Design and operating characteristics of a push type cutter bar mower

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Celik, A. 2006. **Design and operating characteristics of a push type cutter bar mower**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **48**: 2.23 - 2.27. In the small-scale mountainous enterprises of Turkey, forage harvesting is traditionally done by using scythes or sickles. This method is laborious, ineffective, and requires a long time. The aim of this study was to design, fabricate, and test a push type cutter bar mower for use by small-scale enterprises in forage harvesting. Price, land condition, and enterprise size were considered as the main criteria for the design and development process. The cutter bar mower consisted of six main components including the cutting, transmission, power, handling, frame, and transporting units. A two-cycle engine that produced 1.47 kW at 7000 rpm provided power for the cutting unit. Two skids were attached to the cutter bar unit, one on each side, to control cutting height. The total mass of the mower was 41 kg. Performance tests of the mower resulted in an average 0.11 ha/h effective field capacity, 10.00 L/h fuel consumption, 0.875 field efficiency, 2.24 t/h effective wet grass harvesting capacity, 4.43 L/t wet grass specific fuel consumption, and 64 mm cutting height. **Keywords:** forage harvesting, mower, cutter bar.

Dans les petites entreprises agricoles situées dans les régions montagneuses de la Turquie, la récolte du fourrage est réalisée de manière traditionnelle à l'aide de faux et de faucilles. Ces méthodes sont laborieuses, inefficaces et requièrent beaucoup de temps. L'objectif de cette étude était de concevoir, de fabriquer et d'évaluer une faucheuse poussée à barre de coupe pour la récolte du fourrage dans de telles petites entreprises. Le prix, les conditions du terrain et la taille de l'entreprise étaient considérées comme principaux critères de conception et de développement. La faucheuse à barre de coupe était constituée de six composantes principales incluant la barre de coupe, la transmission, la source de puissance, la direction, le châssis et l'unité de transport. Un moteur à deux temps produisant 1,47 kW à 7000 rpm fournissait la puissance nécessaire à l'unité de coupe. Deux patins étaient montés sous la barre de coupe, un de chaque côté, dans le but de contrôler la hauteur de coupe. La masse totale de la faucheuse était de 41 kg. Les tests de performance de la faucheuse ont démontré que la faucheuse avait en moyenne une capacité au champs de 0,11 ha/h, une consommation de carburant de 10,00 L/h, une efficacité au champs de 0,875, une capacité de récolte de 2,24 t/h de fourrage humide, une consommation spécifique de 4,43 L/t de fourrage humide et une hauteur de coupe de 64 mm. **Mots clés**: récolte des fourrages, faucheuse, barre de coupe.

INTRODUCTION

The average size of agricultural enterprises in Turkey is about 6 ha, of which 72% are less than 5 ha in area, and 57% have more than four fields. Forages, mainly grasses and legumes, are grown by more than 75% of the farmers in Turkey on a total area of about 12 million hectares, which is 15% of the total land. Almost 90% of the hay production area is natural pasture and the remaining 10% is cultivated. Hay production in Turkey is about 12 million tonnes per year. Approximately 50 million livestock are directly fed by the harvested dry hay (Karagoz 2000; EFYDPRT 2001; TSY 2001). The current amount of hay production is insufficient to meet the demand in Turkey. Therefore, some projects have been commissioned to improve and develop forage and pasture lands (CMYUGP 2001).

Forage harvesting in Turkey has been mechanized to a lesser extent than is desirable. Especially in the small and mountainous farms, harvesting is still done manually, due to the high prices of mowers and the dependence on tractors. In Turkey, the total number of the mowers is almost 32,000. The mowers can be classified into two groups, tractor-drawn and self-propelled types, with the tractor-drawn type mower accounting for about 95% (Celik 2001). In Turkey, there are three main methods of hay harvesting: harvesting using manual labor, harvesting by mowers, and harvesting by silage machines. Scythes are the main tools used in the manual labor method. In the second method, rear mounted type tractor mowers or self-propelled mowers are used, which, especially on the large and smooth terrains, are very common. Both tractor-mounted and self-propelled mowers have a standard working width of 1.8 m. The tractor-mounted mowers are less expensive than the self-propelled ones. The biggest disadvantage of the tractor-mounted type mower, however, is over-dependency on the availability of a tractor. The third method of harvesting is cutting of forage by a silage machine (flail mower), which is not so common in Turkey because grazing animals are allowed to feed on natural pastures during the harvesting season. Moreover, silage production is not commonly used by farmers.

For these reasons, a push type cutter bar mower was selected for exploring its adaptability in solving farmers' problems in terms of cost and versatility on various terrains of small-scale enterprises. Therefore, the objectives of this study were to (1) design a simple, strong and inexpensive forage-harvesting machine operated by a single person for various topographies for several kinds and characteristics of crops, grown in small-scale enterprises in Turkey, (2) reduce dependency of forage harvesting on tractor-mounted mowers, and (3) reduce human fatigue, compared with scythes or sickles.

MATERIALS and METHODOLOGY

Materials

The cutter bar mower designed in this study consists of six units: cutting, transmission, power, handle, frame, and

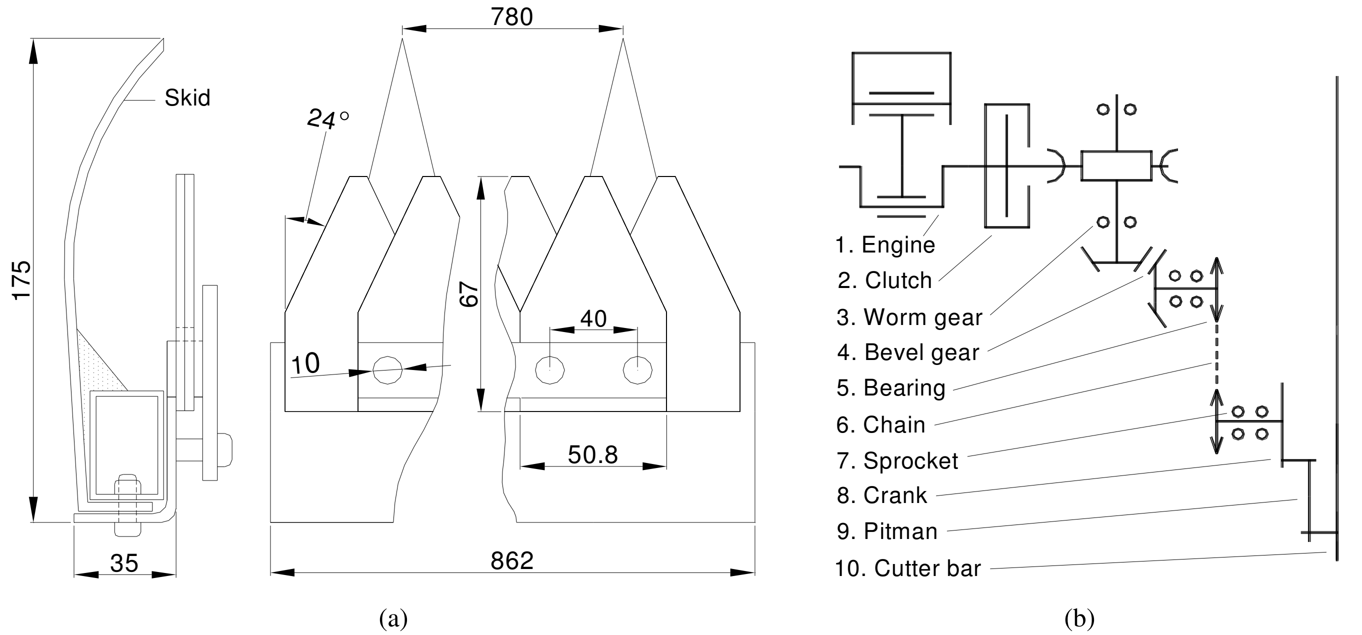


Fig. 1. (a) Dimensions (millimeters) of knife and skids (left side view and top view); (b) Diagram of the mechanical elements of the transmission unit.

transporting. The cutting unit, which was attached to the main frame, has two-knife bar sections; the upper one reciprocates over the stationary bottom one. The stroke length and the width of the standard type knife are 50.8 mm (Fig. 1a). The 10:1 ratio transmission unit which reduced engine speed (Bell 1989) consisted of a worm-gear, bearings, bevel gears, chain and sprockets, crank, and pitman (Fig. 1b). The engine power required for an 862 mm width cutter bar was determined and a two-cycle type engine (1.47 kW at 7000 rpm) was selected (Bainer et al. 1965; Culpin 1987) by considering its cost.

Thereafter, the material, size, and specifications of all machine components were determined accordingly. Human ergonomics were considered in designing the frame (Figs. 2 and 3). The crank diameter was calculated according to knife stroke length. The distance between the connection point on the cutter bar unit and the crank gave the pitman length. The top and side views of the cutter bar mower are shown in Figs. 2 and 3. Also, some technical properties of the cutter bar mower are given in Table 1.

The frame was made of steel angle having a leg thickness of 3.2 mm and of 1 mm thick steel plates. The handles were made of 20 mm outside diameter steel pipes. Two pneumatic rubber tires of 380 mm overall diameter were selected for the transporting unit. Two skids with 5-mm thickness were mounted under the cutter bar, one on each side, to adjust cutting height and to carry the cutter bar unit during mowing (Fig. 1a). All dimensions of the mower were selected to be as small as possible to minimize the amount of material used.

Experimental methods

The experiments were conducted on the Tsukuba International Centre (Japan) experimental fields on different lengths and four grass densities (Greenlees et al. 2000) varying from 300 to 600 mm, and 12.5 to 29.5 Mg/ha (w.b.), respectively. The dry basis moisture content of the grass during cutting (ASAE 2004a) ranged between 72 - 77%. The topography conditions in the field were uneven due to slight roughness.

The maximum engine speed was 7000 rpm and was measured using a mechanical tachometer. The knife speed was calculated using Eq. 1.

$$V_k = \frac{Sn}{30} \tag{1}$$

where:
V_k = knife speed (m/s),
S = length of stroke (m), and
n = crank speed (rpm).

The forward (ground) speed was calculated using Eq. 2.

$$V_f = \frac{3.6D}{T} \tag{2}$$

where:
V_f = forward speed (km/h),
D = harvesting distance (m), and
T = harvesting time (s).

Harvesting time was recorded for a distance of 50 m. Speed ratio was the average reciprocating knife speed over average forward speed. Fuel consumption, in liters per hectare (L/ha) and liters per hour (L/h), was determined by refilling the fuel tank. In this method, before harvesting, the fuel tank was filled and after harvesting a certain area, the fuel tank was refilled (RNAM 1983).

The effective field capacity of the machine was determined using Eq. 3 (Srivastava et al. 1993).

$$F_c = 0.1V_f \cdot w \cdot f_c \tag{3}$$

where:
F_c = effective field capacity (ha/h),
w = effective working width (m), and
f_e = field efficiency (decimal).

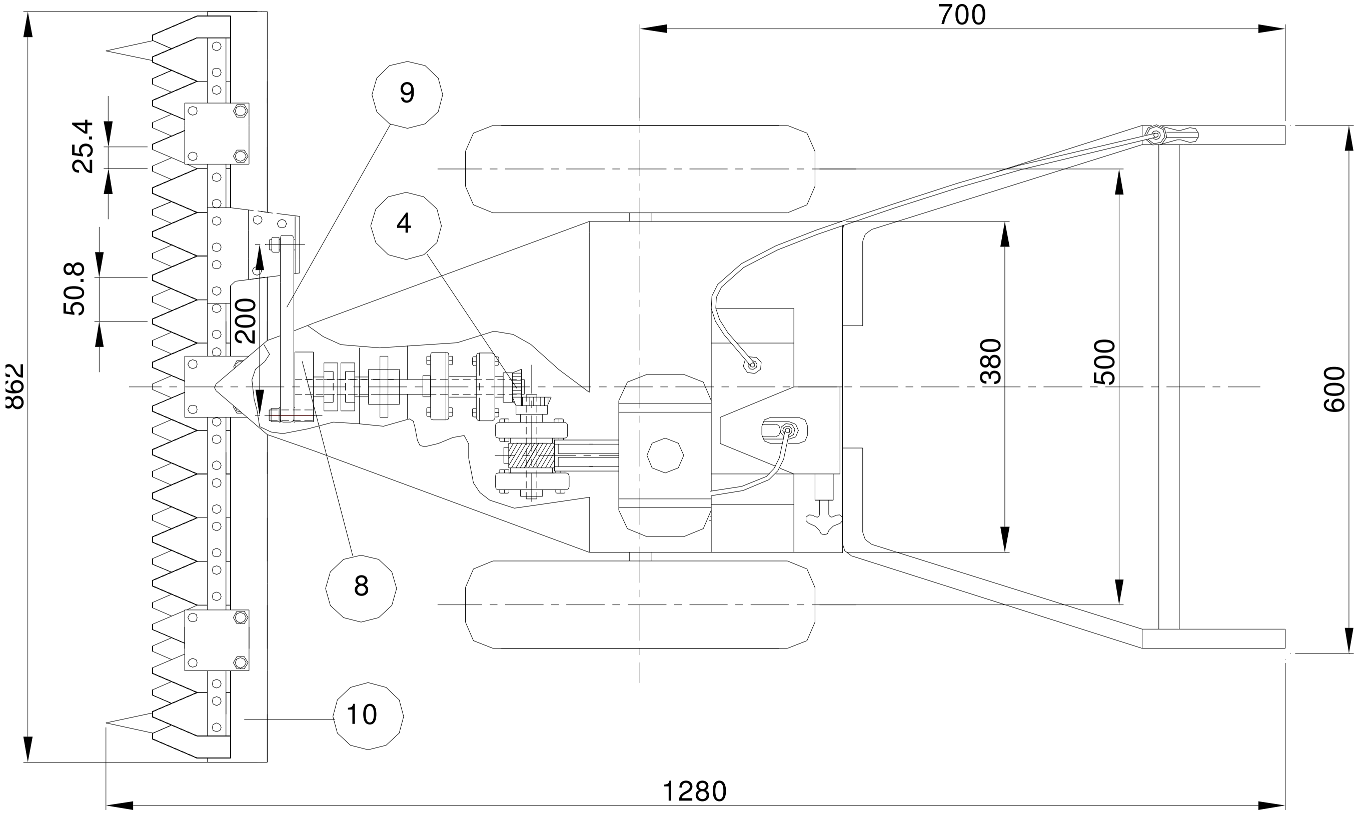


Fig. 2. Top view of the cutter bar mower (dimensions in millimeters).

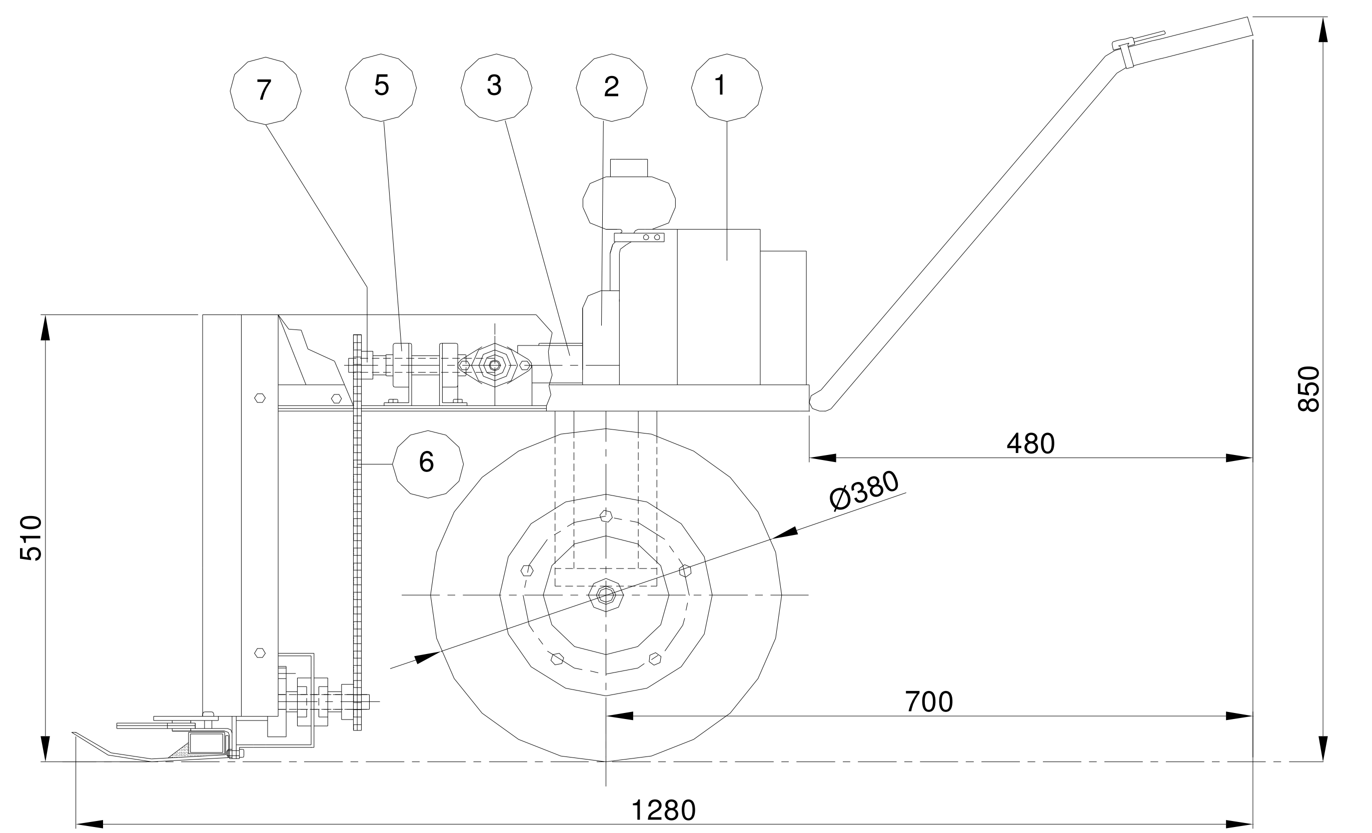


Fig. 3. Side view of the cutter bar mower (dimensions in millimeters)

Table 1. Some technical and operational properties of the mower.

Technical properties		Operational properties	
Property	Value	Parameter	Value
Total height (mm)	850	Effective working width/knife stroke/cutting height (mm)	802/56/64
Total width (mm)	862		
Total length (mm)	1280	Crank speed (rpm)	600
Working width (mm)	862	Knife speed (strokes/min)	1200
Maximum engine speed (rpm)	7000	Knife speed/forward speed (m/s)	1.12/0.45
Maximum crank speed (rpm)	700	Speed ratio	2.49
Engine power (kW)	1.47	Effective field capacity (ha/h)	0.11
Transmission ratio	1.10	Field efficiency (decimal)	0.875
Sharpness of knife (°)	22	Fuel consumption (L/ha)/(L/h)	10/1.05
Hardness of knife (H_{RC})	57	Effective harvest capacity (t wm/h)	2.24
		Specific fuel consumption (L/t wm)	4.43

Field efficiency is described as the ratio of the time that the machine is harvesting at an optimum forward speed and performing over its full width of action to the total time spent in the field (Hunt 2001). During cutting, effective working time, working width, and turning time were recorded by following a certain field pattern (Hunt 2001; ASAE 2004b), and then field efficiency was calculated according to the definition.

Mower harvesting capacity and specific fuel consumption were determined according to wet forage mass (wm) as tonnes wet mass per hour (t wm/h) and kilowatt-hours per tonne wet mass (kW h/t wm), respectively, (ASAE 2001). Harvesting experiments were performed on 30-m length and 5-m wide plots for each grass density. Four measurements were made in each plot.

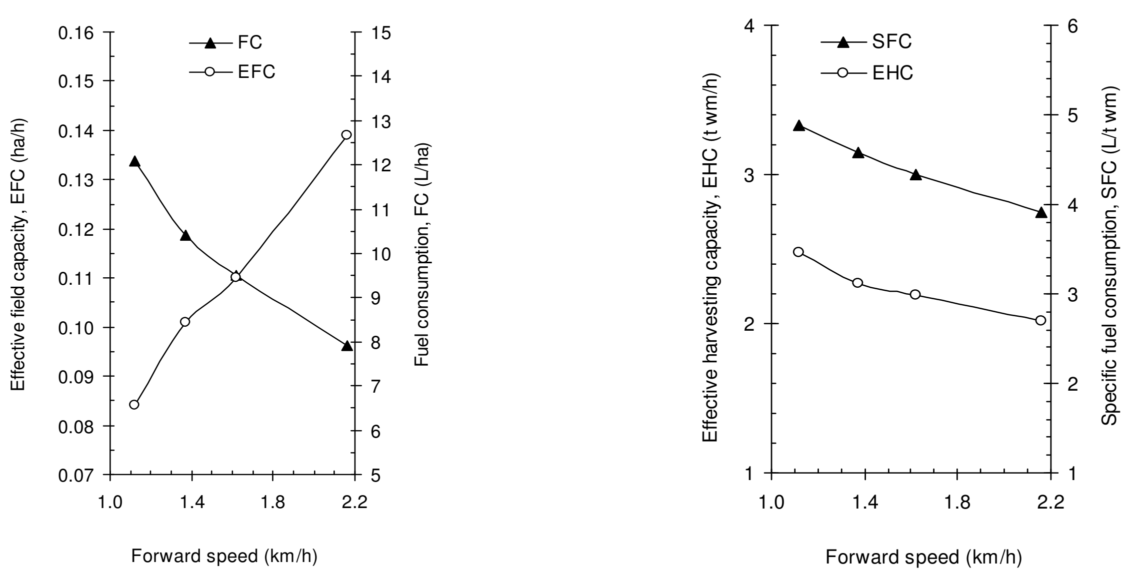
RESULTS and DISCUSSION

The design parameters shown in Table 1 were calculated on the basis of the data obtained during the experiments. Forage was cut at four different forward speeds, which varied according to grass density, ranging from 1.0 to 2.2 km/h, for checking mower motion resistance, running conditions, and harvesting quality. The average forward speed, effective field capacity, field efficiency, and fuel consumption were found to be 1.62 km/h, 0.11 ha/h, 0.875, 10 L/ha and 1.05 L/h, respectively (Table 1).

The effective field capacity increased and the fuel consumption decreased as forward speed increased (Fig. 4a). In addition, at high forward speeds, the field efficiency decreased because the total time lost did not increase proportionally to the increase in the effective harvesting time. The fuel consumption per area decreased as predicted at high forward speeds as shown in Fig. 4a due to the constant engine speed during harvesting.

The forward speed was higher in low grass density and lower in high density. Normally, effective harvesting capacity should be parallel to the x axis (constant) with forward speed; but due to operating conditions, effective harvesting capacity slightly decreased with speed. Also, specific fuel consumption decreased slightly with speed (Fig. 4b). Average effective harvesting capacity and specific fuel consumption for wet mass was 2.24 t wm/h and 4.43 L/t wm, respectively (Table 1).

At forward speeds greater than 2 km/h, blockage was noticed on the cutter bar unit due to the high density of the forage and insufficient engine power. To prevent blockage, harvesting was performed at forward speeds less than 2 km/h. During experiments, it was observed that the actual engine power necessary to power the mower was greater than the engine power requirement that was calculated when the mower was being designed. This was due to changes in forward speed,



(a) (b)

Fig. 4. (a) Effective field capacity and fuel consumption vs forward speed; (b) Effective harvesting capacity and specific fuel consumption vs forward speed.

forage density, and ground topography conditions in the field. To overcome such problems, the engine power should be at least 25% greater than the power calculated for the mower.

It was realized that the worm and worm gear became damaged in harvesting high forage density with higher forward speed. The strengths of the two materials were not compatible for these conditions. One person was required for both driving and harvesting. Normally pneumatic rubber tires damped the vibration of the machine to a certain extent. Hence, vibration did not cause any inconvenience to the user. The 380-mm diameter wheels and balanced weight of the mower were conducive to the very good performance of the mower in transport mode. General safety of the machine was reliable. Except for the cutter bar unit, all the active parts were covered. Maintenance of the machine was simple, as the machine has only seven grease fittings and needed grease only once each eight hours of use.

CONCLUSIONS

The engine power should be at least 25% greater than the power required by the mower, to overcome changes of forward speed, forage density, and ground topography conditions in the field. The worm and worm gear should be selected of hardened steel materials to prevent any damage to these parts and the number and size of transmission unit parts should be minimized in order to minimize power losses. The forward speed of the machine should be selected by considering grass density to avoid any blockage on the cutter bar. All the components of the machine, especially the parts used in the transmission unit, should be simple, strong, and inexpensive. A balanced crank should be used to reduce vibrations on the cutter bar caused by unbalanced forces of reciprocating parts. To control cutting height, adjustable type skids should be used on both sides. For harvesting dense and tall forage plants, the width of the cutter bar knife should be selected as 76.2 mm.

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