and 50O D (mm)	1	600.00
3	Bottom arm pipe	500 L and 45O D (mm)	1	500.00
4	Brush	550 H and 40O D (mm)	1	2,000.00
5	Brush frame	600 L and 30 W (mm)	1	1,500.00
5	Sump pump	1 hp	1	8,000.00
6	$\frac{3}{4}$ inches hose	10 m	2	1,500.00
Total				14,900.00

the dirts. This is possibly why the improvement in transmittance is not very high. A repeated washing after the dirts must have been softened will remove further debt and improve the transmittance.

This equipment has a number of advantages over the traditional ladder cleaning method. Only one person can operate the equipment as against the ladder method in which at least two people are required with one to secure the ladder. The load imposed on the roof is also reduced as only the weight of the brush as against that due to the ladder and washmen is imposed on the roof, while the time for equipment movement is also reduced.

Another advantage of this equipment is that it could be used in small roofs where the ladder may not be appropriate even if desired.

CONCLUSION AND RECOMMENDATIONS

To facilitate cleaning of greenhouse roofs especially in Nigeria, a simple roof cleaning device was conceptualize, designed, fabricated and tested. When tested on three greenhouses, an improvement of between 6.03 and 16.36% in transmittance was recorded. Compared to the ladder method which is the common method employed in the country, the equipment has great potentials as a suitable alternative considering the inherent advantages of faster operation, less labour demand, less load imposed on the roof and operator safety. The cleaner is adaptable to various types of greenhouses and it is simple to set-up, operate and maintain.

In order to derive the maximum benefits from this equipment, it is recommended that further research be carried out on the possibility of reducing the self weight of the cleaner through the use of small diameter pipes. The wood base for the brush will be prone to decay after prolonged use because of contact with water. Appropriate timber species and possible preservative treatments to curtail this hazard are recommended.

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