UJEAS

UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 5(1), June (2025), 2326-2333
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

Determination of the Field Capacity and Field Efficiency of String-Cutter Grass Mower

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Abstract
Grass mowers with nylon string-blade cutters are becoming a common-place lawn maintenance machinery owing to their low initial cost, deployment capability in hard-to-reach areas and versatile applications. However, very little is known about their field performance which is important for their proper use and management. This study determined the field performance of two string cutters; coded C1 and C2, having nylon cutting-string blades. Direct measurement of mowed area, and productive and idle operation times was done. Effective field capacity was obtained as 0.0785 ha/hr for C1 and 0.0748 ha/hr for C2. Field efficiency of 83.78% and 85.18% were obtained for C1 and C2 respectively. A 2.98 kW push-type lawn mower also studied had 0.0821 ha/hr field capacity and 81.93% field efficiency. The field performances were similar to those reported by other researchers. The mowers with string blades gave higher specific field capacities; 0.0842 ha/kW.hr for the 0.932 kW C1 and 0.1004 ha/kW.hr for the 0.745 kW C2 as against 0.0288 ha/kW.hr obtained for the push-type mower. Statistical T test conducted at 0.05 level of significance showed no significant difference between the 3 studied mowers' performances. Ascertaining the mowers field performance will give the buyers and operators some purchase and management decisions support information.

Keywords: Field operation, Field performance, Grass mowers, Lawn maintenance, Nylon material.

1. Introduction

Efficient lawn maintenance is a major challenge in the tropical region as the higher average rainfall experienced brings about rapid growth of tall grasses. Unkempt lawns constitute a sore sight and create conducive habitats for insect pests, rodents and harmful reptiles that pose threats to lives. Mowing increases grass density and leads to the protection of the soil from erosive elements, while improving the aesthetics and reducing pest infestation (Pirchio *et al*., 2019). Grass management technology had continued to advance with better techniques of grass cutting being invented; many designs are now available on a commercial scale, each suited to specific grass, climate and topography (Okafor, 2013).

Nylon is a thermoplastic polymer with considerable strength and stiffness, excellent toughness, and outstanding wear and bearing resistance (Kumar & Reddy, 2020). It is also chemical resistant and offers reduced weight making it a suitable material replacement for metals in certain engineering applications. Nylon and other plastics are widely employed in agricultural machines and equipment construction materials for fertilizer, chemicals, etc containers, reactor vessels, and structural members. They are also used as blades construction materials in low-shear cutting applications. They are immensely advantageous in their deployment in lawn mowers string blades. Mech Marvels (2021) described string trimmers string blades as durable and flexible; allowing the possibility of trimming of unknown areas without having to worry about blade damage from unseen obstacle. They fit into awkward spaces and easily trim around, near and along trees, fences, etc (Mech Marvels, 2021; Esparcia, 2023). See Plate (1).


Plate 1: The String-blade Mower in Operation

Rotary mowers are more versatile and widespread for home lawn maintenance (Trenholm *et al*., 2009; Nkakini & Yabefa, 2014). They are generally moved manually by a single operator, while the prime movers only power the cutting blades or strings (Pamujula & Bhaskar, 2015). The most common types are fitted with wheels and are pushed/pulled. The newer variants are compact and borne on the shoulder, and have lighter and much smaller IC engines. The shoulder-borne string cutters are currently becoming a common place machine for lawn trimming possibly because of their suitability for small and undulating lawn and their low initial cost. Mech Marvels (2021) reported that string cutters (also called line trimmers) blades are offset and allow the cutting path to be viewed clearly while possessing the capability of trimming areas having obstacles without blade damage. This their capability of fitting into awkward spaces and trimming very odd angles and steep embankments around and near a variety of features easily was also reported by Esparcia (2023) who stated that they can handle weeds that cannot be reached by other mowers. Cordless electric motor-driven versions powered by rechargeable, and designed to be borne with both hands are currently advertised online (amazon.com, undated). Ergonomic considerations are important in man-machine systems. Esparcia (2023) recommended that the mower dimensions should be fitting to the users' anthropometric configurations. Ergonomic issues are also important in human-controlled mowers field performance.

Amaefule *et al.* (2018b) and Ahiakwo & Isirima (2023) reported that agricultural machines should be techno-economically appropriate to be attractive and acceptable. Machine mowing must likewise be done in an efficient manner for it to be profitable, considering factors like equipment capacity, field efficiency and cost. Functional, mechanical, capacitive and economic performances have been identified as necessary in evaluating agricultural machines. Hunt & Wilson (2015) agreed with this and presented field capacity and field efficiency as essential field machine performance parameters. Sale *et al.* (2013) reported that capacitive performances help in ascertaining whether a proposed machine will complete a given job in a given time and under given field conditions. Good machinery management is important and requires a techno-economic analysis of the actual or proposed operations. Oduma *et al.* (2015) reported that accurate performance data is required for efficient management of machinery. While string-blade cutters are getting increasingly popular, their performance characteristics are little known. The determination of field capacity, field efficiency and other important operational parameters of lawn mowers is therefore necessary for informed decisions on their selection and use.

The work rate of a field machine is referred to as its field capacity, which is measured as the area covered by the machine in performing the desired operation. The average speed and working width of the operation are utilized in calculating the theoretical field capacity (C); evaluated as in Equation (1) on the basis of the area processed.

$$C = \frac{S\,w}{c} \qquad (1)$$

Where the variables are as defined in the nomenclature section.
When C is evaluated in ha/hr and the other variables in the above stated units, c is valued as 10. The effective field capacity is evaluated by multiplying the theoretical field capacity with the field efficiency (e). The field efficiency is a decimal dimensionless factor that modifies the field capacity for fractional machine width use and for loss of time to operator's personal time (*Zaied et al*., 2014; Shinde *et al.*, 2016). It also accounts for time lost to tasks different from the actual field processing. In string mowers, field efficiency also covers for the operation time spent on overlaps and reworking of skipped portions in the mowed area. For string-blade cutters operation, maintaining

constant speed and swath of cut even when the field conditions are similar is very difficult. Operators' differences and uneven distribution of vegetation will definitely affect the feed of the standing grass into the cutting mechanism, and consequently the mowing speed. Hunt & Wilson (2015) explained that an operator's ability, motivation, alertness and training can affect his performance significantly, and that the field geometry has a serious influence on turning time.

Direct measurement of the area processed and time spent may be a better technique for evaluating the field capacities for string cutters and other operations lacking in repeatability of working width and speed of operation, rather than using the earlier field capacities equations. Shinde *et al.* (2016) obtained the directly measured effective field capacity (C_{ed}) for tractor-drawn Rotavator with Equation 2 using the area of processed field A and effective operation time t_e and total idle time t_i. Falana *et al.* (2020) evaluated the effective and theoretical field capacities of a modified shoulder-borne brush cutter having a 240 mm diameter metal blade for kenaf harvesting, based on the area processed and time taken.

$$C_{ed} = \frac{A}{t_e + t_i} \qquad (2)$$

Capacity-based field efficiency is the ratio of the effective field capacity to the theoretical field capacity. Shinde *et al.* (2016) evaluated the field efficiency of the Rotavator based on the ratio of the field capacities. Field efficiency can also be evaluated as the ratio of the theoretical field capacity-based operation time to the practical time spent in the field operation. The time-based field efficiency (see Equation 3) is the ratio of the time spent in the actual processing of the field to the total time spent in the field operation (t_t).

$$e = \frac{t_t}{t_e + t_i} \qquad (3)$$

The combination of human factors like eye-brain coordination and on-the-go tasks control efforts will ultimately contribute to varying field efficiencies. This will definitely be significant in string cutter-based mowing operations, portraying the need to synchronize operations control. Mowed area observation must be synchronized with the operator's locomotive pacing, movements of the fingers and arms, and whole trunk rotation. The idle time t_i can further be divided into time spent on activities that that are proportional to area (eg refilling the fuel tank and replacing cutting string) and that spent on activities that are not proportional to area (eg due to field geometry). String cutters are able to mow the lawn during the turning process, but not without incurring some level of reworks. The fraction of the area mowed during the turning that is eventually reprocessed or the extent of backtracking needed to ensure complete field processing after the mow-turn motion may not be easily evaluated.

T test is a statistical tool for testing the difference in the means of two groups of measurements (Bevans, 2020) and can be applied to a sample size of less than 30. The analysis can be done using a number of application software; including Microsoft Excel. This study is aimed at determining the field capacity and field efficiency of string-cutter mower in lawn mowing operation. The study is limited to the field performance determination and not extended to techno-economic analysis. The outcome of the study will assist users of string cutters and managers of lawn mowing in carrying out informed management decisions; including those done for selection and use.

2.0 Materials and methods

The grass mowing field experiment was conducted at Nnamdi Azikiwe University, Awka Anambra State Nigeria (6.2459 ˚N and 7.1199 ˚E). The mowed plots were dominated by carpet grass (*Axonopus compressus*) with sparse presence of spear grass (*Imperata cylindrica*), and were partitioned into 20 m-by-20 m portions. Mowing was done at different intervals of grass regrowth in regularly mowed lawns of the campus; with the mowing in each treatment done with 2 different string cutter types, see Table 1. The performance of a push-type lawn mower was also obtained as well for comparison purposes. The cutter types were expressed as codes. The average of the results for each machine type were used. Time was measured with stop watch. Personal protective equipment was used.

Cutting blade-string, petrol and engine oil were among the consumables used. The petrol and engine oil were mixed in the recommended proportion and poured into the fuel tank to the full and the quantities noted. The time taken for the filling and oil mixing were noted. Replacement string was fitted to the cutter head and the time taken also noted. The string was replaced each time it got totally worn as seen in the observed width of cut. The time for refilling fuel and oil, and replacing string blades, and the refilled/replaced quantities were measured. Other operation idle times incurred, like time spent in cleaning grass and soil deposits on the blade guard were also recorded. The time interval and the area mowed in between the refill, replacements and in-field maintenance were also measured and recorded for each run. Following the method used by Shinde *et al.* (2016) and Falana *et al.* (2020), the field capacity was evaluated from direct measurement of the area covered and time taken using Eq. (3). The width of operation was also determined from the average of 10 runs of the traversing the plot length during mowing operation.

Table 1: Relevant Parameters of the String-blade Mower

String Cutter Parameter	**Parameter Values for String Cutter Type**		
Code	C1	C2	C3
Drive Option	43-cc 2 Cycle	28-cc 2 Cycle	167-cc 4 stroke
Power Output (kW)	0.932 (1.25 hp)	0.745 (1 hp)	2.980 (4 hp)
Fuel Tank Capacity (L)	1.2	1	1.5
Weigh (kg)	7	6.1	27
Lubrication Method	SAE 40 mixing with fuel @ 40:1 ratio	SAE 40 mixing with fuel @ 40:1 ratio	SAE 40 from a separate 0.4 L tank
Cutting Device	Nylon Strings	Nylon Strings	Rigid Swing blades
Price (₦)	120,000	180,000	300,000

Microsoft Excel 2013 ® was used in calculating the T-values (t_{cal}) for testing the significant difference between the theoretical and effective field capacities obtained. A paired t-test was conducted at 95% confidence level; with degree of freedom (DOF) given by $n1 + n2 - 2$. With the 2 parameters the critical t-values (t_{tab}) was picked from table. Based on the 6 samples in each group the DOF was obtained as 10 (NIST, undated), and (t_{tab}) from Turney (2022) as 2.228. Calculated t-values greater than or equal to t-critical means there is a significant difference between the groups of values.

3.0 Result and Discussion

The Theoretical and effective field capacities obtained from the experiments for the string-blade cutters and the push-type mower are shown in Table 2. C1 had higher theoretical and effective field capacities than C2, while higher capacities were observed for the push-type mower than for the string cutters. The field capacities obtained were in increasing order of their power rating. Statistical analysis of the mowers effective and theoretical capacities gave a t_{cal} of 0.011522, 0.019604 and 0.001044 for mower C1, C2 and C3 respectively. These were less than the t_{tab} of 2.228, meaning that there is no significant difference between the effective and theoretical capacities of the mowers. Similarly, there was no significant difference between the push-type mower theoretical capacity and the string cutter mowers average theoretical capacity. The t_{calc} was obtained as 0.307348, and was less than 2.228 t_{tab}. Their effective capacities values had same case with a t_{calc} of 0.30097.

The field capacities were comparable to that obtained by other researchers. Falana *et al.* (2020) got 0.14 ha/hr theoretical field capacity; a 0.0968 to 0.1137 effective field capacity from a 1.67 kW modified brush cutter with metal blade for kenaf harvesting. 0.127 ha/hr effective field capacity was obtained by Okoro (2010) for a locally fabricated engine-powered mower fitted with horizontal cutting blade. Nkakini and Yabefa (2014) reported 0.115 ha/hr effective field capacity for a 0.934 kW manually powered spiral blade mower operating at 1500 rpm fabricated locally. A modified 0.745 kW electric motor- powered push-type rotary mower had 0.07 ha/hr field capacity. This locally fabricated mower operates at 1520 rpm and 0.5 m width of cut, and is manually pushed on 4 wheels (Magar *et al.*, 2010).

Table 2: Selected field performance parameters of the studied grass mowers

Field Performance Parameter	String Cutter Type			Push-type
Mower (code)	C1	C2	Average	C3
Working width (m)	0.415	0.430	not applicable	0.480
Theoretical Field Capacity (ha/hr)	0.0925	0.0900	0.0912	0.1008
Effective Field Capacity (ha/hr)	0.0785	0.0747	0.0918	0.0821
Specific Effective Field Capacity (ha/kW.hr)	0.0995	0.1220	0.1108	0.0339
Field Efficiency (%)	83.78	85.18	84.48	81.93

The studied push-type mower with 2.98 kW power rating had the least work rate for each kW power size. This can be attributed to the reduced power needed to rotate the lighter materials of the string blade and transmission. In comparison to the light nylon strings and their transmission unit, the push-type mower blades and transmission unit are made of steel which are heavier and need higher torque and sturdier transmission components to operate. Even among the string cutters the heavier 7 kg C1 cutter lags behind the 6 kg C2 in their specific field capacity. The 0.1004 ha/kW.hr higher work rate per kW for C2 translates to lower level of pollutants for each hectare mowed compared the 0.0842 ha/kW.hr obtained for C1 and 0.0288 ha/kW.hr for C3. 5,500 ppm Hydrocarbon content is reported to be contained in exhaust emission of conventional 2-stroke engines as against 850 ppm for 4-stroke (Koshy & Mehrunkar, 1993). Carbon monoxide emission of 250-600 g/kW.h is attributed to conventional 2- stroke engines and 1.25 g/kW.hr to the 4-stroke engines (Ikeda *et al.*, 1998). This shows that the push-type mower is better based on exhaust emission. Both engines emission level are within acceptable level of 603 standard (Koshy & Mehrunkar, 1993; Hochgreb, 1998) Environmental sustainability is important in considering any anthropological activity, so that today's activity will not jeopardize that of tomorrow.

The obtained work rate translated to 7.725 x 10^{-7} ha/hr per Naira of the purchase price for C1. For C2 it was 5.044 x 10^{-7} ha/hr per Naira and for C3 3.367 x 10^{-7} ha/hr per Naira. Again C3 had the least work rate per purchase price. Thus based solely on purchase price, mower C1 may be the cheapest option and C3 the costliest. The observed field efficiencies are also shown in Table 2. Mower C2 (a string cutter-type) had the highest value (85.17%) while the push-type mower C3 had the lowest (81.90%). The average field efficiency observed for the string cutters (C1 and C2) was 84.07%. There was no significant difference between the field efficiencies of C1 and C2, since the t_{calc} as 0.468492. The average string cutter average efficiency was also not significantly different from the push-type field efficiency, as the t_{calc} was 0.284913.

In terms of ergonomic assessment, the more idle time observed for C3 mower may be because of more resting and turning times requirement. The heavier 27 kg push-type mower is more difficult to maneuvre, even though it is merely pushed. This presumably connotes more turning efforts. The rolling wheel of C3 needs back and forth movements during turning, while its ground tractive resistance will result in lower forward mowing speed. In contrast, the shoulder-borne string mower requires simple hand grip and gentle trunk gyration. This will favour an easier advance and reduced turning time for the operator. The lower field efficiency of 70% reported by Magar *et al.* (2010) for a push-type locally fabricated mower could have also resulted from these ergonomic challenges. The mower had a lower field capacity than the 3 mowers in this study in spite of its higher 0.5 m working width. Demir (2021) reported higher power to weight ratio (specific power) as an advantage in machineries. Lower mower weight correlated with higher field efficiency. Heavier tools are known to demand more energy. Equally, mower C3 blade had vertical enclosure and top cover. Thus clearing its clogged blade will require more effort and idle time.

Other ergonomic issues included anthropometry-related challenges. The handle height of the push-type mower has adjustable inclination, which affords individual operator's arm-height compatibility to the mower handle push height. The string mower hanging belt is flexible and allows the adjusting of arm grip height to differing operator's anthropometry. However the cutter head may not always be guaranteed of horizontal plane spinning for the string. New mower versions has telescopic transmission shaft and adjustable cutter head inclination which obliterates this problem. Flue gas emission from the exhaust will pose more challenge with the string-cutter mowers; whose engine is just behind the back of the operator, than for the push-type. However the exhaust discharge is designed to face away from the operator. However lawn mower operators wear nose mask to reduce dust and fume inhalation as one of their personal protective equipment. Mower travel against and across the wind direction for the string-cutter and pushed types should be advantageous in reducing the operators problems with exhaust fumes.

The field efficiencies obtained were slightly lower than the findings of Okoro, (2010) whose locally fabricated engine- powered lawn mower gave a field efficiency of 88.4%. A field efficiency of 69.15 – 81.21% was obtained by Falana *et al.* (2020) for kenaf harvesting with a 1.67 kW modified brush cutter having metal blade. Nkakini & Yabefa (2014) obtained 63.2% field efficiency for the manually powered Spiral Blade Mower. Magar *et al.* (2010) reported a 70% field efficiency for the modified manually-pushed electric motor-powered rotary mower.

4.0. Conclusion

To bridge the knowledge gap in the field performance data of string-cutter mowers, the field capacity and field efficiency of two such mowers were determined by direct measurement. The 0.932 kW mower gave an effective field capacity of 0.0784 ha/hr and its 0.745 kW counterpart 0.0747 ha/hr. The field efficiencies were 83.78% and 85.18% respectively. A 2.98 kW push-type also studied gave a 0.08 ha/hr field capacity and 81.93% field efficiency. No significant difference was found between the performances of the 3 studied mowers. Lower field efficiency and specific field capacity were observed for higher mower power. Higher mower power requires more petrol consumption also, which will ultimately lead to increased environmental pollution. The push-type mower required more turning effort, while more fumes; which translates to higher environmental problems were likely with the string-cutter types. The emission from both mower types were lower than the maximum acceptable levels. The mowers field performance data will be a good guide to mower buyers and operators, and lawn managers in purchase and management decisions.

5.0 Recommendation

The use of the string-cutter mowers will suit prospective buyers and lawn managers with low initial capital investment and hard-to-reach awkward-shaped small lawns, than do the push-type mowers. Wind direction must be considered in the deployment of these mowers so as to minimize the problems of fumes o the operators. Cost and quantitative ergonomic and environmental analysis of the mower operation is recommended.

Acknowledgements

The authors acknowledge the managers of grass lawns and mower operators in the Nnamdi Azikiwe University Awka campus for allowing in situ measurements and affording us the information that aided the experimental design in this study.

The authors hereby declare that there is no conflict of interest in the study and publication.

Nomenclature

C= theoretical field capacity, ha/hr
S= average operation forward speed, km/hr
w= average working width of machine, m
c= dimensionless constant
C_{ed}= directly measured effective field capacity, ha/hr
A= area of processed field, ha
t_e= effective operation time, hr
t_i= total idle time, hr
t_t= total field operation time, hr

e = field efficiency, dimensionless or %
C1 = the 0.932 kW string-cutter mower
C2 = the 0.745 kW string-cutter mower
C3 = the 2.98 kW push-type mower
ppm = parts per million
t_{cal} = the calculated statistical T-value
t_{tab} = the critical T-value
DOF = degree of freedom
p = statistical confidence limit
n = number of samples

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