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PRODUCTION OF THE GREEN-FERTILIZER USING AN ENHANCED CUTER-MIXER MACHINE

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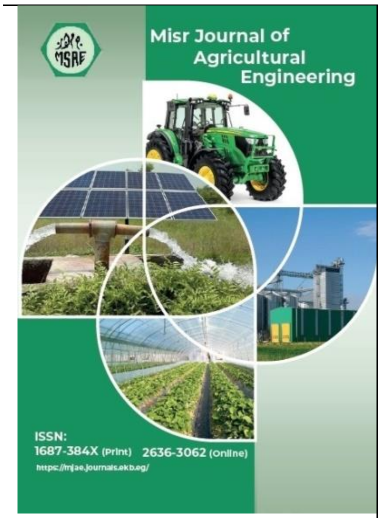


Keywords:
Mixing time; Shaft speeds; Tracers; Mixture; Mixing Efficiency; Energy requirement

ABSTRACT

The benefits of agricultural residues include several opportunities for processing them into economically products. Therefore, this study aimed to adapt the cutter-mixer machine "CMM" to manufacture green-garden residues (GGR) as the form of soil green-fertilizer (SGF). This process is the primary step for converting the GGR into fertilizer by constructing the cut-mixer machine. The cut-mixer machine (CMM) is tested and evaluated under three levels of mixing time (5.0, 7.5 and 10 mints) and three levels of cut-mixer shaft speeds (60, 90 and 120 rpm). The results concluded that the CMM can produce the green-fertilizer (SGF) at the appropriate levels of the studied variables: 7.5 min mixing time and the cut-mixer shaft speeds of 90 rpm. Comparing the calculated values of tracers (moisture and ash content) for the mix components (St) with the existing materials in the mixture, it was found that the moisture content decreased by 0.016% and the ash content decreased by 0.345%. The coefficient of variation for tracers (MC) and ash percentages were zero values and 1.37%, respectively. The mixing efficiency was about 99.06%, and the energy requirement was 7.77 kWh/ton.

INTRODUCTION

Appropriate management of agricultural residues is the suitable selection of the optimal and best benefit in social and economic terms during the process and usage **(Lutade, et al., 2020)**. In Egypt, the quantity of plant residues has reached 25 million tons, representing approximately 3% of agricultural income and about 5.5% of the value of plant output in 2019 (**Ismail et al., 2021**). Furthermore, these residues increased to reach 29.645 million tons during 2021, according to **Khidr et al. (2024)**. This is an indication of the faulty management of agricultural residues. Gardens and yards residues are representing 20% of the total green waste. This waste results from the fall of green leaves, especially in autumn or during tree pruning. Thus, these residues can be used as a valuable natural resource. This is a good source of organic matter, nutrients and others. While it contains more than 80% of its dry matter consisting of polysaccharides **(Ismail, et al., 2021)**.

In famous knowledge, the evergreen trees drop their leaves at once, to replace the oldest leaves. This operation is known in gardens. For this, the tree leaves residues can be used as the best green fertilizer. These dropped tree leaves are about 36.980 million tons in the year 2023. **Kumar et al. (2015)** clarified that the significant effect of plant residues as nutrients in ecosystems, especially through decomposition, for preserving soil fertility. Mixed plant residues have been used to slow the decomposition and release set free. Enhanced soil nutrients from mixed decomposition surpass individual plant residues. This process involves complex physical and chemical transformations that impact biological processes. While **Qiu et al. (2022)** found that effects plant tissues, tree species and plant leaf tissue sequester carbon in soils. Which, plant residue chemistry, especially the lignin/N ratio and K content, can affect the efficiency of microbes utilizing the residue-derived C substrate and the release of dissolved organic carbon “DOC” from plant residues. That influences the decomposition of the native soil organic carbon “SOC”. Considering the chemical compositions of plant residues are allowing for a more accurate estimation of soil carbon dynamics.

To produce green fertilizer essential to reduce the size of tree leaves residues by cutting, shredding, and/or stripping machines (**Hadidi and Ismail, 2006; El-Gendy et al., 2008; Ismail et al., 2012; Hande and Padole, 2015; Lutade et al., 2020; Abdelraouf et al., 2024**). Additionally, it needs to integrate with other benefits to function as a comprehensive green fertilizer. Also, many experimental works have been investigate the effect of mixer design and various parameters (e.g., powder properties and mixer operating conditions) on the performance of continuous horizontal mixers (**Industrial Mixers (2022), Osorio and Muzzio (2016) and Pernenkil and Cooney (2006)**) using a variety of experimental techniques, such as visual tracking (VT), positron emission particle tracking (PEPT), particle image velocimetry (PIV), electrical capacitance tomography (ECT), computed tomography (CT) and magnetic resonance imaging (MRI) **(Huang and Kuo, 2014)**. Furthermore, **Dodo et al. (2024)** conducted that the shredder-mixer machine's throughput capacity was tested using a two-way factorial design. They studied the variables of operating times (15, 20, 25, and 30 minutes) and speeds (150, 300, 450, and 600 rpm). Napia grass and dry Guinea corn stalks were used in the experiments. The findings that increased the machine's throughput capacity were done at increased operating time and speeds.

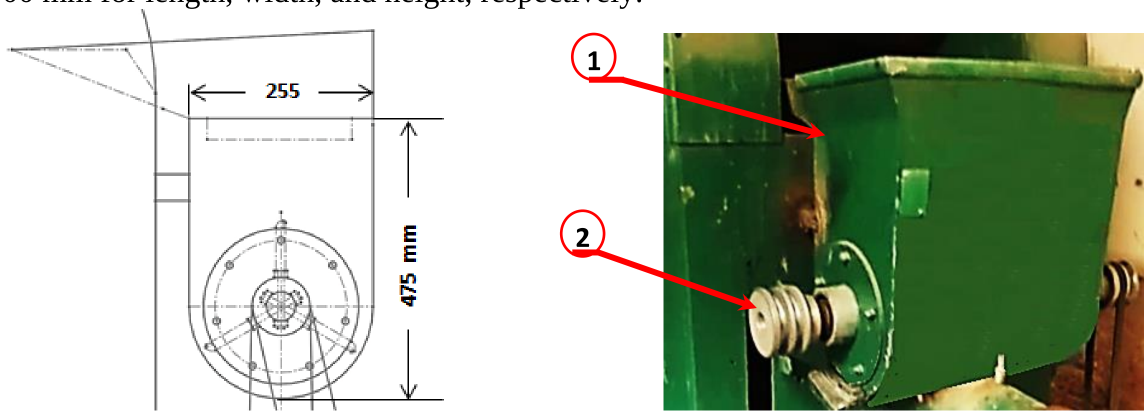
Biroun et al. (2023) concluded that the change of the mixer filling in horizontal mixers, followed by a change in the more important factor, is the bulk density of the mixture. Previous studies have indicated that as the bulk density of the fed powder decreases, the mixer loading increases (**Muňoz et al., 2018**). This action is also important to note that the mixer filling is influenced not only by the bulk density of the powder but also by the other rheological properties. The increase in water amount on particle surfaces gradually increases the particle contact area and causes the powder to become more cohesive **(Harnby et al., 1996 parts 1 and 2)**. The variety of materials for their dimensions, physical and chemical properties and water content allowed the main factors influencing the powder rheology. **Opalinski et al. (2021**) explained that the static and dynamic conditions of powders composed of fine particles of hygroscopic nature impact their surface properties. The optimal moisture content favorably affects the rheology of moist powders; damaging fluctuation is markedly diminished and the processes with powders handled under low external forces proceed fluidly. To enhance powder flow, a relatively new method known as interactive mixing is being utilized, which falls under the category of mechanochemical approaches. The mixing is a multi-parametric process that needs optimization of the process values. So that the Design of Experiment (DOE) technique and response surface methodology (RSM) were used. By identifying the factors that most affect the fluidity of powders, the mixing process can be improved at the suitable parameters **(Thakur et al., 2014 and Sarnavi et al., 2013)**. While **Suryawan et al. (2022) and Zawiślak et al. (2012)** explained that thermogravimetric analysis (TGA)/derived thermogravimetric analysis (DTG) and water, ash, and heat values were used to analyze the parameters of a mixture of paper and garden waste that was processed utilizing material flow analysis. A waste paper shredder was used for this. Paper waste and garden trash were combined and pelletized. There was a relationship between mixing paper waste and rising calorific value. The water evaporation, devolatilization, and carbonization reactions caused the mass to decrease in the TGA/DTG study.

The current study focused on adapting the cutter-mixer machine (CMM) to produce green-garden residues as a form of soil green-fertilizer (SGF).

MATERIALS AND METHODS

The manufacturing process was implemented within the cutter-mixer machine (CMM) of the Agricultural Engineering Department, Faculty of Agriculture, Mansoura University and a special workshop located in Mansoura city, to evaluate the cutting and mixing machine. It was modified from the machine used by **Mostafa (1979) and Ismail (2001)** which built, manufactured, pre-tests, and certified in a workshop in a Dakahlia Governorate from 2020 to 2022. The experiments were done at 2023 at the Farm Machinery Laboratory Research that constructed by **Ismail (2004)** as part of outcomes from a project financed by Researching Unit of Mansoura University.

The modified machine consists of two parts in one cutting and mixing unit (Fig. 1). The auxiliary parts of the cutter-mixer unit are the power source, transmission system, and frame. Furthermore, the main parts include the cutting and mixing: hopper, shaft, and knives. The three coordinate dimensions of the cutter-mixer machine investigated were 900 mm, 720 mm, and 1700 mm for length, width, and height, respectively.



1- Hopper 2- Pulley

Fig. 1: The sketch and photograph of the cutter-mixer machine "CMM"

The power source: A three-phase motor of 2.237kW and 1500 rpm was used to supply the rotational speed of the shaft, which carries the knives through the pulleys and belts.

The transmission system: A double pulley with a diameter of 100,130 mm transmits rotation from the motor to a pulleys of different diameters mounted on the shaft.

The frame: The box frame with dimensions of 900, 720, and 1700 mm was made of 7 mm thick steel. On the front wall, the “CM” was supported by two bolts.

The hopper: The hopper has dimensions of 475, 388, and 255 mm, respectively, for depth, length, and width. It was made from stainless steel of 4 mm thickness.

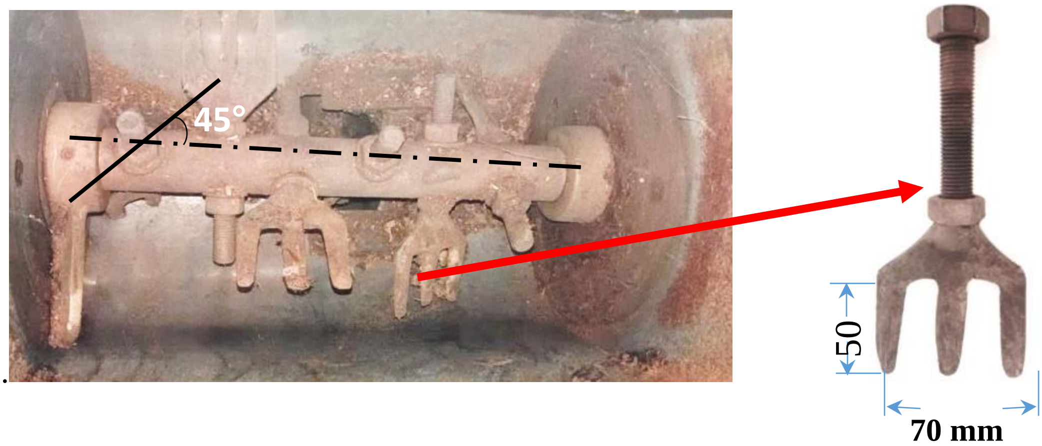


Fig 2: The shaft and knives inside the “CM” hopper

Shaft and knives: The shaft of 44 mm diameter with 6 holes around its circumference (120 degrees between each). Each hole is far, about 45 mm, from the other. In each hole the screw bolt was fit in. The screw bolt is the part of knife. The effective part was shaped like a fork to cut and mix the tree leaves and the other mixture components. The sides of each finger of fork tine were sharpened at an angle of 30 degrees. The finger length was 50 mm. The effective part of fork has 92 × 70 mm length and width respectively.

Component of green-fertilizer (GF)

The green fertilizer mainly consists of three components in addition to water. The first is the main component, which is the green residue from garden trees as fresh leaves. The second component is clay. The additions are the main fertilizer components as liquid and water. The properties and amount of each component can be illustrated as follows:

- Residues leaves: The fresh leaves from garden trees that dropped on the ground were collected by Collecting-Packing Machine "CPM" (**Ismail et al., 2021**). The fresh leaves were separated, and some physical, mechanical, and chemical properties were identified (Table 1).

- Additions materials: The clay with about 15.76% Mc, liquid fertilizer as a major nutrient of NPK and water were added with the ratios of about 6.5, 1 and 7.5 %, respectively. These additions provide not only nutrients but also acts as binding materials.

Table 1: Some properties of green-fertilizer components

Component / Element	Fresh leaves	Clay	Water
MC, %	65.33	15.76	100
PH	5.5-6.5	6-6.5	5-7
Ash	87.95	100	0.00
NPK, ppm	(13600-200-3700)	-	-
Bulk density, g/cm^3	0.293	2.43	1.00
Mass ratio, unit	10	5	1

Laboratory experiments:

The experiments are divided into two parts:

- Construct and test the cut-mixer machine "CMM" to determine the levels of the studied variable during mixing the green-fertilizer components. The collected leaves were chopped at 1700 rpm and cutting time of 10 min. Then the mixing operation tested at the studied variables of:

    1- Three levels of cut-mixer speeds (60, 90 and 120 rpm)

    2- Three levels of mixing times (5.0, 7.5 and 10.0 min)

    3- Three samples from location in mixer (right "R" – middle "M" – left "L")

- Collect and analyze the cutting-mixing materials to determine the suitable mass ratio to be added of each. The volumetric ratio of green tree leaves, clay, and water was 10:5:1. The separate properties for each component and calculate for the mixture resulting in the mixture moisture content, bulk density and NPK were 52%, 0.387g/m^3, and 13600, 200 and 3700 ppm respectively.

The CMM evaluations embrace:

1- The tracer component (two tracer used) mixture moisture content (MMC, %wb) and ash component (Ash, %). Three samples for each test were taken to measure, determine and calculate each of the:

- The moisture content was determined using the oven-drying method.
- The ash content "Ash" was determined using the stove method described by **Ismail, (2002)** as follows:

$$\boldsymbol{Ash} = \frac{(\mathbf{As - Ss})}{\mathbf{As}} \times \mathbf{100}, \% \tag{1}$$

where: As = Ash mass in sample (g)

Ss = Stove ash mass in sample (g)

2- The mixing efficiency "M_{eff}" which can be determined using the following formula:

$$M_{eff} = \left[\mathbf{1} - \left|\frac{S_0 - S}{S_0}\right|\right] \mathbf{100}, \% \tag{2}$$

where:

S_0 = Target crude tracer content in sample, decimal

S = Crude tracer content in the tested sample, decimal

$\left|\frac{S_0 - S}{S_0}\right|$ = Absolute value

3- The bulk density "Bd" and reduction rate of residues volume "Rv" after and before tests were determined as:

$$\boldsymbol{Bd} = \frac{\mathbf{ww}}{\mathbf{Vs}}\ \boldsymbol{kgm^{-3}} \tag{3}$$

$$Rv = \frac{\mathbf{Vsb - Vsa}}{\mathbf{Vsb}} \times \mathbf{100}\ \%$$

where: Vs = Volume of sample, (cm^3)

Vsb = Volume of sample before cutting-mixing, (cm^3)

Vsa = Volume of sample After cutting-mixing, (cm^3)

4- The variance of sample can be calculated using the formula used by **Shenoy (2014)** as follow:

$$\mathbf{S^2} = \frac{\sum_{i=1}^{n}(C_i - C_{Av})^2}{n}$$

where: S^2 = Variance of sample

C_i = The tracer concentration in sample (i), (%)

C_{Av} = The average tracer concentration in sample, (%)

n = Number of samples

5- The quality of mixture can assess by the coefficient of variance according the following formula:

$$\mathbf{C_{oV}} = \frac{\vec{x}}{\mu} \qquad (4)$$

where: C_{oV} = Coefficient of variance of sample

$\vec{x}$ = Standard deviation of sample

μ = Target composition of tracer in sample

6- The consumed energy "Ec" was determined as the following formula:

$$\textbf{Energy consumed} = \frac{\mathbf{kW}}{\mathbf{W}} \times \mathbf{C} \qquad \mathbf{kW\ h\ Mg^{-1}} \qquad (5)$$

where: kW = The consumed power, kW

$$\textbf{Total consumed power} = \frac{\sqrt{3} IV \cos\theta\eta}{\mathbf{1000}} \qquad kW$$

$$\textbf{No load power} = \frac{\sqrt{3}\mathbf{IV}\cos\theta\eta}{\mathbf{1000}} \qquad kW$$

Net consumed power = Total consumed power - Load power, kW

where: W = Productivity of "CMM", Mg h^{-1}.

C = component constant

$$\mathbf{W} = \frac{\textbf{Mass of the outlet sample (Mg)}}{\textbf{Operating time (h)}} \qquad Mg.h^{-1}$$

RESULTS AND DISCUSSION

1- Effect of mixing time on green-fertilizer moisture content

The percentage of moisture content in each sample is illustrated in Fig (3). The figure shows that the calculated moisture content "St" was about 52.01%. While in Fig 3-A, the moisture content was found in the mixed samples at cutting mixer shaft speed of 60 rpm of 48.0, 49.3, and 48.0 % at R, M, and L, respectively, and mixing time of 5.0 min. Moreover, the data of moisture content noted mixing times of 7.5 and 10.0 min were 48.0, 48.7, 48.0, and 49.3, and 49.3, and 45.3 % respectively at different locations in a mixer (R, M, and L) and cut-mixer shaft speed of 60 rpm. Then Fig (3-B) shows that the average moisture content at mixing times of 5.0, 7.5, and 10.0 min was about 52.22±1.39, 52.00±0.00, and 52.22±0.38% respectively at a cut-mixer shaft speed of 90 rpm. However, Fig (3-C) illustrates that the corresponding average data at 120 rpm cut-mixer shaft speeds were 50.44±1.68, 52.00±0.00, and 51.11±1.02%, respectively. These results may be due to the balance component of the mixture at all positions in the mixer. There is no definitive trend in the moisture content of the samples based on their locations; however, increasing the mixing time results in improved homogeneity of the moisture content within the sample. The results agree with **Ismail (2001), Ismail (2002), Ansuree et al. (2021), and Opalinski et al. (2021).**

2- Effect of mixing time on green-fertilizer ash content

The percentage of ash content in each sample is explained in Fig (4). From the figure, it can be realized that the calculated ash content "At" was about 40.46%. Whereas, in Fig (4-A) the average ash content was found in the samples of the mixture at a cut-mixer shaft speed of 60 rpm of 42.26±0.79, 42.77±1.16, and 41.48±3.56% at mixing times of 5.0, 7.5, and 10.0 min, respectively. At that time, Fig (4-B) shows that the average ash content at mixing times of 5.0, 7.5, and 10.0 min was about 42.52±1.43, 40.60±0.56 and 41.92±0.73%, respectively at a cut-mixer shaft speed of 90 rpm. However, Fig (4-C) illustrates that the corresponding average data at 120 rpm cut-mixer shaft speeds were 43.32±1.19, 45.72±0.12, and 46.00±0.53 %, respectively. The all trend data clearly shows that the nearest form of CMM and the calculated ash content "At" were established at 90 rpm cut-mixer shaft speed and 7.5 min cut-mixer shaft speed. These results may be due to the adequate mixing time and speed to obtain the balance component of the mixture at all positions in the mixer. The results agree with **Ismail (2001), Ismail (2002), and Ansuree et al. (2021)**.

3- Effect of average cut-mixer speed on green-fertilizer moisture content

The effect of cut-mixer speeds on the average of mixture moisture content was illustrated in Fig (5). From the figure, the data trend has a positive normal distribution curve. It shows that the highest average of green-fertilizer moisture content was found at the cut-mixer speed of 90 rpm, which recorded 52.22, 52.00 and 52.22% at mixing times of 5.0, 7.5 and 10.0 min, respectively.

4- Effect of average cut-mixer speed on ash component in green-fertilizer

Likewise, Fig (6) shows that, at average mixing time, the ash content was 43.99, 42.13, and 40.38% at the sample positions of (R, M, and L), respectively and cut-mixer shaft speed of 60 rpm. The conforming average data at cut-mixer shaft speeds of 90 and 120 rpm were 41.62, 41.68 and 41.73% and 45.46, 44.98 and 44.83%, respectively, at the sample position of (R, M, and L).

Furthermore, the effect of cut-mixer shaft speeds of 60, 90 and 120 rpm was 42.17, 41.68, and 45.01% ash content, respectively. All the trend data indicate that the nearest condition of CMM and the calculated ash content "At" were established at 90 rpm cut-mixer shaft speed and 7.5 min cut-mixer shaft speed.

A

B

C

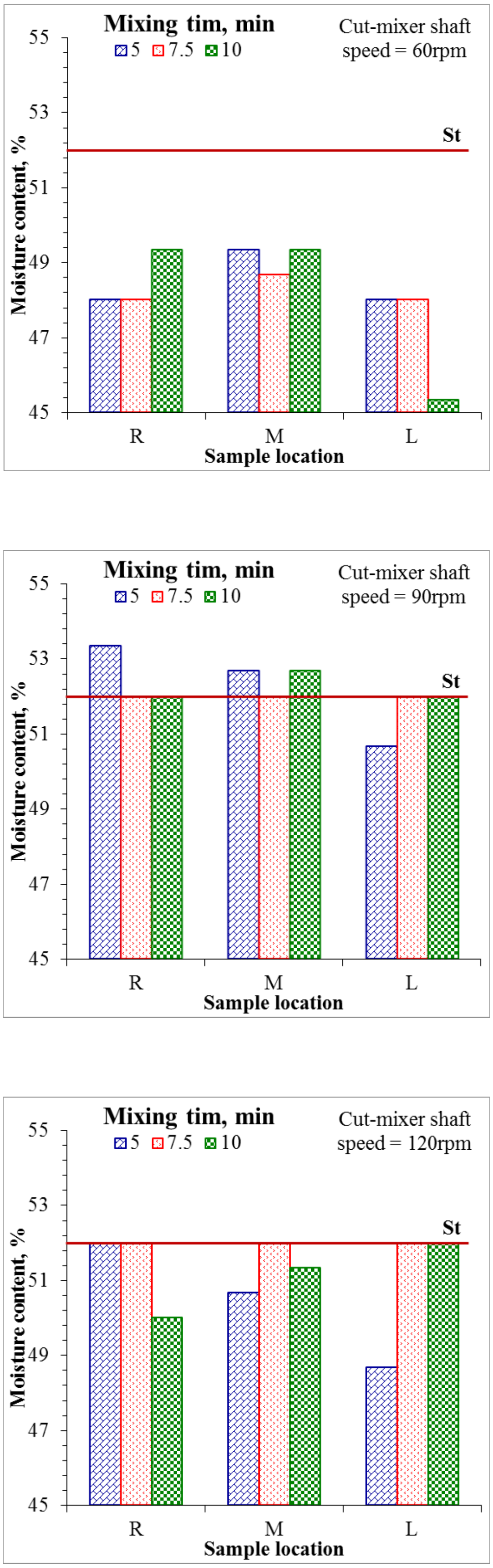


Fig 3: Mixture moisture content via samples location at different mixing time.

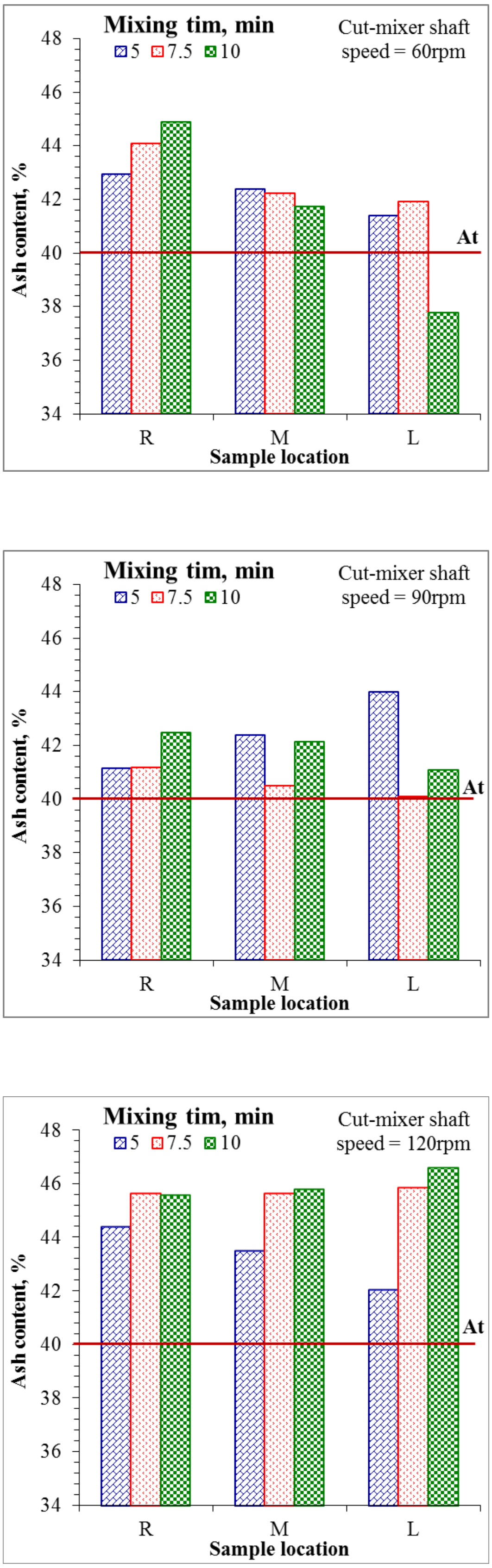


Fig 4: Mixture ash content via samples location at different mixing time.

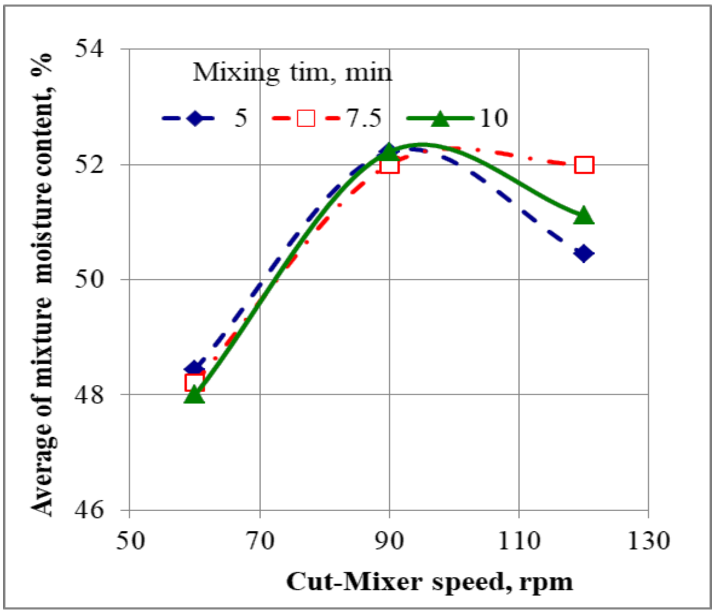


Fig 5: Effect of cut-mixer speeds on the average of mixture moisture content

The effect of cut-mixer speeds on the average of mixture moisture content was illustrated in Fig (5). From the figure, the data trend has a negative normal distribution curve. It shows that the highest average of green-fertilizer ash content was found at the cut-mixer speed of 120 rpm, which recorded 43.32, 45.72 and 46.00% at mixing times of 5.0, 7.5 and 10.0 min, respectively. But the lowest average of green-fertilizer ash content was found at the cut-mixer speed of 90 rpm, which recorded 42.52, 40.60 and 41.92% at mixing times of 5.0, 7.5, and 10.0 min, respectively.

Generally, the two tracers tested in the present study cleared the best level of the studied variables is the mixing time of 7.5 min and the cut-mixer shaft speed of 90 rpm. These results are agreement with **Ismail (2001)** and **Ismail (2002).**

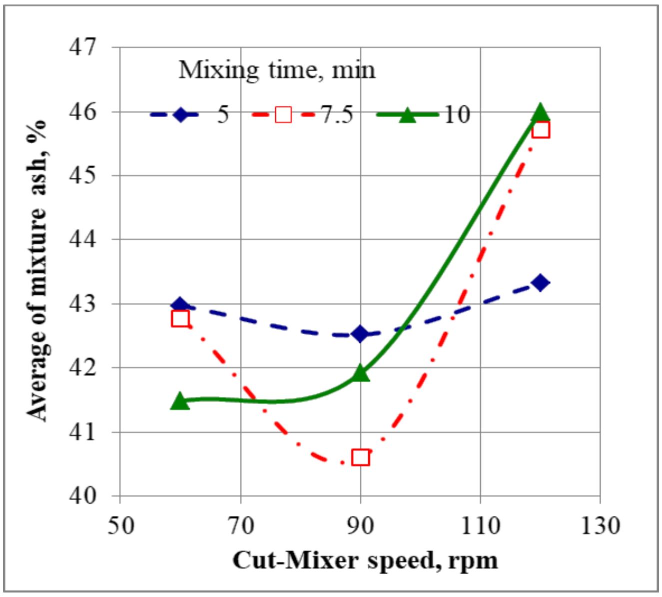


Fig 6: Effect of cut-mixer speeds on the average of ash content

5-The effect of the studied variables on cut-mixer efficiency

The effect of mixing times, cut-mixer speeds, and location of samples on mixing efficiency was calculated according to Eq. (2) and illustrated in Fig (7). The figure clearly shows that the maximum mixing efficiency was 99.90%, considered at 7.5 min of mixing time, 90 rpm of cut-mixer speeds, and "M" of location of samples. While the minimum mixing efficiency was 84.83%, considered at 10.0 min of mixing times, 120 rpm of cut-mixer speeds, and "L" of location of samples. However, at the average location of samples, the maximum and minimum of covariance of 5.04 and 0.33 % were found at mixing times of 5.0 and 7.5 min and cut-mixer speeds of 60 and 120 rpm, respectively. But at the minimum Cov the mixing efficiency was 87.01% at the average location of samples. Consequently, the appropriate mixing efficiency may be found at 7.5 min of mixing times, 90 rpm of cut-mixer speeds, and the average of locations of samples that achieve the Cov of 0.87%. The results agree with **Ismail (2001), Ismail (2002), Marczuk et al. (2021), and Ansuree et al. (2021).**

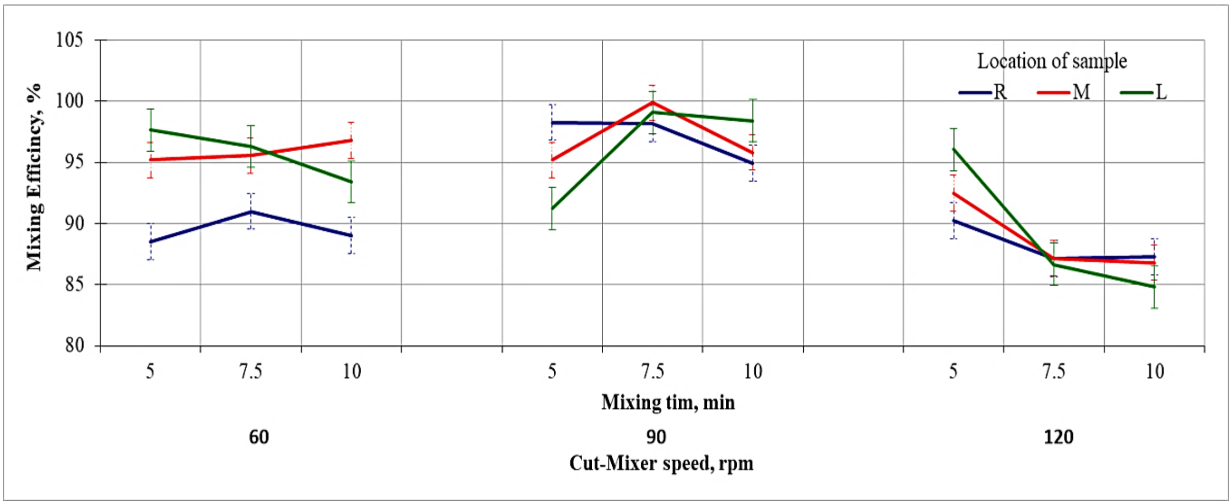


Fig 7: Effect of mixing times, cut-mixer speeds and location of samples on mixing efficiency

6- The required energy for cut-mixer

The effect of mixing times on energy requirements for the cut-mixer machine at different cut-mixer speeds was illustrated in Fig (8).

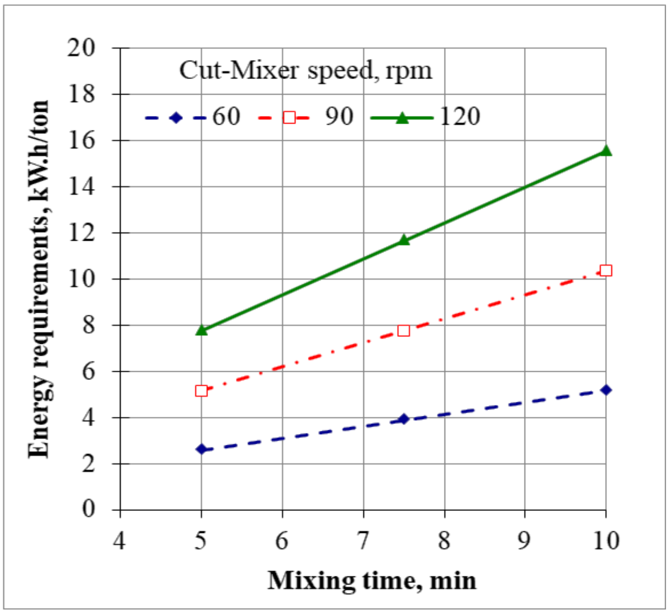


Fig 8: Effect of mixing times on energy requirements for a cut-mixer machine at different cut-mixer speeds

From the figure, it can be realized that a proportion relationship exists between the energy requirements and both mixing times and cut-mixer speeds. Furthermore, the data show that the increase in mixing times from 5 to 10 min, the energy requirements increase from 2.59 to 5.18, 5.18 to 10.37, and 7.77 to 15.55 kW h/ton, respectively, at cut-mixer speeds of 60, 90, and 120 rpm. While the energy requirements increased from 2.59 to 7.77, 3.69 to 11.6,6 and 5.18 to 15.55 kW h/ton, respectively, at increased tine cut-mixer speeds from 60 to 90 rpm at different mixing times of 5.0, 7.5, and 10.0 min.

CONCLUSION

The results concluded that the cut-mixer machine can successfully produce green fertilizer at appropriate levels for the studied variables. The optimal parameters include a mixing time of 7.5 minutes and cutter shaft speeds of 90 rpm. Comparisons with the tracers indicated a decrease in moisture content (MC) of 0.016% and in ash content of 0.345%. The coefficients of variation for the tracers' MC and ash were 0.00% and 1.37%, respectively. The mixing efficiency achieved was approximately 99.06%, with energy requirements of 7.77 kWh per ton.

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إنتاج السماد الأخضر باستخدام آلة القطع والخلط المحسنة

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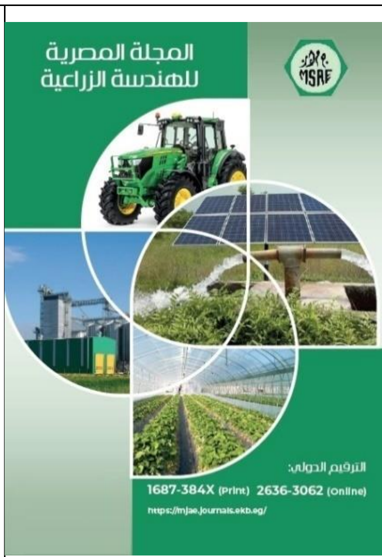

الكلمات المفتاحية:
زمن الخلط؛ سرعات العمود؛ المواد المتتبعة؛ الخليط، كفاءة الخلط؛ متطلبات الطاقة.

الملخص العربي

تتمثل فوائد المخلفات الزراعية في تحقيق فرص متعددة لمعالجتها كمنتجات اقتصادية. ولهذا الغرض، هدفت الدراسة إلى مواءمة آلة القطع والخلط "CMM" لإنتاج مخلفات الحدائق الخضراء كسماد أخضر للتربة. تُعد هذه العملية الخطوة الأساسية لتحويل المخلفات الخضراء إلى سماد من خلال بناء آلة القطع والخلط. حيث تقوم أسلحة القطع بخلط مكونات السماد بعد عملية تقطيع الأراق النباتية الخضراء. وقد تم اختبار آلة القطع والخلط وتقييم أدائها عند ثلاثة مستويات من زمن الخلط "٥,٠، ٧,٥، ١٠,٠ دقائق" وثلاثة مستويات من سرعات عمود الخلاط "٦٠، ٩٠، و ١٢٠ دورة في الدقيقة". خلصت النتائج إلى أنه يمكن استخدام آلة القطع والخلط لإنتاج السماد الأخضر عند المستويات المناسبة للمتغيرات المدروسة، وهي زمن الخلط ٧,٥ دقيقة، وسرعة عمود الخلط ٩٠ دورة في الدقيقة. وقد تبين عند مقارنة قيم المواد المتتبعة "المحتوى الرطوبى والرماد" المحسوبة لمكونات الخليط "St" مع المواد الموجوده بالمخلوط لوحظ انخفاض المحتوى الرطوبى بنسبة ٠,٠١٦٪ والرماد بنسبة ٠,٣٤٥٪، وكان معامل التباين للمواد المتتبعة المحتوى الرطوبة والرماد ٠,٠٠ و١,٣٧٪، وكانت كفاءة الخلط حوالي ٩٩,٠٦٪، ومتطلبات الطاقة ٧,٧٧ كيلو وات ساعة/طن.

ختامًا، يعد استخدام الأشعة فوق البنفسجية في تعقيم روث الدجاج تقنية معالجة موفرة للطاقة واقتصادية.