CONILON Coffee

3rd Edition
Updated and expanded

The Coffea canephora produced in Brazil

Romário Gava Ferrão
Aymbiré Francisco Almeida da Fonseca
Maria Amélia Gava Ferrão
Lúcio Herzog De Muner
TECHNICAL EDITORS

© 2019 - **Incaper**
Capixaba Institute for Research, Technical Assistance and Rural Extension
Rua Afonso Sarlo, 160 - Bento Ferreira - CEP: 29052-010 - Vitória-ES - Brasil - Caixa Postal: 391
Telephone: 55 27 3636 9888; 55 27 3636 9846 - coordenacaoeditorial@incaper.es.gov.br | www.incaper.es.gov.br

ISBN: 978-85-89274-32-6
Editor: Incaper
Format: digital/printed
May 2019

GRAPHIC DESIGN, ELECTRONIC EDITING, FINAL ARTWORK AND COVER
Laudeci Maria Maia Bravin

ENGLISH TRANSLATION
Marcelle Gualda Pasolini

CATALOGING
Merielem Frasson da Silva

PHOTO CREDIT
Augusto Barraque, Incaper and authors' collection

EDITORIAL COORDINATION AND PROOFREADING OF STANDARDIZATION
Liliâm Maria Ventorim Ferrão

Incaper - Rui Tendinha Library
International Cataloging Data in Publication (ICP)

C129 Conilon Coffee / technical editors, Romário Gava Ferrão ... [et al.]; english translation Marcelle Gualda Pasolini. - 3 edition updated and expanded. - Vitória, ES : Incaper, 2019.
974p.: il. color.

Translated from: Café Conilon, 2017 - Incaper.
System Required: Adobe Reader
Access mode: https://bibliotecaruitendinha.incaper.es.gov.br/
ISBN: 978-85-89274-32-6

1. Brazil. 2. Espírito Santo (State). 3. Coffee Cultivation. 4. Conilon Coffee I. FERRÃO, Romário Gava (Ed.). II. FONSECA, Aymbiré Francisco Almeida da (Ed.). III. FERRÃO, Maria Amélia Gava (Ed.). IV. DE MUNER, Lúcio Herzog (Ed.). V. Capixaba Institute for Research, Technical Assistance and Rural Extension. VI. Title.

CDD: 633.73

Elaborated by Merielem Frasson da Silva - CRB-6 ES/675


CAFEE

21

Conilon Coffee Mechanical Harvesting

Gustavo Soares de Souza, José Antônio Lani, Maurício Blanco Infantini,
Fábio Moreira da Silva, Enrique Anastácio Alves and Rafael de Lima Bueno

1 INTRODUCTION

The cost and shortage of workforce are currently two important bottlenecks in the conilon coffee production areas in Brazil. This is due to many rural families migration to urban centers looking for income increase and financial stability, as well as better access to health and quality education.

The low workforce offer in the field has cost and limited the culture exploitation in periods of great demand, especially at harvesting time. The harvesting, which occurs from April to August in conilon coffee case, can last up to five months, depending on the interaction between the genetic characteristics of the plants in the crop (early, middle or late maturation) and the climate conditions, mainly outlined by temperature and rain (quantity and distribution of rainfall). However, most coffee growers do this activity in a period of less than 90 days and manually.

The ideal harvesting point occurs when the crop presents 80% of the fruits at the ripe stage (FERRÃO et al., 2012). Due to the labor scarcity, many coffee growers can not harvest all the crops lands with the fruits in that maturation interval. Thus, fruits harvested late or remaining in the crop can be attacked by coffee borer, which results in damages in yield and bean quality, besides greater pest infestations in the next harvest. There are also producers who anticipate the harvesting, which interferes with the filling and beans quality. Thus, this lack of workforce results in higher production costs and an unfavorable environment for the production of quality coffees. This makes the product less competitive in the domestic and international markets. Agricultural mechanization has contributed, along with other management practices, to a significant increase in crops yeld of several products and reduction in costs over the last century. In Brazil, agricultural mechanization has been one of the foundations of the crop production system, such as soybean, corn, rice, cotton, sugarcane and arabica coffee. The machines insertion into agricultural production systems contributed as a multiplying agent of human labor, raising labor productivity, expanding agricultural frontiers, reducing the time spent on hand management activities and increasing the financial return for farmers (LOPES et al., 1995; OLIVEIRA et al., 2007b; FERNANDES et al., 2013).

Mechanical harvesting is one of the most important activities in the agricultural crops management. The harvesting stage stands out due to the difficulties, the high cost involved and the product to be converted into a financial resource (SOUZA et al., 2001; OLIVEIRA et al., 2007a). That way, the fruits are harvested as the most important step in the coffee plantations management in which the coffee grower recovers the investments made (SILVA et al., 2001; OLIVEIRA et al., 2007a, 2007c). The main benefits of mechanical harvesting are better quality products, reduction of losses and increase in profits (OLIVEIRA et al., 2007b). These authors observed, in arabica coffee plantations, a reduction of 62% in the total cost of the mechanical harvesting compared to the manual. Analyzing economic indicators, Lanna and Reis (2012) classified the manual harvesting of arabica coffee as unfeasible, while in the mechanical harvesting, they identified a lower cost and higher rate of return on investment.

The conilon coffee harvesting mechanization is a viable alternative that can reduce harvesting time, workforce demand, and production costs. This might positively contribute to a greater activities qualification and income improvement for the farmers and other self-employed workers involved in that period. There is still no consolidated mechanical harvesting method for conilon coffee. In the State of Espírito Santo, from 2010 on, the Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural - Incaper (Capixaba Institute for Research, Technical Assistance and Rural Extension), in partnership with public and private institutions and coffee growers intensified efforts to study and make the mechanical harvesting of conilon coffee possible, basically by means of the adaptation of production technologies and upgrades of existing machinery and processes.

Therefore, this chapter will discuss the main results already obtained and the discussion of future trends related to the studied topic.

2 CLASSIFICATION OF HARVESTING SYSTEMS

The conilon coffee harvesting encompasses a series of operations performed in sequence to hand strip harvesting and fruits cleaning. The mechanisms used to carry out the operations and their order define the harvesting systems. According to Balastreire (1987) and Silva et al. (2001), harvesting systems are classified into:

- **Manual**: system in which all the activities involved in the harvesting are manually performed, with the exception of transportation, requiring a substantial number of workers per area. It is characterized, so far, as the predominant system in the different crop producing regions. This harvesting process can be total or selective hand stripping.

In the total hand strip harvesting, all the fruits are removed from the plants at once, which predominates in Brazil.

The selective fruits harvesting is performed in a step wise manner, choosing only the ripe fruits (cherry, raisin and dry). The number of passes will be defined by the homogeneity of the flowering, development and fruit maturation processes. Selective harvesting is little used for increasing the demand for labor and, consequently, costs. It is most common in properties that work with premium and coffees and micro batches.

- **Semi-mechanical**: consists of the use of machines only during the execution of harvesting operations; the rest of the process is carried out manually. In the conilon coffee harvesting, the fruits strip harvesting, depending on the collection system, is performed manually, while the other activities are predominantly performed by machines. This system has the potential to expand and attend small, medium and large coffee grower.

- **Mechanization**: the strip harvesting, cleaning and transportation operations involved in harvesting are mechanically performed, which are feasible on large, technologically advanced and favorable topography (slope <30%) properties. Although the system is called mechanical, it does not completely eliminate the use of manual service, because the machines can not harvest all the fruits of the plant lacking, most of the time, another strip harvesting. Thus, fruits remaining after the mechanical strip harvesting are removed manually or even mechanically in an operation called transfer, depending on the quantity and technical and economic viability.

This classification given to the harvesting systems has a didactic character, since, in practice, this does not happen, since the manual harvesting uses mechanical activities, as in the transport, just as the mechanical harvesting lacks manual stages, as the manual transfer. From the technical point of view, the harvesting systems vary from manual to mechanical, depending on the level of workforce or machines use in the operations execution. The trend that is verified in conilon coffee culture is an expansion of mechanical operations with the balanced use of manual and mechanical work.

3 MACHINERY AND OPERATIONS IN USE AND UNDER TESTING FOR THE HARVESTING

Currently, there are several machine models designed to perform the operations involved in conilon coffee harvesting. It follows a description of some these machines, available in the national or developing market, that are being used in mechanical harvesting of conilon coffee, with technical and performance characteristics, according to information presented by manufacturers, coffee grower and execution tests carried out by Incaper, in partnership with public and private institutions and coffee grower as well.

3.1 COFFEE HARVESTER MACHINE

3.1.1 Coffee harvester machine operation

They are machines pulled by tractors that perform the picking of the vegetal material on the ground, after manual hand stripping and the cutting of productive branches (Figure 1). These machines collect the productive branches that were previously cut and the fruits strip harvested and deposited between the lines, on the ground, separate the impurities and deposit the cleaned fruits in the grain tank. In this process, the leaves and branches are separated, partially crushed and returned to the soil. Depending on the machine dimensions, they are collected in crops with lines spaced from 2.8 m; however, it is is recommended a spacing of 3.0

to 3.5 m between the planting lines to avoid breaking branches and fallen stems. In this system, the coffee tree pinching and pruning is already done during the harvesting, which helps to reestablish the plants and reduces production costs.

Figure 1. Machine used in the collection of conilon coffee fruits, strip harvested and left on the ground (A); detail of the strip harvesting associated with pruning (B); of the vegetal material collection operation (C); and image after the machine be used(D), in the harvest of 2012/13, in Nova Venécia/ES.

There are already in the market options of machines and models to meet the specificities of the conilon coffee plantations. Thus, this equipment are more aligned to the profile of small and medium conilon coffee producers.

3.1.2 Technical characteristics of the coffee harvester machine

Table 1 describes the main technical characteristics of the coffee picker machine currently used in the conilon coffee harvesting in Espírito Santo.

Table 1. Technical characteristics of coffee harvester machine pulled by tractor being used in the semi-mechanical harvesting of conilon coffee

Characteristics	Model
	Master Cafe 2C
Required power in the engine	75 cv
Coupling	TDP
Rotation	540 rpm
Length	6.360 mm
Width	1.700 mm
Gauge	1.750 mm
Working Width	1.200 mm
Height	3.980 mm
Type of harvester	Roller
Type of cleaning	Suction
Bulk tank	2.500 L
Road	2 tires
Weight	2.700 kg

Source: Miac Máquinas Agrícolas (2016) *Miac Agricultural Machinery.

3.2 THRESHING MACHINES

3.2.1 Threshing machines operation

The harvesting system with the use of a threshing machine consists of the manual cutting of the orthotropic branches (whole plant) and manual bundling between the lines. Then, these branches are transported manually to the trail system, which separates the fruits from the branches, leaves and impurities of the crop. The orthotropic branches pruning is performed between 0.2 and 0.4 m of soil height (Figure 2). These machines are pulled by coffee tractors in larger properties, where production is staggered.

This equipment has been used in the plantations renew, with the pruning of all the orthotropic branches. Another use has occurred in the management system under development called "super harvest" or "zero harvest" with dense plantations, described in topic 5.1.

3.2.2 Technical characteristics of threshing machines

Table 2 describes the main technical characteristics of the machines used in the semi-mechanical harvesting system of conilon coffee.

Figure 2. Threshing machine in use in conilon coffee tree with orthotropic branches pruning (A); plantation after harvesting (B); renewed plantation with new shoots (C); and orthotropic branches harvested seven days after pruning (D) in the 2013/14 harvest in Pinheiros and Nova Venécia/ES.

Table 2. Technical characteristics of threshing machines pulled by tractor in use in semi-mechanical harvesting of conilon coffee

Characteristics	Model	
	Master Grãos	**Double Master 4 C**
Required power in the engine	55 cv	75 cv
Coupling	TDP	TDP
Work rotation	540 rpm	540 rpm
Length	5.670 mm	7.154 mm
Width	2.000 mm	3.524 mm
Gauge	1.650 mm	2.075 - 2.575 mm
Height	3.200 mm	4.629 mm
Bulk tank	-	5.500 L
Weight	1.350 kg	4.640 kg
Road	2 tires	2 tires

Source: Miac Máquinas Agrícolas (2016) *Miac Agricultural Machinery.

3.3 STATIONARY HARVESTING AND THRESHING MACHINES WITH CANVAS

3.3.1 Stationary harvesting and threshing machines with canvas operation

The conilon coffee picking and harvesting process was recently modified, adapting harvesting and threshing machines to collect the vegetal material with canvas (Figure 3). In this case, the coffee planter places canvas under the plants crown, on both sides of the planting line that will receive the plagiotropic branches and the fruits adhered after pruning. The fruits adhered to the younger plagiotropic branches (<50% of the productive potential) are only on the canvas.

Figure 3. Machine adapted to collect leaves, branches and fruits (A) on the canvas (B) and detail of the canvas being rolled (C) in the 2014/15 harvest, in Jaguaré/ES.

The adapted harvesting and threshing machines have a device activated by the operator that pulls and wraps the canvas with the vegetal material. So, the canvas is rolled up and the branches, leaves and fruits are dumped into the trail system. Depending on the spacing between the crop lines, polypropylene or shade cloth canvas are used, ranging in width from 2.0 to 3.5 m and length from 40 to 80 m. However, larger sizes have already been tested. In this system, pruning is also carried out simultaneously with the coffee harvesting process, which advances the crop re-establishment and reduces production costs, as described in topic 6.

3.3.2 Technical characteristics of stationary harvesting and threshing machines with canvas

Table 3 describes the main technical characteristics of the machines adapted with canvas and used in the semi-mechanical harvesting system of conilon coffee.

Table 3. Technical characteristics of threshing machines pulled by tractor in use in semi-mechanical harvesting of conilon coffee

Characteristics	Model		
	Master Grains CR	Master Cafe 2 CR	Double Master 4 CR
Required power in the engine	75 hp	75 hp	80 hp
Coupling	Drawbar	Drawbar	Drawbar
Activation	TDP (540 rpm)	TDP (540 rpm)	TDP (540 rpm)
Fruits transportation	-	Bucket elevator	Bucket elevator
Bulk carrier capacity	-	3.000 L	4.000 L
Discharge system	-	Dumping	Dumping
Length	6.660 mm	6.990 mm	8.040 mm
Width	2.220 mm	2.500 mm	3.860 mm
Gauge	1.450 mm	1.750 mm	2.155 mm
Height	3.250 mm	3.150 mm	4.070 mm
Discharge height	-	2.790 mm	3.160 mm
Weight	2.150 kg	2.900 kg	4.640 kg
Tires	7,50 x 16”	10,50 x 16”	400/60 x 15,5”

Source: Miac Máquinas Agrícolas (2016) *Miac Agricultural Machinery.

3.4 AUTOMOTIVE HARVESTER

3.4.1 Automotive operation

Automotive harvesters are machines that have been designed to strip harvesting the fruit and cause minimal damage to the plants in order not to affect the next crops production. They are recommended machines for perennial crops, such as conilon coffee.

Two concepts of machines can be pointed out, such as the strip harvesting made by rods (Figure 4A) and by stickers (Figure 4B). When the machine moves in the coffee trees line, these rods and stickers start a friction and transmit vibration to the plants, making the fruits fall on both sides of the coffee line.

Figure 4. Automotive harvester with Braud New Holland (A) rods and Case IH (B) stickers tested for conilon coffee, in the 2014/2015 harvests, in Pinheiros/ES and São Mateus/ES, respectively.

In the machine with rods, the strip harvested fruits fall into rubber buckets on the underside of the machine that transport the fruits to the upper part (Figure 5), where they are discharged on a conveyor belt along with leaves and plagiotropic branches removed from the plant during the harvesting process. An exhaust fan performs the cleaning, separating the leaves and branches from the harvested fruits, which are transported to a bulk tank, where they are stored until they are discharged by dumping the tank. There is also the possibility that the fruits, after exhaust fan cleaning, are discharged in a container pulled by tractor through a lateral nozzle.

Figure 5. Braud New Holland harvester details. Rubber buckets that receive the strip harvested fruits on the underside of the machine (A); exhaust fan for fruit cleaning (B); and bulk tank (C).

In the machine with stickers, the strip harvested fruits fall on plastic plates, which open to allow the coffee tree orthotropic branches to pass inside the machine and return to the original position through compressed springs when the plates are open. The fruits slide on the plates and are directed to horizontal conveyors that lead the fruits to the elevators, equipped with a ventilation system and sieves that separate the leaves and lateral branches from the fruits. The fruits are transported through the elevators to the upper part of the machine where they are discharged through a lateral nozzle or stored in a bulk tank. Details are presented in Figure 6.

Figure 6. Case IH harvester details with plastic bottom sealing plates and side conveyors (A), elevators (B) and bulk tank (C).

3.4.2 Technical characteristics of automotive harvester

Currently, automotive harvesters are widely used in the arabica coffee harvesting and have also been adapted for the conilon harvesting, considering the differences between the two species regarding to crop management, plant size and architecture, fruit detachment force, pruning system, maturation uniformity, genetic variability, among other aspects. Table 4 describes the main technical characteristics of automotive harvesters in test for conilon coffee in the State of Espírito Santo.

Table 4. Technical characteristics of the automotive harvesters tested for conilon coffee in the harvests from 2012/13 to 2015/16 in the northern region of Espírito Santo

Characteristics	Brand/Model	
	Coffee Express 200/Case IH [1]	Braud 9090X [2] / New Holand
Engine power	55 cv	175 cv
Consumption	5.0 L h^{-1}	9.5 L h^{-1}
Road	3 pneus	4 pneus
Length	5.220 mm	6.500 mm
Width	3.500 mm	3.200 mm
Gauge	3.285 mm	3.231 mm
Height	3.270 mm	4.000 mm
Bulk tank	2.000 L	2.000 / 4.000 L
Weight	5.000 kg	11.000 kg
Work declivity	17%	25%

Source: [1]Case IH Agriculture (2016), [2]New Holland Agriculture (2016).

4 OPERATING CHARACTERISTICS OF HARVESTERS

4.1 SEMI-MECHANICAL SYSTEMS

The first tests carried out with machines for conilon coffee semi-mechanical harvesting began in the 2010/11 harvest, in the northern region of Espírito Santo, with a concept of picking the fruits from the ground. This concept passed through profound changes and currently has been replaced by manual and canvas picking process. Therefore, the results presented are limited to semi-mechanical systems with the use of a threshing machine ("super harvest") and the picking with canvas. The data presented by the harvesters were obtained from execution tests, field surveys with coffee grower and consultants and technical data from companies in the agricultural machinery sector (Table 5).

Table 5. Operational characteristics of a threshing machine and stationary harvesting machine with canvas in use in the coffee conilon harvesting in Espírito Santo

Characteristics	**Semi-mechanical system**	
	Threshing machine	**Stationary Harvesting machine with canvas**
Required labor	3-7 pessoas	9-18 pessoas
Operational capacity	0,20-0,40 ha h^{-1}	0,15-0,35 ha h^{-1}
Harvesting capacity	80 sacos h^{-1}	100 sacos h^{-1}
Strip harvesting efficiency	100%	100%
Harvesting efficiency	97 - 99%	97 - 99%
Losses	1 - 3%	1 - 3%

Source: Miac Máquinas Agrícolas (2016) *Miac Agricultural Machinery.

Threshing machine and the stationary harvesting machine with canvas are used with the number of people ranging from 3-7 and 9-18, respectively. This results in an operating capacity of 0.20-0.40 and 0.15-0.35 ha h^{-1}. Thus, these machines are equivalent to between 40 and 50 rural workers, considering a harvesting average of 16 bags per day^{-1}. The average harvesting capacity observed in the field is 80-100 bags h^{-1}; however, these results depend directly on plant productivity and harvesting speed. The strip harvesting efficiency was considered as 100%, since it is performed manually. However, this depends directly on the manual stripping quality. Harvesting efficiency of the threshing machine and the stationary harvesting machine with canvas ranges from 97 to 99%, depending on the machine settings and the training of workers involved in the activity, with soil losses of 1 to 3%.

4.2 AUTOMOTIVE MECHANICAL SYSTEMS

4.2.1 Operational characteristics in traditional crops

The trials were carried out in the 2013/14 harvest, in the municipalities of Jaguaré and Pinheiros, in traditional producers crops, initially implanted for manual harvesting, with three orthotropic branches per plant and in the spacing of 3.0 to 3.5 mx 1.0 m. Crops with lands of one clone per line and with several clones mixed in the line and two automotive harvesters, Case and Braud New Holland, were selected for the work. Table 6 presents the average results regarding the operational capacity.

Table 6. Operational capacity average data of two automotive harvesters in the conilon coffee harvesting evaluated in traditional crop, 2013/14 harvest, in Jaguaré and Pinheiros/ES

Harvesters	Harvesting Speed	Efficiency		Ground Loss
		Strip harvesting	Harvesting	
Case	1,0 - 1,6 km h^{-1}	85 - 93%	70 - 83%	10 - 21%
Braud New Holland	1,0 - 1,2 km h^{-1}	85 - 94%	80 - 89%	5 - 11%

Source: Unpublished research data.

The automotive test harvesters presented operational capacity and harvest yields from 0.30 to 0.40 ha h^{-1} and from 100 to 130 bags h^{-1}, respectively, according to the displacement speed and crop productivity. The increase in harvester speed resulted in higher operational capacity with lower harvesting time per area, which coincides with results obtained by Oliveira et al. (2007a). The increase in the machine speed, in general, decreased the efficiency of strip harvesting and harvesting of conilon coffee fruits, caused by the shorter contact time of the plants to the action of rods or stickers, which was also observed for arabica coffee (SILVA et al., 2006; OLIVEIRA et al., 2007c).

These machines presented strip harvesting and harvesting efficiency ranging from 85 to 94% and 70 to 89%, respectively, which depends on the losses, mainly of not stripped fruits and left on the ground. The reduction of the strip harvesting efficiency in the mechanical systems resulted in a greater pending load, which would justify the manual transfer as described by Santinato et al. (2013).

The ground losses were lower in the Braud New Holland harvester compared to Case. The fruit picking was considered unfeasible for the arabica coffee (OLIVEIRA et al., 2007a), due to the reduced volume and the high operational cost. However, this ground picking may be viable for conilon coffee, which requires further operational and economic studies. The management of multicaulis plants (three to four orthotropic branches) made it difficult to seal the fruit reception system, resulting in similar losses to Oliveira et al. (2007a, 2007b) and Silva et al. (2013) works, both for arabica coffee. The presence of arched plants also contributed to the increase of ground losses. So, the development of a new clonal conilon cultivar, derived from the clustering of clones with erect growth, can minimize these losses. The coffee conilon, in general, does not show a natural fall of the ripe fruits on the ground as it occurs in the arabica coffee (FONSECA et al., 2007), which favors the strip harvesting efficiency and, consequently, minimizes the losses in the crop. However, there are reports of coffee growers and technicians that some plants in certain regions of Espírito Santo would show this natural detachment, but these issues still need to be investigated and the causes, elucidated.

Table 2 presented results which were considered satisfactory; however, slightly lower than those obtained from the arabica coffee harvesting (SANTINATO et al., 2013, 2014; SILVA, F. C. et al., 2013; SILVA, F. A. et al., 2013). It is worth noting that the crops were not prepared for the harvesters, with the presence of irregularities on the ground, fallen plants and with uneven growth, and in some cases, showing uneven fruit maturation in the line. In these execution tests, the machines configuration and the number of passes in the line, the harvesting speed, the agitation frequency, the fruits maturation level and the plants architecture changed the strip harvesting and harvesting processes requiring specific adjustments to crop conditions.

4.2.2 Operational characteristics in experimental crops

From the year 2013, conilon coffee plantations of the northern region of Espírito Santo were prepared for the mechanical harvesting, being conducted with one, two and three orthotropic branches and spacing between lines of 3.2 to 3.5 m and between plants in the line ranging from 0.5 to 1.0 m. So, in the 2014/15 and 2015/16 harvests, the performance and efficiency of automotive harvesters (Table 7) were evaluated in plants previously prepared for the mechanical harvesting, as described in topic 5.2. It was verified the strip harvesting and the harvesting efficient ranging from 85 to 97% and 75 to 92%, respectively, with an average higher than the tests performed in traditional crops. Ground losses were again lower in the Braud New Holland harvester than in Case and reduced comparing with the previously mentioned tests (Table 6). However, it is worth to point out that, in the evaluated harvests, there was a marked period of water stress in the State, especially in the 2015/16 crop, which severely compromised the plants development and production. As a consequence, there was a reduction in the expected productivity of the experimental crops and, concurrently, in the operational harvesting capacity, which ranged from 0.20 to 0.40 ha h^{-1} and from 90 to 120 bags h^{-1}.

Table 7. Average data on the operational capacity of automotive harvesters in the conilon coffee harvesting evaluated in experimental crops in the 2014/15 and 2015/16 harvests in São Mateus/ES

Harvesters	Harvesting Speed	Efficiency		Ground Loss
		Strip harvesting	Harvesting	
Case	1.0 - 1.6 km h^{-1}	85 - 97%	75 - 87%	10 - 14%
Braud New Holland	1.0 - 2.0 km h^{-1}	85 - 96%	81 - 92%	4 - 8%

Source: Unpublished research data.

The results are similar to those described in the scientific literature for the arabica coffee harvesting (SANTINATO et al. 2013, 2014; SILVA, F. C. et al. 2013; SILVA, F. M. et al. 2013), which indicate a technical feasibility of the machines use, but which also demonstrate the need for continuity of the research work related to the machines adaptation to the crops and the crops to the machines.

The studies on coffee mechanical harvesting indicate high efficiency of the operation since the harvester is with the rods or stickers vibrations and operational speed correctly set and adapted to each variety type (OLIVEIRA et al., 2007a, 2007b; SANTINATO et al., 2014). Therefore, adjusting these settings, as well as technically defining the crop characteristics and conilon coffee management are essential for the success of the mechanical operations.

4.2.3 Harvesting selectivity future perspectives

The lack of labor has led many coffee grower to anticipate harvesting by beginning this activity with a high proportion of green fruits (<80% ripe), which decreases beverage quality and grain yield in the drying process (FAVARIN et al., 2004; FERRÃO et al., 2012). Coffee is an agricultural product whose price is based on qualitative parameters and whose value increases with quality improvement (OLIVEIRA et al., 2007a). Thus, the mechanical harvesting system of conilon coffee can help to improve the beverage quality, since it will no longer be necessary to anticipate the harvesting season, which will have a higher ripe fruits proportion.

Seminal crops uneven maturation between plants, since they are formed by the recombination of different genotypes. Similarly, when the clonal cultivars are planted with the clones mixed, without the use of the “in-line planting” technology, there is also a maturation unevenness between the different plants in the crop. Thus, crops with uneven maturation could be harvested selectively, aiming the strip harvesting of the ripe fruits (cherries and dried fruits) without harvesting the green fruits of the plant. The selective harvesting system already occurs in the arabica coffee tree and generally, two or three passes of the automotive harvesters are performed in the field (SILVA, F. C. et al. 2013; SILVA, F. M. et al.. 2013). Basically, in arabica coffee trees, the first pass (selective) with lower vibration frequency of the strip harvesting unit (750-850 rpm) and/or greater harvester speed (1,30^{-1},60 km h^{-1}) and a second pass with higher frequency (950 rpm) and lower speed (≤1.0 km h^{-1}) for total fruit harvesting (SILVA, F. M. et al. 2013; SANTINATO et al., 2014).

The selective harvesting system through the use of automotive machines, already consolidated for the arabica coffee, was tested for conilon coffee. In the 2013/14 crop, in not prepared clonal crops in Pinheiros/ES, the potential of selective harvesting with the strip harvesting of ripe fruits was observed using a sticker automated harvester, while the greens were not strip harvested (Figure 7).

The fruit removal or detachment force is an important characteristic to evaluate the cultivar suitability for the automotive mechanical harvesting, since the harvesting devices efficiency is directly related to the detachment force of the fruits from the plant (CRISOSTO; NAGAO, 1991). Within this approach, the detachment force of two conilon coffee clones was measured in the 2015/16 crop, in São Mateus/ES (Table 8). It is possible to verify a difference in the detachment force between the genetic materials (3,00 N), characterizing the need for continuous adjustments of the harvesting process. Such results were similar to those found for arabica coffee tree (CRISOSTO; NAGAO, 1991; SILVA et al., 2010) indicating that there is no restriction regarding the detachment force for conilon coffee harvesting with automotive harvester.

Figure 7. Selectivity in the harvesting of the conilon coffee fruits using an automotive sticker machine in the 2013/14 crop, in Pinheiros/ES. Green fruits adhered to the plagiotropic branches (A); and ripe fruits harvested by the machine (B).

Table 8. Fruit detachment force of two conilon coffee clones in two maturation stages, in the 2015/16 harvest, in São Mateus/ES

Fruit maturation	Detachment force (N)	
	Clone 1	Clone 2
Green (G)	3.60	6.60
Cherry (C)	3.00	6.00
Difference (G - C)	0.60	0.60

Source: Unpublished research data.

The required force for the ripe fruits detachment was lower than for the green fruits, which also occurs for the arabica coffee (SILVA et al., 2010). The force difference between the green and the ripe fruits were similar for both clones (0.60 N). The greater the difference, the greater the potential for success of the selective harvesting (SILVA, F. M. et al., 2013). Crisosto and Nagao (1991) found differences in the detachment force between green and ripe arabica fruits of up to 7.3 N. According to Silva et al. (2010), the force difference between green and ripe fruits should be greater than 3.0 N to obtain a good selectivity in automotive harvesting in arabica coffee tree.

In the 2015/16 harvest, another study was carried out to measure the conilon coffee fruit detachment force of three clones from Incaper ('ES8122' - Jequitibá, 'Centenária ES8132' and 'Vitória Incaper 8142') and a seed propagation cultivar (Emcaper 8151 - Robusta Tropical). The clonal cultivars are formed by the grouping of 9 to 13 clones. The work was carried out at Bananal do Norte Farm, municipality of Cachoeiro de Itapemirim/ES in lands with five years old plants. The detachment force for green, cherry and dried fruits was measured (Figure 8). The results were similar for the four cultivars, with average results ranging from 5.97 to 6.72; 3.61 to 4.60 and 1.98 to 2.40 N, for green fruits, cherries and dry, respectively. Fruit maturation resulted in a decrease in the detachment force from the plant, which was 32-40% for cherry and 61-71% for dried, both compared to green fruits. It was also observed that clones with a difference in the detachment force of green and ripe fruits of up to 5.40 N, which highlights a perspective of more selectivity with the use of automotive harvesters.

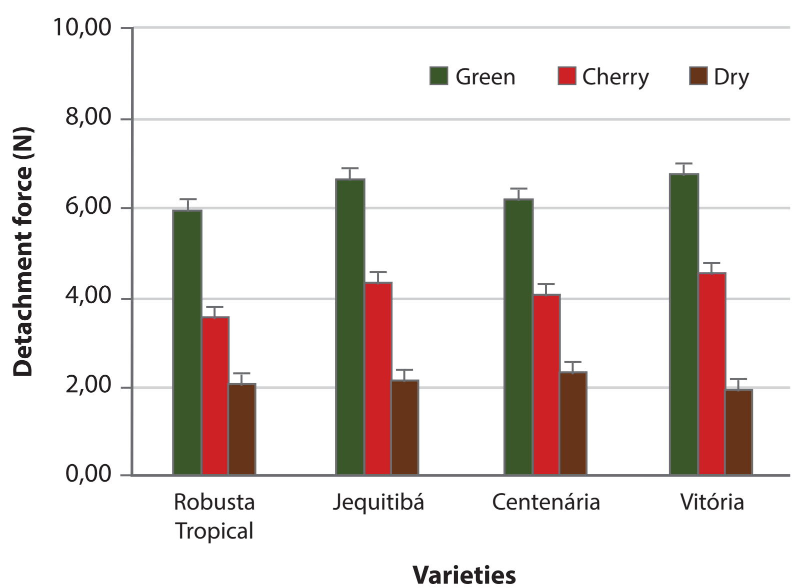

Figure 8. Detachment force of fruits from four conilon coffee cultivars at different maturation stages in the 2015/16 harvest, at the Experimental Farm of Bananal do Norte, Cachoeiro de Itapemirim/ES.

Source: Unpublished research data.

Considering that studies regarding the detachment force of the conilon fruits are still incipient, there is an enormous perspective to develop cultivars with characteristics that are suitable for the selective harvesting. Other aspects that influence the efficiency of mechanical harvesting, such as plant architecture, leaf quantity and size can not be neglected. Finally, evaluating different genetic materials through tests with harvesters will be fundamental to validate the performance of the next cultivars to be recommended for the selective and mechanical harvesting system.

5 CROP MANAGEMENT FOR MECHANICAL HARVESTING

5.1 SEMI-MECHANICAL SYSTEMS

An important aspect of conilon coffee culture mechanization is the need for plants with erect orthotropic branches (Figure 9). Fallen branches can be easily broken by tractors and harvesters during the performance of management activities. Field observations indicate the need to reduce the number of orthotropic branches per plant to reduce the damping off.

Figure 9. Detail of conilon coffee crop with selected erect material for the mechanical harvesting (A) in the 2012/13 harvest, in Nova Venécia/ES; and orthotropic branches pruning for automotive tests (B) in the 2013/14 harvest in Pinheiros/ES.

For the use of conilon coffee ground harvesters, it is necessary initially to systematize the terrain, mainly between the lines, to remove irregularities that will reduce the harvesting efficiency. The leveling between the lines is usually done with a planer (Figure 10). Studies on soil conservation, erosive process, mineralization of organic matter and soil compaction in these management systems still need to be carried out.

In order to increase ground harvesting efficiency and avoid losses in the conilon planting, a blower is used to enclose the strip harvested/pruned material that lies between the lines (Figure 11). Thus, this material dispersed under the plants crown is enclose between the lines, increasing the harvesting efficiency and reducing the losses of fruits on the ground. Due to the machines movement between the plants lines, the recommended minimum spacing is 3.0 m, with 3.5 m being more appropriate.

The threshing machines have been used in the renew of old or even new coffee trees, in regions with lack of labor, with all the orthotropic branches pruned. Another use has occurred in the under development management system by Incaper and partners, called "super harvest" or "zero harvest" with dense crops. In experimental units, the plants were placed at a spacing of 1.75 m x 0.80 m. In this system, the harvesting is performed every two years, time required for the formation of the new crown. In this way, the producer will need to stagger the lands, with alternation of areas in production. In dense management (“super harvest”) in producers’ areas, the first harvesting crops showed productivity of up to 150 bags ha^{-1} (60 kg with processed beans) for some genetic material, with an average of 75 bags ha^{-1} $year^{-1}$.

Figure 10. Planer coupled to the tractor used for leveling the ground before picking the strip harvested fruits on the ground (A); and terrain detail after the operation of the implement (B), in the 2012/13 harvest, in Nova Venécia/ES.

Figure 11. Traditional blower pulled by tractor used in the lining of the vegetal material before picking the strip harvested fruits on the ground (A); and ground picking process (B), in the 2012/13 harvest, in Nova Venécia/ES.

In the harvesting with threshing machines, another possibility evaluated by a coffee grower in Pinheiros/ES, in the harvest of 2013/14, was the harvesting seven days after pruning, obtaining a reduction in drying time of 40% (Figure 12), without the observation of fruit fermentation, which is influenced by the climate of the region. According to the observations, there was practically no fruits detachment from the plagiotropic branches, which could result in an increase in the losses. During the 2013/14 harvest, it was also carried out in Ouro Preto do

Oeste/RO, a test on the effect of the harvesting done with the help of a threshing machine on fruit drying and conilon coffee quality (unpublished data). Two types of pruning (total pruning and plagiotropic branches pruning) with mixed drying (field and farmyard) were analyzed, comparing to the traditional system (manual strip harvesting and immediate drying on the farmyard) (Table 9).

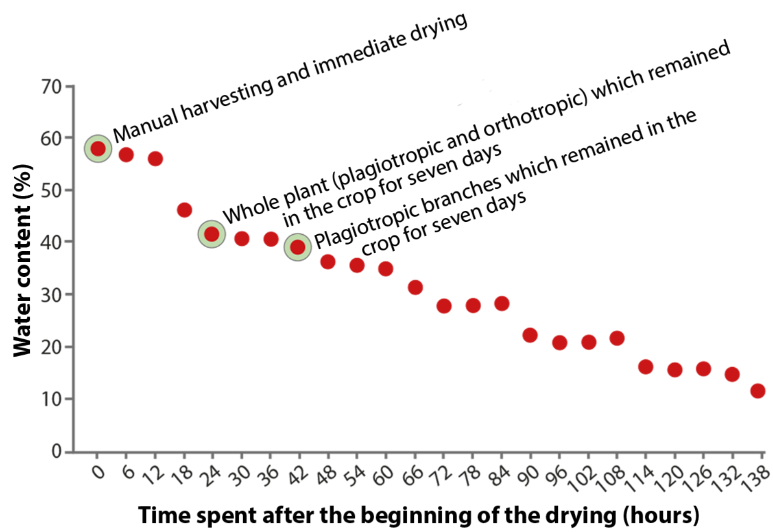

Figure 12. Drying curve of conilon coffee fruits on cement yard, in the 2013/14 harvest, in Ouro Preto do Oeste/RO.

Source: Unpublished research data.

Table 9. Conilon coffee tree water content and drinking quality comparing the drying on the farmyard right after harvesting and mixed drying (field and farmyard) in Ouro Preto do Oeste/RO

Treatment	Management	Drying	Drinking Quality (Grade)*	Water content of fruits (%)*
T1	Pruning (plagiotropic branches)	Field + farmyard	74.0a	39.6c
T2	Pruning (whole plant)	Field + farmyard	73.9a	42.0b
T3	Manual Harvesting	Farmyard	71.2a	61.0a

Source: Unpublished research data.

* Averages followed by the same letter in the column do not differ (Test: Tukey, $p \leq 0.05$).

T1- plagiotropic branches pruned and left in the field for seven days before harvesting with threshing machine and beginning of drying; T2- orthotropic branches pruned and left in the field for seven days before harvesting with threshing machine and beginning of drying; T3- manual harvesting and drying immediately after the harvesting.

The results of the sensory analysis showed that the pre-drying time of the fruits on the branches (T1 and T2) were not damaging to the drinking quality when compared to the samples submitted to the traditional drying (T3). Thus, these harvesting systems during the driest period may be favorable for allowing greater flexibility in the time arrangement of the harvesting and manpower, as well as a lower drying cost due to the shorter use of farmyards and dryers.

The water content in conilon coffee fruits presented a significant difference when introduced on the farmyard, with lower management values, whose pre-drying was carried out in the field (Table 5). Based on the drying curve of the conilon coffee fruits (Figure 12), it can be observed that the approximate time to reach the ideal drying humidity was 140 hours. So, drying in the field, in seven days reduced the time of this operation on the farmyard between 24 to 42 hours, without harming the sensory quality. Despite the favorable results, such practice is still not recommended because it is a preliminary analysis that requires the research work continuity.

It should be pointed out that, up to now, the stationary machines with canvas are more adapted to the characteristics of traditional crops in the productive regions. Therefore, they have been preferred by coffee grower who use semi-mechanical systems.

5.2 AUTOMOTIVE HARVESTING SYSTEM

The harvesting with automotive machines requires greater changes in the implantation and management of the crop. Figure 13 illustrates the major adjustment points in traditional crops for the automotive harvesting. Plants with uneven heights make it difficult to regulate automotive machines, given the basic premise of association of good harvesting efficiency with minimum damage to the plants' crown. In crops with plants of variable height, it would be necessary to adjust or change the height of the stickers or rods whenever there was variation making the harvesting with automotive machines not feasible. In practice, this characteristic causes the lower plants to have their crown damaged, while taller plants whose coffee fruits are higher are not properly strip harvested, since the height of stickers or rods is fixed. The ideal is to have a uniform height in the plant line for the rods and stickers adjustments at a suitable height so that they remove the fruits and do not damage the plants' crown.

Regarding the heterogeneous maturation in the planting line, it is important to emphasize that, in general, the green fruits have a greater detachment force than the mature ones (see topic 4.2.3). Thus, when harvesting plants with a predominance of green fruits, the efficiency of the strip harvesting decreases in comparison with the harvesting of plants with ripe fruits, and so, requiring different adjustments. Starting the harvesting when the plants are in a more advanced stage of development (≥ 90% of the cherry, raisin and/or dry fruits) will increase the efficiency of the strip harvesting.

With respect to plants with multicaulis architecture, it has been verified that they significantly increase the ground losses with the use of automotive machines, since the plastic plates or the bulks do not properly seal the inferior part of the machines. Another important aspect is that the plants have a larger frontal area, which hinders the alignment and the entrance of the stems in the machine and, with this, there is more occurrence of lesions in the plants.

Regarding the stems damping off, it can be mentioned again that they make it difficult the alignment between machines and plants. Thus, the plants do not enter properly in the harvesting unit and, as a result, they are not efficiently strip harvested and can still be broken by the machines. The damping off happens due to a characteristic of the genetic material (clone or progeny) and/or the crop high productivity, whose stems tend to open in crops with three or more stems.

It is important to highlight that a good harvesting performance with automotive machines depends on the machine suitable regulation, as well as a design of crop implantation and continuous actions of plants conduction that favor mechanical harvesting, as Table 10 summarizes.

Figure 13. Illustration of a traditional crop, with uneven height plants in row (A); heterogeneous maturation in the same planting line (B); stems with multicaulis architecture below 0.40 m from the ground and inferior plates opening of the harvester (C); and damping off plants (D).

For the use of automotive machines, it is possible to verify the possibility of reducing ground losses with a single main stem between 0.40 and 0.60 m of soil height and, from this, to conduct the sprouts always aligned to the planting direction (Figure 15). This improves the lower sealing of automotive machines and minimizes fruit losses on the ground, during the harvesting process.

Due to the difficulties of working with automotive machines in traditional crops and in the search for better technical rates, experimental test areas were prepared in partnership with companies and coffee growers to evaluate mechanical harvesting with automotive machines. The results were presented in previous topics. Thus, based on the conducted tests and performed, Table 11 suggested spacing Table 12, aiming at a better adaptation to the mechanical management systems. However, there are no conclusive results of this research.

Table 10. Main technical actions recommended for the conilon coffee crop preparation for mechanical harvesting with automotive machines

Actions	Objectives
Aligning the holes in the planting.	- Facilitating the entry of plants into the unit, reducing ground loss and preventing machine damages to plant stems.
Plant only one clone per line, alternating the clones planting order of the recommended cultivar.	- Standardizing the plants height, the fruits high on the plants and the fruits maturation.
Pruning the meristematic region (apex) between 0.20 and 0.55 m, about 6 months after planting, when the plant is nearly 0.60 m high (Figures 14 and 15). After sprouting, select orthotropic branches aligned to the planting direction and close to the apical cut region.	- Standardizing the plants height, the fruits high on the plants, aligning the stems in the line and reducing the ground losses.
For crops in renovation process, make the pruning at 0.60 m and conduct the sprout as described above.	
Selecting sprouts to form a new crown and the periodic excess pruning.	- Maintaining plants architecture with stems aligned in the planting direction.

Source: Unpublished research data.

Table 11. Management systems under tests for mechanization of conilon coffee plantations

System	Machine	Spacing (m)		Number of stems per plant
		Interline	Line	
Traditional	Manual	2,5 - 3,0	1,0 - 1,5	3 - 5
Semi-mechanical	Ground harvester	3,2 - 3,5	0,8 - 1,0	2 - 3
Semi-mechanical	Stationery threshing machines with canvas	2,8 - 3,5	0,8 - 1,0	3 - 5
Mechanical	Automotive machines	3,0 - 3,5	0,5 - 0,6	1 - 2
dense	Threshing machine	1,5 - 1,7	0,7 - 0,8	3 - 4

Source: Prepared by the authors.

6 OPERATIONAL COSTS OF HARVESTING SYSTEMS

The type of fruit harvesting, manual or mechanical, significantly influences the cost structure of the coffee activity (LANNA; REIS, 2012). In the state of Espírito Santo, the harvesting represents 22 to 40% of the total production cost of conilon coffee (CEDAGRO, 2016; INCAPER, unpublished data) depending on the technological level and crop productivity. One of the concerns of coffee grower is regarding the availability of workers in the producing regions, generally insufficient to meet the demand for service. This generates speculation in the harvest prices and the need to collect malformed fruits, with lower yield in the processing reducing the profitability and the competitiveness of the coffee sector (LANNA; REIS, 2012).

In this aspect, the mechanical and semi-mechanical conilon coffee harvesting has the potential to reduce costs in relation to the manual. In works performed in mechanical harvesting in arabica coffee crops, reductions in cost vary from 24 to 62% compared to manual harvesting (SILVA et al., 2003; OLIVEIRA et al., 2007a; SANTINATO et al., 2015).

Figure 14. Crop prepared for harvesting with automotive machines: 3.5 x 0.5 m spacing and apical pruning at 0.20 m from the ground (detail of the rods aligned at the top right).

Figure 15. Six months old plants, with apical pruning at 0.55 m height (A); three year old plants receiving 0.60 m in the 2014/15 crop (B); and aligned budding (C) being conducted in the 2015/16 crop, in São Mateus/ES.

The operational costs of three mechanical harvesting systems for conilon coffee were evaluated in the 2013/14 harvest in the north of Espírito Santo. Table 12 shows the percentage distribution of harvesting systems operational costs. The harvesters, in general, presented a variable cost superior to the fixed one. These results are consistent with those found by Oliveira et al. (2007a) and Santinato et al. (2015) for arabica coffee.

Table 12. Percentage distribution of the operational costs of different mechanical harvesting systems in the 2013/14 harvest in the north region of Espírito Santo

Cost Items	Stationary threshing machine with canvas	Automotive machine with stickers	Automotive machine with rods
		%	
Depreciation	23,31	39,67	39,95
Interest	0,71	1,21	1,22
Insurance rate	0,52	0,88	0,89
Hosting fee	0,26	0,44	0,44
Fixed cost	**24,80**	**42,20**	**42,50**
Fuel	14,44	6,14	7,83
Lubricant	1,73	1,54	1,23
Maintenance	25,90	44,08	44,39
Labor	33,13	6,04	4,05
Variable cost	**75,20**	**57,80**	**57,50**
Total cost	**100,00**	**100,00**	**100,00**

Source: Unpublished research data.

Note: Methodology: Balastreire (1987), Pacheco (2000) and Santinato et al. (2015).

The estimated manual harvesting cost for the 2013/14 crop in the north of Espírito Santo was R$15,30 bags^{-1} (80 L) with taxes, resulting in a cost per worker of R$244,80 a day^{-1}, for an average harvesting by the workers who acted in the understudy area of 16 bags day^{-1}. However, it is known that, depending on the region and the plants productivity, many workers harvest more than 20 bags per day^{-1}.

The results indicate a reduction in the harvesting cost with the use of mechanical systems varying from 56 to 79% in relation to the manual harvesting, in the harvest of 2013/14, when the labor cost was considered high. In the following year, Gomes and Constatino (2015) found a reduction in the harvesting cost with the use of semi-mechanical systems for conilon (35 to 41%), which was attributed to the greater offer and lower labor costs in the period. It is worth to point out that these evaluations were carried out under conditions of dissimilar crops, with different management, plant architecture and productivity, which do not allow average comparison between systems years, but only between the potential of reducing harvesting costs in mechanical systems in relation to the manual.

The allowed to realize that mechanical harvesting is not able to completely replace the need for labor, both in mechanical systems with automotive machines systems and in semi-mechanical systems. In the case of automotive machines, due to the need for manual transfer, which represents the removal of the fruits that remain attached to the plant, while in semi-mechanical systems, due to the necessity of strip harvesting on the canvas or because of the pruning and transport of the orthotropic branches to the threshing machine looking for the plants removal for the crop renewal or the pruning of dense plantations.

In the case of automotive harvesting, the manual transfer may be gradually replaced by the mechanical harvesting, with the use of repetition of harvester operations increasing harvesting efficiency and minimizing the need for manual transfer, as also observed for arabica coffee tree (SANTINATO et al. al., 2015). The transfer cost tends to increase as the efficiency of the strip harvesting is reduced. For this, the viability of repeated operations depends on the plants productive load, the maturation stage of the fruits, the machines availability (rented or own), the price of the bag and the damages caused to the plants (SILVA et al., 2010; SANTINATO et al., 2014, 2015).

The tests with automotive machines allowed to observe a reduction in the harvesting cost with increase of the movement speed, considering a constant harvesting efficiency, which corroborates other works results. (SILVA, F. M. et al., 2006; OLIVEIRA et al., 2007). However, in practice, harvesting efficiency tends to decrease with the increase of the speed (> 2.0 km h^{-1}), being necessary specific machine adjustments for each field situation.

Finally, it should be highlighted that the market price of the processed coffee bag has a significant influence on the economic viability of the coffee infrastructure investment, being fundamental for the sector profitability and competitiveness. In order to maximize the economic efficiency of the agricultural activity, coffee growers must carry out a management that prioritizes cost management in order to better allocate the productive resources applied to coffee plantations (LANNA, REIS, 2012).

7 FUTURE IMPLICATIONS

Given the advantages of mechanical harvesting, an important issue of analyzing and working together refers to the proper management of machines and soil not to establish over the years a new potential problem in the region, due to the traffic of agricultural machinery, which is soil compaction.

This effect is caused by the stationary loads applied to the ground and dynamics resulting from the agricultural machinery vibration, wheel spinning, abrupt changes of direction and in acceleration/braking (HORN et al., 1995; ALAKUKKU et al., 2003). When the load applied to the soil exceeds its internal resistance, additional compaction happens with changes in the soil characteristics (HORN et al., 1995). The compaction increases the soil density and its mechanical resistance (HAMZA; ANDERSON, 2005; MATERECHERA, 2009) and decreases the pores volume, mainly macro-pores (SOUZA et al., 2012). Silva, AR et al. (2006) and Araújo-Junior et al. (2008) observed structural soil changes associated with compaction caused by the traffic of agricultural machines in arabica coffee crops in the southern Minas Gerais. However, conilon coffee producing regions lacks related studies. The lower porosity and rate of water infiltration in the soil, resulting from the soil soil compressibility by the pressure imposed by the agricultural machinery traffic, increases the superficial runoff during rainy periods, which can increase the erosive process of the soil.

The main effects that soil compaction can cause to the agricultural crops are: failure or delay in the seedlings survival, reduced size of plants and beans, non-characteristic color of the leaves, superficial root system and roots malformation (BENGOUGH et al., 2006; SOUZA et al., 2014, 2015). Soil compaction reduces root system development and access to water and nutrients (CHAN et al., 2006; COLLARES et al., 2008). This physical impediment to root development results in a lower root volume, concentrated on the superficial layer, which makes the plant more susceptible to summer. Thus, the lower root volume promoted by soil compaction might reduce conilon coffee productivity.

Compaction reduces the water infiltration in the soil and can intensify the erosive process by carrying fine particles, organic matter and nutrients in the eroded fluid. The main consequences are soil depletion, loss of productive potential and the rivers and lakes contamination, which can make coffee activity unsustainable in economic and environmental aspects.

Recent studies have used mathematical models to estimate the load carrying capacity of soils, quantifying the pressure levels that can be applied to avoid compaction from occurring (SILVA, A. R. et al., 2006; ARAÚJO-JÚNIOR, 2008, 2011). For this, the soil moisture evaluation is used, since the higher it is, the lower the internal resistance of the particles, which makes it more susceptible to the compressive process (SILVA, A. R. et al., 2006; SOUZA et al., 2012).

For this reason, monitoring soil compaction and physical quality are necessary actions in intensively mechanical areas in order to keep the soil as a favorable environment to the coffee tree root development and, thus, contribute to the crops longevity and the agricultural activity sustainability.

8 FINAL CONSIDERATIONS

The current scenario of *Coffea canephora* production in the Brazilian regions, characterized by insufficient labor availability, low operational yield, harvesting insecurity and high cost, converges to the expansion and intensification of agricultural mechanization in the production process, mainly in mechanical harvesting of the conilon coffee fruits. This will allow a greater guarantee of the harvesting, with greater speed and agility, with the strip harvesting of a greater ripe fruits proportion and a greater reduction in the production cost, which can improve the beverage quality and add value to the product in the domestic and international market, contributing to greater sustainability of the sector.

The mechanical harvesting will not be able to completely replace manual harvesting, even in areas with favorable topography, such as in northern Espírito Santo, southern Bahia and Rondônia, mainly due to the coffee grower interests, access to technologies, availability of financial resources and agricultural ability. So, new research has been carried out to allow the continuous evolution of mechanical harvesting systems, boosted by partnerships between public and private institutions and the coffee sector.

9 ACKNOWLEDGMENTS

Luiz Antônio Vizeu, from the company Miac Máquinas Agrícolas, Carlos Eduardo de Carvalho Visconti, from the company CNH Industrial and Walmi Gomes Martin, from the company Jacto Máquinas Agrícolas, for the partnerships in the research. We would also like to thank the coffee grower involved in the conilon mechanical harvesting project, particularly, Amistrong Luciano Zanotti, Jésus Roque Lubiana, Tarcisio Duarte, Moisés Alvino Covre, Isaac Covre, Roberto Altoé, consultants José Sebastião Machado Silveira and Rogério Emílio Chiabai, Coffee Research Consortium - Embrapa Café, the Agricultural Cooperative of the Coffee Growers of São Gabriel da Palha (Cooabriel) and the System of Credit Cooperatives of Brazil (Sicoob).

10 REFERENCES

ALAKUKKU, L.; WEISSKOPF, P.; CHAMEN, W. C. T; TIJINK, F. G. J.; VAN DER LINDEN, J. P.; PIRES, S.; SOMMER, C.; SPOOR, G. Prevention strategies for field traffic-induced subsoil compaction: a review. Part I - Machine/soil interactions. *Soil and Tillage Research*, v.73, n. 2, p. 145-160, 2003.

ARAÚJO-JÚNIOR, C. F.; DIAS JUNIOR, M. S.; GUIMARÃES, P. T. G.; PIRES, B. S. Resistência à compactação de um Latossolo cultivado com cafeeiro, sob diferentes sistemas de manejo de plantas invasoras. *Revista Brasileira de Ciência do Solo*, v.32, n. 1, p. 23-32, 2008.

ARAÚJO-JÚNIOR, C. F.; DIAS JUNIOR, M. S.; GUIMARÃES, P. T. G.; ALCÂNTARA, E. N. Capacidade de suporte de carga e umidade crítica de um Latossolo induzida por diferentes manejos. *Revista Brasileira de Ciência do Solo*, v. 35, n.1, p. 115-131, 2011.

BALASTREIRE, L. A. Gerenciamento de operações agrícolas mecanizadas. In: BALASTREIRE, L. A. (Ed.). *Máquinas agrícolas*. São Paulo: Manole, p. 30-61; 1987.

BENGOUGH, A. G.; BRANSBY, M. F.; HANS, J.; MCKENNA, S. J.; ROBERTS, T. J.; VALENTINE, T. A. Root responses to soil physical conditions; growth dynamics from field to cell. *Journal of Experimental Botany*, v. 57, n. 2, p. 437-447, 2006.

CASE IH AGRICULTURE. *Colhedoras e colheitadeiras*: Café. Disponível em: <http://www.caseih.com/latam/pt-br/products/colhedoras-e-colheitadeiras/colhedoras-de-caf%C3%A9>. Acesso em: 20 maio 2016.

CEDAGRO. Centro de Desenvolvimento do Agronegócio. *Coeficientes técnicos e custos de produção na agricultura do Estado do Espírito Santo*. Disponível em: <http://www.cedagro.org.br/coeficiente_planilhas.php>. Acesso em: 6 maio 2016.

CHAN, K. Y.; OATES, A.; SWAN, A. D.; HAYES, R. C.; DEAR, B. S.; PEOPLES, M. B. Agronomic consequences of tractor wheel compaction on a clay soil. *Soil and Tillage Research*, v.89, n. 1, p. 13-21, 2006.

COLLARES, J. L.; REINERT, D. J.; REICHERT, J. M.; KAISER, D. R. Compactação de um Latossolo induzida pelo tráfego de máquinas e sua relação com o crescimento e produtividade de feijão e trigo. *Revista Brasileira de Ciência do Solo*, v. 32, n. 3, p. 933-942, 2008.

CRISOSTO, C. H.; NAGAO, M. A. Evaluation of fruit removal force of coffee cultivars. *Horti-Science*, v.26, n. 2, p. 210-230, 1991.

FAVARIN, J. L.; Vill4ela, A. L. G.; Mor4aes, M. H. D.; CHAMMA, H. M. C. P.; COSTA, J. D.; DOURADO-NETO, D. Qualidade da bebida de café de frutos cereja submetidos a diferentes manejos pós-colheita. *Pesquisa Agropecuária Brasileira*, v. 39, n. 2, p. 187-192, 2004.

FERNANDES, H. C.; BURLA, H. R.; LEITE, E. S.; MINETTE, L. J. Avaliação técnica e econômica de um “Harvester” em diferentes condições de terreno e produtividade da Floresta. *Scientia Forestalis*, v. 41, n. 97, p. 145-151, 2013.

FERRÃO, R. G.; FONSECA, A. F. A da; BRAGANÇA, S. M.; FERRÃO, M. A. G.; De MUNER, L. H. (Eds.). *Café Conilon*. Vitória, ES: Incaper, 2007. 702 p.

FERRÃO, R. G.; FONSECA, A. F. A da; FERRÃO, M. A. G.; VERDIN FILHO, A. C.; VOLPI, P. S.; De MUNER, L. H.; LANI, J. A.; PREZOTTI, L. C.; VENTURA, J. A.; MARTINS, D. dos S.; MAURI, A. L.; MARQUES, E. M. G.; ZUCATELI, F. *Café Conilon*: Técnicas de Produção com variedades melhoradas. 4. ed. Vitória, ES: Incaper, 2012. 74p. (Incaper. Circular Técnica, 03-I).

FONSECA, A. F. A. da; FERRÃO, R. G.; FERRÃO, M. A. G.; VERDIN FILHO, A. C.; VOLPI, P. S. Qualidade do café conilon: operações de colheita e pós-colheita. In: FERRÃO, R. G.; FONSECA, A. F. A. da; BRAGANÇA, S. M.; FERRÃO, M. A. G. & De MUNER, L. H. (Eds.). *Café conilon*. Vitória: Incaper, 2007. p. 501-517.

GOMES, W. R.; CONSTATINO, C. O. R. Colheita semi-mecanizada no café conilon. *Órgão Informativo da Cooperativa Agrária dos Cafeicultores de São Gabriel*, v. 29, n. 201, p. 3, 2015.

HAMZA, M. A.; ANDERSON, W. K. Soil compaction in cropping systems: A review of the nature, causes and possible solutions. *Soil and Tillage Research*, v. 82, n. 2, p.121-145, 2005.

HORN, R.; DOMZZAI, H.; SLOWINSKA-JURKIEWICZ, A.; VAN OUWERKERK, C. Soil compaction processes and their effects on the structure of arable soils and environment. *Soil and Tillage Research*, v. 35, n. 1-2, p. 23-36, 1995.

LANNA, G. B. M.; REIS, R. P. Influência da mecanização da colheita na viabilidade econômico financeira da cafeicultura no sul de Minas Gerais. *Coffee Science*, v. 7, n. 2, p.110-121, 2012.

LOPES, J. D. S.; MANTOVONI, E. C.; PINTO, F. A. C.; QUEIROZ, D. M. Desenvolvimento de um programa computacional para selecionar, economicamente, um sistema de mecanização agrícola. *Pesquisa Agropecuária Brasileira*, v. 30, n.4, p. 537-542, 1995.

MATERECHERA, S. A. Tillage and tractor traffic effects on soil compaction in horticultural fields used for peri-urban agriculture in a semi-arid environment of the North West Province, South Africa. *Soil and Tillage Research*, v. 103, n. 1, p. 11-15, 2009.

MIAC MÁQUINAS AGRÍCOLAS. *Colheita de Café*: Recolhedoras e trilhadoras. Disponível em: <http://www.miac.com.br/Site/Sub-Produtos.aspx?subCategoria=21&categoriaid=7>. Acesso em: 12 jun. 2016.

NEW HOLLAND AGRICULTURE. *Colhedora*: Braud. Disponível em: <http://agriculture1.newholland.com/lar/pt-br/equipamento/produtos/colhedoras/braud>. Acesso em: 15 abril 2016.

OLIVEIRA, E.; SILVA, F. M.; SALVADOR, N.; SOUZA, Z. M., CHALFOUN, S. M.; FIGUEIREDO, C. A. P. Custos operacionais da colheita mecanizada do cafeeiro. *Pesquisa Agropecuária Brasileira*, v. 42, n. 6, p. 827-831, 2007a.

OLIVEIRA, E.; SILVA, F. M.; SOUZA, Z. M.; FIGUEIREDO, C. A. P. Influência da colheita mecanizada na produção cafeeira. *Ciência Rural*, v.37, n. 5, p. 1466-1470, 2007b.

OLIVEIRA, E.; SILVA, F. M.; SALVADOR, N.; FIGUEIREDO, C. A. P. Influência da vibração das hastes e da velocidade de deslocamento da colhedora no processo de colheita mecanizada do café. *Engenharia Agrícola*, v. 27, n. 3, p. 714-721, 2007c.

PACHECO, E. P. *Seleção e custo operacional de máquinas agrícolas*. Rio Branco: Embrapa Acre, 2000. 21p. (Documentos, 58).

SANTINATO, F. et al. Comparação entre o custo da colheita manual e mecanizada de uma a seis passadas da colhedora. In: CONGRESSO BRASILEIRO DE PESQUISAS CAFEEIRAS, 39., 2013, Poços de Caldas. *Anais*... Poços de Caldas: MAPA/PROCAFÉ, p. 195-198, 2013a.

SANTINATO, F.; RUAS, R. A. A.; SILVA, R. P.; DUARTE, A. P.; SANTINATO, R. Análise econômica da colheita mecanizada do café utilizando repetidas operações da colhedora. *Coffee Science*, v. 10, n. 3, p. 402-411, 2015a.

SANTINATO, F.; SILVA, R. P.; CASSIA, M. T.; SANTINATO, R. Análise quali-quantitativa da operação de colheita mecanizada de café em duas safras. *Coffee Science*, v. 9, n. 4, p. 495-505, 2014.

SILVA, A. R.; DIAS JUNIOR, M. S.; GUIMARÃES, P. T. G.; ARAÚJO-JÚNIOR, C. F. Modelagem da capacidade de suporte de carga e quantificação dos efeitos das operações mecanizadas em um Latossolo amarelo cultivado com cafeeiros. *Revista Brasileira de Ciência do Solo*, v. 30, n. 2, p. 207-216, 2006b.

SILVA, F. C.; SILVA, F. M.; ALVES, M. C.; BARROS, M. M.; SALES, R. S. Comportamento da força de desprendimento dos frutos de cafeeiros ao longo do período de colheita. *Ciência e Agrotecnologia*, v. 34, n. 2, p. 468-474, 2010.

SILVA, F. C.; SILVA, F. M.; SILVA, A. C.; BARROS, M. M.; PALMA, M. A. Z. Desempenho operacional da colheita mecanizada e seletiva do café em função da força de desprendimento dos frutos. *Coffee Science*, v. 8, n. 1, p. 53-60, 2013a.

SILVA, F. M.; SALVADOR, N.; RODRIGUES, R. F.; TOURINO, E. S. Avaliação da colheita de café totalmente mecanizada. In: SIMPÓSIO DE PESQUISA DOS CAFÉS DO BRASIL, 2., 2001. Vitória. *Anais*... Vitória: Consórcio Pesquisa Café, v. 1, p. 741-749, 2001.

SILVA, F. M.; SALVADOR, N.; RODRIGUES, R. F.; TOURINO, E. S. Avaliação da colheita do café totalmente mecanizada. *Engenharia Agrícola*, v. 23, n. 2, p. 309-315, 2003.

SILVA, F. M.; OLIVEIRA, E.; GUIMARÃES, R. J.; FIGUEIREDO, C. A. P.; SILVA, F. C. Desempenho operacional e econômico da derriça do café com uso da derriçadora lateral. *Coffee Science*, v. 1, n. 2, p.119-125, 2006.

SILVA, F. M.; OLIVEIRA, E.; FIM, E.; FIGUEIREDO, V. C. Desempenho e influência da colhedora mecanizada na produtividade da lavoura cafeeira em 4 safras. In: Simpósio de Pesquisa dos Cafés do Brasil, 8., Salvador, 2013b. *Anais* ... Salvador, BA: p. 1-6, 2013b.

SOUZA, C. M. A.; QUEIROZ, D. M.; CECON, P. R.; MANTOVANI, E. C. Avaliação de perdas em uma colhedora de fluxo axial para feijão. *Revista Brasileira de Engenharia Agrícola e Ambiental*, v. 5, n. 3, p. 530-537, 2001.

SOUZA, G. S.; SOUZA, Z. M.; COOPER, M.; TORMENA, C. A.Controlled traffic and soil physical quality of an Oxisol under sugarcane cultivation. *Scientia Agricola*, v. 72, n. 3, p. 270-277, 2015.

SOUZA, G. S.; SOUZA, Z. M.; SILVA, R. B.; ARAÚJO, F. S.; BARBOSA, R. S. Compressibilidade do solo e sistema radicular da cana de açúcar em manejo com e sem controle de tráfego. *Pesquisa Agropecuária Brasileira*, v. 47, n. 4, p. 603-612, 2012.

SOUZA, G. S.; SOUZA, Z. M.; SILVA, R. B.; BARBOSA, R. S.; ARAUJO, F. S. Effects of traffic control on the soil physical quality and the cultivation of sugarcane. *Revista Brasileira de Ciência do Solo*, v. 38, n. 1, p. 135-146, 2014.

Support

Consórcio Pesquisa Café

FAPES
FUNDAÇÃO DE AMPARO À PESQUISA E INOVAÇÃO DO ESPÍRITO SANTO

GOVERNO DO ESTADO DO ESPÍRITO SANTO
Secretaria de Ciência, Tecnologia, Inovação e Educação Profissional

Realization

Incaper
Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural

GOVERNO DO ESTADO DO ESPÍRITO SANTO
Secretaria da Agricultura, Abastecimento, Aquicultura e Pesca

Rua Afonso Sarlo, 160 - Bento Ferreira - Caixa Postal: 391
CEP: 29052-010 - Vitória, ES - Brasil
Telephone: 55 27 3636 9846 - biblioteca@incaper.es.gov.br
www.incaper.es.gov.br

ISBN 978-85-89274-32-6
9 788589 274326