Misr J. Ag. Eng., 25(4): 1478-1492 BIOLOGICAL ENGINEERING

MANUFACTURE AND PERFORMANCE EVALUATION OF A SELF-PROPELLED COMPOST TURNING MACHINE

Morad , M . M* A . F. Abdel Mottaleb T.Z. Fouda*****

ABSTRACT

A self- propelled compost turning machine was developed and locally manufactured from a low cost, local material to be suitable for Egyptian farms. Performance evaluation of the manufactured machine was carried out in terms of compost density, composting time, machine capacity, energy requirements, final product quality and turning cost. The machines performance was studied as a function of change in machine forward speed, rotor peripheral velocity pile height and number of compost turning per month. The experimental results reveal that final product quality and turning cost were in the optimum region under the following conditions:

- Machine forward speed of about 1500 m/h.
- Rotor peripheral velocity of about 240 rpm.
- Pile height of about 100 cm.
- Number of compost turning of four times per month

INTRODUCTION

Field crop residues are considered one of the most critical problems which face the Egyptian farmer. In Egypt, there are about 25 million tons yearly of the field raw material, the most important of which are rice straw (4 million tons), corn stalks (3.5 million tons) and cotton stalks (2 million tons) (according to the statistics of the control Authority for Agricultural Economy in 2005).

Accumulation of these residues in large quantities results not only in deterioration of the environment but also in a loss of potentially valuable material. Manuring with these residues through composting is a promising route , especially with the increase in fertilizer price.

* Prof of Agric. Eng., Fac. of Agric. Zagazg Unvi.
** Senior Res Agri. Eng. Res. Inst. (A.R.C.), Egypt.
*** Assoc. Prof. of Agric. Eng., Fac. of Agric. Tanta Unvi.

The good composting structure depends on the correct mixing and turning of materials. Turning mixes the materials , rebuilds the porosity of the windrow, and releases trapped heat, water vapor and gasses. Turning exposes all material equally to the air at the surface and to the high temperatures inside the windrow.

The compost turning in Egypt is still carried out manually, which is tedious and consumes long time with low production, or by many developed technologies which require high cost.

Rynk (1992) stated that a number of specialized machines have been developed for turning compost. These machines greatly reduce the time and labor involved, mix the materials thoroughly and produce more uniform compost. Some of these machines are designed to attach to farm tractors or front loaders, others are self- propelled. They added that the loader simply lifts the materials from the windrow and spills them down again, mixing the materials and reforming the mixture into a loose windrow. The loader can exchange material from the bottom of the windrow with material on the top by forming a new windrow next to the old one.

Yousef (2001) tested the feasibility of using fodder beet chopper as a dual purpose machine for turning and mixing the compost under local conditions comparing with the use of loader and manual method. He concluded that the optimum operating conditions were chopper peripheral speed of between 4.54 to 5.34 m/s, cutting lengths of stalks of less than 50mm and compost moisture content of less than 37.6 % .

Abd El-Mottaleb (2006) studied the performance of three different compost turning machine (front loader, side mounted machine in tractor and self-propelled turning machine. He concluded that the optimum operating conditions were forward speed of about 600 m/h for both side – mounted machine and self-propelled turning machine, rotor speed of about 240 rpm for the both two machines and compost turning of four times per month under all conditions.

Alfano et al (2007) compared two different compost aeration processes : aeration by mechanical turning or by forced air-injection . The results showed that after the maturation phase both compost piles had a similar chemical composition and the same level of organic matter degradation (around 55%). However the time necessary to reach the thermophilic phase was shorter for the mechanical turned pile (2 months) in comparison to 3 months for the air injected pile.

Abd El-Mottaleb (2008) designed a simple upright machine for turning compost at a level of small farmer . He compared the designed machine performance with the manual turning taking compost quality into consideration. He recommended to use the simple designed machine for turning both round and long – shape piles at a rotor speed of about 350 rpm and forward speed of about 1000 m/h .

It is clear from the literature review that most compost turning machines are designed to work under conditions of large scale farms. So, such studies had to be carried out to solve the problem of compost turning under conditions of small Egyptian farms. So, the objectives of this study are to:

- Manufacture a self-propelled compost turning machine for conditions of Egyptian farms.
- Optimize some different operating parameters (machine forward speed, rotor peripheral velocity, pile height and number of compost turning per month) affecting the performance of the manufactured machine
- Evaluate the manufactured compost turning machine from the economic point of view.

MATERIAL AND METHOD

Experiments were carried out through years of 2006 and 2007 at Ramsis company for management of Agric. Projects and super Bio company for compost, Sharkia Governorate to manufacture and evaluate the performance of a small scale self-propelled compost turning machine.

Material

-The used raw material

Crop residues (especially rice straw) were used as a raw material for producing compost . Poultry and live-stock manure were also used to accelerate composting process. Added to that a finished compost was used as a supply of microorganisms.

- The local manufactured machine

A local small scale self propelled compost turning machine , suitable for local Egyptian farms, was manufactured from low cost, local materials to overcome the problems of high power and high cost requirements under the use of the imported machines. The manufactured self-propelled compost turning machine mainly consists of power source, transmission system, frame, distribution unit, and turning rotor as shown in fig. 1

- The power source

Four stroke – Diesel engine 87 hp (65.3kW) was used as a power source

-The transmission system

Power is transmitted from the engine to both turning rotor and ground wheels by means of pulleys, belts, gears and shafts with different reduction speed ratios.

-The frame

The frame is made of rectangular iron sheet steel .The frame is of 200 cm length, 200 cm width and 120 cm height. It includes elements to fix the engine, the gear box, turning rotor, distribution unit and transmission system. It was carried by six ground wheels, four rear wheels of 60 cm diameter and two front wheels of 60 cm diameter.

-The turning rotor

The turning rotor exchanges the material at the windrows surface with material from the interior .The turning rotor is of 200 cm length, 65 cm diameter.

-The distribution unit

The distribution unit is a top tank divided from inside into two parts: the first part is used for providing the compost pile with the necessary water for pile humidity during the turning operation, while the other part is used for spraying macro-organization during the same operation.

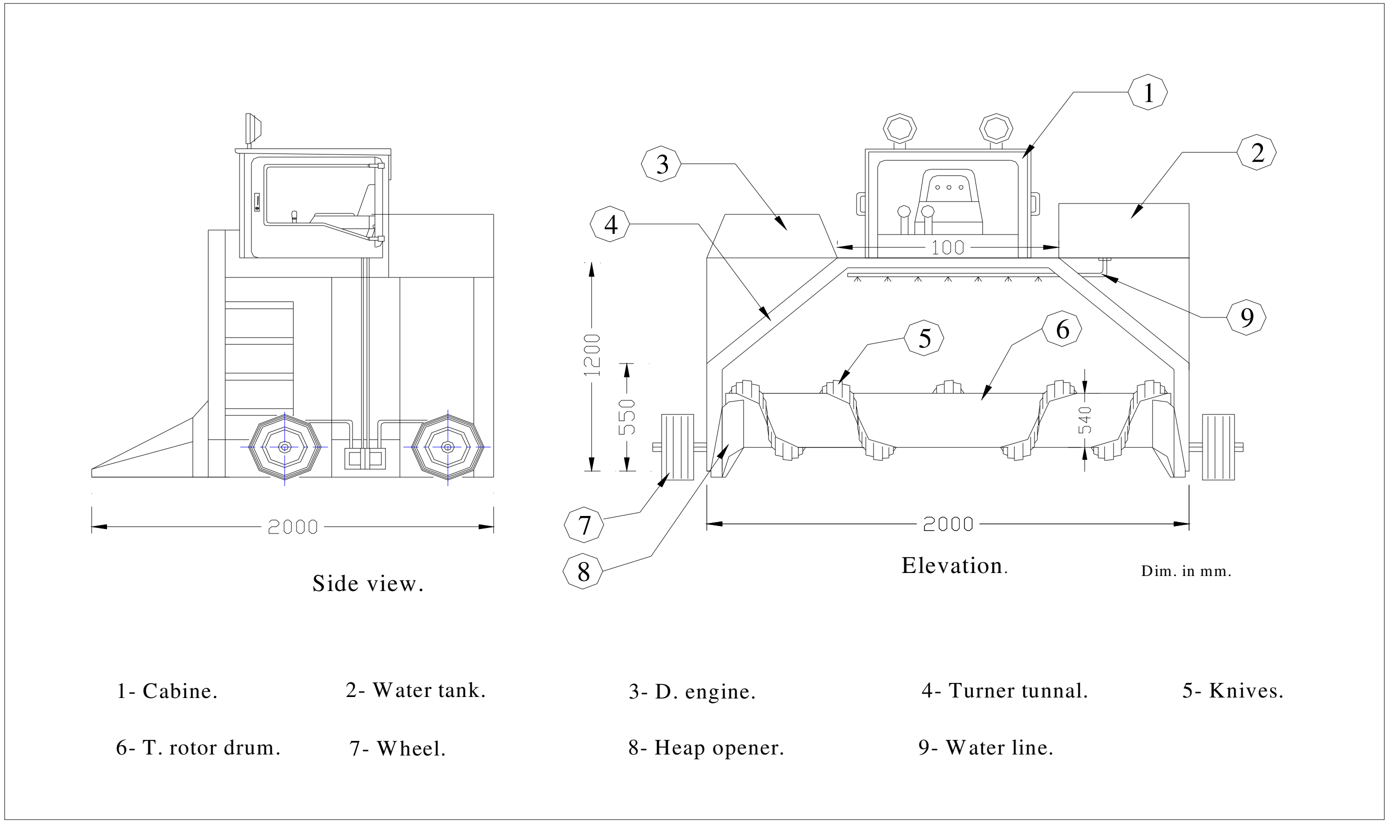

Fig. 1: The manufactured self-propelled compost turning machine

Methods

Field experiments were carried out to study the effect of some operating parameters on the performance of the imported turning machine as follows :

- Five different machine forward speeds (1200, 1300, 1500, 1800 and 2000 m/h.)
- Four different rotor peripheral velocities (80, 160 , 240 and 320 rpm)
- Four turning numbers (1, 2, 3 and 4 turnings / month)
- Four different pile heights of 60, 80, 100 and 120 cm.

Measurements

1-Compost density ρ

Compost density was determined according to the following formula :

$$\rho = \frac{m}{v}$$

where ρ - compost density ,k g / m^3 ; m – compost sample mass , kg
v – compost sample volume , m^3 .

2-Composting time

The required time (period) from the beginning until the compost maturity was recorded .

3-Machine capacity (M. C)

Machine capacity (m^3 / h) was determined using the following equation :

$$M.C = A \times V$$

Where A – operational cross sectional area, m^3;
V – machine forward speed , m / h .

4-Fuel consumption (F. C)

Fuel consumption was recorded by accurately measuring the decrease in fuel level in the fuel tank immediately after excuting each operation.

5-Turning power (T. P)

The turning power was calculated by using the following formula (Barger et. al., 1963).

$$T.P = F.c \times C.v \times \eta_{th} . \times 427 \times \frac{1}{75} \times \frac{1}{1.36} \text{ kW}$$

where F. c - Fuel consumption , kg/s ;
C.v – Calorific value of fuel , k cal / kg (C. v = 10000 k cal / kg)

427 – Thermo mechanical equivaleut , kg.m / k cal;

η_{th} - Thermal efficiency of the engine , % (η_{th} = 30% for diesel engine)

6-Energy requirements (E.R)

Energy requirement can be calculated using the following equation :

$$E.R\,(W.h/ton) = \frac{T.P(W)}{M.C(m^3/h) \times \rho\left(ton/m^3\right)} \times turning\ .number\ .to.moturity$$

7-Turning cost (T.C)

Machine cost was determined using the following formula (Awady 1978)

$$c = \frac{p}{h}\left(\frac{1}{e} + \frac{i}{2} + t + r\right) + \left(0.9hp \times f \times s\right) + \frac{w}{144}$$

where c- hourly cost. p- capital investment h- yearly operating hours e- life expectancy i- Interest rate t- Taxes and over heads ratio r- Repairs ratio of the total investment Hp- Horse power of engine. f- Specific fuel consumption, lit/hp-h s- Price of fuel per liter w- Labor wage rate per month in L.E. 144- Reasonable estimation of monthly working hours.

Turning cost can be determined using the following equations :

$$Operationa\ l\,cost\ (L.\,E.\,/\,m3\,) = \frac{Machine\ \ cost\ (L.\,E.\,/\,h\,)}{Machine\ \ capacity\ \ (\,m3\,/\,h\,)}$$

$$T.C(LE/ton) = \frac{Operationa\ l\,cost}{Composting\ \ density\ \ (\,ton/m3\,)} \times turning\ .number\ .to.moturity$$

8-Final compost quality

Final product quality was measured in terms of chemical , physical and biological properties for both developed and imported turning machines.

Final product quality can be measured as follows :

- Percentage of Nitrogen, % - Percentage of organic carbon, %
-Percentage of organic material, % -C / N ratio- water holding capacity%

RESULTS AND DISCUSSION

The discussion will cover the obtained results under the following heads:

1-Effect of rotor peripheral speed on compost density and compositing time

Results show that compost density and composting time are highly affected by rotor peripheral speed.

Results in figs. 2 and 3 show that increasing rotor speed decreased both compost density and composting time. Data obtained show that increasing rotor speed from 80 to 320 rpm at constant turning number of 4 turnings per month, decreased compost density from 620 to 490, from 640 to 500, from 660 to 510 and from 700 to 530 kg/m^3 with the use of local manufactured machine under different pile heights of 60, 80, 100 and 120 cm respectively. Also decreased composting time from 18 to 11, from 19 to 12, from 20 to 13 and from 23 to 16 weeks under the same previous conditions.

The decrease in both compost density and composting time by increasing rotor speed is attributed to the high impacting forces applied to the compost materials added to the more cutting and mixing by the rotor blades per unit volume of the disturbed compost. This action increased the material volume resulting in a decrease in compost density.

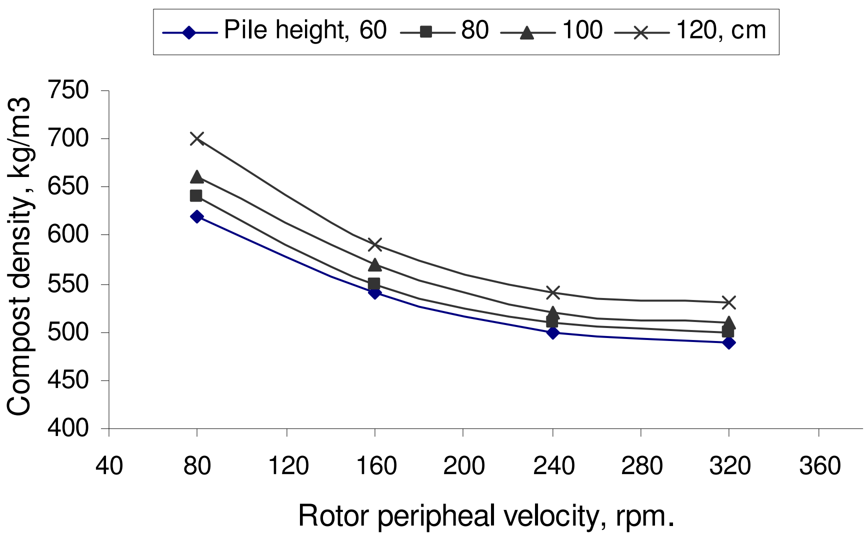

Fig. 2 Effect of rotor peripheral velocity on compost density at different pile heights for local manufactured compost turning machine.

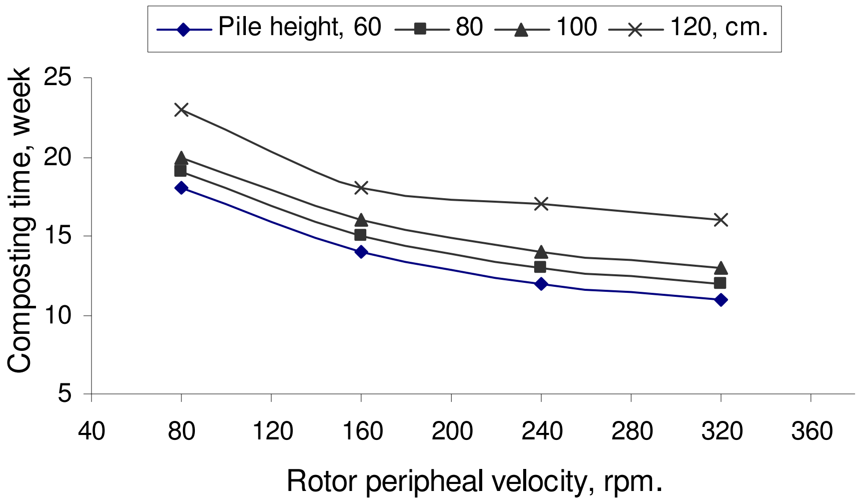

Fig. 3 Effect of rotor peripheral velocity on composting time at different pile heights for local manufactured compost turning machine.

Moreover, the high break down of compost material accelerate compost maturity which reduced composting time. The same results show that compost density as well as composting time values were very close at rotor speeds of 240 and 320 rpm. So, a rotor speed of 240 rpm is recommended to reduce the required energy and approximately achieve the same results of 320 rpm.

2- Effect of turning number on compost density and composting time

Representative turning number values versus both compost density and composting time are given at different pile heights for manufactured turning machine in fig. 4 and 5

The obtained results show that increasing turning number from 1 to 4 turnings per month, at a constant rotor speed of 240 rpm, reduced compost density from 640 to 500, from 660 to 510, from 680 to 520 and from 730 to 540 kg/m3 with the use of local machine under different pile heights of 60, 80, 100 and 120 cm respectively. Also decreased composting time from 23 to 12, from 24 to 13 from 25 to 14 and from 32 to 17 weeks using local machine under the same previous conditions.

The decrease in both compost density and composting time by increasing turning number is due to the large amount of carbon dioxide, heat and water vapor which released from compost material

into the air, resulting in high reduction in the mass of the initial material and consequently in compost density. At the same time composting is rapid when conditions
encourage the growth of the microorganisms that reduced composting time. So, four turnings per month is recommended in order to accelerate composting operation and obtain final product as quickly as possible.

3- Effect of machine forward speed on machine productivity

The most critical factor in productivity of turning machine is its machine forward speed. Fig. 6 shows the effect of machine forward speed on machine productivity. Results show that increasing machine forward speed from 1200 to 2000 m/h. at constant turning number of 4 times per month and pile height of 100 cm, increased machine productivity from 670 to 770, from 900 to 1020, from 1100 to 1270, and from 1300 to 1400 m^3 /h with the use of local machine under different pile heights of 60, 80, 100 and 120 cm respectively. The increase in machine capacity by

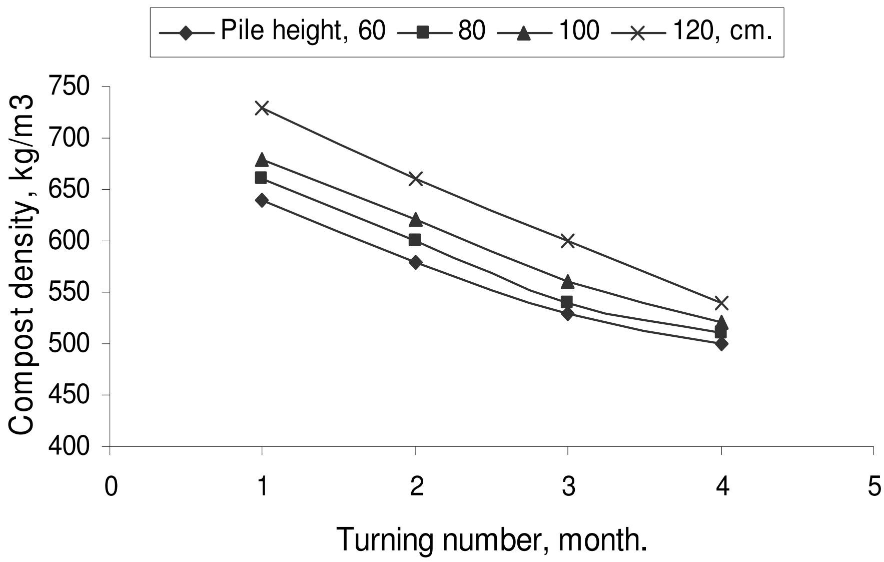

Fig. 4 Effect of turning number on compost density at different pile heights for local manufactured compost turning machine.

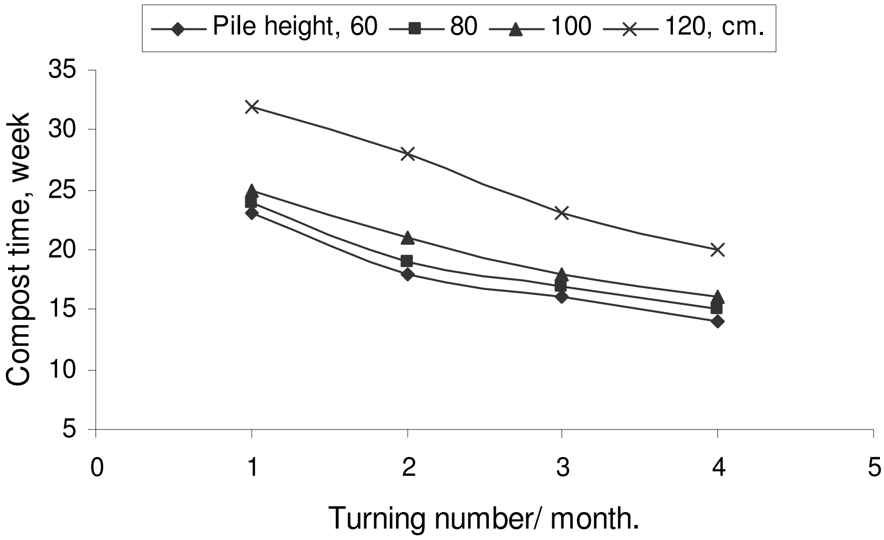

Fig. 5 Effect of turning number on composting time at different pile heights for local manufactured compost turning machine.

decreasing machine forward speed is attributed to the increase in quantity of turning materials per unit time

4- Effect of machine forward speed on energy requirements

Results show that fuel consumption, required power and energy requirements are greatly affected by machine forward speed (fig. 7).

Concerning the fuel consumption, the obtained data show that increasing machine forward speed from 1200 to 1500 m/h. at a constant turning number of four times per month and pile height of 100 cm. increased fuel consumption from 7.5 to 10.0 lit/h. Relating to the required power, data show that increasing machine forward speed from 1500 to 2000 m/h. increased the required power from 26.5 to 35 kW.

As to the energy requirements, results show that increasing machine forward speed decreased energy requirements up to 1500 m/h. any further machine forward speed increase up to 2000 m/h., energy requirements will increase. When the machine forward speed was 1500 m/h., energy requirements value was 640 W. h/ton.

The increase in energy requirements by increasing machine forward speed from 1500 to 2000 m/h. is attributed to the increase in rotor blades knocking number per unit time on compost material. While the increase in the energy by decreasing machine forward speed from 1500 to 1200 m/h. is attributed to the excessive load of compost material on the rotor blades added to the high impact of rotor with the compost material.

5- Effect of machine forward speed on turning cost

The most critical factor in selecting compost turning machine is the cost required for the turning operation.

Results in figs. 8 show the effect of turning machine as well as its machine forward speed on both hourly and turning costs. Data obtained show that increasing machine forward speed from 1200 to 1500 m/h at constant turning number of 4 times per month and pile height of 100 cm. decreased turning cost from 1.34 to 1.05 L.E/ton. Any further increase in machine forward speed from 1500 to 2000 m/h, turning cost will increase from 1.05 to 1.17 L.E/ton.

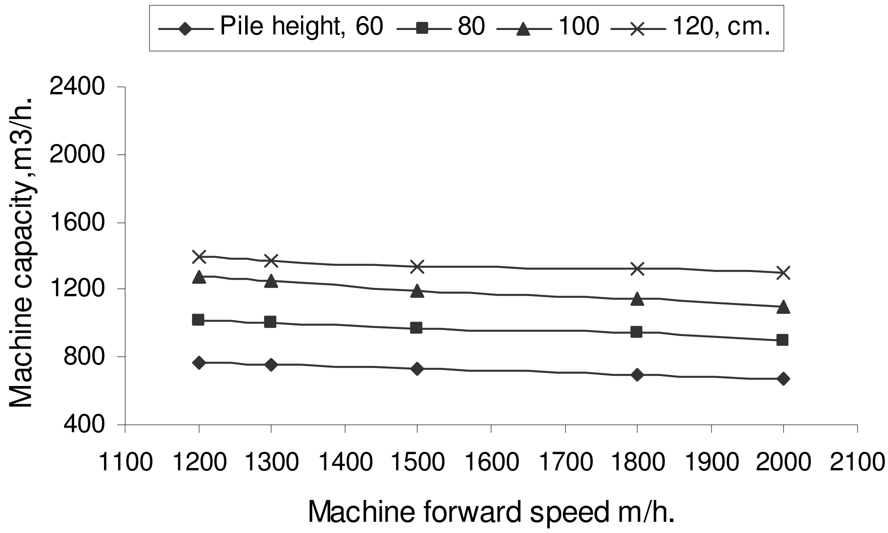

Fig. 6 Effect of machine forward speed on machine capacity at different pile heights for local manufactured compost turning machine.

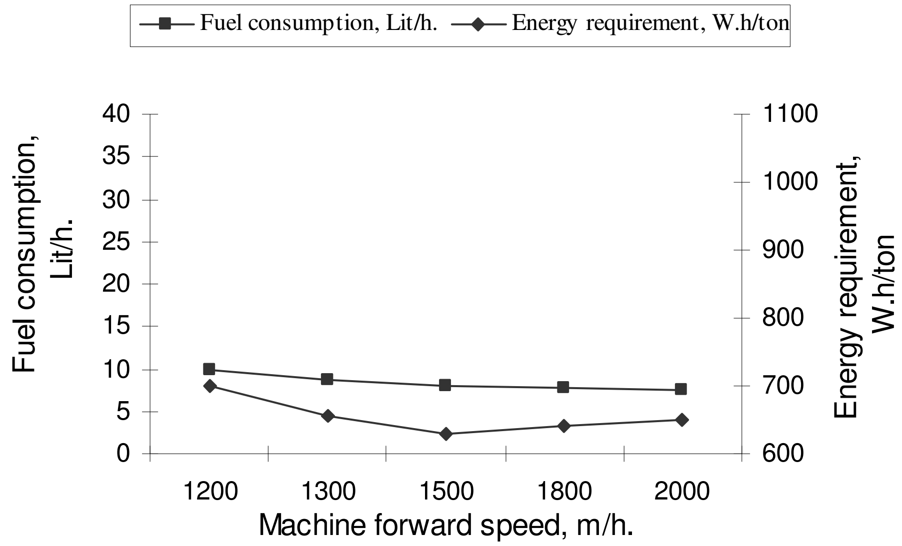

Fig. 7 Effect of machine forward speed on fuel and energy requirement at different pile heights local manufactured compost turning machine.

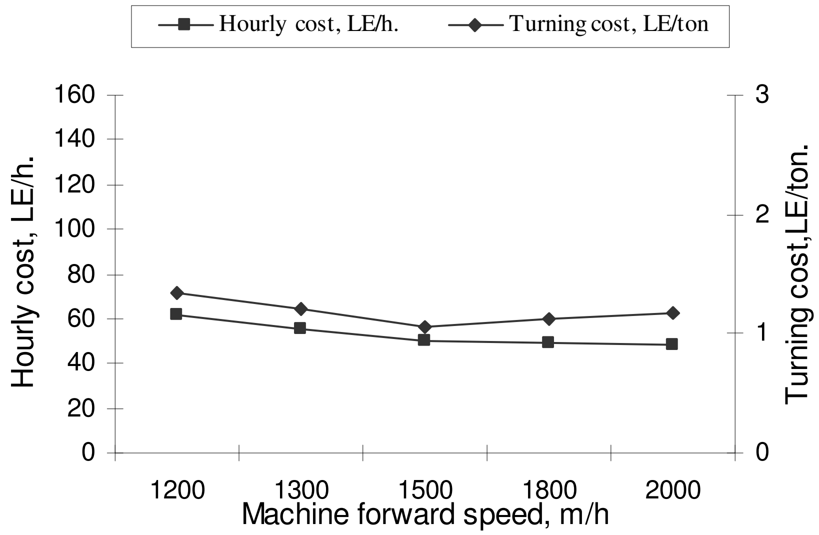

Fig. 8: Effect of machine forward speed on hourly and turning costs at different pile heights for local manufactured compost turning machine.

6- Final compost quality

Data obtained in table 1 show that the final compost quality for Ideal compost quality and local manufactured compost turning machines are approximately similar

Table1: The compost quality for ideal and manufactured turning machine

Term	Nitrogen %	Organic carbon, %	Organic material, %	C/N ratio	Water holding capacity %
Ideal compost quality	1.75	20.4	49.9	18:1	240
Manufactured machine	1.8	18.9	42.4	19:1	240

CONCLUSION

-The use of the small-scale local manufactured turning machine decreases both energy and cost.

- Machine forward speed of about 1500 m/h., rotor peripheral velocity of about 240rpm, pile height of 100 cm and four turnings per month are considered the optimum conditions for compost turning operation.

REFERENCES

Abd El-Mottaleb A.F., (2006). Effect of some operating parameters on the performance of compost turning machines. Misr J. Ag. Eng., 23 (1): 40-54.

Abd El-Mottaleb A. F., (2008) . Design of a simple upright compost turning machine for small farmer Misr J. Ag. Eng., 25(2):1-17

Alfano G., C. Belli, G. Lustrato and G. Ranalli 2007. Pile composting of two-phase centrifuged olive husk residues: Technical solutions and quality of cured compost Waste Management, Volume 27, Issue 9, 2007, Pages1092-1098

Awady, M. N. (1978). Tractor and farm machinery . Txt bk., Col. Ag., Ain Shams U.: 146-167.

Barger E. L.; J. B. L. Edohl; W. M. Carletor and E. G. Mchibben (1963). Tractor and their power units. 2nd Ed, Wileysons Inc., New York U.S.A.

Klenin, N. E.; E. F. popov and V. A. Sakun (1985). Agricultural machines. America publishing Co. prt. Lid., New Delhi. 633pp.

Rynk, R. (1992). On farm composting hand book. N R A E S-54. Ithanaca, N.Y. North East Regional Aggricultural Engineering services.

Yousef, I.S., (2001). A study on mechanization of compost turning and mixing. Misr J., Ag. Eng., 18 (1) : 45-58.

الملخص العربي

تصنيع وتقييم أداء آلة تقليب الكمبوست ذاتية الحركة

*محمد محمد مراد **احمد فؤاد عبد المطلب ***طارق زكى فودة

يعتبر تراكم مخلفات المحاصيل الحقلية من أهم المشاكل الحيوية التي تمثل خطرا على البيئة ز ويعتبر اعادة تدوير هذه المخلفات واستخدامها في انتاج أسمدة عضوية أحد الحلول للتخلص منها بطريقة آمنة .

وتعتبر عملية تقليب كومات السماد العضوي المصنع من المخلفات الزراعية واحدة من أهم العمليات التي تؤثر على جودة السماد الناتج .لذلك فقد اتجه هذا البحث الى تصنيع آلة صغيرة ذاتية الحركة لتقليب السماد العضوي لتكون بديلا عن آلات التقليب المستوردة غالية الثمن .

وقد تم تقييم أداء الآلة المصنعة وذلك بدراسة بعض عوامل التشغيل ممثلة في السرعة الأمامية للآلة والسرعة الدورانية للدرفيل وعدد مرات التقليب وارتفاع الكومة السمادية.

وقد تم تقييم الأداء أخذا في الاعتبار كل من كثافة السماد وزمن النضج والسعة الانتاجية للآلة اضافة الى الطاقة المستهلكة وتكاليف عملية التقليب.

وقد أسفرت النتائج عما يلي :- تقل كثافة السماد الناتج كما يقل زمن النضج بزيادة عدد مرات التقليب وأيضا بزيادة السرعة الدورانية للدرفيل.

- تزداد انتاجية الآلة المصنعة محليا بتزايد السرعة الأمامية للآلة

- يمكن الحصول على أعلى جودة للسماد الناتج باستخدام الآلة المصنعة محليا عندما يكون السرعة الأمامية للألة1500 م/ساعة والسرعة الدورانية للدرفيل 240 لفة/دقيقة و عدد مرات التقليب 4 مرات شهريا وأن يكون ارتفاع الكومة السمادية حوالي 100سم.

* استاذ الهندسة الزراعية - كلية الزراعة- جامعة الزقازيق
**باحث اول بمعهد بحوث الهندسة الزراعية – مصر
*** استاذ مساعد الهندسة الزراعية - كلية الزراعة- جامعة طنطا