Technical Background to the Autonomous Self-Actuated Tillage Implement*

Volker Nannen and Damian Bover

Sedewa, Finca Son Duri, Palma-Manacor KM 40, Vilafranca de Bonany 07250, Spain
vnannen@gmail.com, utopusproject@gmail.com

The Invention

What is fundamental to the Autonomous Self-Actuated Tillage Implement is that there are two sets of implement frames that are interconnected by the "alternate approaching and distancing means." There is at least one plow share on one set of frames and at least one anti-rollback means on the other set of frames. It is the rollback means on one frame that actuates, i.e., that provides traction for the plow share(s) on the other frame. There can be two plow shares on one frame, and two crampons on the other frame; there can be two plow shares and crampons on each frame; etc. Plow shares and crampons can be connected, or can be placed separately. The rearward portion of a plow share might be shaped in such a way as to provide anti-rollback for its counterpart on the other frame, without crampons. But there is always at least one frame with at least one plow share, the traction for which is provided by the anti-rollback means on the other frame. This allows the implement to autonomously crawl forward while tilling the soil.

For a quick appreciate of how the Autonomous Self-Actuated Tillage Implement operates, please see the video clips showing prototypes of the claimed invention in operation at http://sedewa.com/prototypes.html. These video clips show the potential for autonomous, low (or no) outside energy consumption operation of the invention that is a claimed combination that is believed to be both novel and unobvious over the prior art.

The "anti-rollback means" refers to any mechanism that provides traction, and both the anti-rollback means in the claims and the phrase self-actuated in the title refers to the fact that this is the primary source of traction.

Technical Background

Tillage is mechanical agitation of the soil to create suitable conditions for crop growth. Soil agitation can be soil fragmentation, soil mixing, cutting of weed roots, and more. Tillage is one of the most work intensive activities in agriculture, both in terms of man power and in terms of fossil fuel consumption. The mechanical force to agitate the soil is conventionally provided by dragging a tillage implement horizontally through the soil by means of a wheeled or tracked tractor. The draft force of the tillage implement depends on how deep the tillage implement penetrates the soil, its geometry, speed, soil properties, and other factors. A wheeled or tracked tractor generates the mechanical force that pulls a tillage implement through some portion of the soil by letting its tread make contact with another portion of the same soil, and by letting the tread apply a force on that other portion with a direction opposite to the direction of travel of the tillage implement. The force of the wheel needs to be at least equal to the draft of the tillage implement. It is in fact always greater as it also needs to overcome the motion resistance of the tractor.

According to ASABE standard D497.5 [1], the tractive efficiency of wheeled and tracked tractors is 55% on soft or sandy soil and can reach 77% on firm soil. That is, a wheeled or tracked tractor loses between 23% and 45% of axel power to generate traction. This inefficiency is independent of motor technology and transmission technology and depends only

* Originally filed with the USPTO on Aug. 5, 2013 as applicant arguments to support US Patent Application 13/810,158—Autonomous Self-Actuated Tillage Implement

on the interaction between the wheels or tracks and the soil. The lost energy is attributed to soil deformation under the tire or track, flexing of the tire or track, and slip.

Without ballast, a wheel or track will slip excessively and will not pull the tillage implement. For the wheel or track to generate forward force, ballast is needed to force its tread downward into the ground. The optimal downward force depends on the draft of the tillage implement. The scientific consensus is that it is about 3 times the required draft force [2]. This downward force compacts the soil [8]. The work by W. Söhne is from the 1950s but is considered to be the standard work on deep soil compaction even today. In the upper soil layer, compaction means that more energy is needed to pull the tillage implement through the soil. Below the reach of the tillage implement, compaction remains over many years and significantly reduces crop yield, in the short term by impeding root growth, and in the long term by creating an anaerobic layer that is poor in nutrients [9]. Deep compaction also inhibits water percolation, with the effect that soil erosion increases significantly when excess rain runs off [10].

The subject invention is a tillage implement that generates traction by means of an anti-rollback mechanism. The preferred implementation of the anti-rollback mechanism is a crampon that slides over the ground when its frame moves forward. When the alternating motion is reversed the crampon is driven into the ground, first at a shallow angle, but it gradually rotates so that it ends up perpendicular to the direction of travel, i.e., at 90 degrees. Alternative anti-rollback mechanisms as would be known by those skilling the art or hereafter be discovered anti-rollback mechanisms can be used as well, once the skilled artisan understands the invention.

Crampons can generate traction if and only if their rearward motion resistance in the soil (their rearward draft) is significantly greater than the forward draft of the tillage implements that they pull. The tractive efficiency of a crampon depends on the energy it costs to anchor it, and how firm it will hold in place. The crampon is anchored by driving it into the soil with force. This force can be provided either as part of the alternating motion of the implement, or by an actuator attached directly to the crampon. The energy required to drive it into the ground increases with its width and with its depth in the soil. The rearward draft it generates increases with its width, its depth in the soil, and its angle in the soil. These draft forces have been studied extensively both theoretically and empirically in a number of scientific articles that study the draft of narrow tines, e.g., articles [3], [4], and [5]. The motivation for these studies was to minimize the draft. The current invention tries to maximize it. The physical laws that govern the draft are the same.

These articles show that a crampon that enters the soil at an angle of 90 degree produces the highest draft or traction, while at 60 degrees the traction will be only half of this maximum for a given depth. For this reason it is important that the crampon will rotate into a perpendicular position after being driven into the soil. They also show, but with less agreement, that when the width of a crampon is increased by a certain factor x, the draft increases by a factor y smaller than x. Assuming, however, that the energy required to drive the crampon into the soil grows linearly with width, the Applicant considers that it is more efficient to have a narrow crampon that anchors deep than a wide crampon that does not anchor deep.

Because the crampon needs to be anchored only once for every alternating step and because it can be anchored firmly if it can penetrate the soil deep enough, its tractive efficiency can be significantly better than that of a wheeled or tracked tractor. The Applicant expects energy savings of between 20% to 40%, depending on soil conditions.

Because the crampon generates traction without ballast, it can allow for a significant reduction in soil compaction. However, not only the weight of a tractor compacts the soil. Part of the force of a tillage implement is oriented downward, below the soil it can agitate, and creates a compacted layer of soil called the plow pan. This plow pan is of lesser extension than the compaction created by ballasted tractors, yet it still remains an obstacle to root growth. Scientific research like article [6] indicates that if a compacted layer is perforated at only 0.2% of its area, its inhibition to root growth is largely overcome. The crampons will do exactly this. Since they are narrower than the plowing implements that they actuate, they have to penetrate the soil to a greater depth in order to generate sufficient resistance. To give an example, for a typical plowing depth of 12 inches, the crampons will likely need to penetrate to a depth of 20 or 30 inches, depending on soil properties, thus perforating the plow pan that has formed just below 12 inches depth.

It is also important to mention that the use of alternative energy sources like solar panels is not economically viable with current practice. A modern tractor consumes 6.3 gallons of diesel per hour in order to generate a now typical axel power of 100 hp [7]. With an efficient electrical drive train, solar panels of the best quality and with optimal sun exposure it would take about 2,500 square feet of solar panels to generate the same axel power. It is difficult to conceive how even a part of this could be safely mounted on a tractor. If the panels were stationary and the energy was stored in batteries on the tractor, at current prices the battery storage for one hour of tractor work costs over $40,000, and will need several replacements over the life time of the tractor.

Only a combination of automatization with innovative traction will make on-board solar panels economically viable. Automatization means that without an expensive human driver the vehicle can be sized down and operated at far lower speeds, spreading the work efficiently over all suitable work days. Besides power, total energy consumption is also reduced. Reduced speed reduces implement draft by as much as 20%, and the higher precision of an autonomous implement can save another 25% of energy.

The claimed traction mechanism promises to save another 20% to 40% of energy. Without wheel slip, its engine load is a reliable indicator of soil resistance, making it easier to build maps of soil physical properties, and to continuously optimize tillage depth and other work parameters to the current soil properties. Only if all these technologies are used together, it becomes conceivable that a vehicle can plow with on-board solar panels that cover 100 square feet or less.

References

[1] ASABE, "Agricultural Machinery Management Data," American Society of Agricultural and Biological Engineers, ASAE D497.5 FED2006.

[2] F. M. Zoz and R. D. Grisso, "Traction and Tractor Performance," American Society of Agricultural and Biological Engineers, 913C0403, Feb. 2003.

[3] D. R. P. Hettiaratchi and A. R. Reece, "Symmetrical three-dimensional soil failure," J. Terramechanics, vol. 4, no. 3, pp. 45–67, Jan. 1967.

[4] E. McKyes and O. S. Ali, "The cutting of soil by narrow blades," J. Terramechanics, vol. 14, no. 2, pp. 43–58, Jun. 1977.

[5] R. D. Grisso and J. V. Perumpral, "Review of models for predicting performance of narrow tillage tool," Trans. ASAE, vol. 28, no. 4, pp. 1062–1067, 1985.

[6] E. K. S. Nambiar and R. Sands, "Effects of compaction and simulated root channels in the subsoil on root development, water uptake and growth of radiata pine," Tree Physiol., vol. 10, no. 3, pp. 297–306, Apr. 1992.

[7] R. D. Grisso, J. V. Perumpral, D. H. Vaughan, G. T. Roberson, and R. Pitman, "Predicting Tractor Diesel Fuel Consumption," Virginia Polytechnic Institute and State University, 442-073, 2010.

[8] W. Söhne, "Fundamentals of pressure distribution and soil compaction under tractor tires," Agric. Engin., vol. 39, p. 290, 1958.

[9] W. R. Whalley, E. Dumitru, and A. R. Dexter, "Biological effects of soil compaction," Soil Tillage Res., vol. 35, no. 1, pp. 53–68, Aug. 1995.

[10] M. A. Fullen, "Compaction, hydrological processes and soil erosion on loamy sands in east Shropshire, England," Soil Tillage Res., vol. 6, no. 1, pp. 17–29, Sep. 1985.

[11] ASABE, "Terminology and Definitions for Agricultural Tillage Implements," American Society of Agricultural and Biological Engineers, ASAE S414.2 MAR2009, Mar. 2009.