FORCE MODELLING AND ENERGY OPTIMIZATION FOR SUBSOILERS IN TANDEM.

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SUMMARY

FORCE MODELLING AND ENERGY OPTIMIZATION FOR SUBSOILERS IN TANDEM.

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In the recent past, as more farm power is being demanded on farms, due to increased farm sizes and operating speeds, larger and heavier farm machines are deployed in various farming operations. Their cumulative negative effects have become more apparent with increased incidences of soil compaction problems. This has forced many farmers to practice deep tilling, using subsoilers to break up compacted subsoil layers.

In some maize growing regions of South Africa, conventional subsoilers are used in a tandem configuration. The farmers believe that the use of subsoilers in this mode reduces the draft force per unit area tilled. This probably happens because the critical depth for the rear subsoiler is increased beyond its working depth of 600 mm. Operating in this mode necessitated this study, with the ultimate goal of testing an appropriate existing force model for a single tine in predicting the force requirements of the front subsoiler in a tandem configuration. Secondly, to develop an alternative model for the rear subsoiler based on the three-dimensional failed soil-profile and to determine the relative position of the front subsoiler at which energy utilization is optimized.

To develop the proposed model, an analytical approach based on limit equilibrium analysis was used and a Matlab-based computer program was coded to solve it. Its verification was conducted through field experiments in sandy clay loam soil. The experiments consisted of a continuous measurement of the horizontal and vertical forces acting on each subsoiler by a two-dimensional force transducer system. At the same time, the three-dimensional and thus the cross-sectional areas of the disturbed soil-profiles at different sections were measured, as well as the soil characteristics. A manual method employing a pin-profile meter was used to measure the vertical cross-sectional areas of the failed soil-profiles at 100 mm intervals. Further more, a technique using an automatic penetrometer and a computer program was developed to identify and map the three-dimensional failed soil-profiles. This technique indicated that the subsoiler failed the soil beyond its maximum operating depth and width.

The results also indicated that the soil-failure pattern at close spacing is in phase at both subsoilers, leading to reduced total draft force requirements. At a wider spacing, the soil-failure pattern was out of phase, thus resulting in increased total draft force requirements. At the same time, the cross-sectional area tilled per unit draft force increased with increased spacing. This was because the failed maximum cross-sectional area increased in size faster than the total draft force as the spacing was increased.

The proposed model verification results show that the predicted and recorded forces at the rear subsoiler correlated reasonably well at a wider spacing. When the front subsoiler was shallow working and close to the rear subsoiler, the model under-predicted the measured forces on the rear subsoiler, whilst the Swick-Perumpral model over predicted the applied forces to the front subsoiler and this was generally the case at wider spacings.

Furthermore the efficiency of the subsoilers was maximized when the longitudinal spacing was such that it allowed the soil failed by the front subsoiler to stabilize before the rear subsoiler reached it. The maximum cross-sectional area failed per unit draft force was recorded when the depth of the front subsoiler was equal to about 80% of the rear subsoiler-operating depth.

The knowledge contributed by this research will not only facilitate qualitative field operations and optimize energy use, but also promote better management decisions.

Key terms: draft, dynamometer, energy, modelling, optimization, passive, power, subsoiler; soil-failure, tillage.

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I dedicate this thesis to my children Vicky, Isaac, Carolyn and Alice.

May they mature into women and man respected by all.

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NOMENCLATURE

A	Area (m^2)
A_c	Maximum cross-section area of a failed 3-D soil profile (m^2).
A_f	Maximum cross-section area failed by the front subsoiler (m^2).
A_r	Maximum cross-section area failed by the rear subsoiler (m^2).
b	Width of an extended octagonal ring transducer (m)
C, C_1, C_2	Soil cohesion force (N).
c_c	Soil cohesion coefficient (Pa)
C_a	Soil/tool adhesion force (N).
c_a	Soil/tool adhesion coefficient (Pa)
D	Operating depth of the rear subsoiler (m).
D_f	Draft force exerted on front subsoiler (N).
D_r	Draft force exerted on the rear subsoiler (N).
D_m	Measured draft force at front and rear subsoilers (N).
D_p	Predicted draft force at front and rear subsoilers(N).
d	Operating depth of the front subsoiler (m).
d_{op}	Optimum depth of the front subsoiler (m).
E	Modulus of elasticity (MPa)
F_1, F_2	Acceleration force (N).
F_a	Force applied to a load-cell (N).
F_d	Draft force under dynamic conditions (N).
F_s	Static draft force component (N).
F_{cal}	Load-cell calibration factor (VN^{-1}).
F_{tot}	Total frictional force (N).
FSS	Front subsoiler
f(v)	Draft force function containing a soil inertial component (N).
g	Gravitational constant (9.81 ms^{-2}).
H, H_1, H_2	Horizontal force component (N).
H_{ac}	Horizontal force required failing the maximum cross-sectional area (N).
H_d	Horizontal force required failing a 3-D soil profile (N).
H_p	Horizontal force required to pulverizing a tilled soil slice (N).
H_{Tot}	Total draft force required to failing a 3-D soil profile (N).
L_1....L_7	Load-cells.
M	Moment (kN.m).
n	Ring thickness of an extended octagonal ring transducer (m)
P, P_1, P_2	Tool force (N).
p	Soil contact pressure (Pa).
Q_1, Q_2	Surcharge force (N).
q	Surcharge pressure ($N.m^{-2}$).
R_f	Soil-rupture radius of the front subsoiler (m).

R_r	Soil-rupture radius of the rear subsoiler (m).
R_z	Soil-rupture radius of the rear subsoiler at depth d (m).
R_1.... R_7	Load-cell reactions due to loading (N).
RSS	Rear subsoiler
r	Mean radius of the extended octagonal ring transducer (m).
s_f	Maximum width of the side soil-failure wedge of the front subsoiler (m).
s_r	Maximum width of the side soil-failure wedge of the rear subsoiler (m).
t	Distance (m).
V,V_1,V_2	Vertical force (N)
V_{cf}	Soil-volume disturbed by the front subsoiler in the center wedge (m^3).
V_{cr}	Soil-volume disturbed by the rear subsoiler without front shank (m^3).
V_{crx}	Soil-volume between the subsoilers in the center wedge (m^3).
V_{ct}	Soil-volume disturbed by the two subsoilers in the center wedge (m^3).
V_{cx}	Soil-volume disturbed by the rear subsoiler in the center wedge (m^3).
V_f	Vertical force component acting on the front subsoiler (m).
V_m	Measured vertical force at both subsoilers (N).
V_{out}	Transducer output voltage (V).
V_p	Predicted vertical force at both subsoilers (N).
V_r	Vertical force component acting on the rear subsoiler (N).
V_{ra}	Soil volume accelerated by the rear subsoiler (m^3).
V_{sf}	Soil volume disturbed by the front subsoiler in the side wedge (m^3).
V_{sr}	Soil-volume disturbed by the rear subsoiler without front shank (m^3).
V_{srx}	Soil-volume between the two subsoilers in the side wedge (m^3).
V_{st}	Soil-volume disturbed by the two subsoiler in the side wedge (m^3).
V_{sx}	Soil-volume disturbed by the rear subsoiler in the side wedge (m^3).
V_{t1}	Soil-volume disturbed in the center-wedge (m^3).
V_{t2}	Soil-volume disturbed in the side wedge (m^3).
V_T	Total soil-volume of the failed soil-profile (m^3).
v	Operating speed (ms^{-1}).
W, W_1, W_2, W_3	Weight of disturbed volumes of soil (N).
w	Tool width (m).
x	Projected distance between the two subsoilers (m).
z	Effective operating depth of the rear subsoiler in undisturbed soil (m).
α	Rake angle (degrees).
β	Angle between the rupture plane and the horizontal soil surface (deg.).
β_f	Angle between the rupture plane of the front subsoiler and the horizontal soil surface (degrees).
β_r	Angle between the rupture plane of the rear subsoiler and the horizontal soil surface (degrees).
ε_{max}	Maximum strain (MPa).

δ	Interface friction angle (degrees).
ϕ	Internal soil friction angle (degrees).
γ	Soil unit-weight (Nm^{-3}).
θ	Horizontal included angle of the circular side crescent (degrees).
ρ, $\rho^{/}$, $\rho^{//}$	Angle (degrees).
σ_{all}	Allowable stress (Pa).
σ_n	Normal stress (Pa).
τ, τ_0, τ_1	Soil shear strength (Pa).
μ	Frictional coefficient.