Agroforestry in temperate regions, where does the water go?
Electrical resistivity tomography as a tools to help us find out

Sophie Maloteau[a], Tom Coussement[b], Paul Pardon[c,d], Sidonie Artru[a], Simon Ridley[a], Pieter Janssens[b], Bert Reubens[c], Thomas Günther[f], Mathieu Javaux[e], Sarah Garre[a]*,
[a]Liège Université, Gembloux Agro-Bio Tech, Belgium; [b]Soil Service of Belgium, Belgium; [c]Flanders Research Institute for Agriculture, Fisheries and Food (ILVO), Belgium; [d]Ghent University, Bioscience Engineering, Belgium;
[e]Universite catholique de Louvain, Earth and Life Institute/Environment, Belgium; [f] Leibniz Institut for Applied Geophysics, Germany; * *Corresponding author: sarah.garre@uliege.be*

During the last decades, there was a renewed interest in agroforestry systems in temperate climate because of their potential to increase biodiversity, sequester carbon and diversify the landscape (1,2). A central hypothesis in the design of a performant agroforestry system states that the trees should acquire resources that would otherwise not be used by the crop (3). Even though the number of projects studying agroforestry systems in the field is increasing lately (e.g. AGFORWARD, SAFE, TransAgroForest, Agroforestry in Vlaanderen, … (non-exhaustive)), little quantitative information is available about the interaction between trees and the crop for water, especially in temperate climate. In most of the publications, trees and crop are in competition for water (e.g. 4), especially where water availability is a limiting factor. Different methods can be used to monitor soil water dynamics in agroforestry systems. Classical methods to measure SWC such as gravimetric measurements, neutron probes, time domain reflectometry or capacitance probes are well known to provide correct and robust results. However, these methods give only local measurements of the SWC. Geophysical methods, and more specifically Electrical Resistivity Tomography (ERT) has proven to be a method avoiding some of the disadvantages mentioned above (e.g. 5). This study aimed at quantifying the effect in space and time of mature poplar trees (*Populus x canadesis* Moench.) on the dynamics of soil electrical resistivity in an agricultural field sown with maize (*Zea mays* L.).

Material & Methods

Experimental field and setup

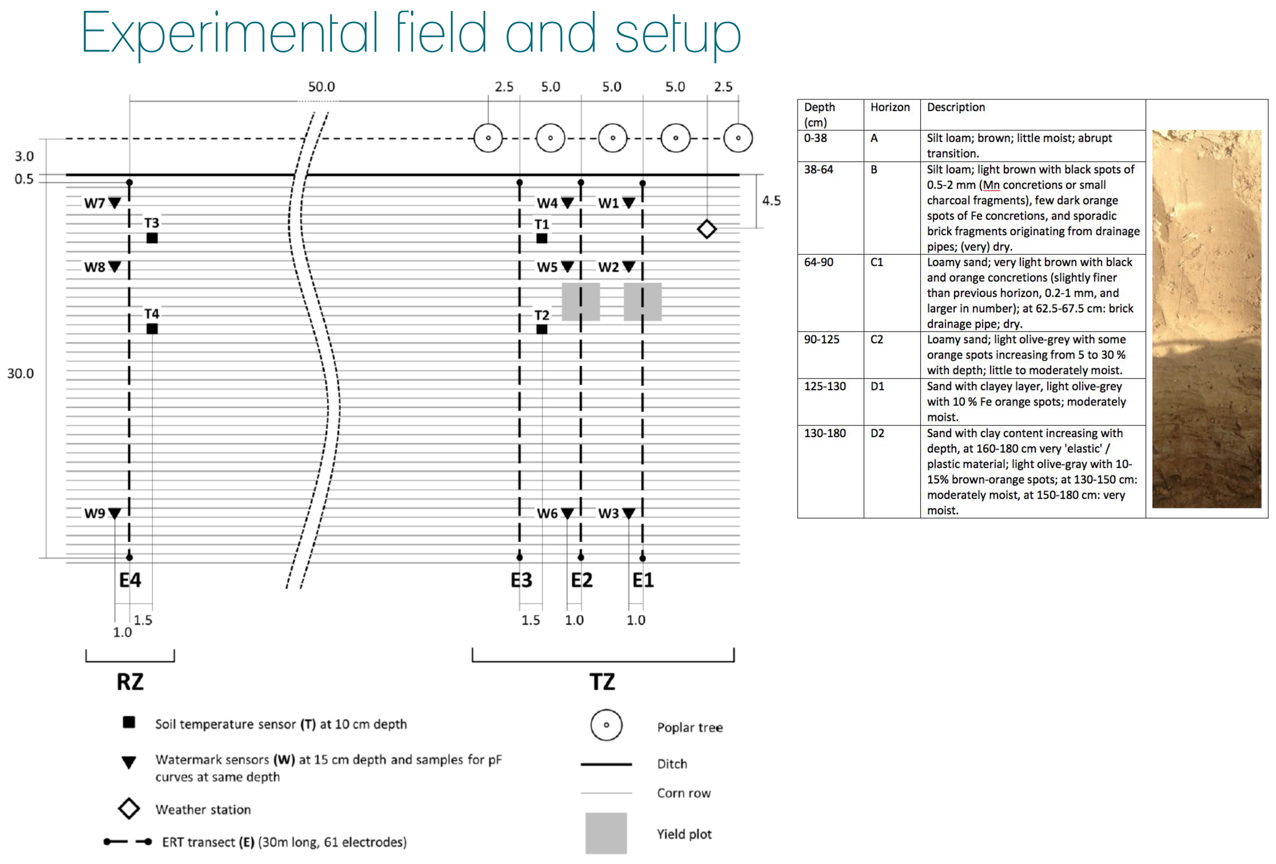

Figure 1: Experimental set-up

We monitored the **soil water dynamics** in a corn field partially bordered by poplar trees in Ieper, Belgium using Electrical resistivity tomography (ERT) and classical soil tension sensors (Watermark) during the entire growing season of 2016. Measurement dates where (May 31st (t0), June 17th (t1), July 1st (t2), July 19th (t3), Aug. 2nd (t4), Aug. 17th (t5) and Sept. 20th (t6)).

We installed four **ERT transects of 30 m** long with an **electrode spacing of 0.50m**. Three transects were placed in a part of the field bordered by trees and one reference transect was located in a part of the field nearby a treeless field border. The electrodes stayed in place permanently during the experiment. The first electrode of the transect was located at 0.50 m from the edge of the cropping zone and at 3.50 m from the tree line.

Next to each transect, Watermark sensors were installed to estimate the **soil water tension**. A local **weather station** located 4.5 m from the tree line monitored the on-site microclimate under influence of the trees. The KMI weather station of Beitem (20 km distance) was used to represent open field conditions.

Climate and soil moisture dynamics

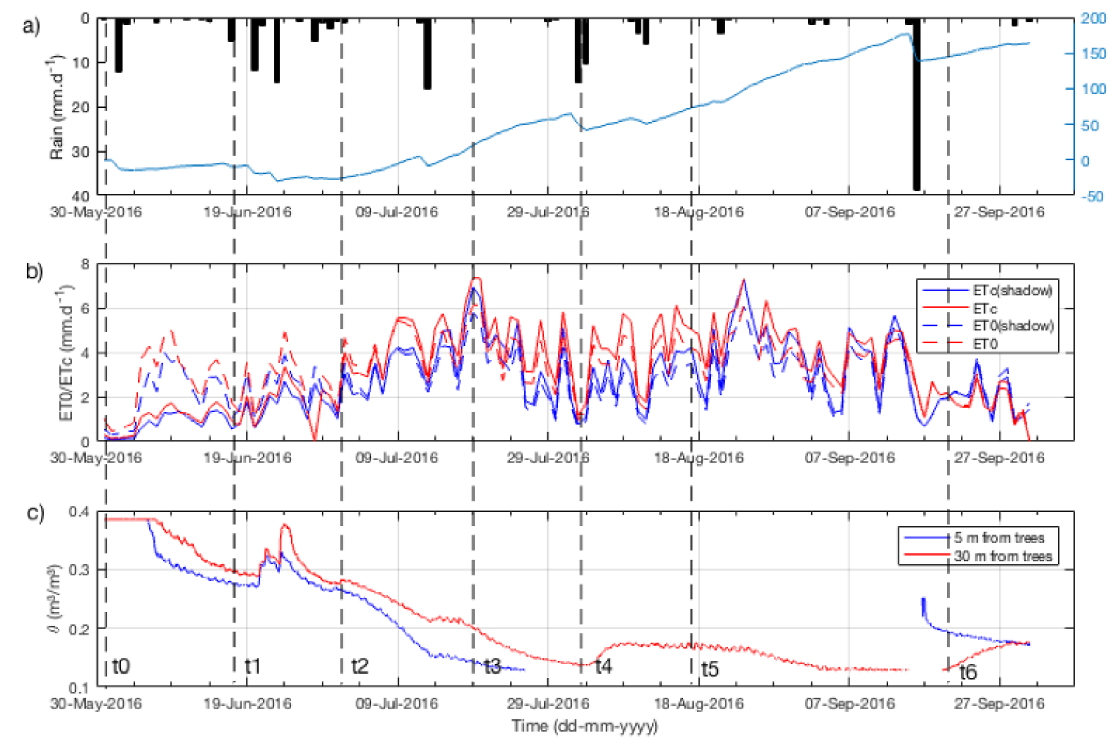

Figure 2: Evolution of (a) rainfall and soil moisture deficit in the tree zone (SMD(shadow)), (b) reference and crop evapotranspiration (ET0, ETc) and (c) soil moisture through time, from May 20th to October 10th. Blue curves of ETc and SWC correspond to data influenced by the trees (TZ); red curves indicate data without impact of the tree line (RZ).

Results

Bulk electrical resistivity gradients & variability

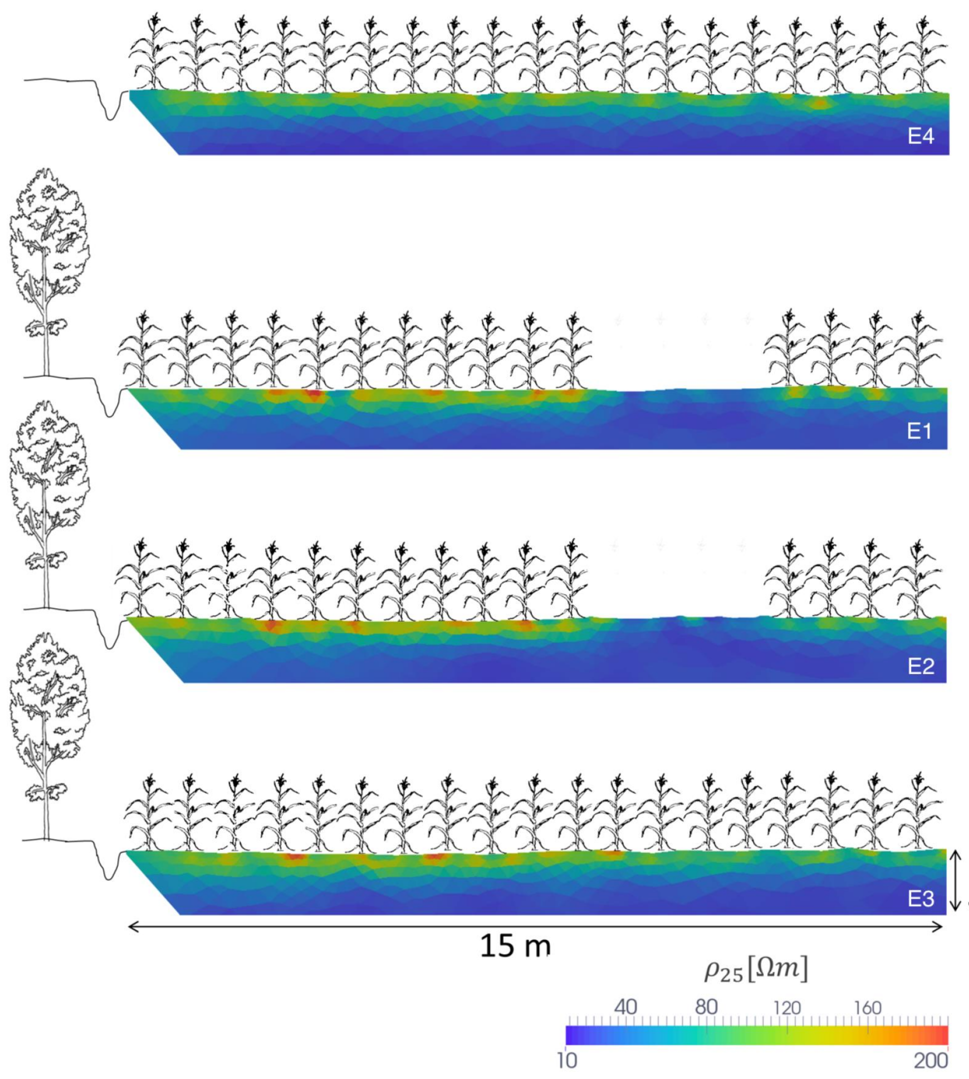

Figure 3: Detail of temperature corrected bulk electrical resistivity tomography, 25 (m) of Aug 2nd, for the first 15 m of the four transects and up till 1m depth: E4 without tree; E1, E2 and E3 with trees.

On the first measurement day (t0) the soil was completely saturated and SWC is characterised by an overall decreasing trend with time until t5 (some smaller rainfall events took place during this period). As can be noticed, the plateau in the soil moisture data during the first week corresponds to the saturated field conditions and very rainy weather. Just before t6, an important rainfall event was registered. In general, the daily ETc is lower close to the tree than in the open field, due to the lower global radiation near the trees. At t0, soil bulk electrical resistivity ranges from 10 to 40 Ohm.m in the upper 0.50m (Figure 5). These resistivity values are rather low, corresponding to high soil water content (saturated conditions at t0). The resistivity differences are always positive, showing the transition from saturation to unsaturated (dryer) conditions.

To quantify the distance of influence of the tree on the soil moisture dynamics in the field, we plotted the weighted average of the bulk electrical resistivity of a block of 0.50 m depth and 1 m width as a function of the distance to the tree in Figure 6. The beginning of the curves in both TZ and RZ is affected by a field ditch, especially in very moist conditions (first measurement dates). The impact of trees on electrical resistivity is clearly visible for E1-3: the closer we come to the tree line, the higher the resistivity becomes (Figure 5). For E3, resistivity curves become stable again at around 15-20 m from the trees. After converting these curves to soil moisture using a pedophysical relationship, we performed a segmented linear regression on these curves (Figure 7). This resulted in pivot points around 15m for the TZ (E3) and no pivot point in the RZ (E4), indicating that the area of influence of the tree corresponds to ca. 15m in this case.

Crop yield

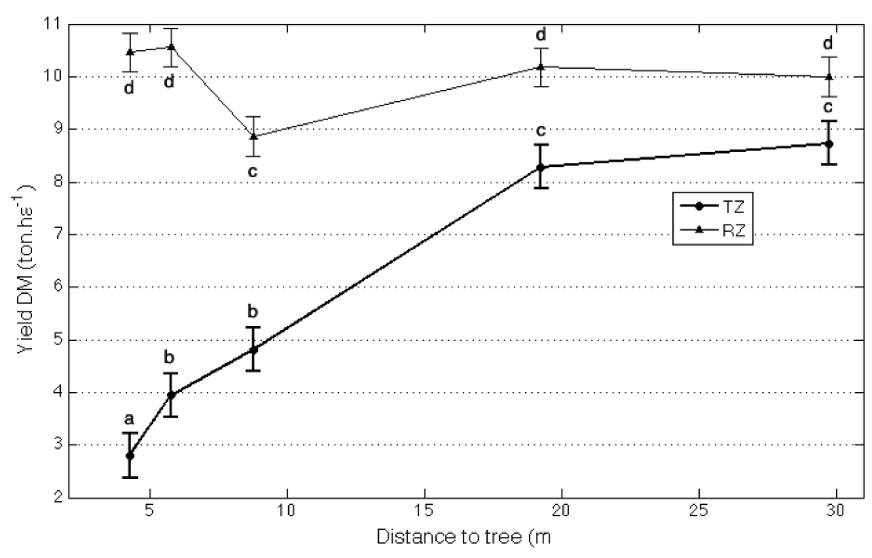

Figure 4: Average yield of transects in the tree-bordered (TZ) and reference (RZ) zone (dry matter in tons per hectare). The error bars indicate the standard deviation, different superscript letters (a-d) indicate significantly differing DM yield.

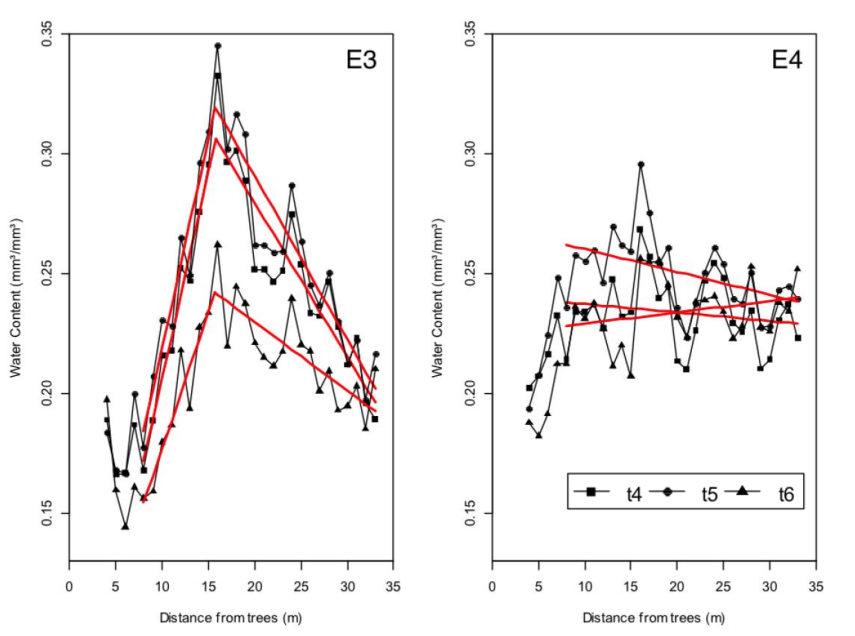

Figure 7: Single (E4) and segmented (E3) linear regression on estimated soil moisture transects for Aug 2nd (t4), Aug 17th (t5) and Sep 20th (t6).

Table: Fischer test comparing single and segmented linear regressions for transects E3 and E4.

	E3		E4
Date	P_{val}	x.pivot (m)	P_{val}
t4	3.125e-11	15.766	0.108
t5	1.712e-10	15.742	0.078
t6	3.889e-08	15.683	0.373

Distance of influence of poplar tree line

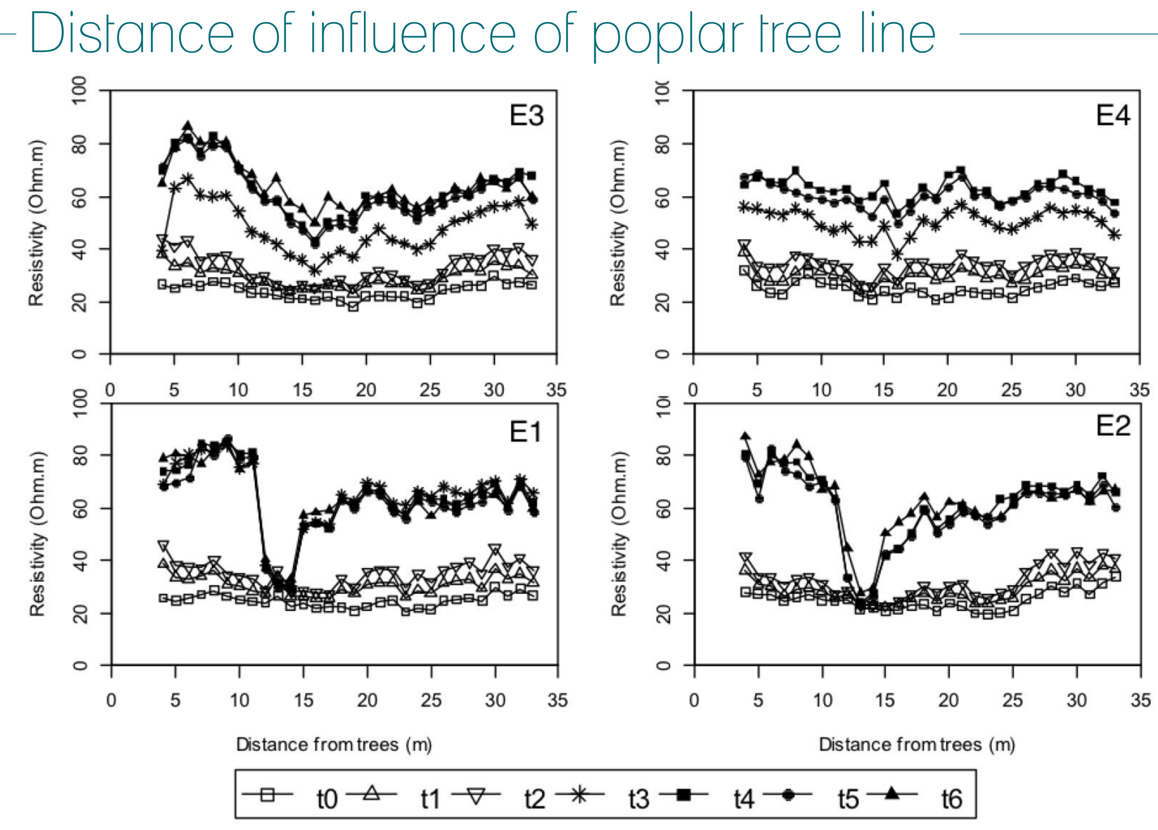

Figure 5: Evolution of bulk electrical resistivity along the transect for each measurement date: May 31th (t0), June 17th (t1), July 1st (t2), July 19th (t3), Aug 2nd (t4), Aug 17th (t5) and Sep 20th (t6); and for transects E1-3 (tree-bordered zone) and E4 (reference zone). Transects E1 and E2 are affected by N mineralization plots at later dates (local depression of resistivity values) (exact location of these plots see Figure 1).

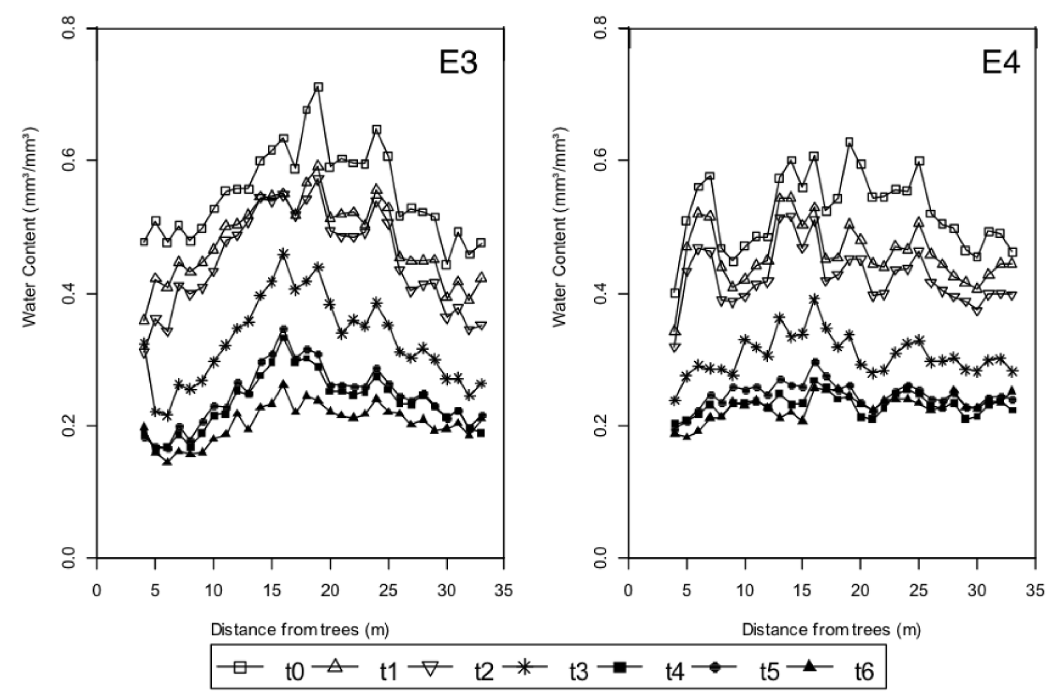

Figure 6: Estimation of soil moisture along the transect for each measurement date: May 31th (t0), June 17th (t1), July 1st (t2), July 19th (t3), Aug 2nd (t4), Aug 17th (t5) and Sep 20th (t6); and for transects E3 (tree-bordered zone) and E4 (reference zone).

Conclusions

We showed that the ERT tomograms in a tree-bordered zone are significantly different from a reference zone without trees along a 30 m transect. The segmented regression also allows the determination of pivot points, which can be used to quantify the area of influence of the tree line on the crop (ca. 15m in this case). ERT tomograms give interesting information on spatio-temporal dynamics of soil moisture and show that the influence of the trees is mainly visible under drier soil moisture conditions.

1--- Sanchez, P. A. (1995). Science in agroforestry. In F. L. Sinclair (Ed.), Agroforestry: Science, Policy and Practice number 47 in Forestry Sciences, pp.5-55. Springer Netherlands.
2--- Quinkenstein, A., Wöllecke, J., Böhm, C., Grünewald, H., Freese, D., Schneider, B.U., Hüttl, R.F., 2009. Ecological benefits of the alley cropping agroforestry system in sensitive regions of Europe. Environ. Sci. Policy 12, 1112–1121.
3--- Cannell, M. G. R., Noordwijk, M. V., & Ong, C. K. (1996). The central agroforestry hypothesis: the trees must acquire resources that the crop would not otherwise acquire. Agroforestry Systems, 34, 27-31.
4--- Miller, A. W., & Pallardy, S. G. (2001). Resource competition across the crop-tree interface in a maize-silver maple temperate alley cropping stand in Missouri. Agroforestry Systems, 53, 247-259.
5--- Michot, D., Benderitter, Y., Dorigny, A., Nicoullaud, B., King, D., & Tabbagh, A. (2003). Spatial and temporal monitoring of soil water content with an irrigated corn crop cover using surface electrical resistivity tomography. Water Resources Research, 39, 1138

www.agroforestryvlaanderen.be