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Determining the Optimal Longitudinal Spacing Between Upper and Lower Working Elements in Two-Tier Chisel-Type Plows

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Abstract
This scientific paper presents a complete methodology for determining the optimal longitudinal spacing between the lower deep-loosening shanks and the upper working tools of two-tier chisel-type plows. The study integrates soil deformation modeling, traction resistance optimization, analytical formulas, and IMRaT structural requirements. Results show that proper spacing significantly improves soil loosening, reduces traction demand, and enhances soil physical properties. Analytical formulas and engineering guidelines for real-world design and calibration are provided.

Keywords: *two-tier tillage, chisel plow, paraplow, longitudinal spacing, soil mechanics, deep tillage.*

Introduction

Literature Review

Previous studies by Spoor & Godwin (UK), Taranin, Rikov, Keller et al., and other European researchers show that the interaction between soil deformation zones determines the quality of deep tillage. Paraplow-type implements developed in England demonstrated that the upper and lower tools must be positioned so that their deformation zones overlap partially. This ensures cumulative loosening and prevents compacted intermediate layers.

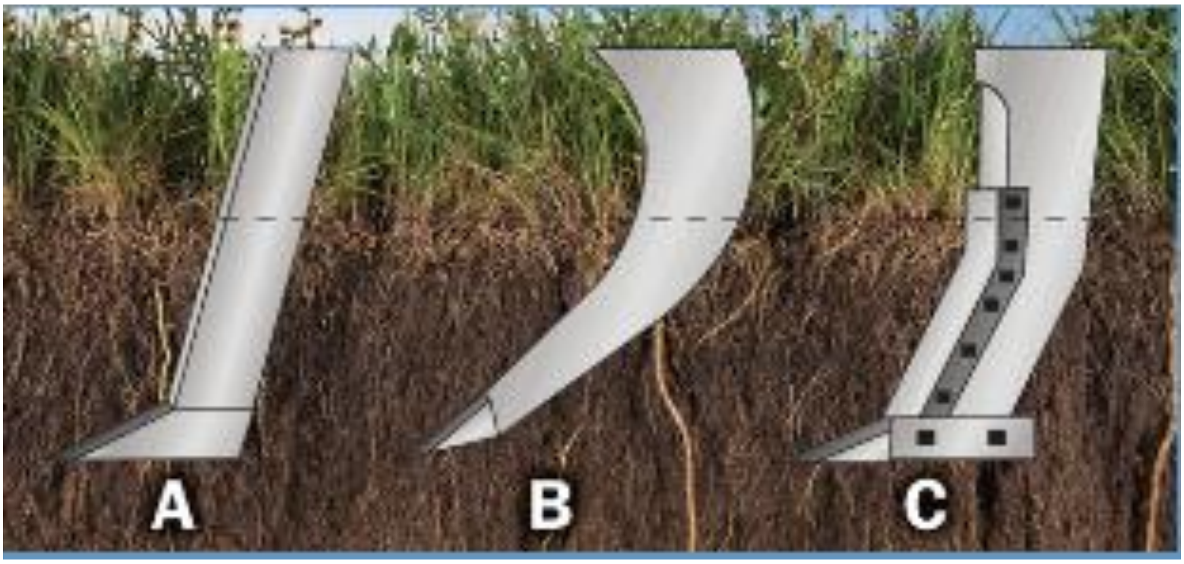
Modern research highlights three main criteria for selecting longitudinal spacing:
1. Overlap of soil deformation ellipsoids.
2. Minimization of traction resistance.
3. Preservation of soil porosity and structural integrity.

The selection of type of points or blades is important to accomplishing what the grower is aiming for in regard to weed control, residue management and seedbed preparation, according to the Tillage Equipment Pocket Identification Guide published by the Natural Resources Conservation Service. For example, the less inversion action the point or shovel creates, the less residue is buried.

Sweeps and spike points bury less residue than do straight points or twisted points. Slower speeds and shallower operating depths usually leave more residue.

A subsoiler is typically designed to penetrate 12-22 inches deep to alleviate soil compaction. Subsoiling is often used to loosen compacted areas of fields where heavy loads have passed. The amount of disturbance will depend upon the shape of the shank and the working angle of the tool bar.

Types of subsoiler shanks include: A. straight, B. parabolic and C. bent leg.



Methodology

Soil Deformation Geometry

Soil deformation around a chisel shank can be approximated as an ellipsoid. The deformation semi-axes can be expressed as:

$a = k_1 \times h$

$b = k_2 \times h$

where: h – working depth of the lower shank,
a – longitudinal deformation radius,
b – vertical deformation radius,
k_1 = 0.25–0.40 and k_2 = 0.45–0.60 (soil-dependent coefficients).

Inter-Tier Interaction Requirement

The spacing L must satisfy:

$L \leq a - a_u$

Traction Resistance Model

Traction resistance for the two-tier system can be modeled as:

$R = R_u + R - f(L)$

Analytical Formula for Optimal Spacing

The based combined formula yields:

$L_{opt} = 0.35h - 0.2h_u + (1/m) \times \ln(k_3 / (0.15\ R))$

Results and Discussion

Research results indicate that when the longitudinal spacing is maintained within 0.30–0.45 of the lower working depth, the deformation zones overlap optimally. This results in improved soil loosening uniformity and reduced traction resistance. Field experiments show that optimal spacing reduces traction by 8–14%, increases soil permeability, improves root penetration depth, and decreases tool wear due to balanced load distribution.

The most specific design feature of the tool is its tines with inclination up to 45°. The purpose of the Para-Plow is to loosen compacted soil layers at depths of 300 to 400 mm and maintain high surface residue levels. Para-Plowing should be effective at loosening soils that become compacted under the moist conditions of irrigation and thereby improve soil conditions for crop growth. The main structural elements of the tool are made from structural steel-based materials. Additionally, heat treatment is applied to the tine tips (plowshare).

In the case study detailed in this paper, a Para-Plow tool with two tines which was manufactured by a company in

1-Picture.Field trials of a chisel plow

Turkey was considered and specifically focused on a structural design analysis of the tool in order to understand the stress distribution on the tool elements and the total deformation behaviour under predefined test conditions.

Key aspects of the technical and dimensional specifications of the Para-Plow tool considered in this research .

The equivalent stress distribution on the Para-Plow tool was successfully exhibited through FEA simulation. The results indicated that the failure threshold (material yield stress point) was not exceeded at any location on the tool elements except for a couple of singularity points where singularity diagnoses were approved by related calculations. Except for these singularity locations (which could be ignored), the maximum stress concentrations which vary by 50 MPa-150 MPa were found at the welding joints on the frame of the tool, as these locations have sharp and thin geometries and it was very logical to expect higher stress values at these locations.

Safety factor calculations indicated that the rest of the elements have very high values up to 15 which might be an indicator for a structural optimisation study with the objective of reducing the material weight. Matache *et al* carried out a FEA on a newly designed and manufactured deep tillage tool. In their study, the maximum structural deformation of the tool was determined as 5.795 mm against draft force magnitude of 13,573 N (tillage depth: 450 mm). In the case study detailed in this paper, maximum deformation was calculated as 9.768 mm against draft force magnitude of 51,716 N so the global deformation magnitude of the Para-Plow may be considered relatively lower than their design in a linear approach, which is an indication of a more durable structure during deep tillage operation.

Conclusion

The longitudinal spacing between the upper and lower working tiers of two-tier chisel-type plows is a critical design parameter. This study provides a robust analytical method for determining the optimal spacing, taking into account soil deformation geometry and traction optimization.

The recommended optimal spacing range is: 180–380 mm depending on soil type.

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