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New geotechnical approaches to soil biological processes

Experiment and numerical investigation of root penetrating process

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scri living technology

1 Introduction

Plant roots grown in compacted soils have to overcome the impedance. This will include a component of resistance required to deform the soil and a component due to the frictional force on the surface of the growing root (Barley, 1962).

Quantitative information on soil resistance is essential for an understanding of the behaviour of roots, there are few experiments in which root penetration forces directly measured (Whiteley et al., 1981).

1) The penetrating ability of plant roots has been assessed from the resistance to blunt and sharp penetrometer probes (Voorhees et al., 1975). Soil resistance to probe penetration is much greater than the resistance to plant roots (Stolzy and Barley, 1968) although the relative responses of probes and roots to soil impedance are strikingly similar. Metal probes must follow a straight path.
2) Although Misra et al. (1986) and Bengough and Mullins (1991) have measured the penetration resistance directly to a growing root tip.
3) The above studies have not discussed the progressive local strain and stress distributions in the soil around the root.

1 Introduction

More detailed mechanical behaviour requires measurement of the localised deformation through the growing processes.

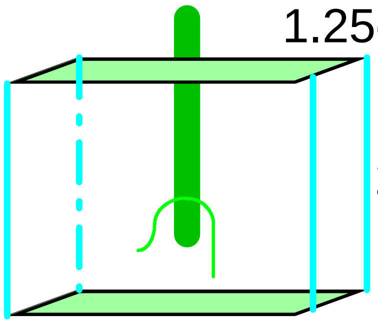
1) Greater resolution of axial and radial strains around the root tip is possible with particle image velocimetry (PIV), which detect the movement of pixels between sequential digital images (Adrian, 1991; Olsen et al., 2000). The PIV methodology was developed for fluid mechanics (Adrian, 1991) and recently it has been extended to measure pre-failure strains in soil tests (White et al., 2003). Mickovski et al. (2007) and Hamza et al. (2006) have highlighted the importance of root-soil interaction.
2) FE analysis to analyze the pressures exerted by root growth in soils have been used to predict the stress distribution around growing roots (Richards and Greacen, 1986; Faure, 1994; Kirby and Bengough, 2002).
3) The aim of this project is to capture the **images** by maize growth consider the **mechanism** of root growth (PIV) and the **dynamics** of its response (FEM) to changes in soil physical conditions,bulk density and water content (Experiments).

2 Experiment

Root Planting

Nikon D300 digital camera with 60mm Nikkor lens

1.25cm thickness



23cm

23cm

Perspex box

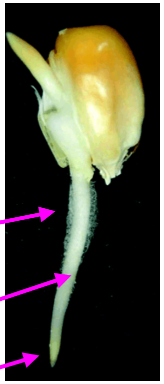
wild type maize cultivar KYS

Root diameter is 1-2mm

Root hair

Elongation

Tip



3-day-old maize primary root

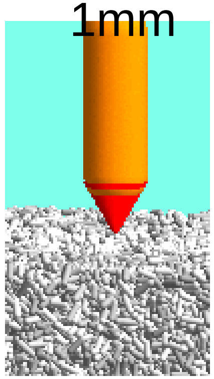
The clay loam used was the Winton Series (Glencorse Tillage Site, Penicuik, UK), with 36% sand, 40% silt and 24% clay (described by Kirby and Bengough (2002)).

The air-dried soil was wetted to a water content of **26.6**% (Kirby and Bengough (2002)) by weight. The experiment was also carried out with varied in water content, **21.6**% and **31.6**%.

2 Experiment

Packed to dry bulk densities of 1.0, 1.3, 1.4, 1.5 g/cm3

The soil resistance to penetration of a 1-mm cone penetrometer (30 cone angle, 4mm per minute rate of advance) was measured for all combinations of water content and bulk density. For each soil and density, the resistance was measured at three locations. A probe was driven down to 2 cm to calculate the mechanical impedance to penetrating.



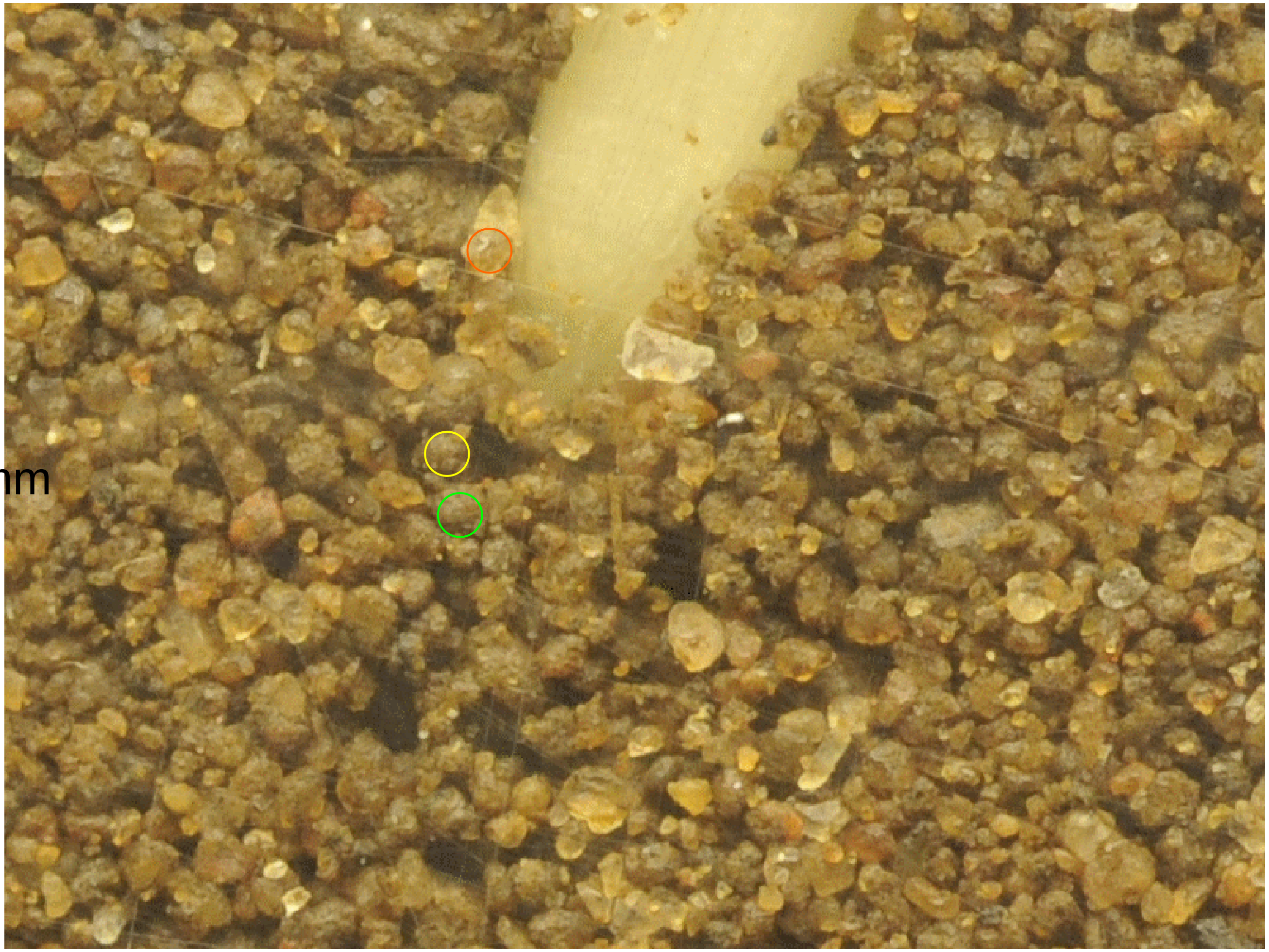
2cm

Penetrameter

a n
frame (Model 5544, INSTRON,
100 Royall St., Canton,
MA 02021-1089, USA)

Taken image 20 sec interval,
image size (640pixels)

2 Experiment – preliminary results

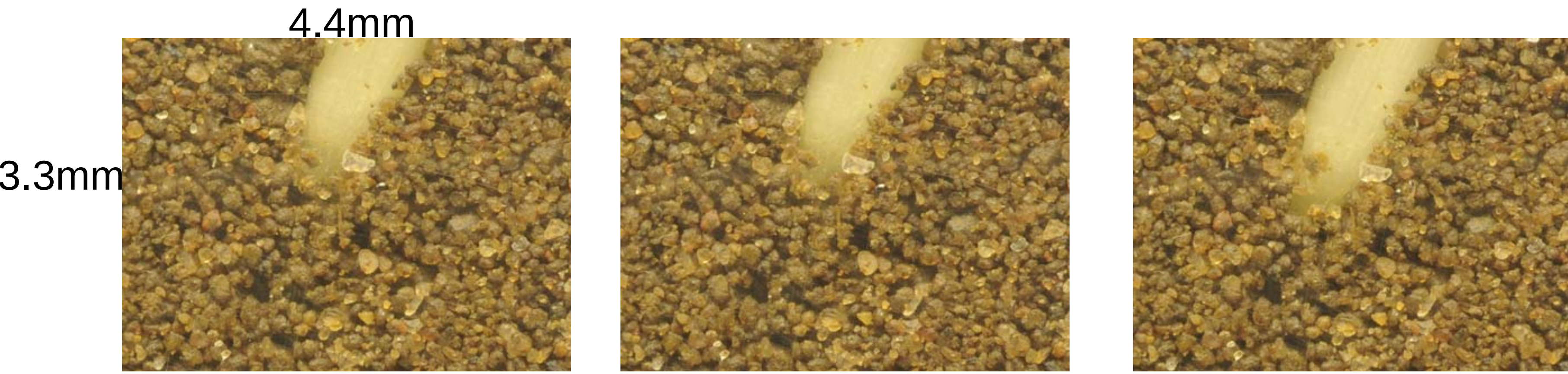


3.3mm

4.4mm

Image taken by time interval 2 minutes and runs for 20 minutes

2 Experiment – preliminary results



(a) (b) (c)

Fig. 1 Images showing root growth processes around tip for test case D3.
(a) Image took at the beginning; (b) Image took after 2 minutes; (c) Image took after 20 minutes. (Original image resolutions: 4288 2848 pixels. In this figure, trimmed image size is 800 pixels in width and 600 pixels in height; 180 pixels equal to 1mm. (Dry bulk density 1.4g/cm3; water content 26.6%)

2 Experiment – PIV analysis

Using GeoPIV8 (coded by Matlab environment) (White et al., 2003) , instantaneous local deformation along the whole or part of a plant root can be quantified alongside soil displacement adjacent to the roots between

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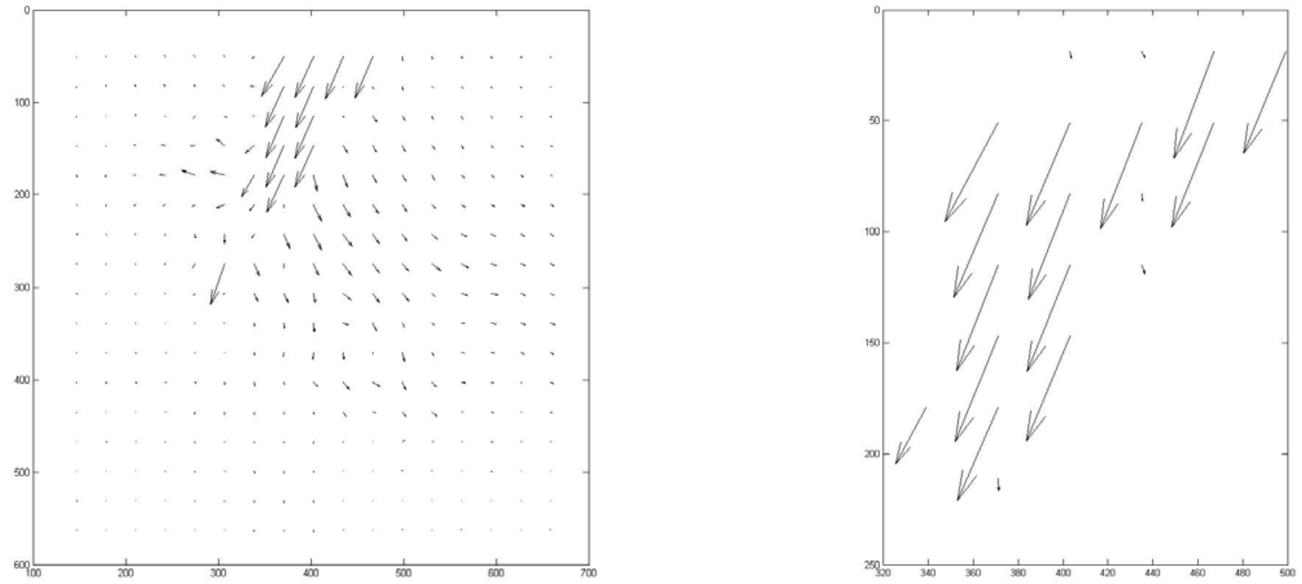


Fig. 2 Displacement vector diagram between the initial image and the image took after 2 minutes (A) Root-soil system; (B) Root. (Unit: pixels in x and y direction, 180 pixels equal to 1mm)

2 Experiment – PIV analysis

Based on finite element discretisation on shape functions, shear strains can be derived from the displacements field (Zienkiewicz and Taylor, 1998).

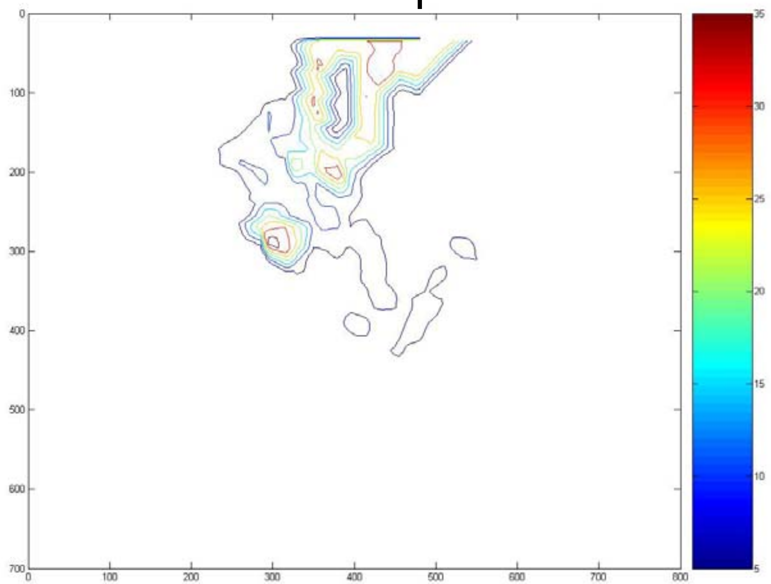


Fig. 3 Contours of maximum shear strains of Root-soil system (Unit: pixels in x and y direction; shear strains (dimensionless), with contours at 5% intervals)

The dimensions of the zone influenced during root penetration is localised within 4 mm2. A large strain development around root tip and soils ahead the tip can be found, 15%-20%, in the area of high strain gradient.

The clayey loam was the compressible soil and the frictional sensitivity under different water contents and density, and this might account for the differences in root growth. A numerical prediction of the stresses around roots in the soils was used to investigate this explanation.

3 Numerical prediction

Soil: Modified Cam Clay critical state model

Refer to (Kirby et al., 1998); (Kirby and Bengough, 2002)

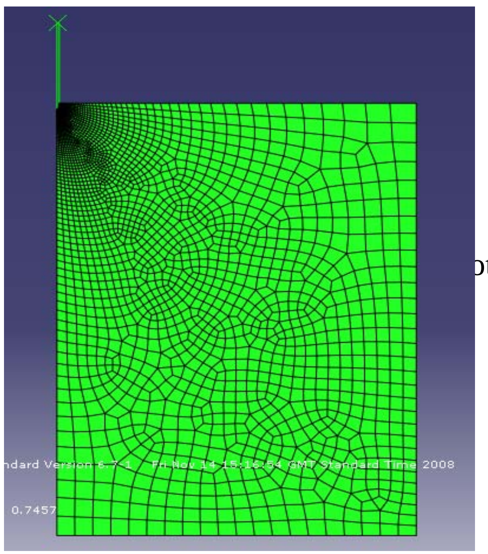
		Density(1.3/**1.4**/1.5)	Water content (21.6/**26.6**/31.6)
slope of critical state line	M	0.38	0.68/0.38/0.18
slope of normal consolidation line	λ	0.033	0.063/0.033/0.013
slope of unload-reloading line	κ	0.002	0.012/0.002/0.001
Young's modulus	E	27000	27000
Poisson's ratio	ν	0.3	0.3
initial void ratio	e_i	1.038/0.893/0.767	/0.893/
Pre-consolidation pressure	P_{cr}	27/75/180	65/75/105

Root-Soil interface: assumed the soil and root are both deformable bodies and can undergo finite sliding. A basic Coulomb frictional model was used to govern the interaction between the root and soil surfaces, coefficient is 0.1.

Root: Elastic model, rigid body; assumed to penetrate at constant shape but not expand radially.

3 Numerical prediction

A model was constructed in ABAQUS. Due to the root shape and load application angles being axial the problem was discretized using 2-D finite elements. Soil stresses have greater spatial variation close to the curvilinear tip of the root, thus the finite element mesh is denser.



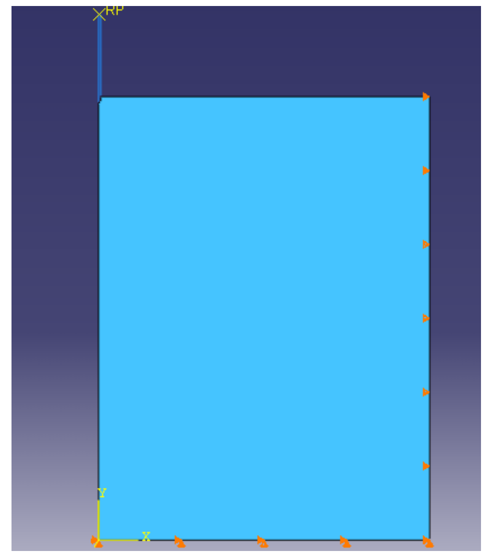
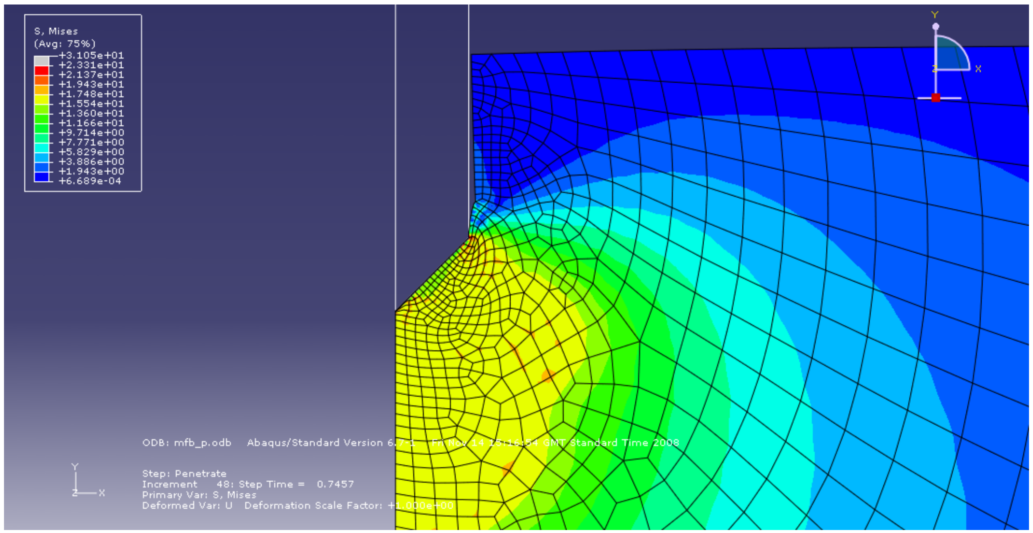


Fig. 5 Element mesh and boundary conditions for analysis

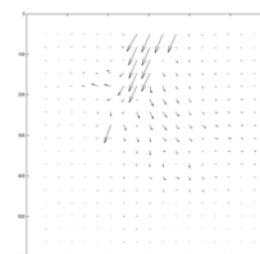
The model is then equilibrated with this stress field as initial condition, assuming linear elastic behaviour of the material and using the *GEOSTATIC option to verify that the geostatic stress field is in equilibrium with the applied loads and boundary conditions

3 Numerical prediction



it appears that the peak shear stress occurs in the soil adjacent to the apex of the root cap

predicted penetrating force can match the applied stress of root growth during the experiments?



3.4.1 Comparison with the laboratory data
3.4.2 Bulk density
3.4.3 Water content
3.4.4 Surcharge load
3.4.5 Friction coefficient influence on root-soil interface response
3.4.6 Mesh size

4 Discussions

Exempting from some biological phenomena, especially at the cellular level, cell enlargement or cell expansion, the mucigel acts as a lubricant to elongating roots, sensitivity of roots to gravity.

The FE force predicted for various soil physical conditions appeared to capture the general trend of measured root force data but the problem being modelled is complex and simplifications have to be made to obtain a solution.

Coupled with circumnutation (which would need a full 3D analysis with spatial statistical distribution of strength properties).

Two of the governing factors in this study which have a vast impact on both the real and model root growth are: a) the constitutive properties of the soil; and b) the root-soil interaction at the interface over the root surface. Different modelling for soil and root-soil interaction would be a interesting topic.

Earthworm burrowing process

Root penetration   Earthworm burrow

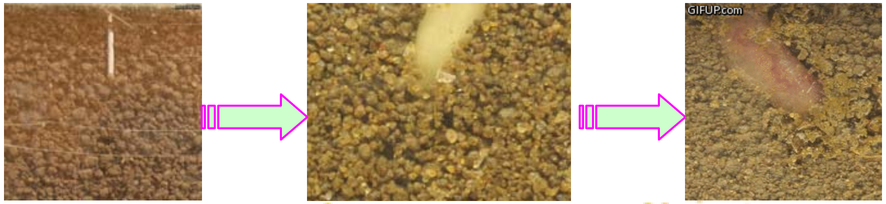
During burrowing, earthworms squeeze the anterior end forward into the soil by pushing against other parts of the body that serve as anchors. The anterior segments then expand as a new anchor that helps pull forward segments behind them. Obviously these stages are rather complicated and difficult to model in detail, both numerically and experimentally.

Attenuate→Extend→Pull

1) Hopefully **Penetration** + **Expansion** process will simulate this
2) Various density; water content to investigate the soil deformation patterns and the frictional properties of the surface during the burrowing
3) It can be helpful to design of novel earthworking machinery that reduces soil frictional resistance

Earthwor

Conclusions



- Experiments and image analysis and numerical simulation can be used in conjunction with the soil biological processes, to enable the quantitative prediction of soil deformations and stresses distributions around roots growing in compacted soil.
- Particle image velocimetry (PIV) was used to visualize and quantify soil displacement near the root based on the experimental images, which was an approach to measure localised displacement fields along such materials between sequential digital images.
- ABAQUS/Standard was used to solve the simulation of soil-root contact pair interaction using a frictional property, and a critical state soil model was used to simulate the root growth state in various soil physical conditions (bulk density and moisture content).
- The comparative results between the deformation pattern by using finite element analysis and the localised deformation around roots with PIV analyzing showed that the FE model captured the root penetration trend in soil and the peak root penetration resistance.
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Big thanks

thanks

Thanks

thanks

Cooperation

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