Mechanism of Mulch Film Cutter on Transplanting System for Mulching Cultivation of Early Season Culture Rice in Japan

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ABSTRACT

The mechanism of the mulch film cutter assembly designed as an integral part of a rice transplanting device was developed for mulching cultivation of early season culture rice. This mulch film cutter assembly was directly attached to the transplanting device of the rotary type Japanese transplanter. The principle is that the knife cut a planting slit on the polyethylene film while the planting finger immediately plants seedlings into the soil through the planting slit.

Computer results implied that the knife of the mulch film cutter assembly can make appropriate planting slit on the polyethylene film as the planting finger effectively plants the seedlings into the paddy soil through the same planting slit.

Key Word : Early season culture rice, Mulching cultivation, Early harvest, Mulch film cutting mechanism, Transplanter

INTRODUCTION

The cultivation of early season culture rice is popular in western part of Japan, especially in Southern Kyushu and Southern Shikoku because these areas are warmer than other areas. This type of cultivation can produce early harvest which can be marketed earlier than the conventional one. So, to capture the early market, this research investigated the significance of polyethylene mulch as adopted to paddy field cultivation.

Past research on mulch cultivation of early season culture rice revealed that the soil temperature of the paddy field mulched with transparent polyethylene film increased by about 5 ℃ in a depth of 3 cm and the harvesting time was 7 days earlier than the conventional cultivation.

The mulch cultivation system requires laying of polyethylene film as mulch on the surface of the paddy field, and transplanting seedlings at the same time. To do this, at first a trial transplanter with rotary transplanting device and mulch layer was used. However, there were some problems encountered in using this transplanter. Laying the polyethylene film on the paddy was very difficult because the soil was soft and submerged in water. Transplanting seedlings through the film was also difficult because the planting finger could not easily pierce the film. Moreover, the planting finger stretched the film and made it sink. Hence, an effective mulch film cutter knife is required to make a planting slit through which the seedlings are transplanted.

MATERIALS AND METHODS

Rotary type planting mechanism

In order to examine the planting slit which should be made by the knife, the locus of planting finger was drawn using a computer. The configuration (e.g. angle, length) of the planting finger of the riding type rice transplanter (YANMAR RR40, four rows) with the rotary planting mechanism served as data. The rotary planting mechanism, which is basically a planetary gear mechanism constituted with the sun gear and planet gears as eccentric gears, was originally invented by Konishi et al. (1989).

Ideal position and size of planting slit

Fig. 1 shows the locus of the planting finger tip during planting. The planting finger tip touches the soil surface at point A, passes the deepest point B, and gets out of soil at point C. When the planting finger passes from point A to point B, the planting fork crosses the soil surface at point D.

While laying the mulch film on the soil surface, there is a need to make a planting slit where the seedling is smoothly planted through without exerting force on the film. The length of planting slit should be between the point where the planting finger tip touches the film the first time and the point where the planting fork crosses the film when leaving the soil surface. Thus, the ideal length of the planting slit cut by the knife is determined by the distance between points A and D.

Factors needed to determine the locus of the knife

In order to cut between points A and D, the knife' s length and style of motion from the back of planting fork to the tip of planting finger in front were considered. If the knife is fixed to the planting arm, the planting finger cannot catch the seedlings from the seedlings mat on the seedling deck. Therefore, the film cutting mechanism is designed in such way that when the planting finger catches the seedlings, the knife is set behind the planting fork, and just before the planting finger plants the seedlings into the soil, the knife is pushed in front of the planting finger tip.

Fig. 2 shows the relative position and motion of the knife and the planting finger. When the planting finger detaches the seedlings from the mat, the knife is set parallel to the planting finger as in A (original knife setting). While the knife is pushed gradually as in B, its length of motion is maximum just before the planting finger reaches the film as in C. Then, the knife starts cutting the film to make a planting slit. When the seedlings have been planted through the planting slit, the knife is put back in its original setting as in D. The planting fork pushes the seedlings into the soil, while the knife cuts the film behind the planting fork as in E. The next motion for transplanting continues as in F.

The motion of knife requires motive power. This power is transmitted to the knife by a cam and a crank from the rotary planting device. The oscillating - block - slider - crank - mechanism (Asano, T. 1977) was used in this study.

Mechanism of the film cutter device

Fig. 3 shows the oscillating-block-slider-crank-mechanism with planting arm. If the crank rotates, the knife can slide with oscillation. At $\Delta O_1O_2O_3$, the relationship between the rotating degree (θ) of crank and the oscillating degree (ϕ) of knife is :

$$\tan\phi = \frac{O_1h}{O_3h} = \frac{r\sin\theta}{l - r\cos\theta} \tag{1}$$

where O_1 is the hinge point where the knife, and one side of crank bar intersect; O_3 is the slider shaft point, point h is the point of right angle from O_1 to line O_2O_3 that ties a slider shaft and crank shaft; l is the distance between O_2 and O_3; and r is the length of one side of crank bar.

The effective knife length (L_{k1}) is :

$$L_{k1} = L_k - L_{k2} = L_k - \sqrt{l^2 + r^2 - 2lr\cos\theta} \tag{2}$$

where L_k is the length of the whole knife; and L_{k2} is the length of the knife's upper part from the slider shaft. Therefore, the knife tip point viewed from the slider shaft point is led by ϕ and L_{k1}.

Aside from the above-mentioned factors, the locus of knife tip is determined by the distance L_s between planet gear shaft point and slider shaft point; angle α between slider shaft point and plant gear shaft point; distance L_c from planet gear shaft point to crank shaft point; and angle β between crank shaft point and planet gear shaft point.

These factors determined the size and shape of the transplanting device, and motion of the knife (Table 1). Then, by combining the expression (1) and (2), and the expression of the rotary planting mechanism, the locus was drawn using Quick BASIC language.

Fig. 4 shows the film cutting mechanism built as an integral part of the rotary planting device. At the left, (a) is a state when knife is pulled back (original knife setting), and at the right, (b) is a state when the knife is pushed. A coil-spring causes the knife to move from (b) to (a). The planting arm revolves in opposite direction with the gear case. With this condition and using a cam and a crank, the knife moves back and forth.

RESULTS AND DISCUSSION

Locus of the knife tip

Fig. 5 shows the loci of the knife and the planting finger drawn using a computer where (a) shows the loci when traveling and the plant spacing is 16 cm; and (b) shows the loci when traveling speed is zero. Looking at the loci, when it reaches the film, the knife is certainly in front of the planting finger tip as in C of Fig. 2. Then, when the planting finger is approaching the bottom of the locus, the knife returns quickly to its original setting because the planting fork will push the seedlings into the soil immediately.

Length of planting slit and planting position

Fig. 6 shows three pairs of locus with original plant spacings of 14, 16, and

18 cm. In this case, since there is one planting arm in the planting device, the spacing is twice the original. The conventional planting device has two planting arms each.

The length of planting slit will be made by the knife from the frontside of the planting finger tip to the backside of the planting fork, regardless of the plant spacing. This result satisfied the ideal length and position of the planting slit mentioned in Fig. 1. In the plant spacings at 14, 16, and 18 cm, the knife could cut planting slits of lengths of 10.5, 9.7, and 8.9 cm, respectively. Therefore, as the plant spacing becomes longer, the planting slit length becomes shorter.

Planting position is supposed to be the place where the planting finger passes the bottom of its locus. With regard to the planting position in the planting slit, the plants will be positioned in front of the center of the planting slit as the transplanting device travels forward. Since the mulch layer attached to the transplanter has the tendency to stretch the film while moving forward, the planted seedlings is expected to be located appropriately through each planting slit.

Theoretical length of planting slit by planting depth

Fig. 7 shows the relationship of theoretical planting slit length by planting depth. Planting depth was varied from 1 to 5 cm with 1 cm interval from the soil surface. The planting depth for conventional cultivation is 2 cm to 3 cm while the plant spacing ranges from 12 cm to 22 cm as specified by this transplanter (YANMAR Co. Ltd. Catalog 1992). Hence, planting slit length would become longer with deeper planting depth.

Though the polyethylene film had 7 cm planting slits in the pot experiments conducted for cultivation of the early season culture rice, the planting slit length did not interfere in the growth of rice tillers per hill. If the planting slit is too long, the heat generated at the soil surface using the transparent mulch film will be reduced, i. e. the soil temperature will decrease. Conversely, if the planting slit is too short, the planting slit itself will seemingly hinder the production of tillers.

By using this mulch cutting device, the length of the planting slit will be from 7.1 cm to 11.4 cm in the standard planting depth. Thus, there is a prospect of incorporating the mechanism of mulch film cutter on the transplanting system for mulching cultivation of early season culture rice.

CONCLUSION

Based on the loci of the knife and the planting finger drawn using Quick BASIC language, the knife could make planting slit on the laid film from the frontside of the planting finger tip to the backside of the planting fork, regardless of the plant spacing. This result satisfied the ideal length and position of the planting slit where the seedlings could be smoothly planted through without exerting force on the film. When the conventional plant spacing would be 16 cm and standard planting depth would be 3.0 cm, the length of planting slit could be expected to be 9.7 cm. If the spacing would be made longer, the planting slit would become shorter and if the planting depth would be made deeper, the slit would become longer.

Moreover, the planted seedlings would be positioned in front of the center of the planting slit as the transplanting device travels forward. Since the mulch film would be stretched as the transplanter travels, this planting position seemed proper for the planting slit.

Thus, there is a prospect of using the mulch film cutting mechanism to make appropriate planting slit on the polyethylene film as the planting finger effectively plants the seedlings into the paddy soil through the same planting slit.

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Table 1 Specification of film cutting mechanism.

l	94.0	mm
r	35.0	mm
L_k	163	mm
L_s	83.2	mm
L_c	17.0	mm
θ	8 - 85	deg.
α	49.0	deg.
β	-2.0	deg.

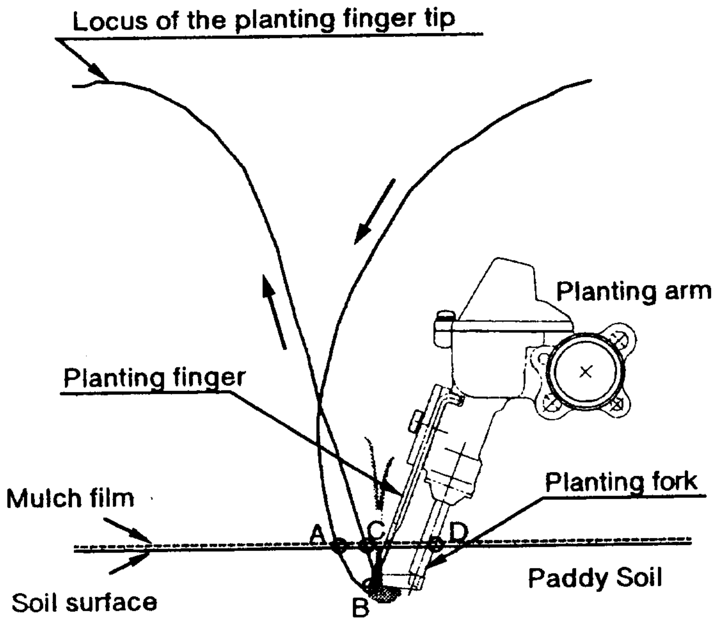


Fig. 1 The locus of the planting finger tip.
------- Mulch on the paddy soil.
—— Surface of the paddy soil.

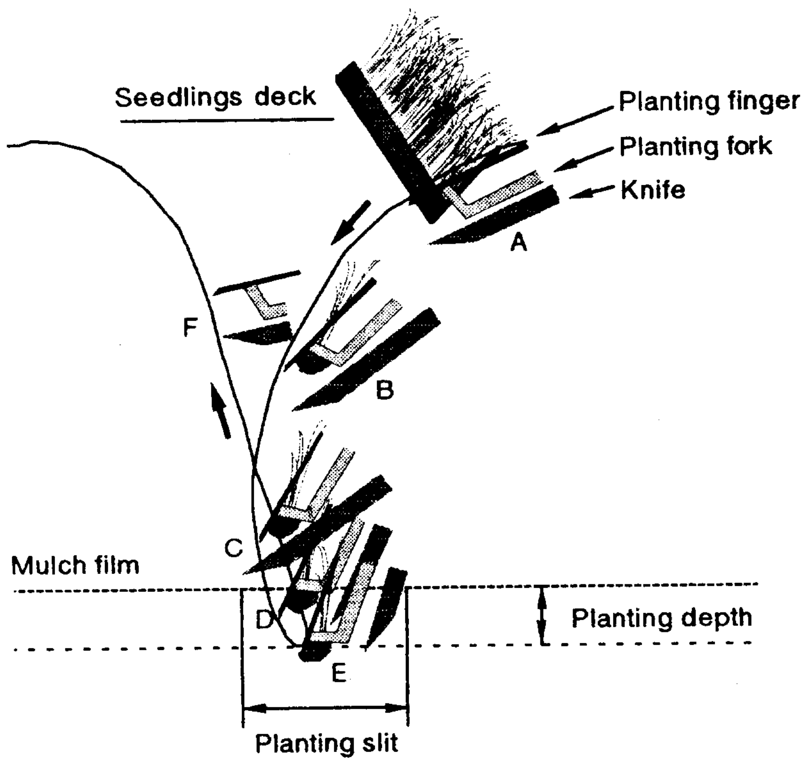


Fig. 2 Relative position and motion of knife and planting finger.

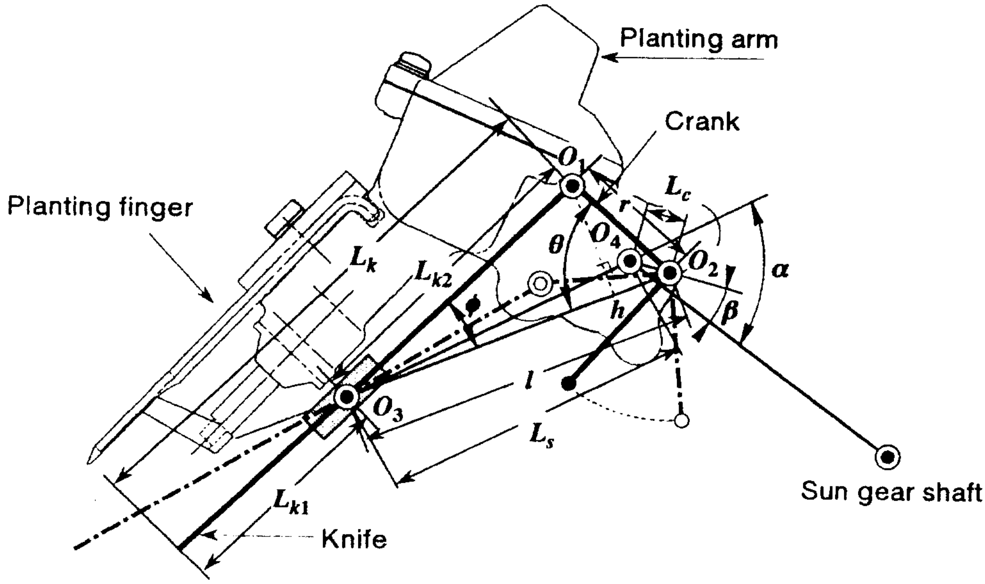
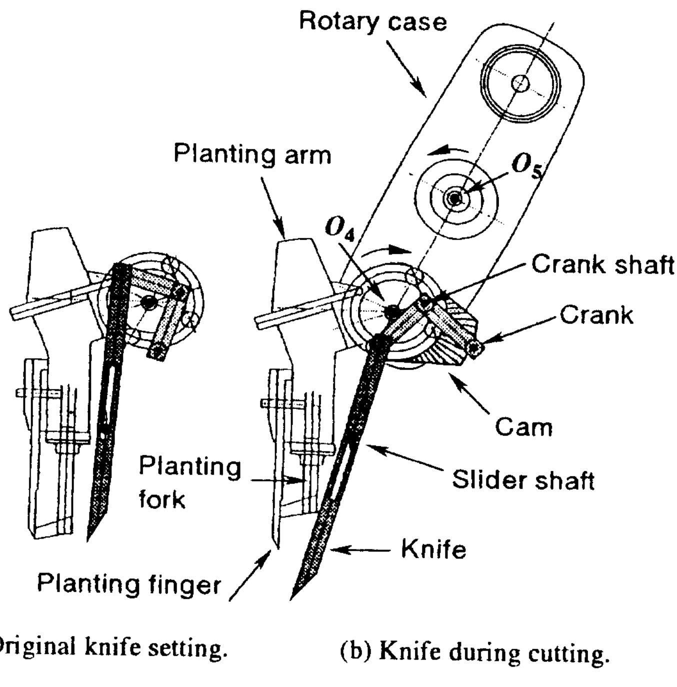
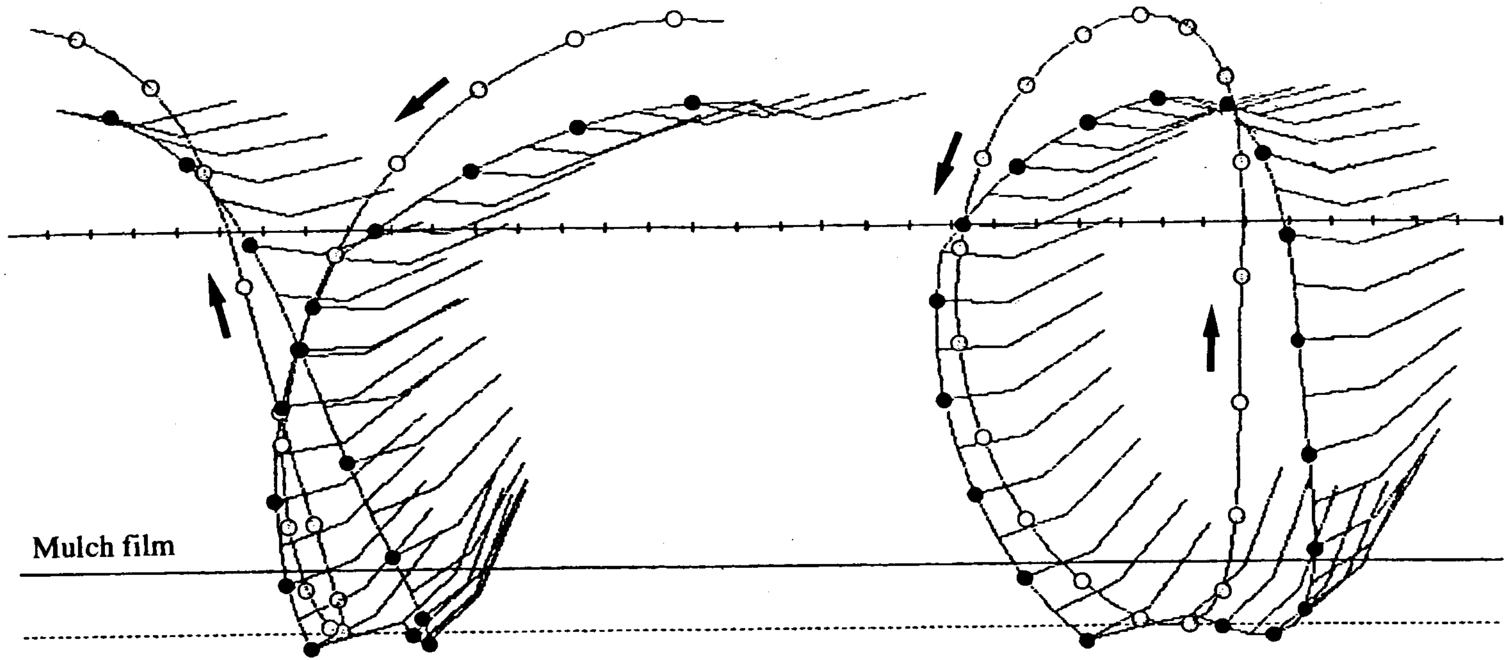


Fig. 3 Ocsillating-block-slider-crank-mechanism with planting arm.



(a) Original knife setting. (b) Knife during cutting.

Fig. 4 Film cutter assembly built as an integral part of the rotary planting device.



(a) Locus when traveling.
(Plant spacing : 16 cm)

(b) Locus when traveling speed is zero.

Fig. 5 Loci of the knife and the planting finger.
(Planting depth : 3 cm, ○: planting finger tip, ●⁄ : Knife tip and its edge)

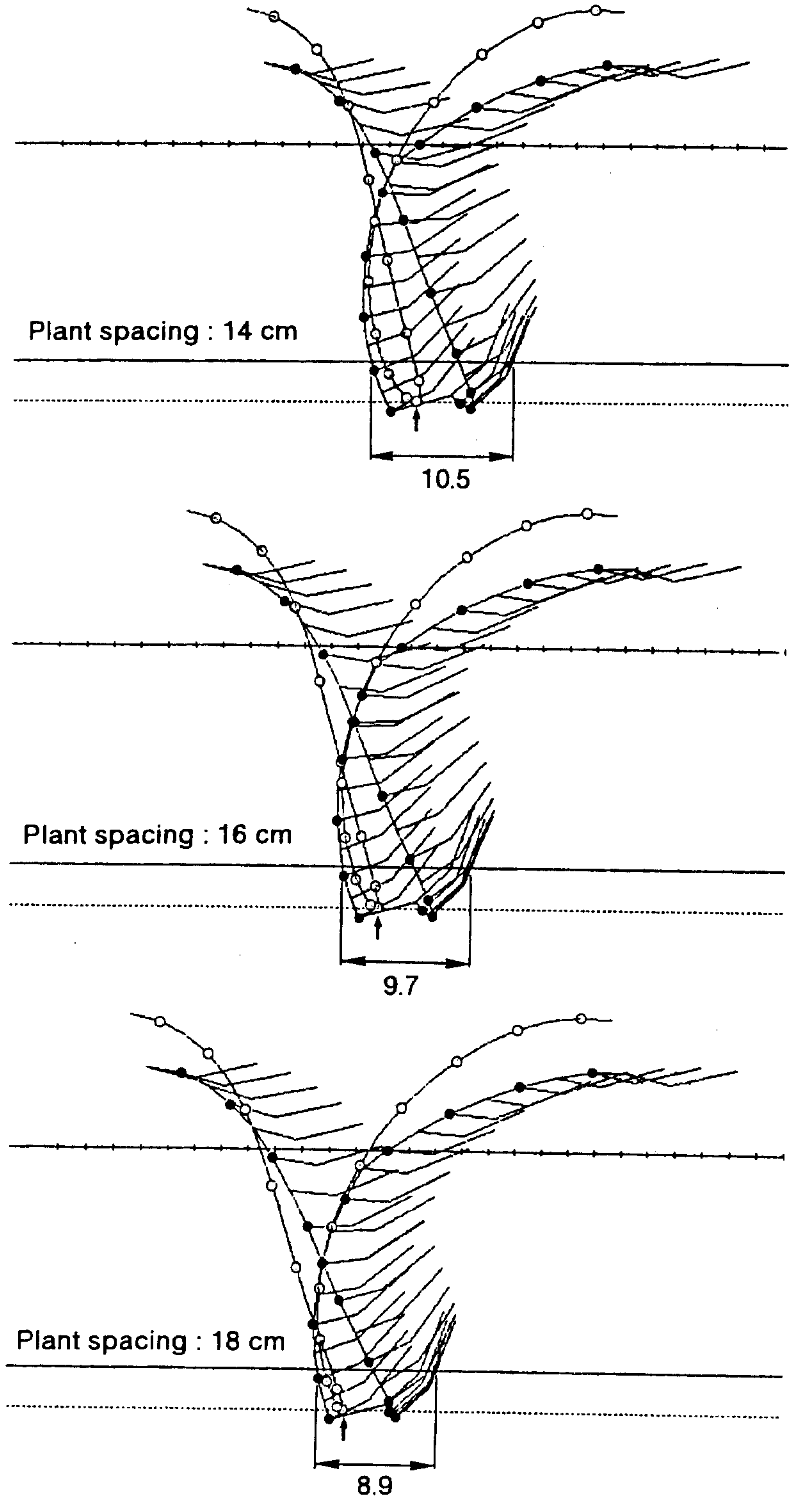


Fig. 6 Theoretical length of planting slit and planting position at plant spacings of 14, 16, & 18 cm .
(Unit : cm, Planting depth : 3 cm, ○: Planting finger tip, ●⌣ : Knife tip and its edge, and ↑ : Planting position.)

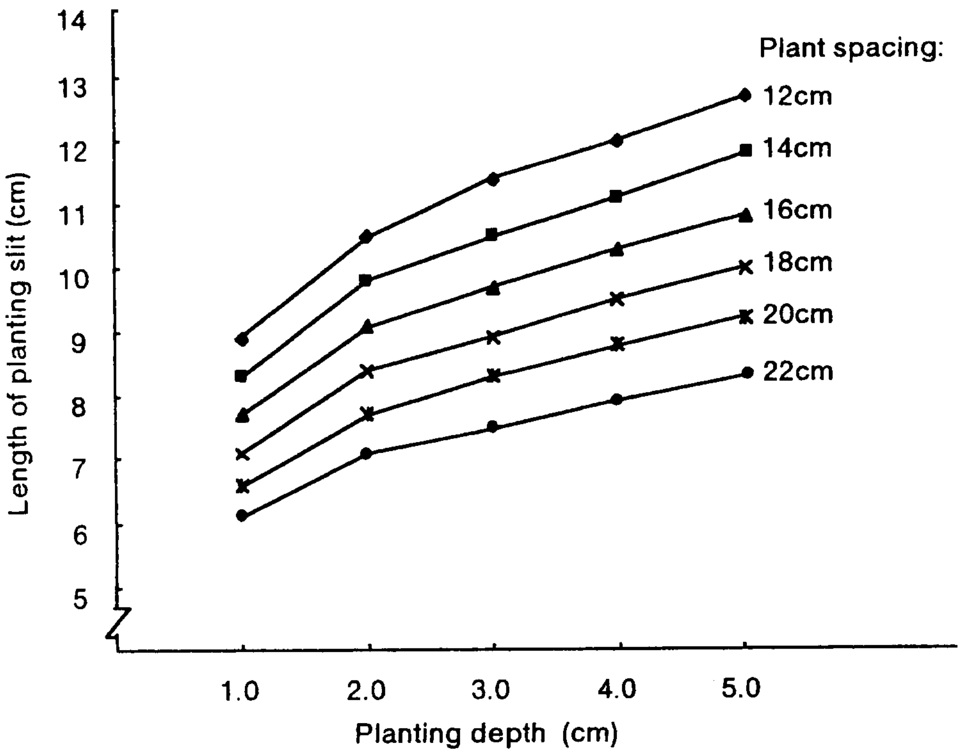


Fig. 7 Theoretical length of planting slit by planting depth