Motion Study of Spike Entering the Soil of the Interlock Drive System

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Introduction

Machines for intensive agriculture require drive power. Until now this has been generated mainly by frictional connection to the soil. A frictional connection needs weight to apply drive power. This weight shears and compacts the soil, reduces soil fertility, reduces water infiltration, increases water runoff and increases erosion. The generation of traction on a field is also possible via the interlock drive system, where narrow articulated spikes penetrate the ground at regular intervals and push the vehicle horizontally over the ground, avoiding the vertical pressure of wheels (Bover, 2011). The interlock drive system can provide high tractive power for productive agriculture using lightweight construction and little energy consumption, as has been demonstrated in over 30 prototypes (Nannen ea., 2016). Many of the fundamental working principles of this new drive system are not yet properly described. This makes it difficult to design a machine for specific soil and operating conditions without adjustment and refitting in the field. So, it is unclear until now whether an implementation with a few long spikes will operate more efficiently than an implementation with more but shorter spikes. It has also not been examined how the degree of compaction and the amount of soil moisture affect the efficiency of the spike and how the horizontal motion of a spike depends on soil conditions.

Material and method

For the present study, we attached a spike with a lever to a movable joint as originally proposed by Bover (2011). When a horizontal backward force is applied to such an articulated spike, it rotates and penetrates into the soil until the opposing force of the soil halts the movement of the spike. A forward force pulls the spike out of the soil. The spike has a backward and downward inclination of 45° from horizontal when out of the soil, and an inclination of up to 80° from horizontal when penetrating into the soil. The system is self-regulating because the spike only penetrates as deep into the soil as needed to generate the required tractive force. For a full description see Nannen e.a. (2016) or view the videos at http://sedewa.com. To study the motion dynamics of such an articulated spike when it enters the soil under force, an articulated spike was attached to a horizontal cable, such that a horizontal pull can be applied to the joint in a controlled manner. As the pull increases, the spike rotates into the soil. Its deepest point (the tip) moves both vertically and horizontally in the soil. During the experiment, the load was increased in increments of 50 N, and the degree of inclination of the lever and the horizontal motion of the joint was measured. From these measurements, the motion of the tip of the spike in the soil can be calculate with basic trigonometric functions. The experiments were done on silty clay loam in Vilafranca de Bonany, Spain. In total three different compaction levels of soil were investigated: loose, medium, and compacted soil. Each compaction level was investigated in dry and wet conditions, resulting in six different soil variations. Each variation was repeated three times and results were averaged.

Results and discussion

Graphs a) and b) in Figure 1 show the horizontal and vertical (depth) motion of the tip in the soil as a function of horizontal pull applied to the spike. The ratio of pull force to tip motion is approximately but not exactly linear and diminishes with increasing pull. This is likely caused by increasing soil strength with depth. a) shows that the effect of pull on horizontal tip motion depends on soil moisture and the degree of soil compaction. In dry soil the horizontal displacement of the tip measured up to twice as much as in wet soil. The maximum horizontal displacement of the tip was measured in dry loose soil and the minimum in wet loose soil. The depth of the tip reached -50 mm in dry compacted soil, while in loose and wet soil the tip went deeper into the soil, with a maximum of -250 mm for wet loose soil.

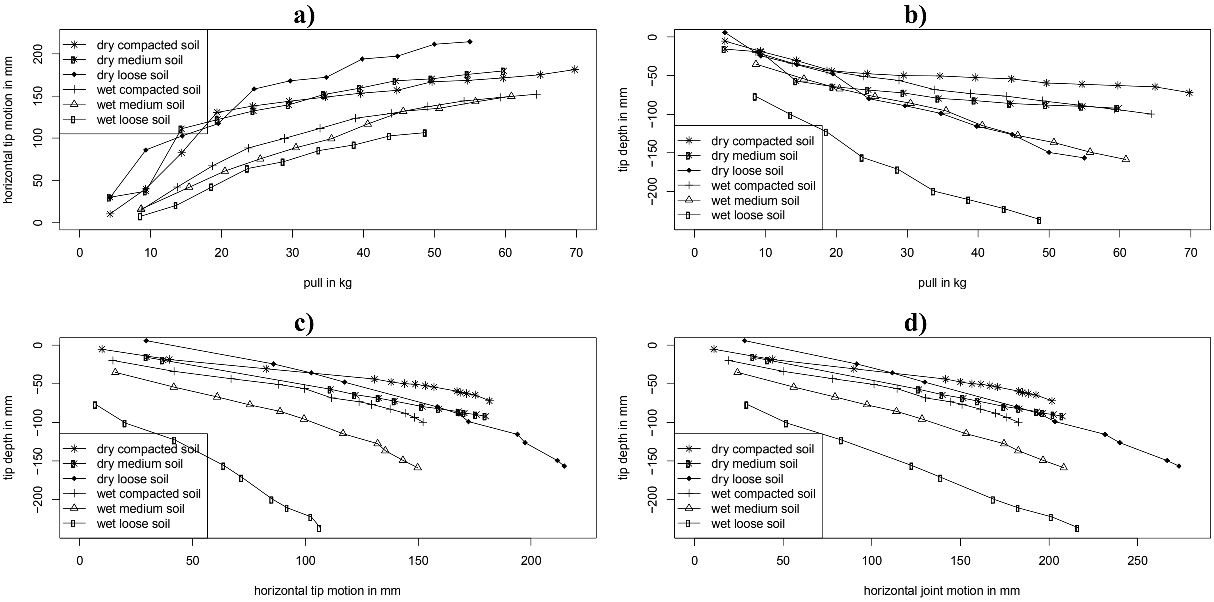

Figure 1: The horizontal x-axes show the applied pull force in N or the resulting horizontal motion in mm. The vertical y-axes show the corresponding horizontal or vertical (depth) motion of the tip in mm.

Graphs c) and d) show how the depth of the tip changes with the horizontal displacement of the tip and the joint. Despite the fact that the articulated spike rotates into the soil, the relation of horizontal to vertical tip motion in the soil is very linear for all soil types. Only the slope changes, especially for wet loose soil. c) and d) also show that for dry soil, the degree of soil compaction has little effect on the slope, while for wet soil, the slope increases with decreasing degree of soil compaction. Especially in wet loose soil, the tip can enter three to four times as deep as in dry loose soil for the same amount of horizontal tip motion.

Conclusion

The results show a close to linear relationship between pull force and horizontal tip motion, as well as between pull force and vertical tip motion. This suggests that for a given pull force, the horizontal tip motion in the soil is inversely proportional to the number of spikes over which an implementation of the interlock drive system distributes the pull force. Likewise, the more spikes an implementation has, the less deep they will penetrate into the soil for a given pull force. The slope of this linear relationship is expected to be steeper in dry than in wet soil. Another conclusion is that the interlock drive system can generate pull on wet soil, and that it penetrates wet soil more than twice as deep as dry soil for the same pull force, which is a factor when designing for the maximum penetration depth of a spike.

References

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