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Vertical Tillage Technology for Primary Soil Preparation

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ABSTRACT

In the last decade in Mexico and other developing countries, soil preparation is the agricultural activity that represents the highest costs per unit of production, due to factors such as lack of appropriate equipment, excessive tillage, high consumption of fossil fuel, lack of knowledge and training for the adequate soil management, among others.

The purpose of this research was to develop a vertical tillage technology that allows primary soil preparation without investment and reduces fuel consumption and effective operating time, improves labor quality and conserves soil and water resources. For this, a chisel plow prototype was developed based on four vertical tillage parameters: (1. Working depth 2. Number of bodies 3. Spacing between chisels 4. Use of wings or sweepers). These parameters determined the criteria and dimensions of the prototype for its development in design parameters such as spacing, position, angle of attack and depth of work.

The performance evaluation of the prototype was compared with the disc plow; an implement that served as a witness as it was the most widely used technology. The standardized test method was used by the National Center for Standardization of Agricultural Machinery "CENEMA". The results obtained show a prototype plow with five chisels mounted on a double platform frame. The front platform is used for the coupling of three shallow chisels and the rear one, for the coupling of two deep chisels with wings. The implement adjusts for two working depths 0.30 and 0.40 meters and two working widths 1.80 m and 2.40 m respectively. The performance evaluation showed that vertical tillage with the chisel plow prototype in its two treatments showed an average saving of more than 45% in the fuel consumption variable and 53% in the effective working time compared to conventional tillage used with a disc plow. In terms of quality of work, vertical tillage shows high performance in soil disturbance, exceeding up to 65% of the work done by conventional tillage. Finally, it is concluded that the proposed technology should be used as technological innovation and replace the conventional disk plow technology, given its technological, economic and environmental advantages.

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1. Introduction

At present time, for the primary or deep preparation of the soil with characteristics of mechanical impedance or compacted soil, a three-body disc plow is traditionally used that does not exceed 0.80 m of effective working width and that uses as a power source an 80 horsepower tractor. Operating times and fuel consumption per hectare are excessive and expensive, averaging three to four hours and consuming up to 25 litres depending on the type, depth and moisture content of the soil. In addition to this problem, it causes the total investment of the soil that consequently hinders the management of the seedbed, severe damage to its structure and minimal moisture retention that result in low profitability of the crops given their low productivity.

In the establishment of crops, soil preparation tasks currently require a large consumption of energy in the form of fuel [1]. It is important to point out that the recent achievements in the yield of basic crops are not enough compared to the high cost of energy consumed; Therefore, it is necessary to optimize the use of resources used in activities that requires the highest costs in agricultural production, such as soil tillage, considered as the agricultural activity that requires the highest amount of energy in food production in the world [2,3]. The objective of tillage or preparation of the soil is to improve its physical, chemical and biological conditions, with these tasks a good emergence and development of the crops is ensured. Primary tillage is used to remove surface compaction, open up the soil, and defragment the size of clods to create a lumpy structure to collect water and create pore spaces for oxygen circulation. Every year more emphasis is given to the use of minimum tillage and the preparation of the seedbed in rainfed agriculture [4]. It is convenient to point out that Vertical Tillage (VT) is a conservation tillage alternative that promotes savings in energy demand and improves the physical properties of soils compared to conventional tillage.

The VT is a system with application in a wide range of soil types, including those that have drainage problems and are susceptible to compaction [5,6]. The VT is carried out with chisels and corresponds to the operation of bursting or breaking the soil and fragmentation up to 0.40 m, without inverting the horizons, due to this, there is less decomposition of organic matter and greater conservation of soil moisture. According to Raper and Bergtold (2007), much can be done to reduce the economic and environmental cost with the use of vertical tillage, by reducing the use of energy, selecting the appropriate geometry of the implements, the appropriate depth of work and moisture content in the soil profile.

Different studies carried out show that the proper management of agricultural work, a reduction of up to 30% is achieved [2].

To reduce such impacts and for adequate energy savings, vertical tillage (VT) is implemented, which is part of conservation tillage and can be realized with implements such as chisel plows, field cultivators, Vibro- cultivator and multi-plow.

The chisel plow produces a rough surface and generally leaves 50 to70% of the existing corn or grain sorghum residue on the surface depending on chisel point selection, shank spacing, operating speed, and depth. Straight, narrow points, about 2 inches wide, leave the most residue. Where erosion is not a primary concern, 3- or 4-inch wide, twisted points invert more soil and bury more residue.

Typically, chiselling is performed in the fall and is followed by one or more secondary tillage operations in the spring. On many soils, a single pass in the spring with a disk, field cultivator, or combination tillage implement provides limited pesticide and fertilizer incorporation on fall chiseled fields. A second tillage pass provides more complete incorporation but can decrease residue and erosion control. Spring chiselling affords erosion control during the winter and allows extended grazing of stalks. However, soil moisture evaporation following spring tillage can result in yield reductions, particularly in lower rainfall areas. Spring chiselling may also produce clods that could require additional tillage operations to prepare a suitable seedbed.

A chisel plow may clog in extremely heavy or wet residue unless stalk shredding or light tillage precedes chiselling. This additional operation increases fuel and labor requirements. Several combination tillage implements have coulters or disks mounted in front of the chisel shanks which often eliminate the need for a pre-chiselling operation.

The coulters or disks are operated just deep enough to cut the surface residue. This reduces the chance of residue clogging in the chisel area. The shank spacing on these machines is usually 15 inches compared to 12 inches for a conventional chisel plow [7].

For the use of systems with chisels and subsoilers it is important to consider the angle of attack in order to obtain low values of traction forces and consequently low values in energy consumption [8], as well as the lowest specific resistance [9,10]. The proper selection and correct use of agricultural machinery should be understood as a component of a process aimed at making resources more efficient and optimizing production.

A rigorous review of published scientific articles [1] determined the influence of four operating parameters that should be considered as work settings before applying deep soil tillage and making the use of energy more efficient. Those integrated parameters were: 1) working depth based on the critical depth theory 2) position and spacing between chisels 3) the number of bodies and 4) use of wings or sweepers.

The present research proposal aims to develop a vertical tillage technology through a prototype chisel plow, which allows primary soil preparation without investment, reducing fuel consumption and effective time by up to 50%. of operation, improving the quality of work and the conservation of water and soil resources in comparison with the conventional system made with a disc plow.

2. Materials and Methods

2.1. Location and Site Characteristics

The present research work was carried out in the Cotaxtla Experimental Station in the department of agricultural mechanization, which is located at km 34.5 of the Veracruz-Córdoba federal highway, Municipality of Medellín de Bravo, Ver. México. The site destined to carry out the prototype tests were a lot (D4) with coordinates (18 ° 56'20''N, 96 ° 11'30.3''W), belonging to the National Institute of Forestry, Agriculture and Livestock Research (Figure **1**). The test site was selected with mechanical impedance or compaction conditions that exceeded the 3Mpa limit and required the application of primary tillage. The soil was classified as loam with 43.20% sand, 19.80% clay and 37% silt. The coverage of the proposed technology would be used in southeastern Mexico with rainfed production.

Figure 1: Evaluation site at the Cotaxtla experimental station.

2.2. Evaluation Description

The evaluation was divided into two phases: the first phase consisted of determining the parameters for the design of the prototype components and the second phase was for evaluations under field conditions of the operational performance of the prototype versus disc plow.

2.2.1. Phase 1 Vertical Tillage Parameters for the Prototype Design

The parameters used for the design of the prototype were considered as follows:

For working depth, the type and degree of disturbed soil is the primary factor when selecting tillage implements, but this must be considered in conjunction with the penetration force and power demand requirements for efficient operation.

There are two main variables in the design and selection of the appropriate geometry for the given tillage implements.

i. Tip depth / width (d / w)

ii. Tool attack angle(α)

Three categories of blades or tips must be distinguished depending on the working depth/tip width ratio [11].

1. Wide tips or blades for a d / w ratio <5
2. Narrow point chisel for a ratio of 1 <d / w <6 and
3. Very narrow blades or tips for a d / w ratio > 6

The angle of attack of the tool (chisel point) is indicated by the angle where the opener creates a horizontal line in the direction of travel. The optimal angle of attack is 25 degrees, due to the greater movement of the ground; As the angle of the tool increases, the demand for the pulling force increases proportionally.

The use of shallow chisels significantly reduces the force on the deep chisel, indicating that loosening the soil surface by a separate operation before deep loosening offers an effective way to reduce the pulling power at the deep chisel.

To successfully operate the position and spacing of this arrangement, the shallow chisel must be ahead of and close enough to the deep chisel.

Practical positions for shallow chisels were given by [11]:

Depth = 2/3 of the working depth of deep chisels

Side clearance = 2.5 of the deep chisel working depth

Front clearance = ≥ 1.5 of the deep chisel working depth

Godwin *et al*. [12] described how to tip spacing can affect the disturbed soil pattern produced by a pair of teeth operating in the same location. The effect of this is the resultant of the total pull force required (N), the disturbed area (m^2) and the specific resistance of the soil (Nm^2).

From this work and from other studies on subsoiler equipment, the practical spaces recommended by [13] for better soil disturbance are:

i. 1.5 of the working depth of single chisels

ii. 2.0 working depth of winged chisels

Wings or sweepers attached to the foot of the tip modify the type of soil disturbance, doubling the disturbed area for an increase in pulling force of 30%. This significantly increases the efficiency of the operation, reducing the specific resistance (pulling force / disturbed area) by 30% [13].

In this first phase, the working depth of 0.30 m was considered in order to determine the adjustments that should be made in terms of the space between the chisels. It is important to note that the depth of work is governed by the deep or rear chisel and that it is established as a design condition: that only the rear chisels may be coupled with wings and it must also be met, shallow always ahead of deep, this framed within of the parameters of vertical tillage and the theory of critical depth. The size of the wing according to the results obtained [14] was used for a median wing of 0.55 m.

2.3. Other Required Design Considerations given the Problems to be Addressed are:

The available power of 80 hp (tractor "most of the vehicle fleet in the country"), working width at least twice (1.60 m) of the disc plow(which allows making efficient the effective operation time and fuel consumption), must be an implement coupled to the third point of the tractor, a double platform for coupling shallow chisels at the front and deep wing chisels at the rear and the chassis must ensure easy coupling of the chisels.

2.3.1. Phase 2 Variables for the Evaluation of the Functioning of the Prototype

Once the design and construction phase was completed, the evaluation phase of the prototype under field conditions was carried out.

2.4. Testing Method

The test method used to evaluate the plowing equipment for primary soil preparation is the one governed and endorsed by the National Center for the Standardization of Agricultural Machinery (CENEMA). For the variables to be measured in the evaluation of the prototype's operational performance, a technical sheet will be made (see Table **1**) with the following parameters:

Table 1: Performance evaluation parameters regulated by CENEMA.

1. Setting of Implement	9. Left Turning Radius	17. Total Time with Header
2. Ease of Operation *	10. Right Turning Radius	18. Total Test Time
3. Working Width	11. Working Depth	19. Fuel Consumption
4. Space between chisel	12. Speed Setting	20. Effective Time ha^{-1}
5. Shallow Chisel	13. Operating Speed	21. Fuel Consumption ha^{-1}
6. Space between platform	14. Travel Length	22. Exploited land area
7. Rear Chisel	15. Implement Weight	23. Surface
8. Platform Spacing	16. Test Surface	24. Slippage

Ease of Operation*. This variable is done through three questions to the tractor operator: Is it easy or not to drive the tractor at the moment of applying the labor? Is it easy or not to couple the equipment to the tractor? and Is it easy or not to uncouple the equipment to the tractor?

2.5. Experimental Design

The test site was made up of three plots of 2875 m^2 each and correspond to the systems evaluated with different arrangements, which are described below in Table **2**.

The experimental design was a completely randomized block with six repetitions for the labor quality variables (working depth and disturbed soil area), since the only independent variable was the tillage systems used. To determine the quality of work variables, the profilometry method described by Spoor and Godwin [13] was used.

Table 2: Tillage System Treatments and Implement Arrangement Configuration

Treatment	Arrangement	Setting
1. Vertical tillage	3CF302CT30CA	Three front chisels at 0.30 m depth on the front platform + two rear chisels at 0.30 m deep with a coupling of the 0.55 m expanders or wings
2. Vertical tillage	3CF202CT30CA	Three shallow front chisels at 0.20 m depth on the front platform + two rear chisels at 0.30 m depth with a coupling of the 0.55 m expanders or wings
3. Disc plow	Three-disc plow	Three-disc chisels on a single platform at a depth of 0.30 m.

For the variable fuel consumption and effective working time, it was carried out in a single continuous type test in the total area of the test surface for each treatment. The fuel consumption in liters per hectare was quantified using the full tank method, which is supported as a valid test and accepted by the NTTL (Nebraska Tractor Test Lab) and referred to [15]. The measurement of the effective working time variable a stopwatch was used for the total time to perform the primary soil preparation.

It is important to point out that for these two variables only one continuous repetition was made, to give greater reliability to the test, and no statistical analysis was made for the aforementioned reasons.

For the determination of the disturbed area of the soil, six profilometers were made for each of the evaluated treatments, selecting one for each of the implement widths. For this purpose, a rod profilometer was used, positioned every 0.10 m using the methodology described by Spoor and Godwin [13].

2.6. Machinery, Implements and Equipment used Test Conditions:

- Ford New-Holland 6610 tractor with the following specifications:
  Engine: 4-cylinder turbo
  Power: 82 hp / 61.1 kW Hydraulic drive
  Rear independent 540/100 Rpm power take-off.
- Conventional three-disc plow
- Chiselplow (prototype)
- Rodprofilometer

As a test requirement, the same operator was used and the conditions of the parameters were the same for each treatment. The soil moisture content at the time of tillage was determined by the gravimetric method AS-05NOM 021 REC NAT 2000; at three different depths 4, 8 and 12 inches.

3. Results and Discussion

3.1. Development of the Chisel Plow Prototype

In Figure **2**, the result of the vertical tillage parameters applied in the design of the chisel plow prototype is shown. Likewise, Table **3** and **4**, shows the results of performance parameters in the treatments evaluated under real conditions and operation.

Table **3**, shows technical specifications of the prototype in dimensioning of components, spaces, number of bodies and positions. Likewise, the results of the performance tests are shown in Table **4**, where it is observed that the variable fuel consumption per hectare, registered saving of 42.58 and 47.35% in the treatments T1 and T2, respectively (both of vertical tillage), compared to the T3 (conventional tillage). Similar behaviour was presented in the variable effective time per hectare where it was reduced by 51.83 and 54.28% in treatments T1 and T2 (both vertical tillage), with respect to T3 (conventional tillage) when applying primary soil tillage.

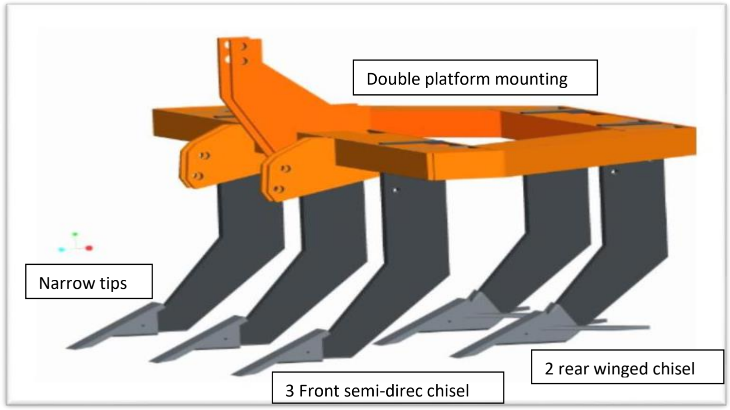

Figure 2: Isometric of the prototype chisel plow for primary vertical soil tillage.

Table 3: Results of the technical specifications of the prototype.

Evaluation Parameters	(T1) Chisel Plow	(T2) Chisel Plow	(T3) Disc Plow
Implement Configuration	3CF302CT30CA	3CF202CT30CA	3D30
Ease of Operation	Easy to operate	Easy to operate	Not easy to operate
Broad Nominal from job of Implement	1.50 m	1.50 m	0.70 m
Effective working width	1.80 m	1.80 m	0.70 m
Front body spacing	0.75 m	0.75 m	NA
Number of chisels	5	5	NA
Rear body spacing	0.75 m	0.75 m	NA
Platform spacing	0.75 m	0.75 m	0.75 m

Table 4: Results of the performance test of the prototype.

Left turning radius	9.75 m	9.75 m	9.73
Righ tturning radius	10.37 m	10.37 m	11.38 m
Working depth	0.30 m	0.30 m	0.30 m
Speed setting	3rd + dual at 1800 Rpm	3rd + dual at 1800 Rpm	3rd + dual at 1800 Rpm
Operating speed	4.5 km h^{-1}	4.5 km h^{-1}	4.5 km h^{-1}
Travel length	115 m	115 m	115 m
Test surface	2875 m^2	2875 m^2	2875 m^2
Total time with header	117 s	113 s	108 s
Slippage	14.04%	7.37%	8.60%
Total test time	22 min 37 s	23 min 7 s	54 min 19 s
Fuel consumption	6 l	5.5 l	10,450 l
Effective time per ha^{-1}	1 h 58 min 16 s	1 h 52 min 33 s	4 h 5 min 48 s
Fuel consumption ha^{-1}	20.87 l	19.13 l	36.34 l
Implement weight	350 kg	350 kg	378 kg
Surface	15.5 cm	13.25 cm	22 cm
Disturbed area	0.5878 m^2	0.5572 m^2	0.2007 m^2

The average moisture content determined for the depths of 4, 8 and 12 inches were 16.6, 17.9 and 18.5 %, respectively, for each of the treatments measured.

For the variable disturbed area, both treatments T1 and T2 of vertical tillage were superior in 65.85 and 63.98% when compared with conventional tillage using disc plows, similar results were obtained by Spoor and Godwin, and Reynolds *et al.* [1,13], given the reduction of the specific resistance of the soil due to the use of fins. Kumar and Thakur [16] indicated that specific soil resistance could be reduced by up to 26.92% using straight-winged chisels compared to conventional tillage at a working depth of o.30 m in clay soil.

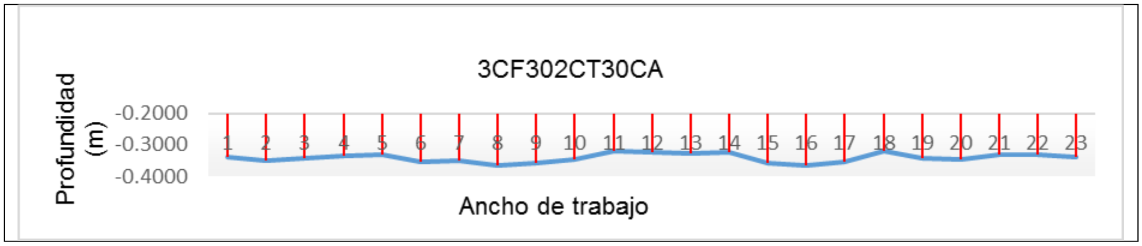

Figure 3: Disturbed soil area with vertical tillage T1.

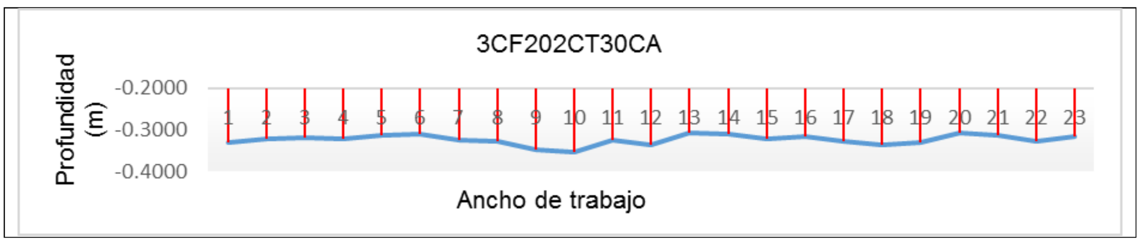

Figure 4: Disturbed soil area with vertical tillage T2.

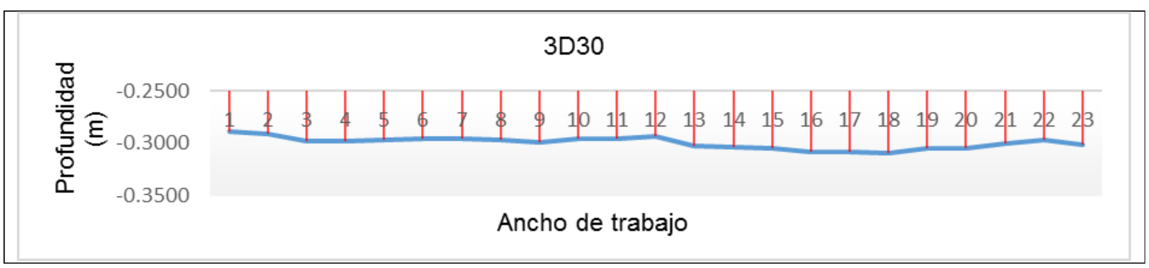

Figure 5: Disturbed soil area with vertical tillage T3.

3.2. Note 1: in the Graphics 3,4 and 5 (Ancho de Trabajo: Working Depth, Profundidad: Deep)

Figures **3**, **4** and **5** shows that, at a greater depth of work in vertical tillage treatments, the disturbed area increases, not so for the system with conventional tillage. These graphs allow observing the differential shown in the working depth variable, which increases the disturbed area of the soil.

Table 5: Anova of labor quality parameters in the application of primary tillage.

Level	Treatment	Depth Labor (m)	Area Disturbed (m^2)
1	3CF302CT30CA	0.3412 a	0.587 a
2	3CF202CT30CA	0.3235 a	0.557 a
3	3D30	0.2994 b	0.200 b

The means that do not share the same literal are significantly different for a (p≤0.05)

Table **5** shows the comparisons between tillage systems and we can indicate that vertical tillage is significantly higher in the variables evaluated in labor quality, which confirms the better performance of the tractor-implement duality. The use of chisels with vertical tillage parameters and the advantage of using wings or sweepers is their ability to significantly increase soil disturbance in the deeper layers. The ground fault planes that develop from the wingtips tend to approach in the direction of the vertical rather than develop at approximately 45 ° from the horizontal. This is due to a change in the configuration of the effort, a stress situation that occurs above the wings,

The 0.55 m working depth wing width has been used successfully on many soils at working depths d between 0.3 and 0.40 m. The width of the wing selected, however, from the resistance, the risk of impact and the general considerations of the pulling force, as well as the specific resistance of the ground. On the other hand, it is also considered that the angle of attack of the wings does not generate significant changes in the disturbance of the ground or in the power demand requirements. According to what was concluded by Reynolds *et al*. [17], we can point out that the integrality of the parameters significantly reduces the use of vertical technology compared to conventional tillage.

Figure 6: (a) in the left picture, shows the prototype chisel plow under evaluation conditions and figure (b) in the right picture, the comparison of conventional tillage versus (left), vertical tillage (right).

4. Conclusions

Technological innovation in vertical tillage was developed for primary preparation without inversion of the soil.

Vertical tillage with the chisel plow prototype in its two treatments showed an average saving of more than 45% in the fuel consumption variable and 53% in the effective operating time compared to conventional tillage used with a disc plow.

In terms of quality of work, vertical tillage shows high performance in soil disturbance, exceeding up to 65% of the work done by conventional tillage.

The proposed technology is a technology that must be used immediately as a technological offer and replace the conventional disc plow technology and the traditional chisel plow given its technological, economic and environmental advantages.

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