# A Mulching Machine for Strawberry Raised Beds Sterilization

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## ABSTRACT

A mulching machine was designed and manufactured to suit different dimensions of strawberry raised beds in Egypt in agriculture. The machine was used to cover the raised beds with plastic films and lay the GR irrigation pipes at the same time before dosing fumigant (Chloropicrin ($CH_3Br$)) in the irrigation pipes network. The machine was tested in loamy sand soil at different forward speeds with different soil cutting depth, turn over angle, kick out angles, and skimmer angle. The results indicated that, the optimum cutting depth of the soil was 10 cm, the optimum skimmer turn over angle was $120^o$, the optimum kick out angle was (30-40) $^o$, and the optimum skimmer angle was $40^o$ when working at speeds of 1.5 km/h. The mulching efficiency ($\eta_{mu}$) was reached upto100%, 100%, 80%, and 45% at tractor forward speed of 1, 1.5, 2.10, and 2.5km/h respectively. On the other hand, the machine field capacity at the optimum tractor forward speed of (1.5 km/h) was 0.43 feddan/h, and 0.54 feddan/h with laying new GR pipes, and without laying GR pipes respectively. Meanwhile, the manual mulching was 1 feddan/day with mulching crew of nine workers. The specific energy at the effective field capacity was 19.95kW.h /feddan with laying new GR pipes and reached to 15.89 kW.h /feddan without laying new GR pipes. The total fabrication cost of the mulch machine was 30000 LE with 2017 price level. The total cost of operating the machine and the tractor was178.4 LE/h. The cost of mulching for one feddan was 330.4 LE without laying new GR pipes and 414.9 LE with laying new GR pipes comparing to 900LE/feddan for manual mulching .The reasonable rental price for the machine with narrow tires tractor was 400 LE/feddan and 500 LE/feddan that indicated (NPV) of 9890 LE and 9844 LE at 14 % interest rate without laying new GR pipes and with laying new GR pipes respectively. Also, the mulch machine payback period (PBP) was about 1.4 year with laying and without laying new GR pipes.

**Keywords:** Chloropicrin, Fumigation, Raised bed mulching machine, Strawberry

## INTRODUCTION

Strawberry (Fragaria ananassa) is cultivated worldwide and plays an important economical role in agricultural trading. Strawberry is not only consumed as fresh fruits but is also frequently found in processed products such as syrup, jam, ice cream. Central agency for public mobilization and statistics (2016) mentioned that on 2014, Egypt produces approximately 0.27millon ton of strawberries from 14869 feddan. To produce a high-quality of strawberries, practices such as mulching and irrigation are essential. Strawberry farmers face many diseases affect directly on their crop productivity such as Nematode, Phythophthora cactorum, Verticillium spp., Rhizoctonia spp., Pythium spp., and Fusarium spp. Chemical fumigants are one of the method used for soil sterilization. Using fumigants always need to cover the soil with plastic sheets then begin to use gas or chemical solution fumigant. Bilck *et al.* (2010) mentioned that mulching increases soil temperature, maintains soil moisture, improves water and fertilizer absorption, reduces weed growth, and most importantly keeps produce high quality until harvesting to avoid fruits direct contact to the soil. Korpela *et al.* (2014) mentioned that globally, over 80 000 $km^2$ of arable land is covered every year by plastic mulch films. Using plastic mulch films, farmers are capable to improve the amount, the yield quality, decreasing the use of pesticides, fertilizers and irrigation water. Plastic mulch films are made predominantly from polyethylene. Guthman, (2016) reported that strawberry industry has relied heavily on chemical fumigants to disinfest soil of a suite of pathogens, as well as to control weeds and nematodes. However, have seen heightened restrictions on the use of these fumigants, and the industry is most favored chemical, methyl bromide, is finally seeing phase-out under the Montreal protocol on ozone-depleting substances. Samtani *et al.*, (2011) mentioned that methyl bromide alternative fumigants are including chloropicrin, metam sodium, and 1, 3-dichloropropene (1, 3-D).They have their advantages and disadvantages, but none have completely replaced methyl bromide. There are Non-fumigant treatments including steam, solar, bio fumigants, mustard seed meal, fertilizers and stabilized urea.

Poling (2016) mentioned that the sandy loam and clay loam soils are ideal for building and shaping raised beds that are a critical component to success in the strawberry plasticulture system. The raised beds dimensions are 20.3-25.4 cm height, and 71.1 – 76.2 cm in width at the base and distance between raised beds 55.9 cm. These beds are fumigated 2-3 weeks prior to transplanting with Methyl Bromide: Chloropicrin (67:33) with dosing of 0.02268 $kg/m^2$ with shank injection. As the fumigant is injected, the beds are immediately warped with an embossed black plastic mulch film that can be "stretched" by the mulch laying/fumigation unit to give an extra tight fit over the bed. The black plastic film needs to be in direct contact with the soil. If there are air pockets between the film and the soil, the black plastic will actually would cool the soil and plant top-growth and root development will be significantly reduced. Ramadan *et al.* (2014) manufactured and tested a mulching machine for laying plastic films under the beds and over the beds. The results indicated that at forward speed of 2.4 km/h with tilt angle of covering blades of 45 degree with the optimum adjustable wheel depth of 20 cm represented the optimum operating parameters which showed soil covering depth (ridge height, cm) of 29 cm, tractor wheel slip, for subsurface mulch, of 5.1%, fuel consumption of 5.1 l/h, for subsurface mulch. Meanwhile, tractor forward speeds 2.4 km/h and 4.60 l/h. For the surface mulch under the same conditions, covering width for surface mulch of 21 cm for both sides and uniformity covering efficiency of 98 % and 92 %for the surface mulch, respectively.

Chloropicrin ($CH_3Br$) is one of methyl bromide alternative. Chloropicrin needs a special technique for soil fumigation process, it usually dissolved in irrigation water then drip in irrigation system under polyethylene films. The strawberry farmers are suffering from high

labor requirements for applying this technique manually. On the other hand, available bed shapers in the local market are differing in dimensions. The common dimensions of strawberry raised beds in Egypt are 90-130 cm width and 30-40 cm height. The distance between raised beds is very narrow 35 cm comparing to dimensions used in other countries. These dimensions are not common in the imported mulching machines and also differ due to the dimensions of the bed shapers used to make raised beds. The imported mulching machines are not designed to operate on the dimensions required for raised beds in Egypt.

Chloropicrin solution injected in the irrigation pipes by dosing pump or by venturi tee fitting. The solution mixed with irrigation water, then dripped from GR pipes drippers to the soil. Polyethylene films (50 $\mu m$) are required to cover the strawberry raised beds to prevent Chloropicrin to evaporate, and then begin to sterilize the soil for two weeks. Although the farmers begin to use Chloropicrin instead of methyl bromide for fumigation, some of them still use the same technique of methyl bromide application. Making raised beds, install two GR irrigation pipes and a middle plan pipe per bed , cover the soil with 8 meter plastic sheets, inject the fumigation solution, wait for 10 days to complete soil sterilization ,remove the 8 meter width cover plastic film, transplant the seedlings, irrigate the plants, then cover each raised bed with individual plastic film . This technique needs high number of labors to replace the plastic films and install the irrigation pipes. On the other hand, the fumigation producer recommended using plastic film mulch individually for each raised bed, injecting the fumigation solution in GR pipes, waiting for two weeks instate of 10 days then planting the seedlings. Both methods were used under Egyptian conditions but the second method is very suitable for mechanizations and decreases the number of handy labor.

The aim of this research is manufacturing a mulching machine suitable for different dimensions of raised bed in Egypt. The machine could mulch plastic film firmly to prevent the leakage of fumigant and equipped with a special unit for laying the irrigation GR pipes underneath the plastic film.

## MATERIALS AND METHODS

The mulching machine was designed to cover different dimensions of raised beds with plastic films and lay the GR irrigation pipes in the same time before dosing fumigant (Chloropicrin (CH$_3$Br)) in the irrigation water.

**The machine was consisted of five sub-systems:-**
**Chassis:**

The main chassis was made of steel square hollow tubes (120×120) mm with thickness of 3mm. All parts were assembled by steel plates welded on the ends of the square tubes along of the machine length. Meanwhile, bolts and nuts were used to assemble the machine parts to suit any dimensions of the strawberry raised bed width. The chassis was consisted of a fixed front chassis and a rear articulated chassis. The fixed chassis contained three hitch points Cat. II. Adjustable height stabilizers were fitted at each corner of the chassis to ease the attachment of the machine to the tractor. The rear chassis was articulated on the rear part of the front chassis by two towing pins and pins holders. The rear chassis was also articulated by double acting hydraulic cylinder takes its hydraulic oil via the tractor hydraulic double acting outlets control valves. The hydraulic towing system allowed the operator to move the machine on roads and make short turns at the end of the narrow felids. Fig. (1) shows the rear chassis in operation position and in folding position.



**The rear chassis in operation position.**   **The rear chassis in folding position.**
**Fig. 1. The rear chassis in operation and folding positions**

**Raised bed mulching device:**

The raised bed mulching device consists of plastic film roll holder that rotates on two bearing holders. The bearing holders were fitted on the front chassis. A PVC tube with a length of 2700mm and diameter of 127 mm rotated on two bearing laid the plastic film on the top of the raised bed. Two pneumatic wheels with depth adjustment were used to lay the plastic film on left and right vertical sides of the raised bed and the bottom of the furrows between the raised beds.

**Soil transferring device:**

Two adjustable soil opener kick out were fitted on the front chassis. The openers were able to be adjusted vertically to suit different heights of raised beds. Each kicker was consisted of a depth adjustable shank, kick out, frog, and heel. The kick out was fitted to the shank with an angle of 35$^o$. The soil openers kicked out and skim a layer of the soil, and transfer it out to the position of the plastic film edge in the distance between rows. After laying the film, another two adjustable skimmer re-transfer the soil back on the laid plastic film. Two pneumatic wheels with

depth adjustment were fitted to the rear chassis and used for compressing the soil above the plastic film to prevent any leakage of the fumigant during the sterilization period.

**Soil compactor roller:**

A steel pipe with 2150mm length and 200mm diameter was fitted by two ball bearing on two adjustable articulated arms fitted on the rear chassis. Two steel chains were fitted on the each end of the arms to adjust the height of the steel roller.

**Drip irrigation GR/tape pipes layer device:**

Three pipe guide devices were fitted on the front chassis before plastic film laying. Each pipe guide was consisted of two steel plates contained a teflon wheel to lay the irrigation pipe in the required position on the top of the raised beds and under the plastic film. Three steel reels (contains the GR pipes) were fitted on the front chassis by a vertical chassis with dimension prevent tube clogging. Each reel was rotated on 20mm diameter axles by two ball bearings could contain the GR drip irrigation roll with length up to 400 m. Each pipe reel contained a disassemble side to put the GR reel. Also, the vertical chassis can easily contain the tape reels. Fig. (2) shows the components of drip irrigation GR pipes laying device.

The components of the strawberry raised beds mulching machine shown in schematic diagram of Fig. (3) .Also, Fig. (4) shows the machine during operation.



| A:GR pipes reels | B: irrigation pipes reels vertical chassis |

**Fig. 2. The components of drip irrigation GR/tape pipes laying device**
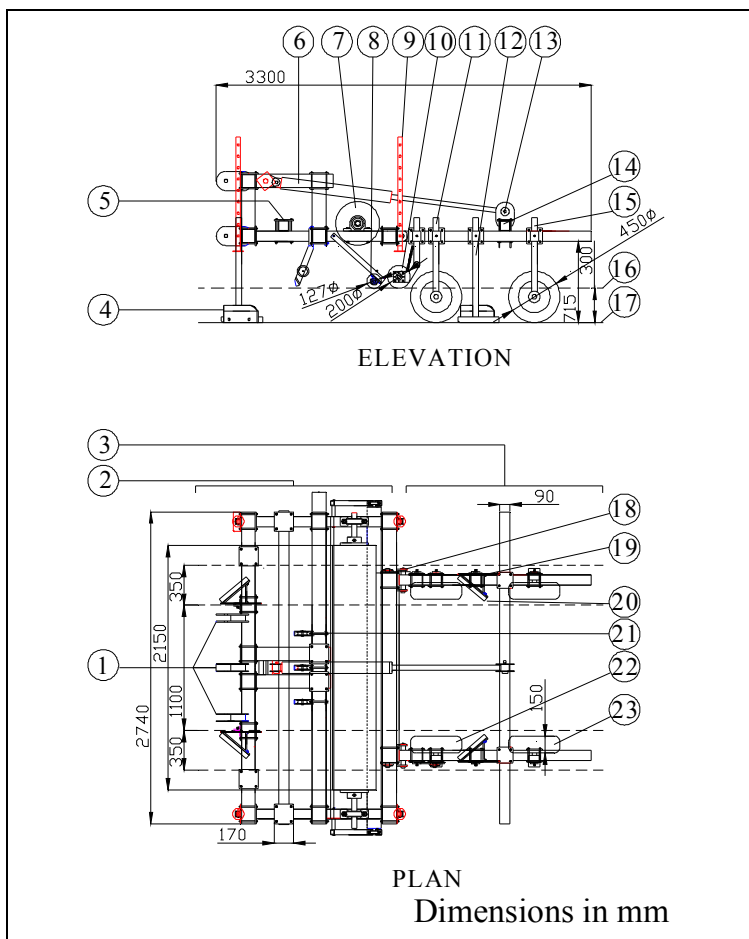


ELEVATION

PLAN

Dimensions in mm

**Fig. 3. Schematic diagram of the components of the strawberry raised beds mulching machine**

**(1) Three points hitch Cat.II, (2)Front chassis, (3)Rear articulated chassis, (4) Soil opener kick out, (5) Reels chassis, (6) Double acting hydraulic cylinder, (7)Film roll, (8) Plastic film laid roll, (9) Stabilizer, (10) Soil compactor roller, (11) Pneumatic wheels, (12)Soil skimmer shank, (13) End of the hydraulic cylinder rod, (14)Rear support beam, (15)Rod depth adjustment, (16)Top of the strawberry raised bed,(17) Bottom of the strawberry raised bed, (18) Towing pin, (19)Kick out heel, (20) Soil skimmer, (21)GR pipe guide device, (22)Plastic film side laying pneumatic wheel, (23)Soil compression pneumatic wheel.**
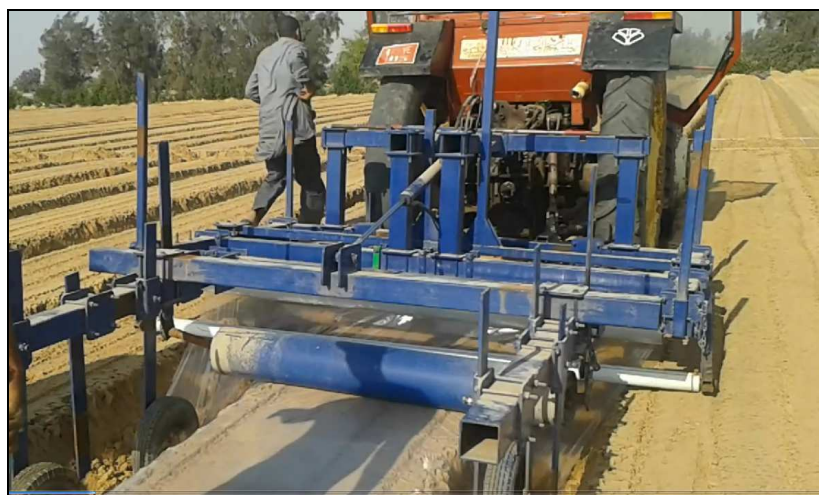
**Fig. 4. The mulching machine during the experimental work**

**Tractor:**

A 110 hp tractor was used during experiments. The tractor was equipped with narrow tires. The rear tires size was 230/9SR44 and the front tires size was 210/9SR32. The distance between tires was adjusted to allow the tractor to path between two raised beds.

**Measuring instruments:**

**1-Measuring tape:** A canvas measuring meter, 30 m long, convoluted, was used during the experiments.

**2-Weighing balance:** To measure the mass of the soil on the plastic film edge (accuracy of 1.0 g).The soil was selected and separated by using rectangle plastic sheets (300 length×500 width×5 mm thickness).

**3-Fuel consumption apparatus:** The consumed fuel was measured by using a fuel consumption apparatus. It was calculated by filling the tractor fuel tank completely then, refilling the tank after making the required treatment by measured flask, record the consumed time, then calculate the fuel consumption (l/h) at examined speeds loaded with the machine and unloaded.

**4-Stopwatch:** To record the consumed time during calculation of mulching machine field capacity at different treatments.

**5-Electreic oven:** To determine soil moisture content at 105Cofor 24 hours.

**Testing procedure:**

The machine was tested at El-Ismailia governorate at loamy sand soil. Soil mechanical analysis was proceeded for samples taken from the distance between raised beds at depth of 0-20 cm .The results of the mechanical analysis was (89% sand, 8% silt and3% clay).Then the soil texture was loamy sand.

Samples of the soil were taken to determine moisture content percentage. The machine was tested with clear plastic film to find out the faults in mulching such as injures ,air pockets and the effect of the compaction roller. The main target of the experiments was testing the machine for stretching the plastic film on the raised beds to control the fumigation process.

The machine was tested for determining the optimum soil depth required to cover the plastic mulch edges which enough to prevent loosing the plastic mulches from raised beds. The covered soil was collected and weighted above one meter length of plastic mulch in each treatment. Then, after mulching three raised bed in each treatment, randomly 10 meter length in the center of the field of the mulched raised bed were taken three times, checked for mulching efficiency ,calculate the average  and comparing the results to the standard raised bed made manually.

**Test factors:**

The following treatments were studied to evaluate parameters affecting the performance of the machine:-

(1) Soil cutting depth with kick out: The kick out was adjusted at depth of 2, 4, 6, 8, and10cm.

(2) Kick out angle: Three angles where examined (30o, 35 o and 40o).Three sets with the experimented angles were manufactured as shown in Fig. (5).

(3) Kick out turn over angle: Three angles where examined (100 o, 110 o and 120 o). Three sets of kick outs were fitted by bolts and nuts on the frog of the kick out. Fig. (6) shows the kick out turn over angle.

(4) Forward speeds: Four forward speeds were tested (1, 1.5, 2.1, and 2.5 km/h).The speeds were controlled by tractor gearbox speed selection lever and adjust hand fuel lever.

**Measurements and calculations:**

**(1) Forward speed (v):**

Mulching machine was tested at 4 forward speeds, which were estimated by recording the consumed time through a travel of 100 meter long. Four forward speeds (1, 1.5, 2.1, and 2.5 km/h) were examined during operation. Forward speed was calculated by measuring the necessary time to cover specified experiment and the travel distance (100 m) as the following formula:
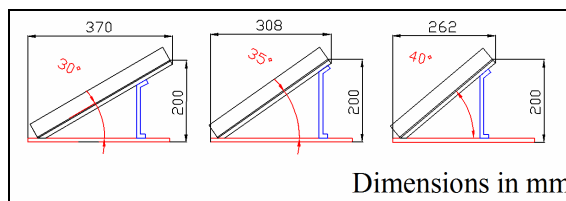


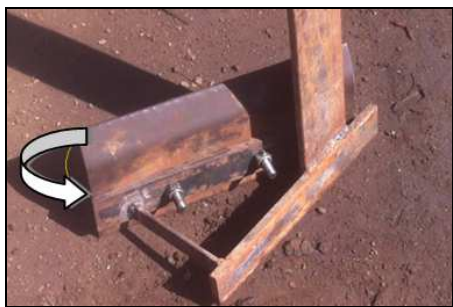**Fig. 5. Schematic diagram of kick out angles**

**Fig. (6): Kick out turnover angle**

$$v = \frac{S \times 3.6}{t} \quad\text{.........................(1)}$$

**Where;**

v = Forward speed, km/h; S = Travel distance, m;
t = Time of experiment, s.

**(2) Machine flied capacity (Fc):**

Actual field capacity was calculated as follows:-

$$fc = \frac{A}{t} \quad\text{.......................(2)}$$

**Where;**

fc= Field capacity, Fed. /h; A =Mulching area, Fed.;
t = Machine operating time, h.

**(3) Mulching efficiency $(\eta_m)$ :**

The mulching performance was evaluated by observing the plastic mulching film through, the length of correct covered mulching film edges, un-covered mulching film edges, injuries in mulching film and air pockets underneath the mulching film in each treatment. During the experimental work, the performance of mulching machine was assessed by taking randomly selected 10 m length of covered raised beds as the following experimental formula:-

$$\text{Mulshing efficiency}(\eta_m) = 100 - (R_u + R_i + R_p) \quad\text{.... (3)}$$

**Where;**

Ru= The percentage of the un- covered mulched film edge length in 10 m, (%);

$R_i$= The percentage of the injured mulched film in 10 length m, (%);

$R_p$= The percentage of the air pockets under the film in length of 10 m, (%).

**(4) Fuel consumption:**

The rate of fuel consumption as quantity per time unit with load and without load, as shown in the following formula (Suliman *et al.*, 1993)

$$FC = \frac{f}{t} \times 3.6 \quad\text{......................(4)}$$

**Where:**

Fc = Fuel consumption, l/h; f = volume of fuel consumption, cm$^3$ and,    t = time, s.

The power and specific energy: The following formula was used to estimate power consumption. Hunt, (1983):

$$P = \frac{FC \times p_f \times LCV \times 427 \times \eta_{th} \times \eta_{mass}}{3600 \times 75 \times 1.36} \quad\text{...(5)}$$

**Where;**

P= power (kW)

FC= Fuel consumption, l/h;

$p_f$ =Density of fuel, kg / l = 0.85 (for diesel fuel),

LCV=Calorific value of fuel (10000 kcal / kg),

427= Thermo-mechanical equivalent, J / kcal,

$\eta_{th}$= Thermal efficiency of engine ($\approx$ 35% for diesel engines)

$\eta_{mec}$= Mechanical efficiency of engine ($\approx$ 80%).

The specific energy was calculated by using the following equation:

$$\text{Specific energy (kW.h /feddan)} = \frac{\text{Power requirement (kW)}}{\text{Effective field capacity}\left(\frac{Feddan}{h}\right)} \quad\text{...(6)}$$

**(5) Cost analysis and economical evaluation:**

The cost analysis was calculated according to Oida, (1997). It was performed in two steps. The first step was to calculate the cost of the materials and fabrication. The second step was to calculate the mulching machine operating cost. In order to evaluate the financial viability of the mulching machine, three parameters computed and analyzed. These parameters are the mulching machine operating cost, the net present value (NPV) and the payback period (PBP). Also, a comparison between the manual mulching cost and the mechanical mulching cost is conducted.

These costs include depreciation (D), annual capital interest taxes (I), housing and insurance cost (THI), repair and maintenance cost (R), fuel cost (F), lubrication cost $(L_c)$ , and labor cost (L).

$$T_c = \frac{\{[(D)+(I)+(THI)+[(R)+(F)+(L_c)+(L)]]}{n_a} \quad\text{..... (7)}$$

**where;**

Tc  = Total cost, LE/h;

$n_a$  = Annual working hours = 500, h/year.

$$T_c = \frac{\left[\left[\frac{P_c-S_v}{n}\right]+\left(\frac{P_c+S_v}{2}\times\frac{i}{100}\right)+(0.05 P_c)\right]+\left[\left[\frac{r_c P_t}{n}\right]+\left\{f_c\times f_p\right\}+(L_c)+(N_l\times L\times n_a)\right]}{n_a} \quad\text{... (8)}$$

**where;**

$P_c$  = Mulching machine manufacturing price, LE;

Sv  = Salvage value= $P_c$×Sp where, Sp=Salvage percentage =$56 \times 0.885^n$ for mulching machine (%), and =$68 \times 0.92^n$ for tractor.

n  = Machine age = 5 years,10 years for tractor;

i  = Interest rate =14%;

$r_c$  =Coefficient of repair and maintenance = 1 for tractor ,0.6 for the    mulching machine;

Pt  = Tractor power (hp) ;

$f_c$  = Actual fuel consumption = measured (l/h) ;

$f_p$  = Fuel price =3.65 L.E = for diesel fuel;

$L_c$  = Lubrication cost =14% of fuel cost;

$N_l$  = Number of labors = Mulching crew(2 labor);

$L_c$  = Labor cost = 100 L.E /day, day(7 hours), LE/h;

$n_a$  = Annual working hours = 500, h/year.

## RESULTS AND DISCUSSION

The machine was tested at El-Ismailia governorate at loamy sand soil with moisture content of 8.72 %. The average mass above the cover edge of plastic film in the standard manual mulching of the strawberry raised bed was not less than 10kg per one meter length. This mass was sufficient to set the plastic film mulching on the raised beds and prevent the effect of the wind. The machine was tested to cover strawberry raised beds with dimensions of (110 cm top , 140 cm bottom ,40 cm height ,and distance between raised beds was 35 cm). Clear polyethylene film with thickness of (50$\mu$m) and width of 2.2 m was used during the experiments.

**1- Effect of the depth of kick out opener and mass of the soil above the plastic film edge:**

The experiments were carried out to determine the optimum depth of cutting the soil by the kick out opener. In principles, the kicks out openers and skimmers angles were adjusted at angle of 35°. Also, skimmer turnover angle was 100°. The parameter of the mass of the soil above the plastic film edge per one meter was taken to determine the optimum soil cutting depth. A depth of 2, 4, 6, 8, and 10 cm was experimented under four forward speeds of 1.00, 1.50, 2.10 and 2.50 km/h. Fig. (7) shows the relationship between depth of opener and mass of the soil above the plastic film edge at different forward speeds.
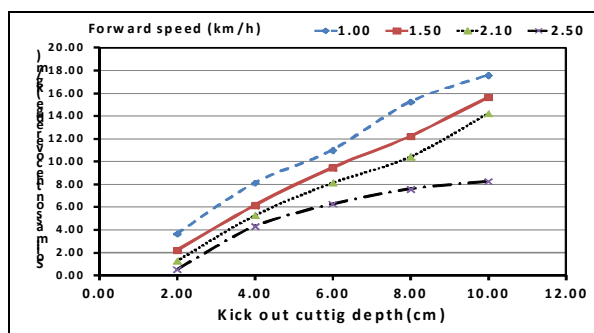


**Fig. 7. Relationship between depth of opener and soil mass above the plastic film edge at different forward speeds**

The results indicated that, the minimum mass of the soil (kg/m̄) was 0.5 (kg/m̄) at 2 cm depth and forward speed of 2.5km/h. Meanwhile, the maximum mass of soil (kg/m̄) length was 17.56 kg/m̄ at 10 cm depth and at forward speed of 1.00km/h. Generally, when increasing the forward speed from 1km/h to (1.5, 2.10, and 2.5km/h) the average soil mass (kg) per one meter of mulch was decreased by 17.84%, 29.40% and 51.65% respectively. The results indicated the optimum depths of the soil cutting ranged from 8 to 10 cm which were obtained at speeds 1, 1.5 and 2.10 km/h. This rang of soil cutting depth resulted more than 10 kg /m of soil above the plastic film edge.

**2- Effect of the skimmer turn over angle above the mass of the soil above the plastic film edge:**

Three turn over angels were experimented (100°, 110° and 120°) to determine the optimum skimmer turn over angle at the soil cutting depths (8 and 10 cm). In principle, the kicks out openers and skimmers angles were adjusted at angle of 35°. The results indicated that the maximum mass of the soil above one meter of the plastic edge was 19.20 kg/m̄ at skimmer turn over angle 120° forward speed 1 km/h and cutting depth of 10 cm. Meanwhile, the minimum mass of the soil was 7.57 kg/m̄ at skimmer turn over angle 100° forward speed 2.5 km/h and cutting depth of 8 cm. Fig. (8) shows the effect of the skimmer turn over angle on the soil mass above the plastic film edge at different forward speeds.
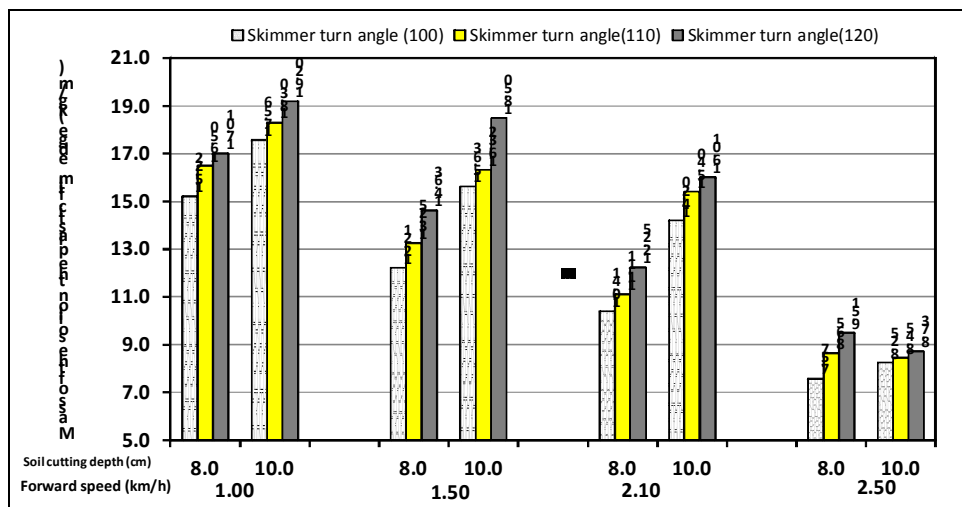


**Fig. 8. Effect of the skimmer turn over angle on the soil mass above the plastic film edge at different forward speeds.**

Generally, the results indicated that the average mass of soil kg/m̄ is decreased by increasing the forward speed from 1 km/h to (1.5, 2.10, 2.5 km/h) by (12.87%, 23.57%, 50.74%) respectively. The results indicted that, the optimum skin operating speed was ranged from 1 to 2.1 km/h that give sufficient soil cover more than 10 kg/m̄ at depth of opener 10 cm. When increasing of turn over angle from (100° to 110°) the soil cover above the edge (kg/m̄) increase by (5.8%, 5.85, 7.17 and 4.49) at forward speeds of (1, 1.5, 2.10 and 2.5 km/h) respectively. Also, when increasing the turn over angle from (100° to 120°) the soil cover above

the edge (kg/m̄) increase by (9.47%, 15.97, 12.92 and 13.27) at forward speeds of (1, 1.5, 2.10 and 2.5 km/h) respectively.

Also, it was realized that increasing the soil cutting depth from 8 to10 cm at forward speeds of (1, 1.5, and 2.10 km/h) increase the soil covered above the plastic edge by 11.5%, 20.54% and 25.96% respectively. From the results mentioned above, the optimum skimmer turn over angle was 120° at cutting depth of 10 cm at speeds ranged from 1 to 2.10 km/h.

**3- Effect of opener kick out angle on mulching efficiency$(\eta_m)$:**

The experiments were carried out at optimum adjustment as the following (opener depth=10cm, skimmer turnover angle = 120°, and skimmers angle 35°). The machine was tested at three different kick out angles (30°, 35°, and 40°) at four forward speeds. The percentage of the correct covered mulched film edge$(R_c)$, the percentage of the un- covered mulched film edge$(R_u)$, the percentage of the injured mulched film$(R_i)$, and the percentage of the air pockets under the film, $(R_p)$in length of 10 m of the plastic mulching are presented in Fig. (9).
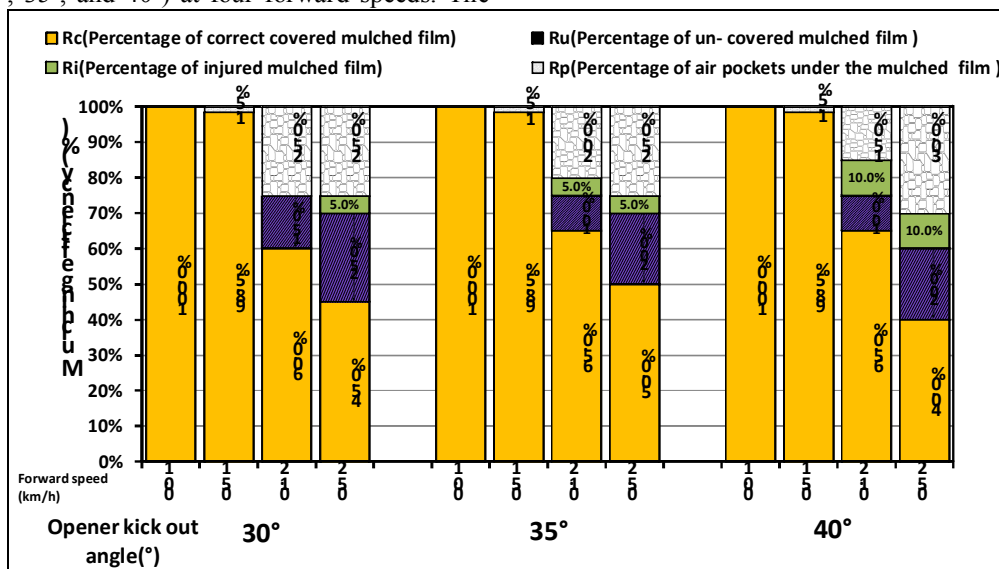


Fig. 9. Effect of opener kick out angle on Mulching efficiency

From Fig. (9), it realized that the kick out angle was not effecting on the mulching efficiency at forward of speeds 1 and 1.5 km/h which has been reached 100%. Any faults in mulching at speeds of 2.10 and 2.50 was not acceptable during the fumigation process.

**4-Effect of skimmer kick in angle on mulching efficiency$(\eta_m)$:**

The experiments were carried out at optimum adjustment as the following (opener depth=10cm, skimmer turnover angle = 120°, and openers set angle 35°). Fig. (10) shows the affect of skimmer angle on mulching efficiency. From Fig. (10), it was realized that increasing of forward speed decreased the correct mulched film percentage $(R_c)$.

Any faults in mulching are not acceptable during fumigation process. At skimmer angle 30°, when increasing the forward speed from 1 km/h to (1.5, 2.1, 2.5km/h), the correct cover mulching $(R_c)$ was decreased by (1.5%, 35.0%, 50.0%) respectively. At skimmer angle 35°, when increasing the forward speed from 1 km/h to (1.5, 2.1, 2.5km/h), the correct cover mulching $(R_c)$ was decreasing by (1.0%, 45.0%, 60.0%) respectively. Also, at skimmer angle 40°, when increasing the forward speed from 1 km/h to (1.5, 2.1, 2.5km/h), the correct cover mulching $(R_c)$ was decreased by (0%, 20.0%, 55.0%) respectively.
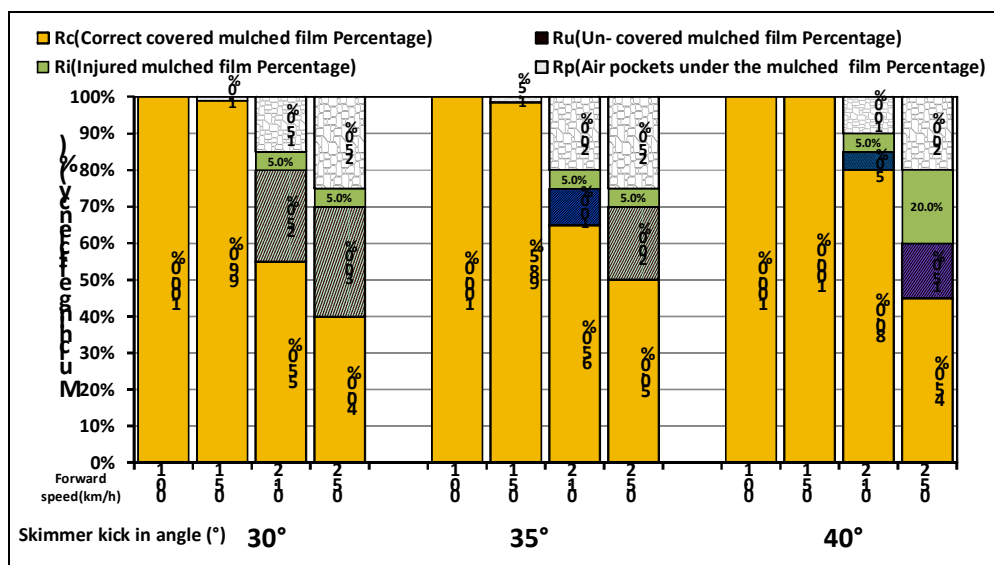


Fig. 10. Effect of skimmer kick in angle on mulching efficiency

The results in Fig. (10) revealed that, the air pocket percentage $(R_p)$ is increased by increasing the skimming angle due to the increasing dimensions of the skimmer (shown in Fig. (5)), that allowed the air enter underneath the mulching.

The percentage of $(R_p)$ was appears at speed of 1.5 km/h with skimmer angles of 30° and 35° and reached (1% and 1.5%) respectively. While, it was not appear at the same speed at 40° of the skimmer angle. The $(R_u)$ and $(R_i)$ take the same trends at the speeds of 2.10 and 2.5 km/h. From the results, the optimum skimmer angle is 40° when working at speeds of (1 and 1.5 km/h).

In general, it could be concluded that ,the optimum cutting depth of the soil is 10 cm, the optimum skimmer turn over angle is 120°, the optimum kick out angle is (30-40)° and the optimum skimmer angle is 40° when working at speeds of (1 and 1.5 km/h).

## 5- Effect of the compaction roller:

Experiments were carried out with the compaction roller and without it. It was realized that the compaction roller decreased the air pockets on the top of the raised beds and buried the irrigation pipe in the soil. The compaction roller was fitted to the chassis by two swing arms. Two chains were used to hang the arms and adjust its height according to the raised bed height. When allowing the roller freely to compress the soil, it damaged the construction of raised beds.

## 6- Performace of the GR/tape pipes layer device:

The machine was designed to lay the irrigation pipes on the top of the raised beds, then covering the raised beds with plastic film. During the experiments, it was realized three types of mulching required, (mulching clear plastic films for solar sterilization), (laying new irrigation pipes and mulching black plastic films), and (laying used irrigation pipes and mulching black plastic films). In the third option the pipe was laid manually on the top of the raised beds then the machine used the pipe guiders to put the pipes in the right positions above the raised bed.

## 7- Mulching machine productivity comparing to manual mulching:

The manual mulching need nine workers (2 workers for spreading the plastic roll on the top of the raised bed, one worker for filling plastic bags and put them on the top of the roll to prevent it from fly by wind, 4workers to buried the side of plastic film edges with soil).Laying GR irrigation pipes also needed two workers. Pipe laying always done at the day light and plastic covering done at evening or daybreak to avoid the effect of wind. This process needs about an average of 7 hours /feddan with cost of 900 LE/feddan. On the other hand, field capacity of the mechanical mulching with the designed machine at the optimum tractor forward speeds (1 and 1.5 km/h) reached 0.17and 0.43feddan/h with laying new GR pipes ,and 0.34 and 0.54 feddan/h without laying new GR pipes respectively. Both forward speeds gave 100% mulching efficiency. From the results, the effective field capacity is at forward speed of 1.5 km/h.

## 8- Power requirement:

The average fuel consumption of the machine was measured at forward speeds of (1, 1.5, 2.1, and 2.5km/h) it was (6, 6.5, 7.0, and 7.5 l/h) without load and reached with load to (9, 9.6, 10.8, and 11.26 l/h) respectively. The calculated power consumed for mulching were (8.30, 8.58, 10.52, and 10.41 kW.h) at the same speeds respectively. The specific energy at the effective field capacity was 19.95kW.h /feddan with laying new GR pipes and reached to 15.89 kW.h /feddan without laying new GR pipes.

## 9- Cost analysis and economical evaluation:
## Plastic film mulching machine operation cost:

The operating costs included fixed and variable costs were calculated for the plastic film mulching machine. The total operating costs for the plastic film mulching machine was 36.51 LE/h. Meanwhile, the same calculations were made for tractor with price of 350000 LE. The tractor cost hour was reached to 141.89 LE/h. The total cost of operating the machine and the tractor was178.4 LE/h. The cost of mulching one feddan was 330.4 LE without laying new GR pipes and 414.9 LE with laying new GR pipes.

## Economical feasibility of the plastic film mulching machine:

The total fabrication cost of the mulching machine was 30000 LE with 2017 price level. The reasonable rental value of mechanical was 400 LE/feddan without laying new GR pipes and 500 LE/feddan with laying new GR pipes.

The mulching machine indicated (NPV) of 9890 LE and 9844 LE at 14 % interest rate without laying new GR pipes and with laying new GR pipes respectively. Also, the mulching machine payback period (PBP) was about 1.4 year with laying and without laying new GR pipes.

## CONCLUSION

1- The machine succeed to mulch plastic film with 100% covering efficiency at the optimum cutting depth of the soil 10 cm, skimmer turn over angle 120o, out angle (30-40) o and the skimmer angle 40o when working at the forwarded speed 1.5 km/h that concur field capacity of 0.43 feddan/h with laying new GR pipes and 0.54 feddan/h without laying new GR pipes.

2- The machine succeeded to lay new irrigation GR pipes on the top of the raised beds by pipe roll device. Also, it has succeeded to lay the used GR pipe in the right position.

3- Using strawberry raised bed shaper equipped with two side furrowers better than using the ordinary raised bed shaper. The side furrowers works to regulate of distances between raised beds, thus the mulching efficiency would increase.

4- The compaction roller decreased the air pockets on the top of the mulched raised beds and buried the irrigation pipe in the top of the raised beds.

5- The specific energy at the effective field capacity was 19.95kW.h /feddan with laying new GR pipes and reached to 15.89 kW.h /feddan without laying new GR pipes.

**The following conclusions and recommendations can be drawn:**

1- The mulching machine can be manufactured locally to suit the Egyptian conditions and could be used in sterilization with fumigants and solar sterilization as well.

2- Providing such a mulching machine is surly decrease the mulching costs from 900LE/ feddan for handy mulching to 400 LE/ feddan for mechanical mulching without laying new GR pipes and 500 LE/ feddan with laying new GR pipes. On the other hand, the machine field capacity at the optimum tractor forward speeds 1.5 km/h with laying new GR pipes was 0.43feddan/h and 0.54 feddan/h without laying new GR pipes respectively comparing to one feddan/day for manual mulching with nine mulching crew persons.

3- It is recommended to use drip tape instead of GR pipe to reduce the consumed time for assembling the pipe into the machine. Drip tape rolls are wrapped in compact rolls with long length and could attached easy into the same roll holders.

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**آله لفرد البلاستيك لتعقيم مصاطب الفراوله**

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تم تصميم وتصنيع آلة لفرد البلاستيك لتناسب الأبعاد المختلفة لمصاطب زراعة الفراوله فى مصر. وتم استخدام الآله لتغطية المصاطب بالبلاستيك ووضع أنابيب الري في نفس الوقت قبل ضخ محلول التعقيم (الكلوروبكرين) (CH₃Br) في شبكه الري. تم تجربه الآله فى ارض طميه رمليه علي سرعات اماميه مختلفه بمعاملات مختلفه لعمق قطع التربه وزاويه قلب طراد التربه وزوايا طرد التربه للخارج وزاويه مكشطه اعاده التربه فوق فيلم البلاستيك. وأشارت النتائج إلى أن عمق القطع الأمثل للتربة كان 10 سم، و الزاوية المثلى لقلب المطرحه كانت 120 درجة، والزاويه المثلى لدفع التربه للخارج (30-40)°، والزاوية المثلي لمكشطه اعاده التربه فوق فيلم البلاستيك 40 ° وذلك عند العمل بسرعه اماميه للجرار 1.5 كم/ساعة. كما تم قياس كفاءة التغطيه (ηₘ) والتى بلغت 100٪، 100٪، 80٪، و 45٪ عند سرعات اماميه 1، 1.5، 2.10، و 2.5 كم/ساعة على الترتيب. كما بلغت الطاقة النوعية 19.95 كيلو وات ساعه/ فدان مع وضع أنابيب الري الجديده فوق المصاطب و بلغت 15.89 كيلووات. ساعة/فدان دون وضع أنابيب ري جديده. ومن ناحية أخرى, بلغت السعة الحقلية للآله عند سرعه تقدم 1.5 كم/ساعة مع وضع أنابيب الري الجديده 0.43فدان/ساعه وبلغت 0.54 فدان/ساعة دون وضع أنابيب الري الجديده مقارنة بواحد فدان/يوم للتغطية اليدوية بطقم تغطيه مكون من 9 عمال. وبلغت التكلفة الإجمالية لتصنيع الآله 30000 جنيه بأسعار عام 2017. ووصلت تكاليف التغطيه بالآله ميكانيكيا إلى 330.4 جنيه/فدان بدون وضع انابيب ري و 414.9 جنيه/فدان بوضع انابيب ري جديده بدلا من 900 جنيه/فدان للعمل اليدوي. وكانت القيمة الإيجاريه المقبوله لتسويقها للآله بجرار مزود بعجل رفيع 400 جنيه/فدان بدون وضع انابيب جديده للري و500 جنيه/فدان بوضع انابيب جديده للري والتي تحقق قيمة حاليه للآله 9890 جنيها و 9844جنيها بدون وضع انابيب ري وبوضع انابيب ري علي الترتيب عند نسبة فائدة 14٪ وكانت فترة استرداد رأس المال حوالي 1.4 عاما.