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Super Stolf plow in Tandem for high power tractors

Super arado Stolf em Tandem para tratores de alta potência

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ABSTRACT

The objective was to design a plow model with a working width of 3000 mm, nonexistent in the agricultural market: From the 1960s, with the transfer of the capital of Brazil to the central plateau, investment in the Midwest began, giving rise to a strong agriculture of large agricultural properties. This fact encouraged harrow designs with large working widths. However, there was no progress in the design of plows; on the contrary, their use was reduced by the replacement with harrows. Nine discs would be required to develop a plow with a working width of 3000 mm. But, in the conventional plow model, this nine-disc implement would be very long (4000 mm). In this way, besides keeping a 3000 mm working width, a plow based on the Tandem system was designed to reduce the length of the plow. As a result, a model consisting of three three-disc plows mounted in parallel (tandem) resulted in a design three times shorter: 1333 mm long. The advantages are that it reduces the effort in the hydraulic lifting of three points (vertical moment, torque), reduces the lateral moment that moves the ground, facilitates the maneuver, and provides more stability to the tractor-plow set. Concurrently with developing the plow, we present the evolution of harrows in text and graphic designs.

Keywords: agricultural mechanization, plaw in parallel, soil management.

RESUMO

O objetivo foi projetar um modelo de arado com largura de trabalho de 3000 mm, inexistente no mercado agrícola: A partir da década de 1960, com a transferência da capital do Brasil para o Planalto Central, iniciou-se o investimento na região Centro-Oeste, dando origem a uma agricultura forte em grandes propriedades agrícolas. Esse fato incentivou projetos de grades com grandes larguras de trabalho. No entanto, não houve progresso no projeto de arados; pelo contrário, seu uso foi reduzido pela substituição por grades. Nove discos seriam necessários para desenvolver um arado com largura de trabalho de 3000 mm. Mas, no modelo de arado convencional, esse implemento de nove discos seria muito longo (4000 mm). Dessa forma, além de manter uma largura de trabalho de 3000 mm, um arado baseado no sistema Tandem foi projetado para reduzir o comprimento do arado. Como resultado, um modelo composto por três arados de três discos montados em paralelo (tandem) resultou em um projeto três vezes menor: 1333 mm de comprimento. As vantagens são que ele reduz o esforço no levantamento hidráulico de três pontos (momento vertical, torque), reduz o momento lateral que movimenta o solo, facilita a manobra e proporciona maior estabilidade ao conjunto trator-arado. Paralelamente ao desenvolvimento do arado, apresentamos a evolução das grades em texto e design gráfico.

Palavras-chave: mecanização agrícola, arado em paralelo, manejo do solo.

INTRODUCTION

Many experts have dedicated themselves to the maintenance and correct use of plows and harrows (Mialhe, 1967; Furlani and Zerbato, 2020; Francetto et al., 2024; Girio et al., 2024), especially harrows, due to the diversity of models and uses in soil preparation (Stolf and Silva 1996; Marchesan, 2011). Plows differ from harrows in that they have a greater working depth and perform soil inversion (Mello and Magalhães, 1995; Silva et al., 2002; Toledo et al., 2007), which are commonly used on small properties. However, there has been a decrease in the number of plows and an increase in the number of agricultural harrows per unit area since the 1980s in sugarcane (Stolf and Oliveira, 2023). The reasons are attributed to the increase in the size of agricultural properties due to the demand for implements with a greater operational capacity than the plow, which were replaced by harrows. The greater the operational capacity of the harrow, the greater the working width and, therefore, the power of the tractor. The latter can be estimated through the dimensional characteristics of the harrows (number of discs, diameter, spacing between discs) and, with this data, also classify the harrow (Stolf, 2007a, 2007b). Given this demand for a greater working width, harrow manufacturers began to offer models with more discs to adapt them to high-powered tractors, from 200 to 300 hp (147-221 kW). However, the same did not occur for the plow. The explanation lies in the high horizontal angle of attack of the plow discs, between 45 and 55 degrees, twice that of the harrow. Therefore, by increasing the number of plow discs, some effects may become relevant: (a) the plow's center of gravity becomes further away from the tractor, which may exceed the capacity of the three-point hydraulic hitch; (b) it increases the lateral moment since the soil is displaced laterally, unbalancing the coupling; and (c) it makes maneuvers difficult. For example, when designing a conventional 9-disc plow, the length of the implement would result in 4000 mm. Therefore, plow manufacturers maintained the models with 3 to 5 discs (or 3 to 5 moldboards), for hydraulic hitch, and 6 and 7 moldboards, for drag; in other words, there was no increase in the plow's operational capacity. Therefore, the objective of this study was to design a shorter 9-disc plow without increasing the distance of the center of gravity (center of mass) in relation to the tractor, by using the Tandem method employed in agricultural harrow designs.

METHODOLOGY

Two technical aspects were detailed as a basis to meet the objective of dimensioning the plow: the resource of harrow manufacturers to adapt to high-power tractors and the difference in the horizontal angle of attack of the plows and harrows, as they lead to differences in soil mobilization.

For the projection of this implement, it is necessary to understand some specific terminologies of this area of knowledge, which are described below:

Length: it is the measure of the length of the implement, i.e., perpendicular to the working width. For implements of the same weight, the longer the length, the greater the distance of the center of gravity from the hydraulic coupling and, therefore, the greater the resulting moment. If it exceeds the maximum limit of hitch support indicated by the manufacturer, there will be damage to the tractor's hydraulic system.

Headboard turning: The shorter the length of the implement, the smaller its turning radius, i.e., the more agile it will be to turn the headland.

Moment or torque (torsional force): Moment supported by the hydraulic hitch when coupling an implement: Distance (longitudinal) from the attachment point of the hydraulic arm (on the tractor) to the center of gravity of the implement (***d***) multiplied by the force-weight of the harrow (***Mg***):

$$Moment = d.\mathrm{Mg} \quad (1)$$

In general, the harrows are dragged due to the high mass. Only light and ultra-light harrows are attached to the hydraulic hitch of the tractor so as not to exceed the capacity of the hydraulic lift (moment).

Tandem: It is an English term used to describe a structure reproduced in series or in parallel, to multiply its function. In agricultural mechanization, it is applied to refer to: "Tandem Trailers," that is, interconnected in series, operated by a load traction unit (tractor), or harrows, in general, two, mounted in parallel, to double the working width, operated by only one tractor.

The types of harrows that can be used should also be considered (Figure 1), being:

(a) Conventional “V”-shaped harrow called “Off-set,” asymmetrical in relation to the direction of travel.

(b) Tandem harrows, in “X” shape (two harrows mounted in parallel). In the “X” shape, the harrow is symmetrical, with no lateral mechanical momentum, that is, perpendicular to the direction of displacement.

The consequences of the horizontal angle of attack of the plow discs and harrow must also be considered. In plowing discs, the horizontal angle of attack of discs is 45 to 55 degrees. Responsible for differentiating it from the harrow, it allows a greater depth of work and inversion of the soil (turnover). However, the discs are positioned farther away from the motor source.

Therefore, when designing a conventional plow, the aforementioned angle will limit the increase in the number of discs by making the implement too far from the tractor. For example, a conventional 9-disc plow would allow a large working width of 3000 mm but with an inadequate longitudinal length of 4000 mm (center of gravity, 2000 mm), as Figure 2 illustrates. There would be an imbalance in the tractor-implement set by causing a high moment (F.d), both lateral by the displacement of the soil by the discs, and a

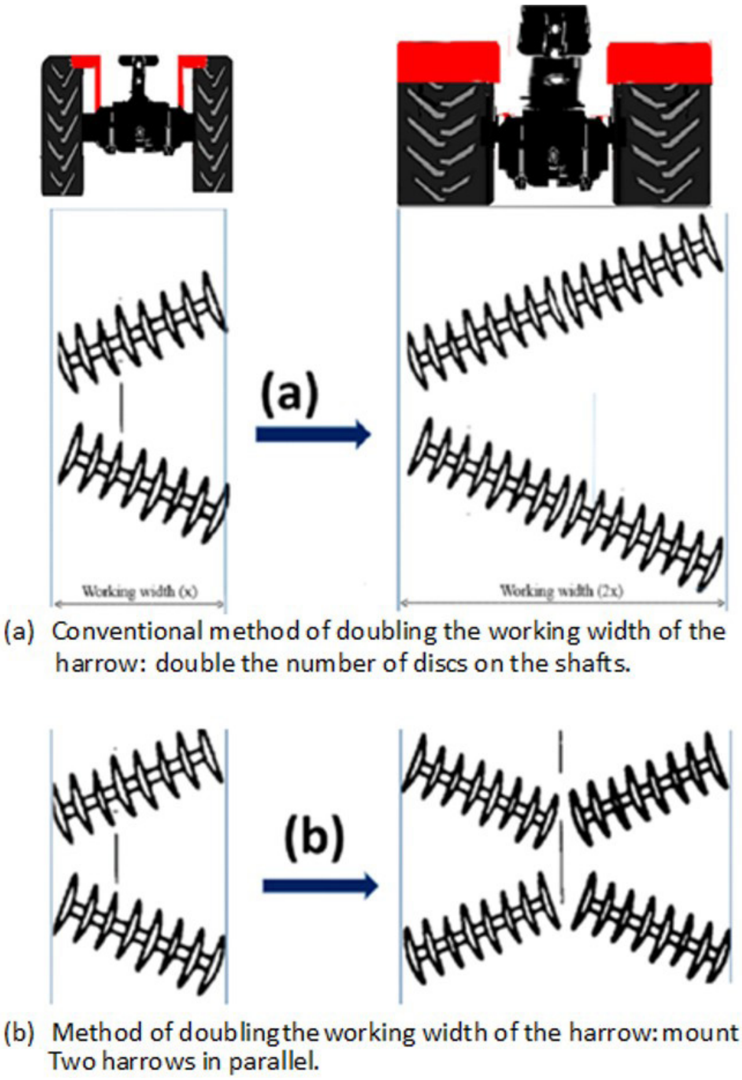

Figure 1. Method for doubling the working width of a 16-disc offset harrow (a) by increasing the number of discs on the two harrow axes; (b) Assemble two harrows in parallel on the same structure (Tandem). Adapted from Stolf and Silva (1996).

longitudinal high moment for the hydraulic lift (Prade et al., 2011; Garay et al., 2013; Veit et al., 2015). Furthermore, long implements, too far back in relation to the tractor, make head turning maneuvers difficult.

Working depth: The working depth of both harrows and plows increases as a function of two variables: disc diameter and angle of attack. However, the angle of attack of the harrow is about twice as small as that of the plow. As a result, roughly speaking, for the same diameter, the plow deepens twice as much, about 1/3 of its diameter, and the harrow 1/6 (practical information).

Horizontal angle: In disc harrows because it has a smaller angle of attack and less depth, it does not invert the law; it only moves it laterally. Thus, the work of the front axle discs needs to be complemented by the rear axle discs. The Harrow angle values are 17 to 22.5 degrees. Plow: 45 to 55 degrees.

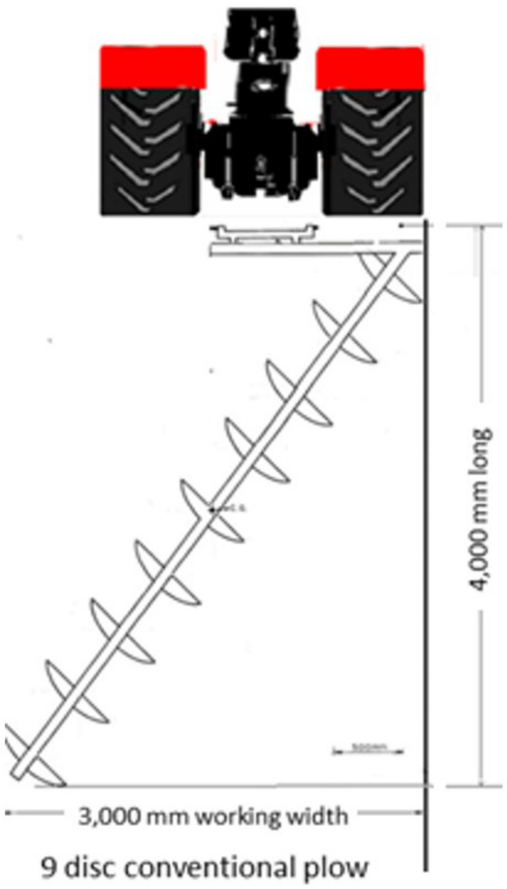

Figure 2. In the conventional plow model, if it were designed for 9 discs, it would result in a large cutting width (3000 mm). However, inadequate in terms of longitudinal length: 4000 mm.
Source: The authors.

The axis on which the harrow discs are mounted would limit their deepening; this is not because the harrow disc is less deep (Figure 3a). On the other hand, the plow cannot have this limitation (axis) because it goes deeper (Figure 3b).

The lower angle of attack of the discs makes them closer to the tractor compared to the plow (Figure 4). Comparing the two types of harrows, the Tandem type brings the implement even closer to the tractor. These characteristics allowed the evolution of the design of harrows for greater working width, unlike plows.

The figure illustrates how the design of the trailing harrows evolved for coupling in high-power tractors. To exemplify an extreme case, the Tandem method allows the development of a three-body drag harrow in parallel, with 72 discs, the only model found in Tandem format for "Offset" (Figure 5).

These elements were used to develop the proposed plow project, presented below.

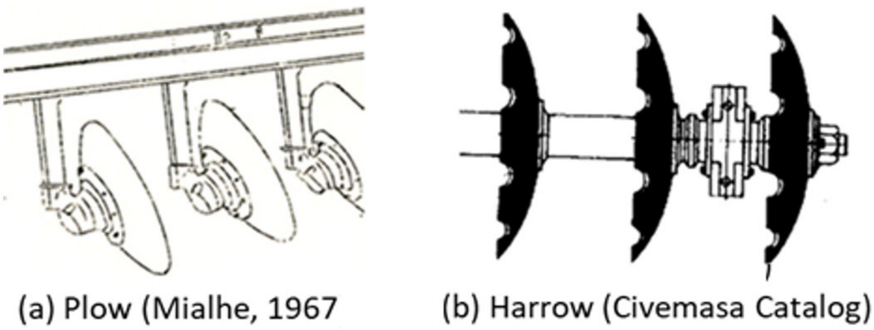

Figure 3. (a) Plow has no obstacle to the deepening of the discs; (b) The harrow has as its limit the axis that joins the discs.

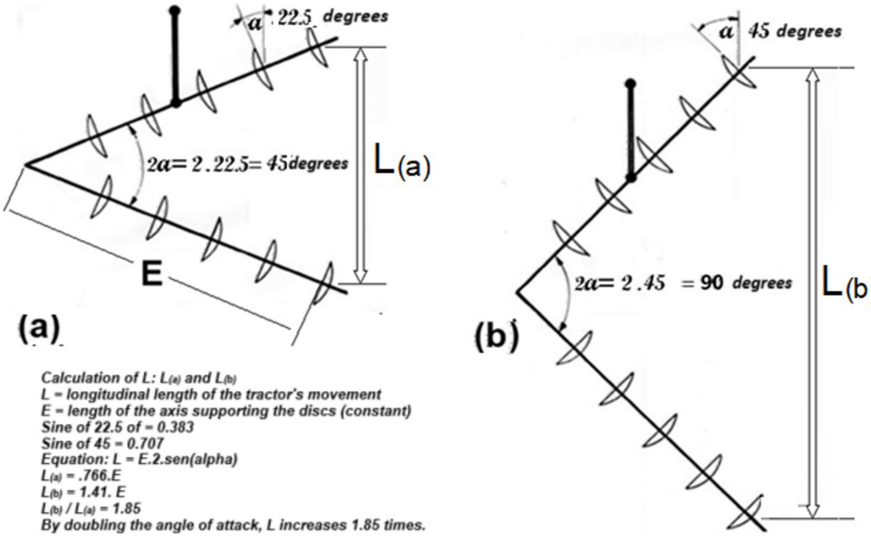

Figure 4. Proof that the greater the horizontal angle of attack of the disc, the greater the length of the implement, distancing it from the tractor. (a) Harrow with conventional angle of attack (22.5°); (b) Same harrow: simulation of the length that the harrow would have to work with the horizontal angle of attack of the plow (45°). Source: R. Stolf, class of the mechanization course at UFSCar.

RESULTS AND DISCUSSION

The proposed project is presented in Figure 6. The idea of a design similar to the Tandem type of harrow (Figures 4 and 5) was applied to the plow: a design of three three-disc plows in parallel was created to achieve a working width of 3000 mm, typical of tractors with high nominal power, above 200 hp (150 kW).

Comparing the Tandem model with the conventional one, more compact equipment was obtained, both for a working width of 3000 mm (Figure 6). However, the conventional model has a length of 4 m, while the Tandem is 1.33 m, three times shorter. This brings the Tandem implement closer to the tractor, reducing the lateral moment caused by the discs, all facing to the left, and shorter headland turning time. In summary, the model (Figure 6b) is more balanced and compact.

As for the tractor-implement coupling, it is necessary to make the capacity of the tractor's hydraulics compatible with the force-weight generated in the equipment's center of gravity (Prade et al., 2011; Garay et al., 2013). Table 1 presents this analysis, and it can be seen that, in the proposed Tandem model, there is no risk of damaging the hydraulic lift of the tractor. The implement has a force weight below the maximum capacity of the hydraulic lift of all tractor models.

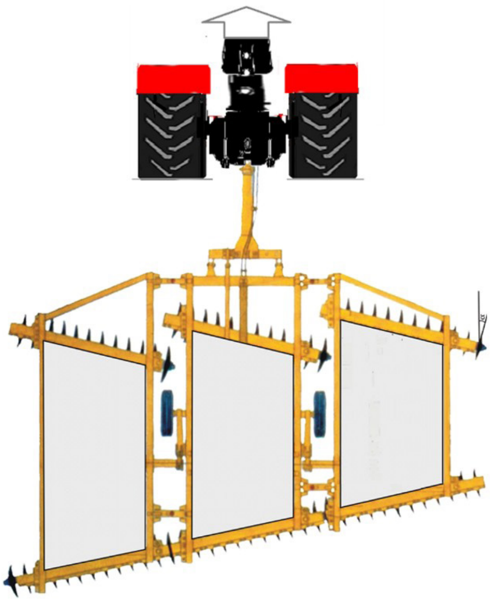

Figure 5. This Tandem Harrow is an exception for three aspects: High number of discs (72); Three action bodies in parallel (usually there are two), V-Harrow Offset (normally the format is in "X").
Source: Stolf et al. (2010).

In contrast to these advantages, the proposed implement has a disadvantage: at each pass of the nine grooves, two of them remain open. A mitigating solution would be to plow level with the implement and harrow the area to level the ground, as this combined operation is common after plowing or subsoiling. On the other

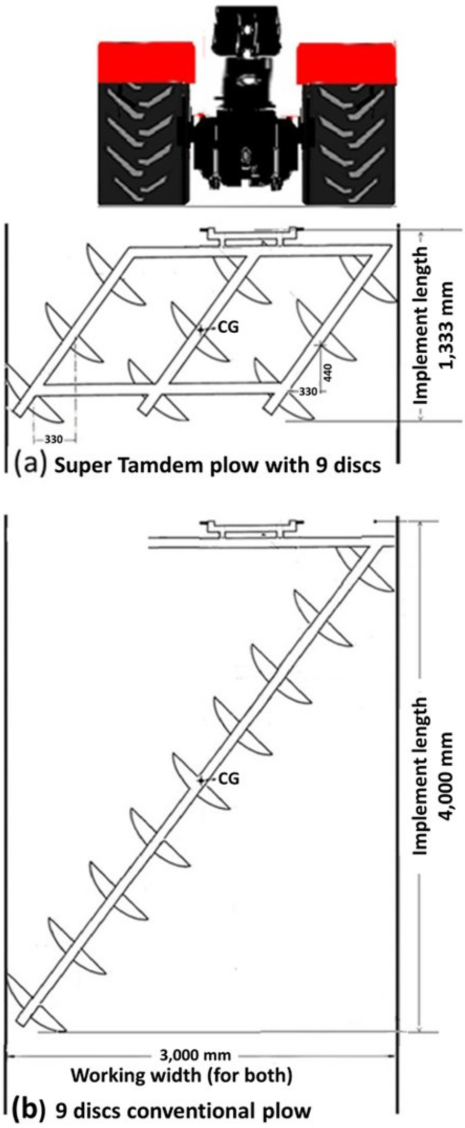

Figure 6. (a) Proposed Tandem super plow design (3 plows of 3 discs in parallel) with 9 discs and length of 1333 mm; (b) Conventional plow design with 9 discs and a length of 4000 mm. Both with a working width of 3000 mm.
Source: The authors.

hand, there is an advantage over the conventional plow, with 3 discs, for example. In this case, the tractor, in the subsequent stride, travels inside the furrow, causing a compacted lane at each passage of 3 discs.

According to Alves et al. (2010), a characteristic in relation to agricultural machinery was the marked expansion of large ones, such as tractors above 200 hp, in the same way with harvesters, from 1975 onwards. We add that the expansion in the Midwest occurred with very low population density, lack of labor, a short planting period in relation to rainfall, as well as in flat areas, with ease for agricultural mechanization. The expansion of distilleries for the production of fuel alcohol is one of the examples. As it was necessary to fully adopt mechanized harvesting before the law prohibiting the manual cutting of sugarcane, due to the ease of mechanized harvesting on flat lands. This agribusiness region is the one that exports the highest value in commodities, for example, soybeans. Alcohol is rarely mentioned because it is not an export product (report of the author's experience).

The need for larger equpment spurred the development of a powerful industry with a giant range of agricultural equipment. In a survey carried out 34 years later (1994), in 4 companies, 431 models of agricultural harrows were renumbered, differentiated by spacing, diameter, and number of discs (Stolf and Silva, 1996), demonstrating a leap in the agricultural machinery and implements industry. Currently, inspecting manufacturers' catalogs, it is verified that the harrow industry has continued to grow in the number of options for spacing, diameter, and number of discs to obtain greater working width (Marchesan, 2011).

Table 1. Comparing a 9-disc conventional with a 9-disc Tandem regarding the effort at the hydraulic hitch.

------------------------Tractor------------------------			Transferring force-weight from CG to hitch	
Pot. Max. engine (cv)	**Templates**	**Max. hydr. lift capacity**	**Conv. plow CG to hitch: *d* =2 m**	**Tandem plow CG to hitch: *d* = 0,66 m**
100-115-125-165	JD 221583 – 6	2550 kgf	***F.d*** = 2 . 1413	***F.d*** = 2 . 1413
135-150-190-210	JD220685 – 6	2550 kgf		
125-135-145	MF6712R_Dyna4	4950 kgf		
299-215-230	JD 557176 -7	6350 kgf	2826 kgf	933 kgf
160-180	MF7300_Dyna3	8000 kgf		
279-320-370-400	JD569230 – 8	8482 kgf		
195-210-230-250	MF7700_Dyna6	9625 kgf		

Note: with the same weight (*F* = 1413 kgf), they present different moments (*F.d*) in the three point hydraulic hitch. JD = John Deere; MF = Massey Fergusson; CG: center of gravity.

The publication of this work aimed to discuss the structure that affects the dynamics of the operation of the plow (and the harrow), whose greatest evolution, the creation of the moldboard plow and the disc plow, stopped in the last century. Based on the information presented, we pointed out a problem and proposed a solution. The reader may test, modify, or give rise to a new conception of the plow. In any case, we want the content to be useful to any of the options.

CONCLUSIONS

Comparing the conventional model with the submitted, in tandem, both with 9 discs and a working width of 3000 mm and couplings in the tractor's hydraulics, the following differences were raised regarding the performance of the equipment.

a) In the conventional model, the length of the implement was 4000 mm, while in the Tandem, it was 1333 m. Thus, the greater proximity of the latter to the power source makes it suitable for coupling to the tractor's three-point hydraulic, as it reduces the load (vertical moment). Likewise, the shorter length of the Tandem reduces the horizontal, lateral momentum generated by the lateral displacement of the ground caused by the discs by the lateral launch of the soil laterally. It also reduces the turning radius and therefore the time lost in turning the head to return to the opposite direction;

b) The proposed implement has the disadvantage, that at each pass of the nine grooves/discs, two of them remain open. A mitigating solution would be to harrow the area by area to level the land after plowing, as these combined operations are common in the crop. On the other hand, there is an advantage over the conventional 3-disc plow. The tractor, in the posterior stride, travels inside the furrow, causing a compacted lane at each passage of 3 discs. In other words, the tractor itself travels, in part, in the area already plowed within the furrow, causing compaction.

As a general conclusion, the shorter length of the implement reduced the vertical moment of the hitch, the lateral moment, and the turning radius of the headland, resulting in a more compact, more balanced tractor-implement combination, as detailed in item (a).

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