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VINCULANDO LA INFORMACIÓN CON ACCIONES POR EL AGUA Y LA ALIMENTACIÓN

Modeling of soil water to insure a suitable depth and spacing of subsurface drip irrigation tubing for alfalfa

THE UNIVERSITY OF ARIZONA

AGRICULTURAL & BIOSYSTEMS ENGINEERING

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Outline

- Introduction
- Materials and methods
- Results
- Conclusions

INTRODUCTION

- Subsurface Drip Irrigation (SDI) systems are low-pressure and high-efficiency irrigation systems.

- Alfalfa is a perennial crop harvested between three and eleven times each year.

Increased alfalfa hay yield as a result of higher water distribution uniformity (Imperial Valley, CA).

SDI Benefits

Saves water and improves yields → Eradicating →
- Surface water evapotranspiration
- Incidence of weeds
- Incidence of diseases on alfalfa leaves

Alfalfa seasonal harvests. (Netafim USA).

- The ability to irrigate immediately prior and after, and even during, the multiple seasonal harvests.

SDI advantages

- More uniform water distribution over time and space during the growing season. (Putnam et al., 2015).

- 20% increase in water use efficiency for alfalfa by using subsurface drip irrigation (SDI) rather than furrow irrigation. (Hutmacher et al., 2001).

Alfalfa field. (Holtville CA).

- Improved the yield by about 25%, while using about 40% less water than flood irrigation. (Godoy et al., 2003).

- Well-designed SDI system decreases the volume of applied water by about 22%, while increasing the yield by 7%, compared to center pivot sprinkler system. (Alam et al., 2002)

Problem

Alfalfa harvest operation requires a tractor and other heavy equipment to be driven over much of the surface of the field.

Drip tubing cannot be placed so close to the soil surface that the surface becomes wetted, or the tractor would be at best leave deep damage in the field or at worst to become “stuck.”

Up to this point in time, appropriate depths for such systems have been determined by “trial and error” for each new soil and equipment condition (Slack, D. et al., 2010).

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Solution

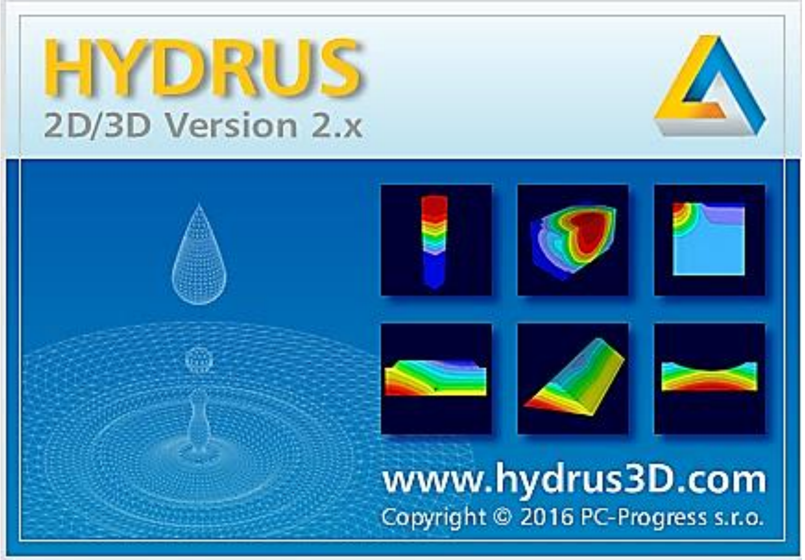
Use	Management alternative to place the drip tubing at a depth high enough that the soil surface will not become wetted but is still shallow enough to deliver water to the plant roots
Use	Numerical modeling techniques and soil data to model the wetting pattern from a subsurface drip emitter in the desired soil.
Use	Classical soil mechanics theory and soil strength properties to calculate increased stress on soil due to a surface load such as a tractor.
Use	Results of these analyses to make recommendations of appropriate depth and spacing of placement of drip tubing

METHODOLOGY

Use of HYDRUS-2D software (Simunek et al., 2008), a detailed numerical soil water flow model.

To determine an appropriate depth of placement of the drip line tubing.

Improved irrigation water management strategies for SDI of alfalfa.



HYDRUS-2D Software. (Simunek et al., 2008).

HYDRUS-2D – Richards equation

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left[K(h)\frac{\partial h}{\partial x}\right] + \frac{\partial}{\partial z}\left[K(h)\frac{\partial h}{\partial x} + K(h)\right] - S(h)$$

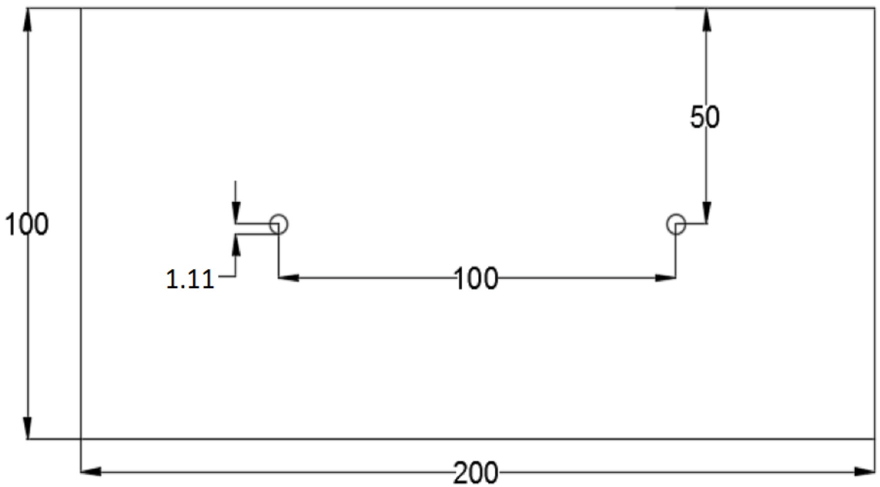
Where:
θ = Soil's volumetric water content [L^3 L^{-3}]
h = Soil water pressure head [L]
$S(h)$ = Sink term [L^3 L^{-3} T^{-1}]
t = Time [T]
$K(h)$ = Unsaturated hydraulic conductivity function [LT^{-1}]
x and z = Horizontal and vertical spatial coordinates [L]

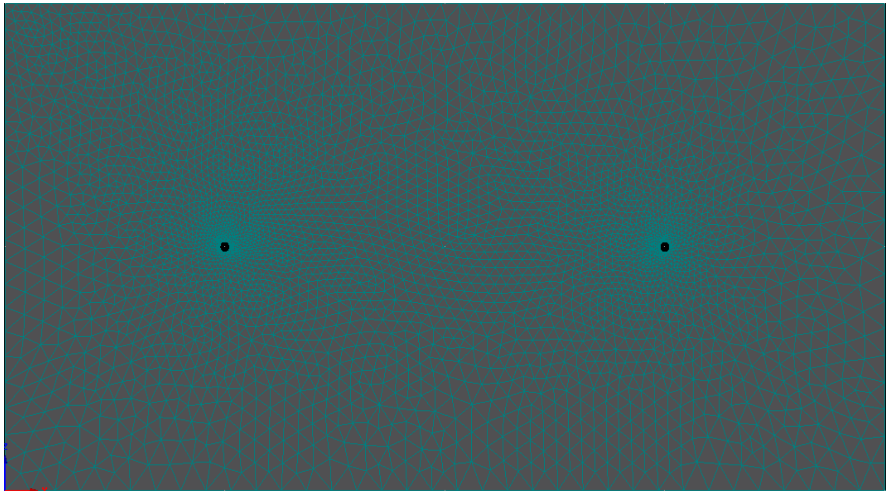
- Application efficiency of 95%
- Climate data: Holtville CA. Station #87, Meloland
- Maximum root distribution obtained from field measurements in Holtville: at 30 cm depth
- Spacing between drip lines: 100 cm
- Depth of placement: 50 cm

Subsurface drip irrigation for alfalfa. Imperial Valley CA.

Space domain

- Assumed homogeneous soil
- Three types of soil: Sandy Clay Loam (SCL), Clay Loam (CL), and Loam (L)
- Irrigation time and frequency: 12 hours, every 3 days.
- Space domain used for simulations: 100 cm height x 200 cm wide
- Spatial domain was discretized using triangular finite elements.





Domain space for drip irrigation simulation (cm) with a 50-cm drip line depth of placement.

Initial conditions

Emitter discharge, q = 2.71 cm/hr.

Emitter spacing: 36 cm.

* Free drainage boundary condition: bottom boundary.

* Atmospheric boundary condition: top boundary.

* Zero-water flux condition: remaining boundaries.

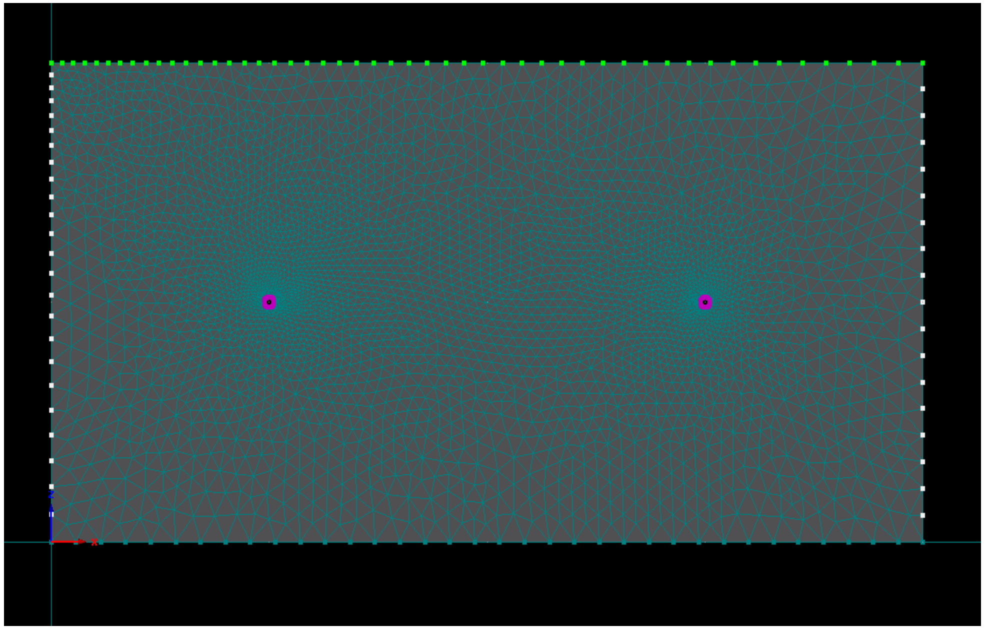
Pressure: -0.3 bars

SDI system configuration for alfalfa crop (Davis, CA).

Drip line tape specifications

Drip line tape specifications of the SDI installed in the alfalfa field at Holtville CA.

Boundary conditions



Edit Bar - Boundary Conditions

Water Flow

- No Flux
- Constant Head
- Constant Flux
- Variable Head 1
- Variable Head 2
- Variable Head 3
- Variable Head 4
- Variable Flux 1
- Variable Flux 2
- Variable Flux 3
- Variable Flux 4
- Free Drainage
- Deep Drainage
- Seepage Face
- Atmospheric Boundary

Boundary conditions assigned to each of the HYDRUS-2D simulations.

Different sensitivity analyses were made with identical climatic conditions (Holtville, CA) to evaluate water soil movement and the effect of drip line depth of placement, and soil texture on the harvest day.

Surface loads and soil shear strength

- **We must be able to utilize farm machinery on the surface while irrigation is occurring**
  - We need to place tubing deep enough to prevent soil failure due to reduced shear strength from wetting.
    - Utilize Boussinesq equations to calculate stress increase at any depth resulting from load on surface.
    - Utilize Coloumb equation for shear strength of mixed soil and mohr’s circle to determine failure envelopes.

Boussinesq's equation

$$\Delta p = \frac{3P}{z^2 * 2\pi * \left[1 + \left(\frac{r}{z}\right)^2\right]^{5/2}}$$

Where P is a point load at the surface (kg), Δp is the increase in stress (kg/cm2) at a depth z below the surface and a radial distance r from the surface point load. This increase in stress is independent of soil properties

Surface load

A 3,300 kg. four-wheeled tractor

- Weight distribution 65% rear, 35% front
- Contact area for rear tires – 87x43 cm

- At 10 cm below the surface as the "critical" depth since near saturation the surface soil would have no cohesion (and thus no shear strength).

Tractor utilized in the study. http://export-tractor.com/187-changfa-cf80.html

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Stress analysis. Boussinesq calculations

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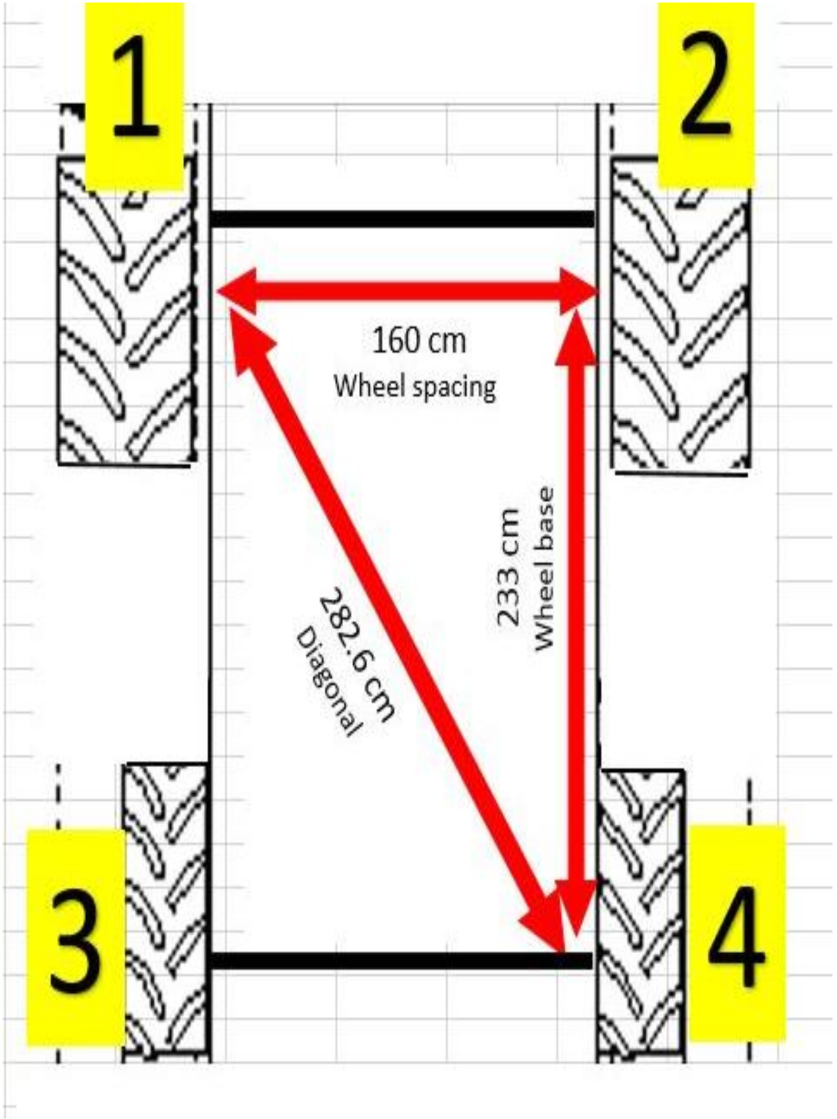
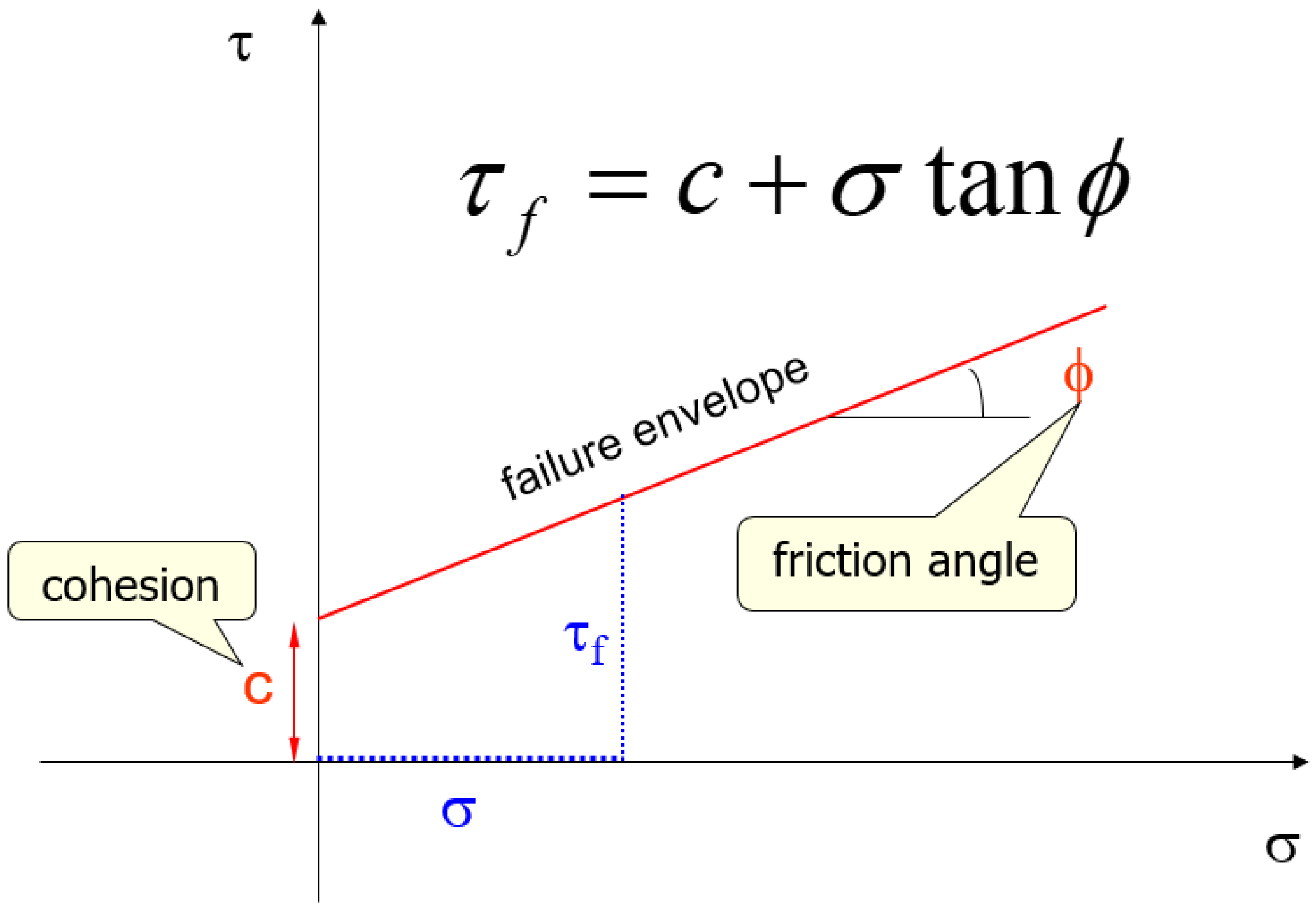
- Calculate increase in stress directly below one rear tire.
- Can treat loads from other three tires as point loads.



Graphical representation of the tractor wheels as each of the point loads.

Mohr-Coulumb Failure Criterion



- τ_f is the maximum shear stress the soil can take without failure, under normal stress of σ.

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Soil properties

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Soil type	Sandy Clay Loam (SCL)	Clay Loam (CL)	Loam (L)
Sand (%)	60.0	30.0	40.0
Silt (%)	15.0	35.0	40.0
Clay (%)	25.0	35.0	20.0
Bulk density (gm/cc)	1.62	1.56	1.51
Saturated MC (%)	43.0	48.0	46.0
50% AWC	5.00	7.00	7.00
FC (90% sat)	27.0	36.0	28.0
Saturated conductivity (cm/hr.)	1.13	0.43	1.55
Angle internal friction (degrees)	32.5	25.0	30.0
Cohesion (kPa) Compacted	62.5	82.5	75.0
Cohesion (kg/cm^2) Compacted	0.63	0.84	0.76
Cohesion (kPa) Saturated	15.0	15.0	15.0
Cohesion (kg/cm^2) Saturated	0.15	0.15	0.15
Cohesion (kPa) 90% Sat.	13.5	13.5	13.5
Cohesion (kg/cm^2) 90% Sat.	0.13	0.13	0.13

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RESULTS AND DISCUSSION

Close up view of drip tape & wetting pattern. (Imperial Valley, CA).

Installation depth:

40 cm SCL and L

35 cm CL

Spacing:

80 cm SCL and L

90 cm CL

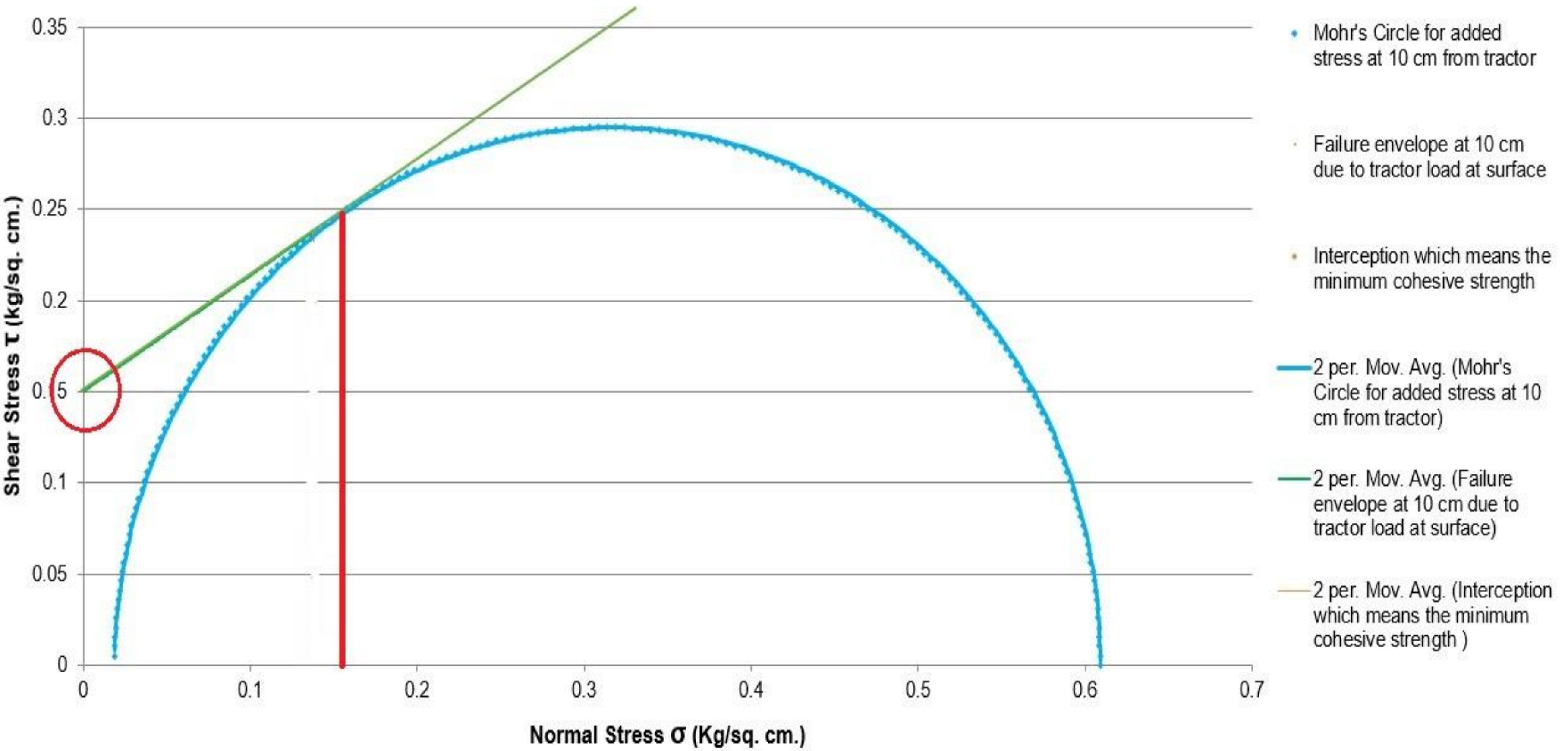
Recommendations

Stress increase due to surface load of tractor

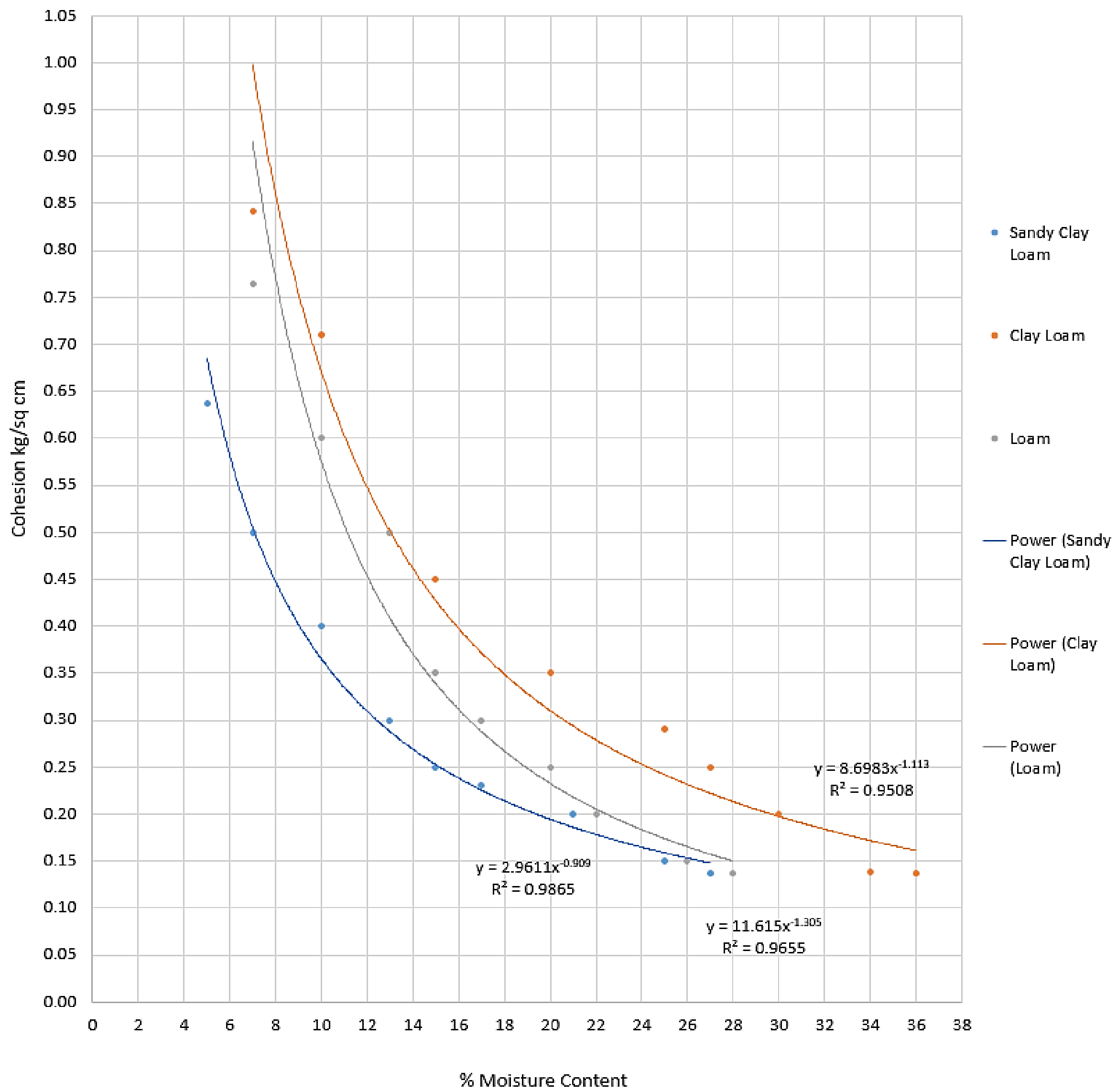
Depth of placement (cm)	Front tire #4 (kg/cm^2)
10	0.590
20	0.447
30	0.320
40	0.167
50	0.119
60	0.098
70	0.073

Increase in stress on soils at any depth due to a load on the surface from a conventional tractor used during harvest operations.

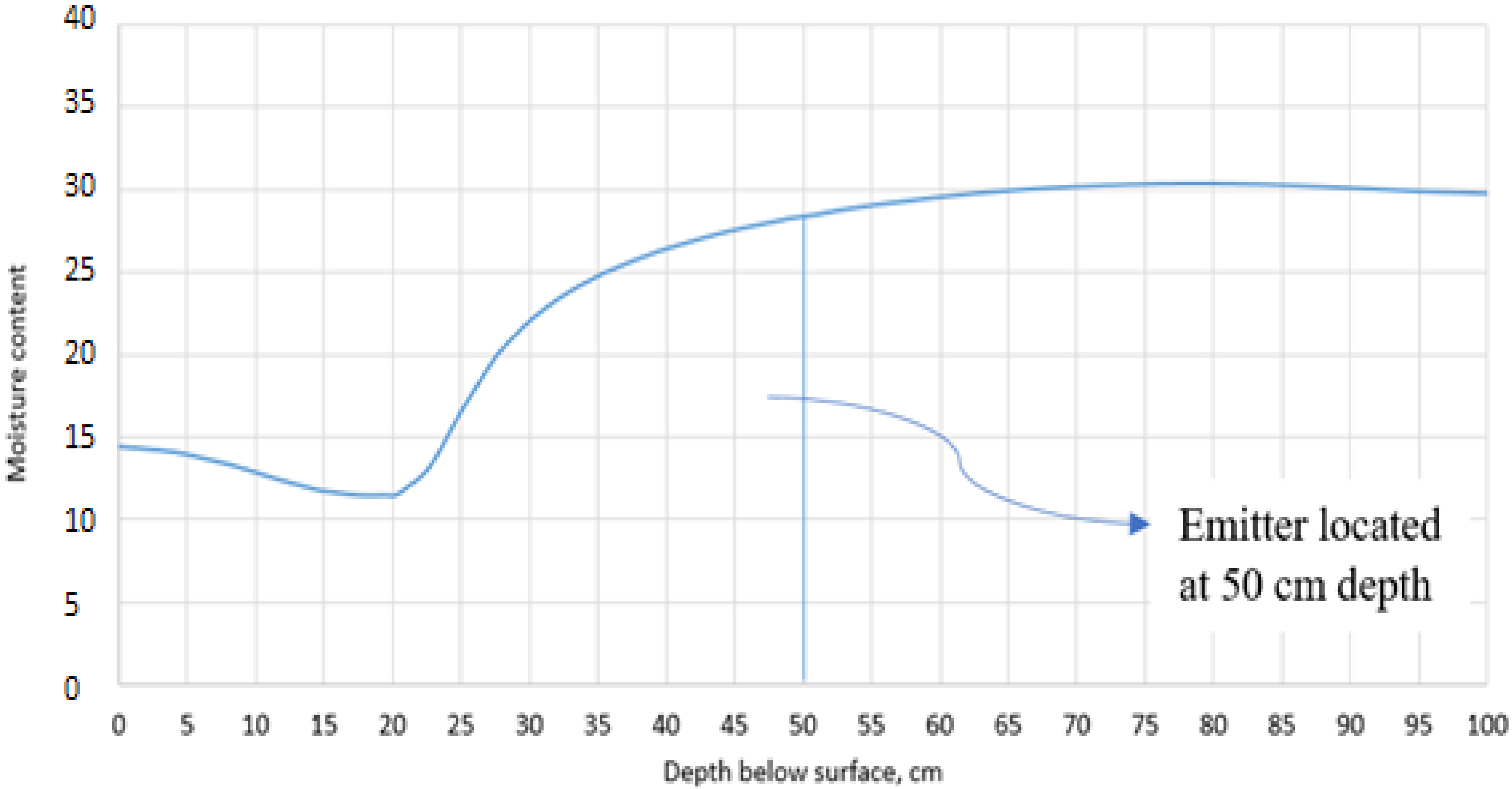
Soil strength results – Sandy Clay Loam



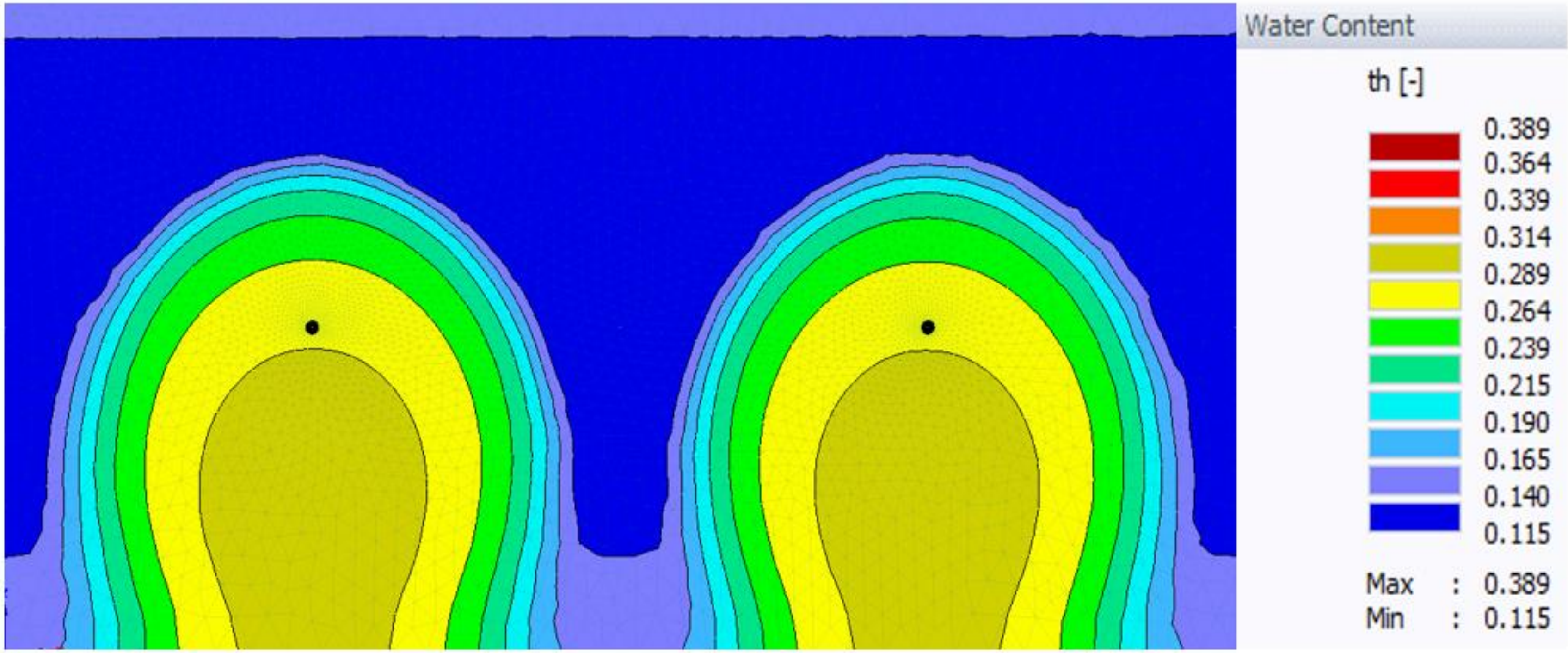
Mohr's circle and failure envelope for SCL at 10 cm depth with a tractor load at the surface. The minimum cohesive strength is of 0.15 kg/cm2



Relationship between cohesive strength and moisture content for the three soils

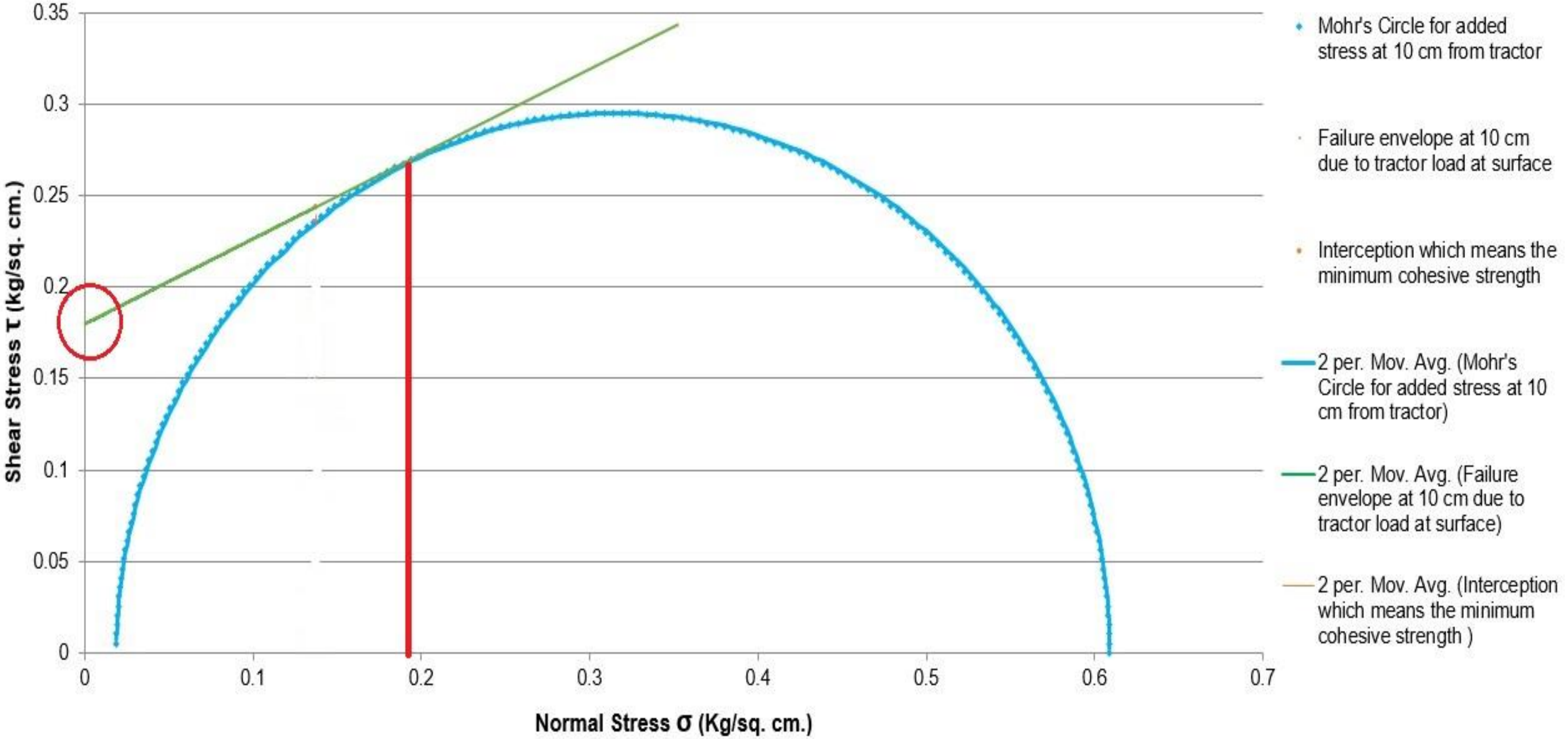


Moisture content (%) on the day of the cut, after 12 hours of irrigation, in SCL soil with a deph of placement of 50 cm.



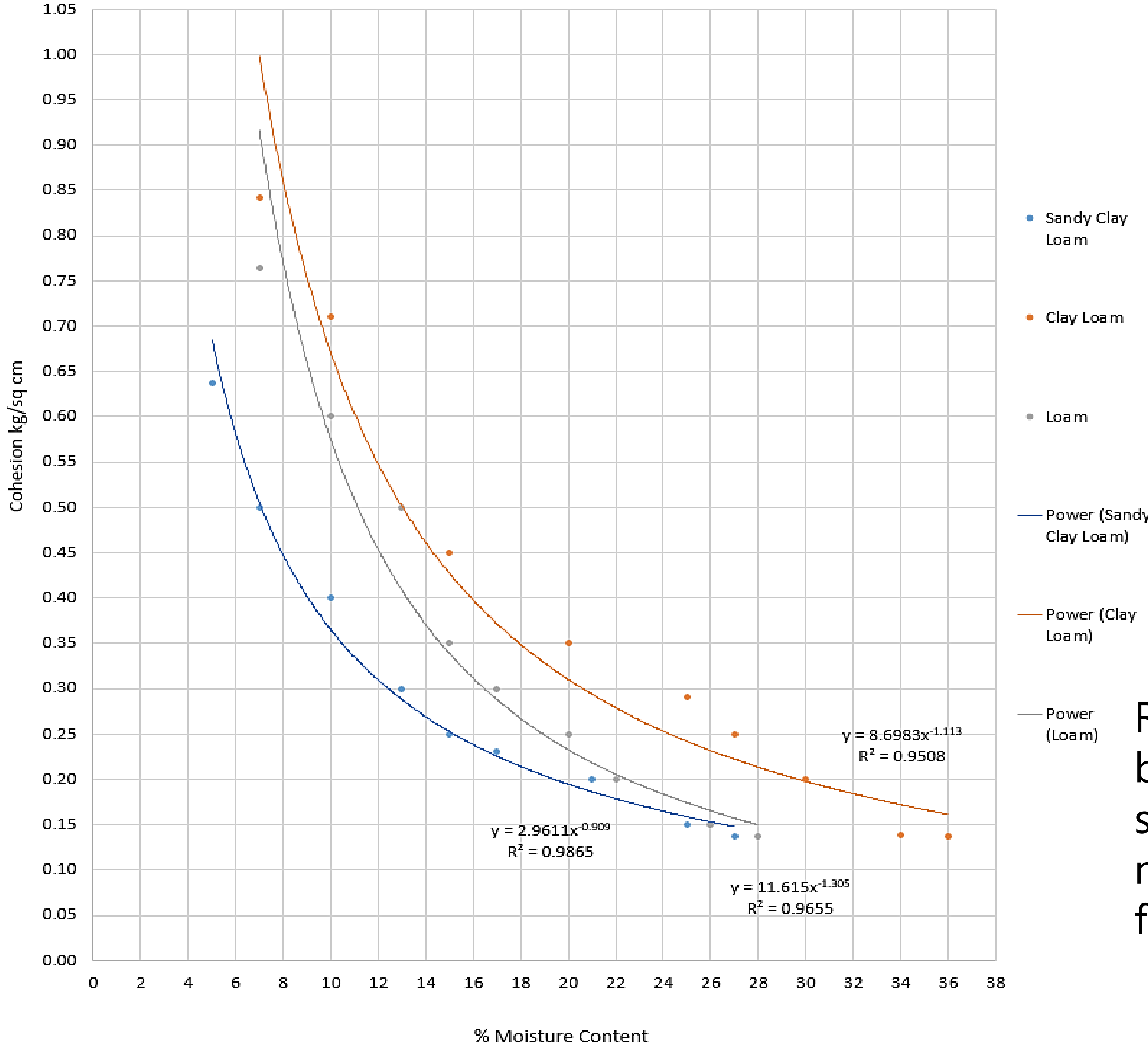
Graphical representation of the moisture content on the day of the cut, after 12 hours of irrigation, in the SCL soil with an emitter placement depth of 50 cm.

Soil strength results – Clay loam

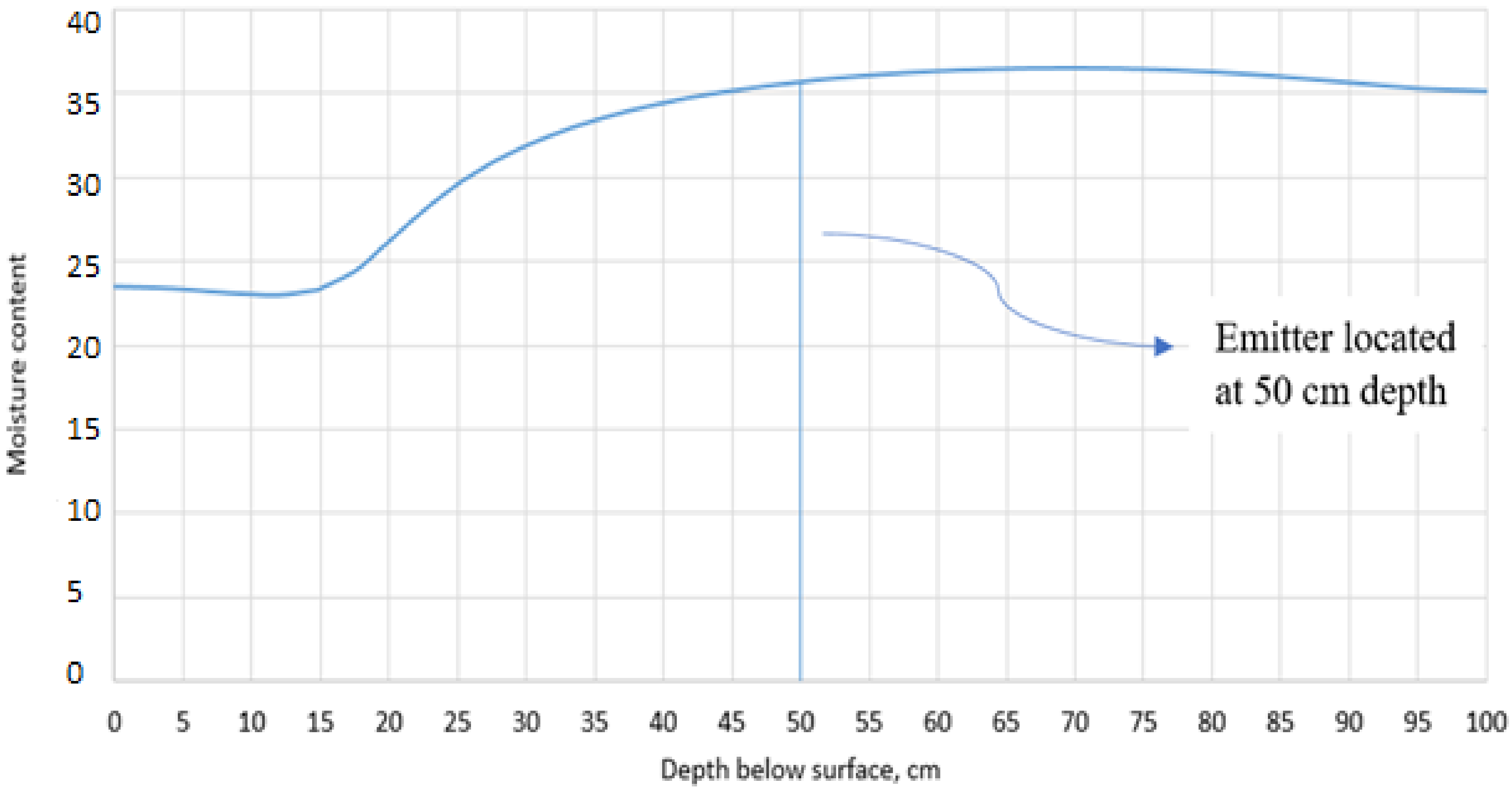


Mohr's circle and failure envelope for CL at 10 cm depth with a tractor load at the surface. The minimum cohesive strength is of 0.18 kg/cm2

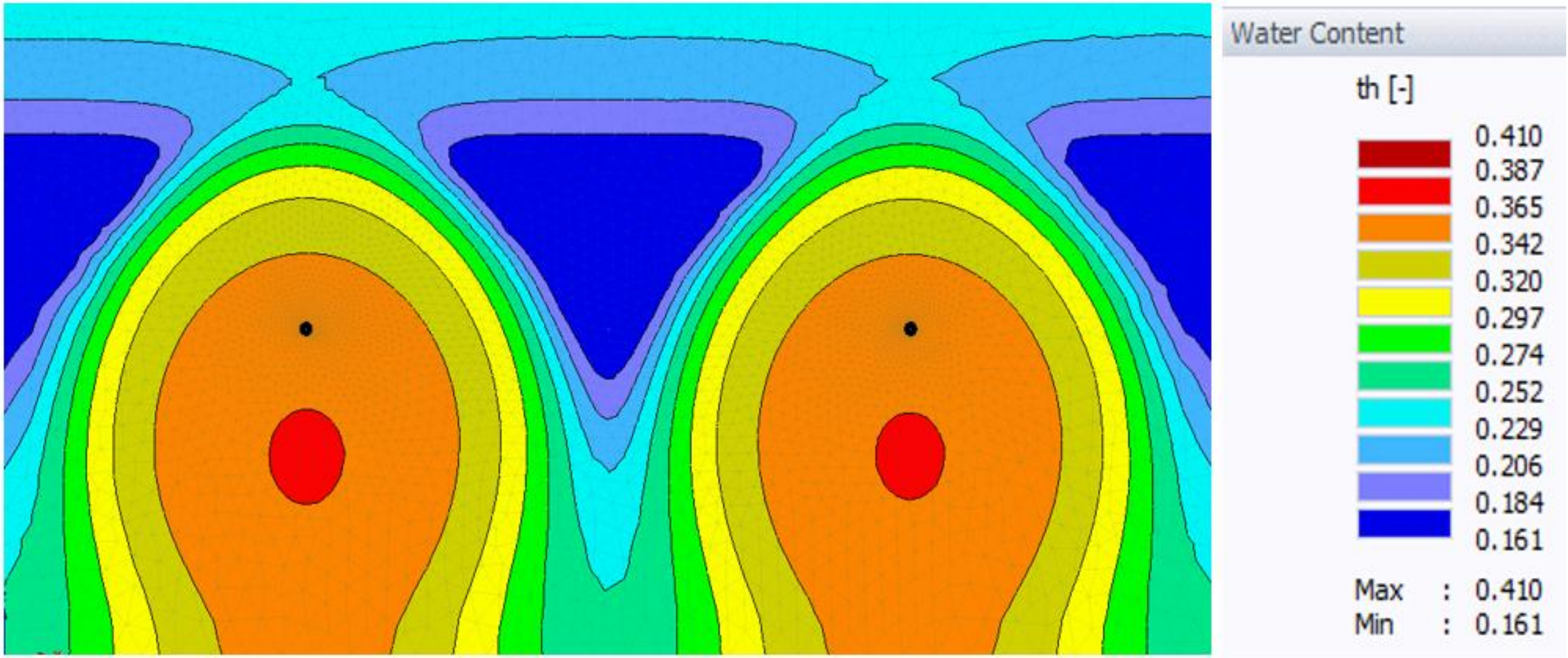
Cohesive strength vs Moisture content



Relationship between cohesive strength and moisture content for the three soils

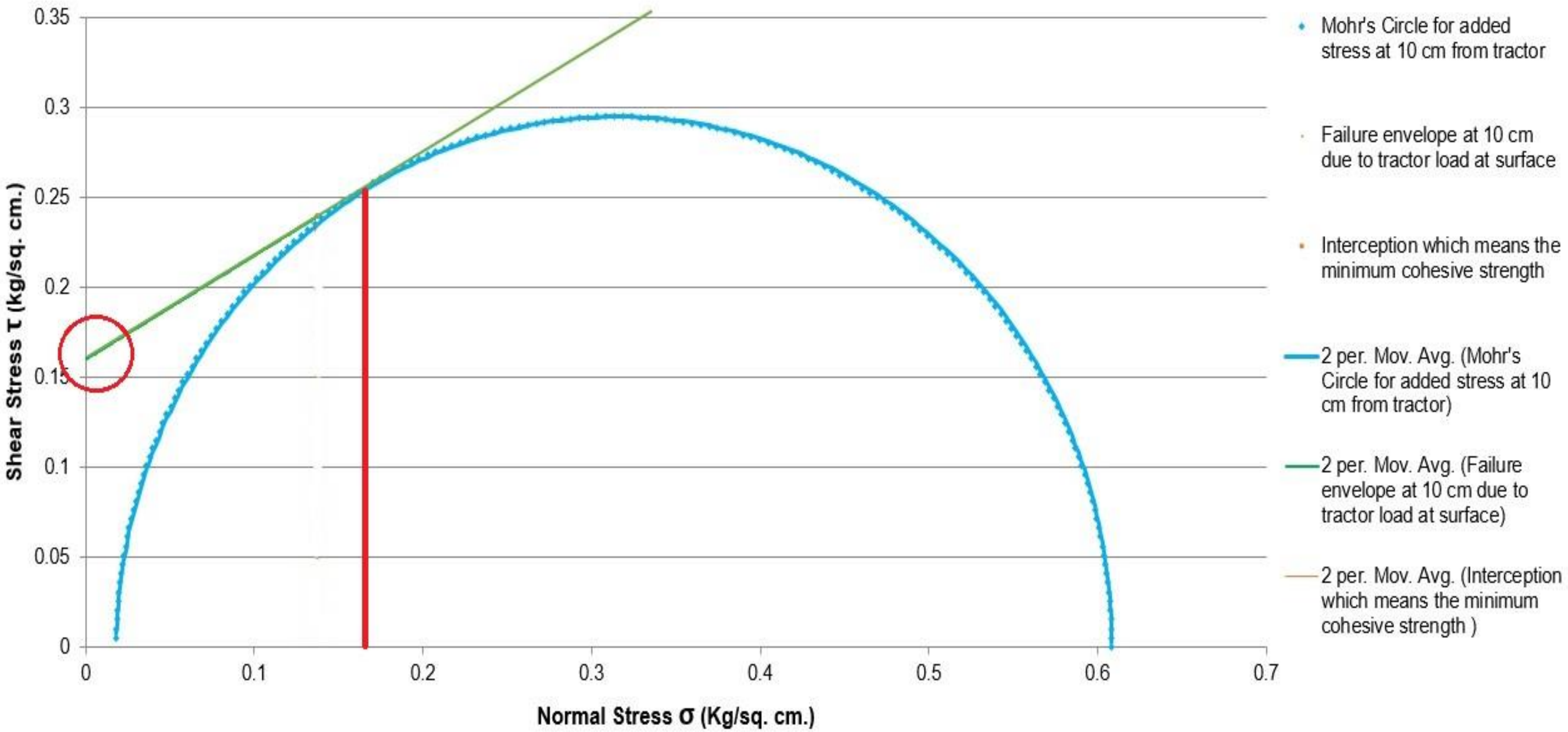


Moisture content (%) on the day of the cut, after 12 hours of irrigation, in CL soil with a deph of placement of 50 cm.

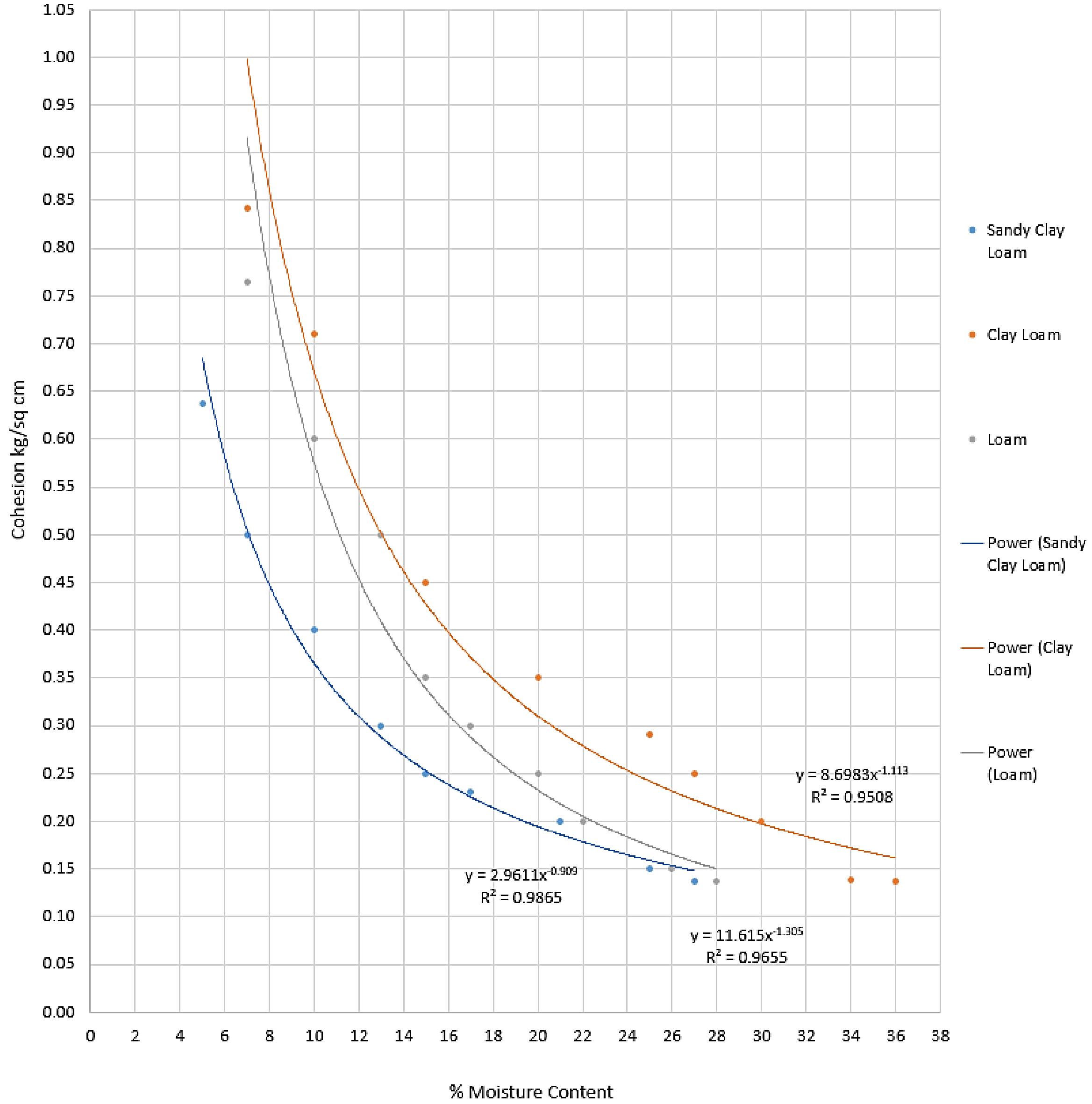


Graphical representation of the moisture content on the day of the cut, after 12 hours of irrigation, in the CL soil with an emitter placement depth of 50 cm.

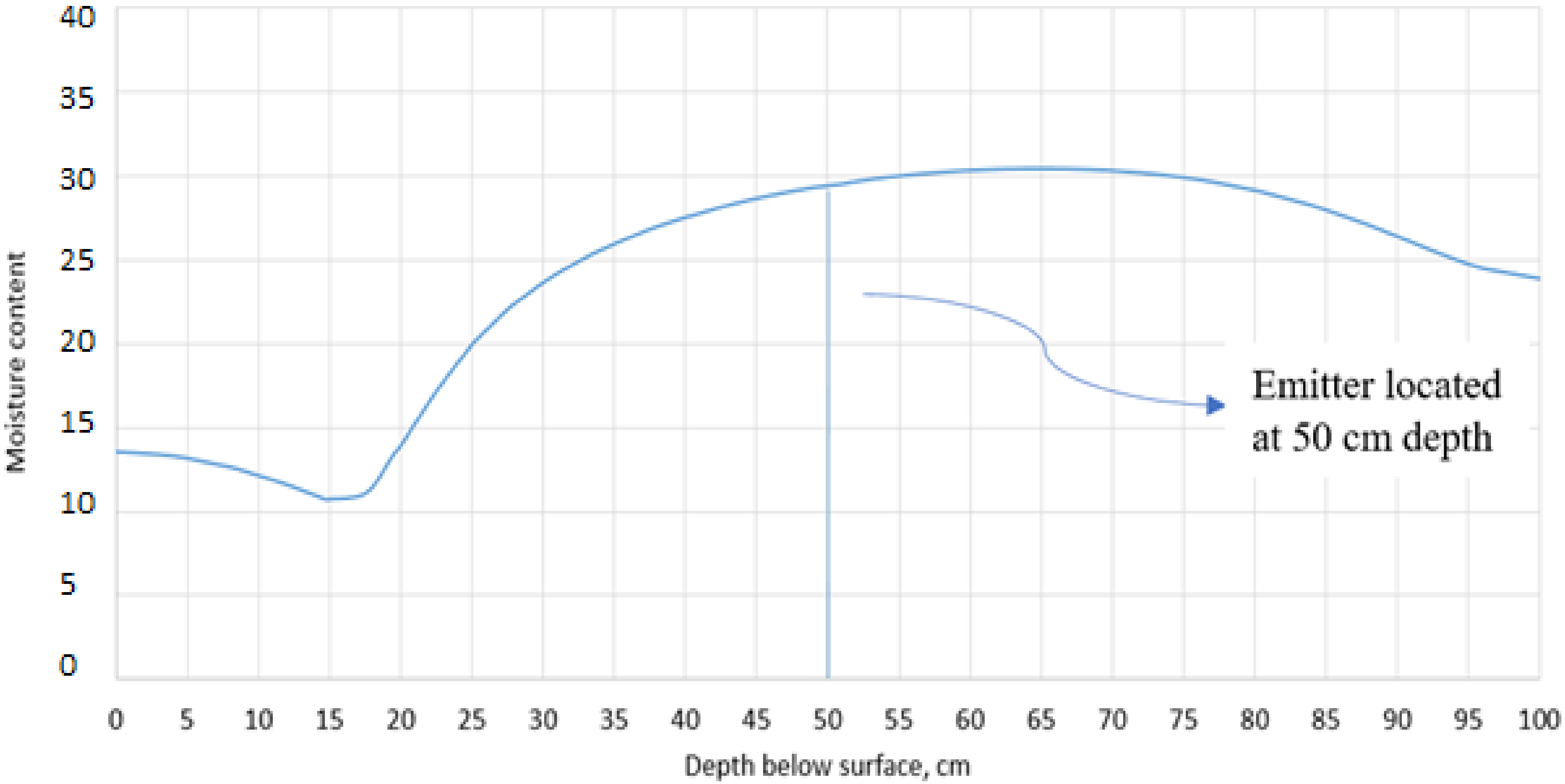
Soil strength results - Loam



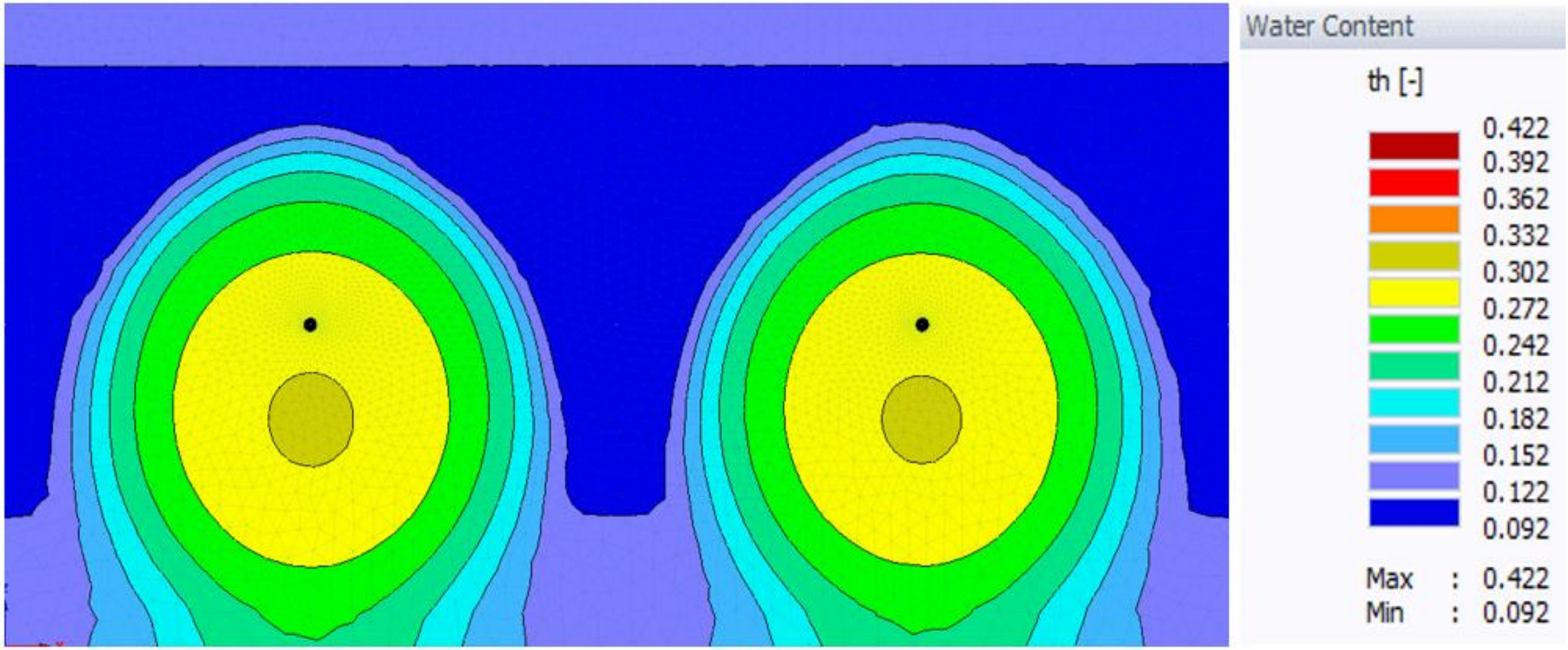
Mohr's circle and failure envelope for L at 10 cm depth with a tractor load at the surface. The minimum cohesive strength is of 0.16 kg/cm^2



Relationship between cohesive strength and moisture content for the three soils

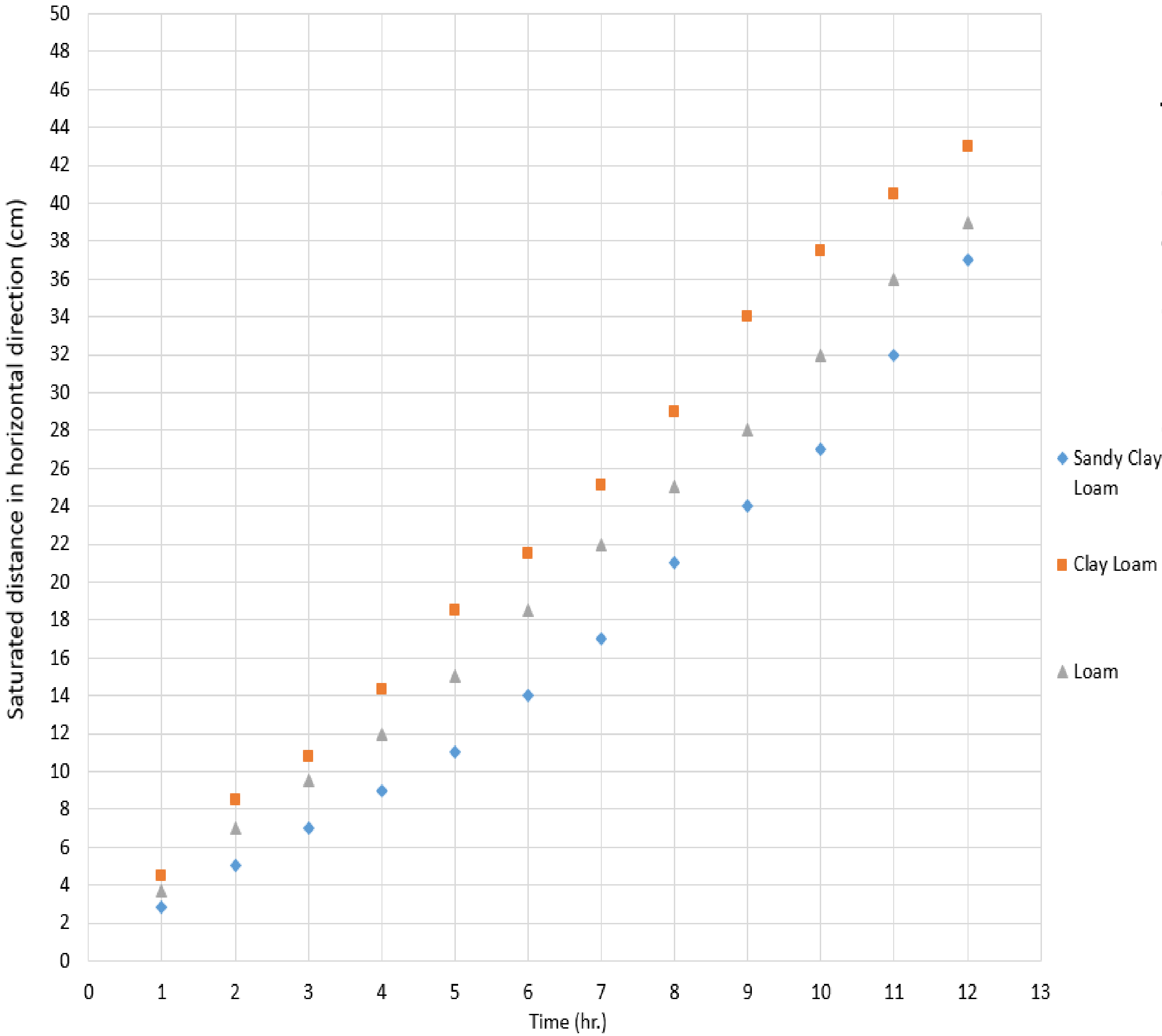


Moisture content (%) on the day of the cut, after 12 hours of irrigation, in L soil with a deph of placement of 50 cm.



Graphical representation of the moisture content on the day of the cut, after 12 hours of irrigation, in the L soil with an emitter placement depth of 50 cm

Spacing between drip lines tapes



To ensure adequate spatial coverage by a drip system we should have maximum horizontal spacings of:

- 80 cm for sandy clay loam and loam
- 90 cm for clay loam

CONCLUSIONS

- The present study illustrates how the HYDRUS-2D model can be used together with soil shear strength and soil stress analysis techniques to determine minimum depth of placement of drip line tubing that ensures dry soil surfaces, especially during harvesting time in order to avoid soil failure due to added loads on the soil surface such as those from tractors and heavy machinery used at harvesting process.
- Also, the maximum horizontal spacing between drip line tapes was determined using wetted patterns generated by the model to ensure an adequate water coverage in order to avoid alfalfa stress.

CONCLUSIONS

Based on the shear stress analysis in this study, minimum depth of placement for a drip line tubing with an emitter flow rate of 2.71 cm/hr. would be:

- ✓ 40 cm, Sandy Clay Loam
- ✓ 35 cm, Clay Loam
- ✓ 40 cm, Loam

The maximum horizontal spacing between drip line tapes would be:

- ✓ 80 cm for Sandy Clay Loam and Loam soils and
- ✓ 90 cm for Clay soils.

Obviously, different emitter flowrates or irrigation durations would change these recommendations.

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Questions?

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