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Manufacturing Vineyard Machinery for Small Business Grape Growers

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***Abstract*— In the viticulture of Latin America, the shortage of manpower and the current competition with new markets, require the automation of the processes for vine handling for the sustainability of the activity. Therefore, it is necessary to seek capability towards a correct mechanization based on local conditions of plant, soil and social profile of grape growers. With this need in mind, a study was conducted in Jundiaí (Sao Paulo), Brasil, between 2010 and 2013. It aimed to develop a grape pruner for application in a small to mid-range vineyard. Results suggested a low cost and low weight prototype of lateral coupling pruner, adequate to be attached to a low power tractor.**

***Index Terms*— Grape, Mechanized pruning, Viticulture.**

I. Introduction

The viticulture in Latin America is characterized by the relatively small number of companies operating in large areas and high number of small farmers, which can be considered as "family business."

In relation to topography, viticulture occurs both on slopes as well as on flat land [7] suggesting two characteristics, size and topography, as of great matter, at first, to be considered in the development of machines for small size areas, more compatible with the reduced investment capability of these producers. For the Brazilian viticulture, it is also necessary to take in account that most of the grape growers are established in soils with considerable risk of compaction due to increased machine traffic.

In some regions of Brasil, vine growing is a significant activity for the small and medium farms with regard to sustainability. It also helps to reduce migration of families from the rural areas and generate income. Activities such as regional tourism also benefit from viticulture [9] [14]. However, increasing production implies costs due to severe competition faced by the vine sector. Such competition is mainly attributable to the pressure of internal and external markets, decreasing the profit margin of the wine chain agents [16].

The manpower is an issue of great importance and a concern to the vine production both for its intensive use at significant costs and increasing scarcity. The latter relates to competition for manpower with other economic activities. Therefore, the vine sector needs to adjust.

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The production of raw material cannot be done without the use of partial or full mechanization of vine management operations to enable production at lower costs. This, in turn, will ensure the supply of grape to the industry.

As reported in [4], [6], and [15], recent advancements in the European vine-growing regions show the refinement achieved in both pruning and mechanical harvesting facilitated through the development of new trellis systems, especially designed for the mechanized handling. Similarly, findings described in Australia [5], highlighted the pressure on the grape market and the need to adopt greater mechanization rates and incorporate new advancements in the vineyard management.

Notably, the mechanization of the pre-pruning and pruning processes is therefore important for the sustainability of grape growers' activity. These management practices are marked by intensive use of labor-skilled workers, not always available.

Studies conducted over the globe have shown the viability of the mechanization of almost all management processes in the vine crop [10] [11] [12] [13]. These studies showed higher operational speeds aiming to increase the work efficiency and lower costs in the production of grape for juice and wine. However, the development of machines in any country should consider its particular conditions such as the climate regime, soil types, and economic-social profile of grape growers.

This paper discusses the development of an equipment for use in the pre-pruning and pruning of the vine for medium and small-sized farms within the Brazilian context.

II. Material and Methods

A. Theoretical conceptualization of the project

The idea of machine vine pruning, for a vineyard trained in an "espalier" system is based upon the fluctuation of a "U" inverted structure over the vine cordon. This structure holds cutting blades, horizontally and vertically oriented, that makes a straight linear cutting of canes, down in the planting line (**Fig. 1**). The obstacles (poles) should be contoured by an opening mechanism, when the machine moves forward in the planting line.

Figure 1. **Diagram of a vine trained in an espalier system and a hypothetical straight cane cutting by rotary blades**

The pruning equipment was designed to be mounted on an articulated frame, which is laterally attached to a tractor. The frame was especially developed to carry different pieces of equipment. Initially, a rigid set of tubes forming a single block (Fig. 2) was bolted to the tractor body at strategic points. The one-piece system allows forces and moments to be transmitted to the rear part of the tractor, which is the strongest part. This action relieves the front of the tractor, avoiding overloading the engine block.

As seen in Fig, 2, the frame has two front and two side pantographic bars. The rear end of the lateral bars are connected to the single block structure, while the front ones are connected to a joint box. At the front end of the bottom side bar, which crosses the entire joint box and projects ahead, one support wheel is fixed. The articulation of the bottom bar with the joint box is made by means of a pin. (Fig. 2B).

It is known that any equipment operating laterally and directly attached to the tractor imposes on it forces and moments that can, under unfavorable conditions, impair the operation stability, making it difficult to steer and maneuver the set. This is due to the fact that the eccentric arrangement of the implement masses generates forces and moments, that must be resisted by the tractor. The articulated frame, operating between the tractor and the pruner, is able to mitigate the cited difficulties, which is an important point to be considered.

The reduction of the effects of forces and moments on the tractor is due to mechanical gains enabled by the geometry of the set. Moreover, application of forces in most favorable points in the structure, results in better load distribution and less risk of soil compaction. In this configuration, the tractor acts as a sort of "counterweight" producing moments of force as opposed to those produced by the equipment attached to it and as power supplier for the work. Therefore, in addition to the ability to follow the irregularities of the ground, regardless of the tractor, the articulated frame contributes to the stability of the set when operating on hilly areas. The terrain inclination up to 15% can be compensated based upon the presence of a hydraulic cylinder and ball joints (Fig. 2B, 2C). A further advantage of the system is that the assembly can be easily disengaged, releasing the tractor for other tasks.

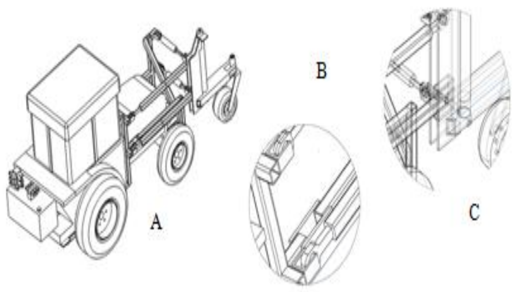

Figure 2. **Articulated pantographic frame developed for lateral coupling of the pruner (A). Details of panthographic articulation are shown (B,C)**

B. Pruning equipment parts

B.1 Cutting system

The cutting system consists of two sub-frames that carry cutting and shearing discs. The frames, articulated in two points, can move angularly, towards and from the working position (Fig. 3). On each of the cutting discs, eight serrated blades similar to those used in combines and mowers are attached. The blades used present 47º cutting edge angle; however, different models (23º angle for example) may also be used if the first ones show unsatisfactory performance.

As shown in Fig. 3A, the discs are firmly attached to the shaft by means of braces, and keyways. The cutting of vertically oriented branches is made by the rotating discs and shearing discs, while the horizontally oriented branches are by reciprocating bars similar to the ones used in combines and mowers. The length of the bars was calculated based on the pre-pruning, pruning and thinning requirements.

The shearing discs (Fig**.** 3A and 6), have fingers fixed at an angle relative to the disc radius, hampering the escape of the branches being touched by the blades. The "U" format of fingers, which are horizontally oriented, features two points of support for more effective cutting of branches. The cutting discs and bars are driven by hydraulic motors (Fig. 3 and 4).

B.2 Obstacles contour system

The contouring of obstacles in the rows is performed by two different systems: 1) machine vision system based on low impact lasers, and 2) mechanical system driven by an auxiliary disc with diameter larger than the cutting discs diameter. The auxiliary discs are concentric with the cutting ones and perform the opening of the sub-frames with certain advance with respect to the obstacles, avoiding damage of the rotating components (Fig. 7).

The electronic system allows proper recognition of the presence of obstacles through four photoelectric sensors, arranged in pairs, and maintaining a strategic distance between them, which helps to differentiate branches and leaves from stakes, eventually present in their field of vision. Furthermore, the photoelectric sensors, after being affected by obstacles present in the row, send electrical signals to the PLC for processing information.

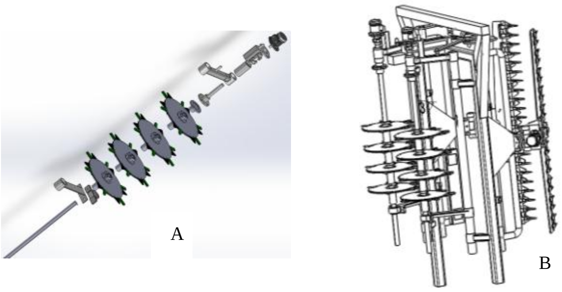

Figure 3. **A) Rotary discs arrangement for the vertically oriented cane pruning; B) Pruner head showing the main axis of rotary discs support**

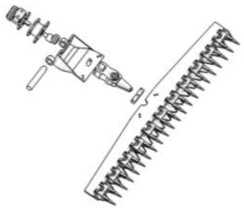

Figure 4. **Cane cutting system for the horizontally oriented branches**

The contouring of the obstacle, down in the row, is made by automatic opening of the disk sets and the closing of them is made by the action of springs, which promote their return to the original position (closed) (Fig. 5A).

The sensors were embedded in "metalon" box (Fig. 5B), which are located ahead, at right and left sides of the pruner system. A programmable logic controller (PLC) was used to receive signals from the photoelectric sensors, interpret them and redirect signals to the hydraulic actuators. The "PLC" was programmed in a computer language called "ladder" [3].

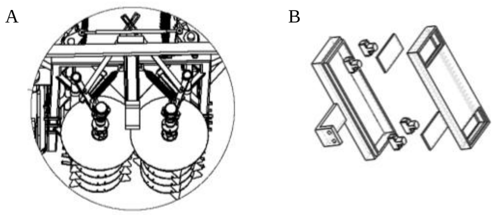

Figure 5. **A) Top vision of mechanical system for angular moving of the sub-frames carrying cutting and shearing discs. B) set for installation of the photoelectric sensors**

B.3 Hydraulic system

The hydraulic system uses three hydraulic gear pumps with individual flow of 40 L/ min (11 gal/min). They are joined together in parallel being driven by the tractor power outlet (PTO) through a multiplication gearbox.

The hydraulic circuit includes directional, relief and flow control valves, in addition to hydraulic cylinders. An oil reservoir with cooling system and temperature control complete the system.

B.4 Braking system for shearing discs

The rotary blades are subject to clogging caused by eventual surplus of branches. Therefore, the shearing discs need to have transient movement. This is accomplished by a braking system, which consists a flat belt transmission, involving the hollow bearing of each shearing disc. The friction force is adjustable by spring tension (Figure 6).

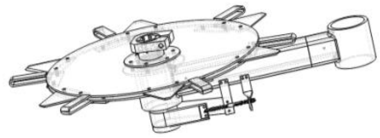

Figure 6. **View of the cutting and shearing discs (up) and breaking system (down)**

C. Final assembly of the system

The final assembly consists of coupling the pruner to an inverted "like-U" articulated structure" which follows the unevennesses of the ground, independently of the tractor. Coupled laterally to a small tractor (Fig. 7 and 8), the pruning head floats over the vine cordon, being partially supported by a wheel, which is part of articulated frame.

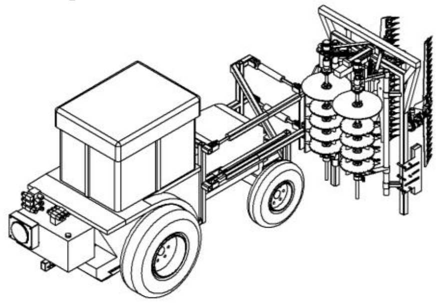

Figure 7. **Arrangement of the discs and bars on the inverted "U" frame**

Figure 8. **Prototype under test in a vineyard in Jundiaí, SP, Brasil**

The pruner was applied in a vineyard containing three cultivars (Cabernet franc, IAC-máximo and Merlot), grafted on four different rootstocks (IAC-766, IAC-572, traviú, and SO4), during the growing seasons of 2011 and 2012. The impact of mechanical pruning (MP) by using the developed pruner was compared to the hand pruning (HP), using the final cane weight as a measure of total assimilates accumulated in the season and as an indicator of possible physiological stress, imparted by changing pruning system.

III. Discussion

Historically, agricultural machinery and implements are pulled by drawbar, or mounted on the three-point hitch and driven by PTO located at the rear of the tractor. Usually, grape pruners have front type coupling [11] or, in the case of large tractor, they are frame mounted, which is very common in traditional vineyards in both old and new "worlds", where there is a consolidated adoption of mechanized vine pruning [8]. However, lateral coupling is also feasible and advantageous in the case of small sized tractors, thus increasing their versatility.

Through a hydraulic cylinder, acting as the upper bar of the front pantograph it's possible to maintain the verticality of the pruner even on slopes, thus enabling the use of small tractors. The monoblock frame bolted to the tractor body, and the articulated intermediate frame, allows for the pruner to be laterally located. Therefore, most of efforts are transferred to the rear part of the tractor, which is more massive and near the wheels. In this way, the stress in the engine block is reduced. The supporting wheel located at the front of the articulated frame, contributes to achieve better load distribution on the ground, reducing risks of soil compaction, in the sites close to the vine roots. This should be observed in clayey soils, predominant in most of the Brazilian vine-growing regions.

Along the vine row, the areas circumvented to the posts where there is a risk of damage to the rotary cutting blades, the pruner discs must pass as close as possible to the obstacles to achieve greater efficiency, aiming at a minimum of non-cut branches left over.

Field observations showed this contouring to be fast enough, not significantly influencing the number of remaining branches and the number of buds per linear meter at this point in the vineyard. However, any remaining non-pruned branches, more concentrated in the boundary region of obstacles can be readily removed by a second manual operation ("touch up").

The contouring of plant stems seldom occurs in practice, as the canes grow upwards from the vine cordon (espalier trellis systems). Whenever the pruning of canes below the vine cordon becomes necessary, at least one cutting disc can be placed in work position. This means that the auxiliary disc must also be placed in the lower part of the pruner head to help the photoelectric sensors to perform their task. In this case, in the vineyard set, it is strongly recommended to keep a distance of at least 2 m between plants in the row in order to decrease the frequency of opening cycle of the cutting sub frame and increase the efficiency of operation. Notably, most of the small growers in the developing grape regions, in Brasil, tend to use small distances between vines in the planting line, due to the pressure on the land use optimization.

Contrary to studies that described the opening cycle of pruning discs based solely on photoelectric control systems on passing through posts and stems [1], the case discussed in this paper accomplished that task by sensors in conjunction with an independent mechanical system (auxiliary discs). This made the pruner less prone to failure at the obstacles contouring points, where there are risks of damage of the cutting blades.

The contouring system is started by a hydraulic cylinder acting upon photoelectric sensors. In sequence, the auxiliary discs embrace and roll over the obstacles, keeping contact with them for awhile. The return of the sub frames to the work position is performed by a spring under tension, being the rate of back displacement dependent on the way back of the hydraulic cylinder.

The weight of a small tractor-attached oil reservoir would make a difference, whenever soil compaction is under consideration, as discussed in the present case. Therefore, the reservoir installed in the rear of the tractor was provided with a refrigeration system including radiator and cooling fan. As a result, the used oil volume was diminished. For a small tractor, working with all described hydraulic actuators, one oil reservoir with a volume of 100 liters (27 gallons) proved to be a good measure.

The prototype weighted approximately 2500 N (560 lb.) (Fig. 8), lighter than those observed in machines developed in other wine-growing regions of the world, usually coupled frontally in larger tractors [2, 11, 12 e 13]. Therefore, the total weight of the manufactured prototype can be considered as of low impact type, well adapted to the reality of vine-growing areas of developing regions of the world, wherever the small business grape growers are present.

The data in the Table 1 shows the initial impact caused by the change in the number of remaining buds as an influence of pruning system. In the first growing season (2011) there was no difference among varieties for the cane weight (Table 1). In the second growing season (2012) two varieties differentiate themselves, decreasing the cane weight from hand pruning (HP) to mechanical pruning (MP). It's reasonable that as a result of a greater number of buds remaining in the mechanical pruning, the cane weight presents decreasing values, due to the greater number of canes per linear meter. However, as observed by [14], the plant compensates for the final production by emitting more clusters with smaller berries, as compared to hand pruned ones, which have less canes per linear meter and smaller number of heavier clusters. This becomes clearer when the mechanical pruning is applied for a greater number of years. Moreover, grape varieties will adapt themselves differently to machine pruning [5].

Table 1: Averaged cane weight for vineyards under two pruning systems, in two growing seasons

		Averaged cane weight (g)			
		2011	2011	2012	2012
Cultivar	Rootstocks	HP	MP	HP	MP
Cabernet Franc	766	25,17	28,5	56,23	12,28
	Traviú	26,62	20,8	40,73	15,53
	572	17,64	21,35	51,65	12,47
	SO4	18,69	15,53	34,37	11,84
	Average	22,03 ac	21,55 ac	45,75 b	13,03 c
IAC-Máximo	766	19,5	27,44	37,84	11,22
	Traviú	20,89	30,29	27,80	9,70
	572	13,43	17,73	28,12	10,75
	SO4	15,52	20,04	26,54	8,94
	Average	17,34 ad	23,88 ab	30,08 bc	10,15 d
Merlot	766	21,4	29,1	39,33	39,37
	Traviú	25,56	35,63	44,50	36,72
	572	20	31,04	25,76	35,02
	SO4	16,3	21,16	23,37	32,09
	Average	20,82 a	29,23 ab	33,24 ab	35,80 b

Among columns, averaged groups with the same letter, do not differ between pruning systems (anova;P<0,05)

IV. CONCLUSION

This paper discussed the development of a grape pruner combined with related innovative tractor attachment for application in small to mid-range vineyards. It showed that an articulated pantographic frame, laterally coupled to a small sized tractor, carrying a low weight grape pruner, makes it's usage feasible by small business grape growers in developing regions of the world.

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