DESIGNING FOR IMPROVED PERFORMANCE FROM A FURROWER-BED-FORMER

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Introduction

Various forms of furrower-bed-formers are used across Australia in both irrigation and dryland farming conditions. In Western Australia the soil and climatic conditions impose somewhat unique demands on this type of machine. Our soils have shallow structureless topsoils which are underlain by dense clayey subsoils at varying depths. These subsoils are also poorly structured and are commonly sodic. The climate is distinctly Mediterranean, with cool and wet winters, sparingly moist but short autumns and springs and almost completely dry summers.

To create permanent raised beds in this environment requires that:

i) the initial ripping (to 20cm depth) and cultivation is done when the soil is at a moisture content close to its Plastic Limit, to maximise the formation of clods and aggregates and minimise soil pulverisation;
ii) the excavation of soil from the furrows/drains/traffic lines and the spreading of the spoil onto the surface of the intervening beds be done in the most gentle way possible, to avoid unnecessary compaction and/or pulverisation.
iii) the formation of the furrows and beds be accomplished with one pass of the machine, consistent with the need to reduce operational time and costs when farming large areas.

Mark I Version

Gessner Industries Inc. Qld., a manufacturer of a large variety of row-cropping equipment, was prepared to assist with the design and supply of a furrower-bed-former for WA conditions. The machine design that evolved from discussions with this company comprised their standard heavy duty (180 mm square section) 3-point linkage toolbar with adjustable furrowers and spoil spreading grader blades. The furrowers consist of four maxitil ripper shanks with furrower (hiller) attachments. These are mounted on the front bar at multiples of tractor wheel-track widths. The small grader blades are mounted on adjustable shanks on the rear bar.

The four pairs of these grader blades are raked backward from the centre of each furrow and they extend laterally to the middle of the beds. The initial rake angle on the grader blades was 56°.

Trailing/gauge wheels are mounted on the rear of the tool bar to provide greater depth control and stability during the bed forming operations. The height/depth of these is adjusted with a ratchet extension arm.

A view of the Mark I version operating in 1997 is shown in Figure1.

1997 Performance

The performance of the Mk I version of the WA furrower-bed-former was satisfactory. With inexpert operators the beds formed with two passes of the machine were quite acceptable (Figure 2).

1998 Performance

This year, with one season's experience, our appraisal of the machine's performance was more critical. We were seeking to achieve good bed formation with a single pass of the machine in soil which had been previously ripped and chisel-ploughed to a depth of 20 cm.

On close inspection over a number of sites in which the soil varied from a gravelly-sand to a sandy loam with some clayey subsoil included, the grader blades were bulldozing too much soil. In consequence, a considerable proportion of the spoil from the furrows was being pushed back into the furrow or compacted beneath the blade, and a fairly large amount of spoil was carried in front of the blade. A relatively small portion of soil actually flowed off the trailing end of the blades. Two passes of the machine were again required to adequately shape and clear the furrows of spoil, and an unacceptable amount of compaction occurred on the tops of the beds.

Design analysis for improving the performance

To have the spoil from the furrowers flow along the grader blades clearly required them to be raked backwards at a steeper angle to the direction of travel.

From the Mohr-Coulomb analysis of soil stresses at failure (i.e. when soil slides across itself) we can calculate the angle of the failure plain of soil (θ_f) for given angles of internal soil friction (ϕ), where

$$\theta_f = 45° + \phi / 2$$

For the sands and sandy loam soils we deal with, ϕ ranges from 20° to 30°, suggesting that a rake angle of around 30° to 35° would be the minimum required for soil to 'fail' and flow easily. That is, the soil would fail at an angle equal or close to that of the blade, with the consequence being that it would roll along the blade surface, assuming the angle of friction between the blade and soil produced a soil-blade failure angle of similar magnitude. Common values of the angle of friction between soil and steel are around 20°, confirming that such a requirement would be achievable. (Both angles of friction vary with soil moisture according to the relative magnitude of cohesive and adhesive forces within and between them.)

To test this semi-quantitative analysis the horizontal draft force required to move a blade and soil was calculated using the method in McKyes (1989, pp. 193-194), where:

$$P = \{ \gamma . h^2 . K_p + c.h.K_c + ca.h.K_{ca} \} .w$$

$$H = P.\sin(\alpha + \delta) + ca.h.w.\cot\alpha$$

and	P	=	blade force on the soil	(kN)
	γ	=	bulk density of soil	(kN/m^3)
	h	=	height of blade	(m)
	c	=	cohesion pressure	(kPa)
	ca	=	adhesion pressure	(kPa)

q	=	bearing pressure	(kPa)
K_p	=	passive pressure coefficient	
K_c	=	cohesion coefficient	
K_{ca}	=	adhesion coefficient	
w	=	width of blade	(m)
H	=	horizontal draft force	(kN)
α	=	blade rake angle	(degrees)
δ	=	angle of surface friction	(degrees)

Results of analysis

Two hypothetical soils with appropriate soil mechanical properties were used for the analysis. These had angles of internal friction covering the range likely to be found in WA's coarse textured surface soils, a bulk density typical of freshly cultivated soil and cohesion and adhesion pressures typical of a range of moisture contents likely to exist when the soil would be worked, i.e. dry and moist. These were: $\phi = 20°$ and $30°$; $c = 5$ kPa and 20 kPa; $ca = 0$ and 5 kPa; $\delta = 20°$; and $\gamma = 10$ kN/m^3.

Table 1. *Horizontal draft forces (kN) for grader blades at two rake angles*

Rake angle	Internal friction angle of 20°		Internal friction angle of 30°	
	Dry soil c = 5; ca = 0	**Moist soil** c = 20; ca = 5	**Dry soil** c = 5; ca = 0	**Moist soil** c = 20; ca = 5
Existing rake angle of 56°	1.36	6.24	2.05	10.14
Proposed rake angle of 35°	0.80	3.97	0.87	4.37
% reduction in draft forces	41%	36%	58%	57%

These calculations confirm the conclusion of the semi-quantitative analysis on soil failure angle relative to internal friction angle. That is, the rake angle has a greater effect in reducing the horizontal draft force on the grader blades when the soil has a larger internal friction angle.

They also illustrate that the cohesion and adhesion forces in soils, which change substantially with soil moisture content, exert a greater influence on horizontal draft force than the internal friction angles of soils, which do not change as much - a conclusion which was not apparent from the earlier analysis.

Field testing

New mounting brackets were constructed which allowed the leading end of the grader blades to be moved outwards and forwards relative to the vertical shank bolted onto the toolbar frame (Figure 3.). New rear mount brackets were also made for the trailing end of the blade, to accommodate the sharper rake angle.

The field performance of the blades raked at 35° has been subject to a field test in a gravelly sandy loam soil at Mt. Barker. At the time the soil was moist to wet.

The performance of the Furrower-Bed-Former was markedly improved. Furrow shape was much more clearly parabolic and deeper, and the flow of spoil along the grader blades was smooth and easy despite its wetness. Beds were well-formed with a single pass of the machine (Figure 4.).

Further improvements

The furrowing tools could be modified to provide a smooth but steeper rake along their surface whilst maintaining the same cross-section. This would improve the throw of spoil from the base and walls of the furrow, reduce side wall compaction and further facilitate the spreading of spoil by the grader blades. Such improvement is subject to on-going negotiations with the Gessner Industries company.

REFERENCE

Mc Kyes, E. (1989). Agricultural Engineering Soil Mechanics. Developments in Agricultural Engineering 10. Elsevier. New York.

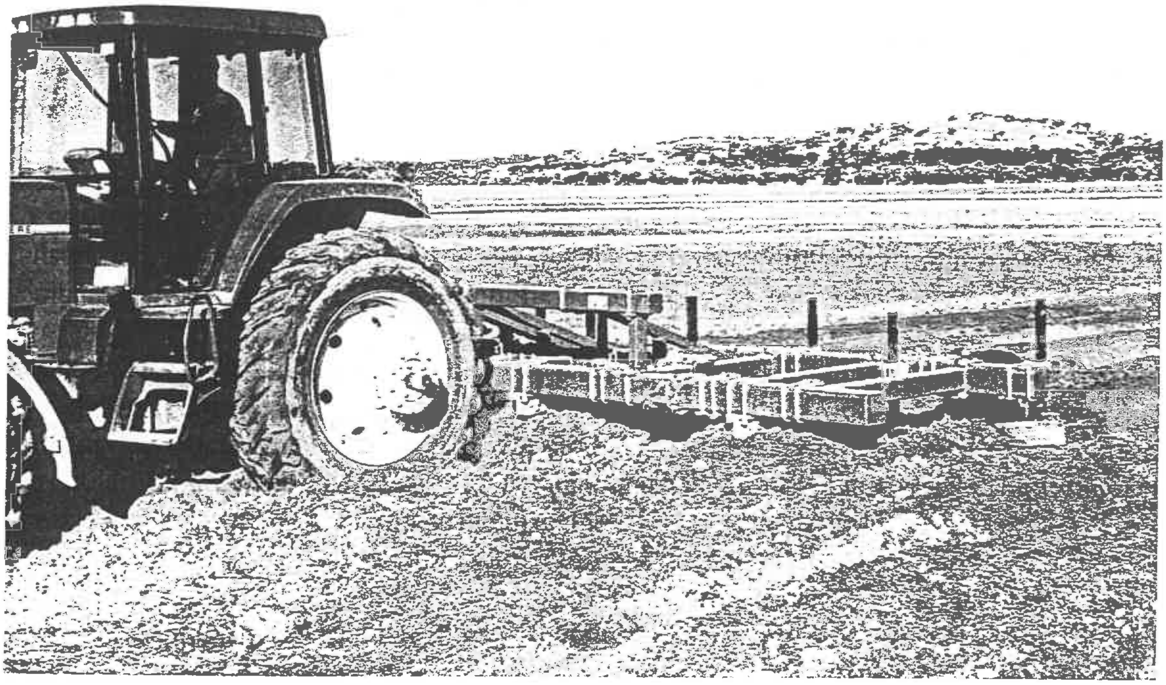

Figure 1. View of the furrower-bed-former in operation in 1997 in a sandy loam soil at Woodanilling, WA. Note the mound of soil being pushed along in front of the furrowers and the grader blades.

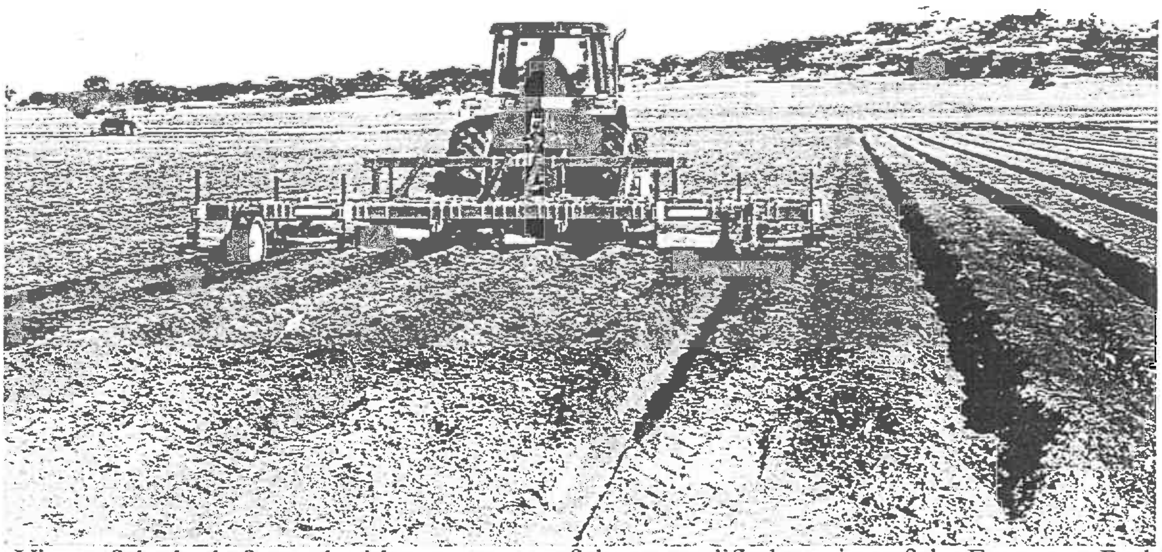

Figure 2. View of the beds formed with two passes of the unmodified version of the Furrower-Bed-Former.

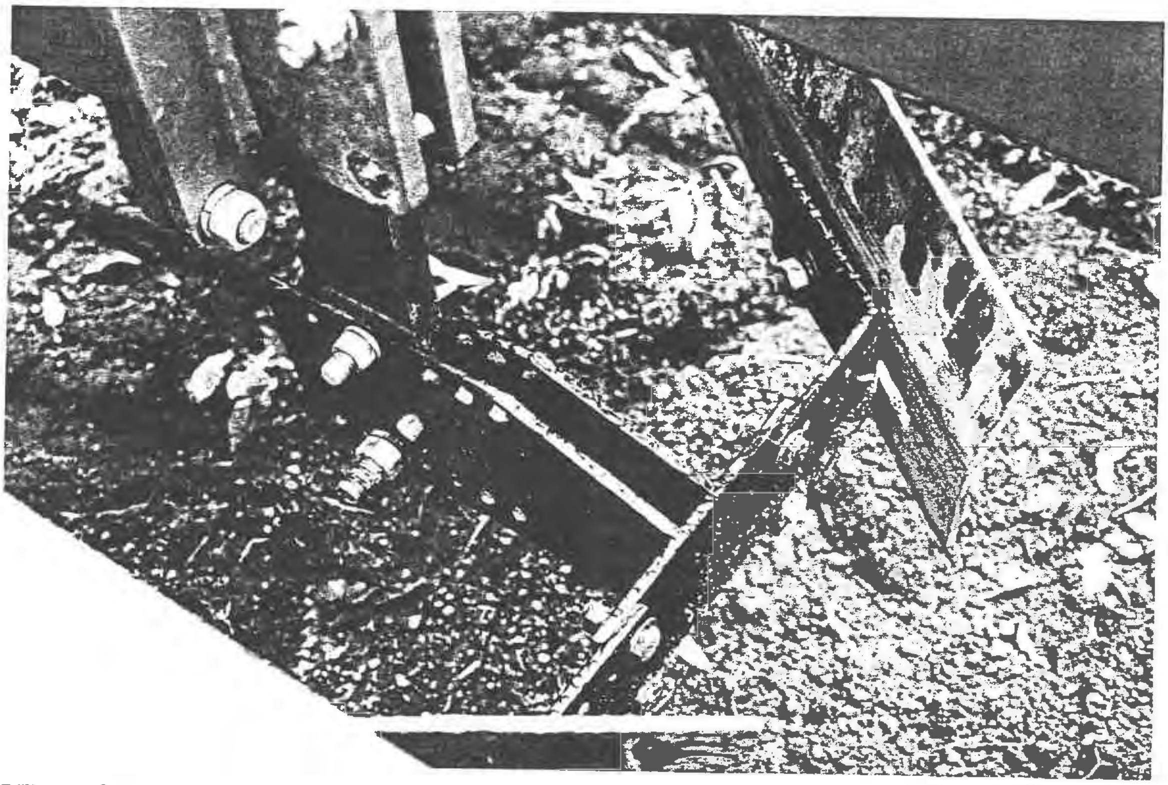

Figure 3. View of the brackets modified to mount grader blades at a rake angle ≤ 35°.

Figure 4. View of the furrows and beds formed by the Furrower-Bed-Former after its grader blades were mounted at a rake angle ~ 35°.