Alessio Fini: Does Soil Sealing Affect Urban TreeHealth? An 8 Year Research

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Music: [00:00:00] "You know, we can, work together and learn what we need to beat the challenge. Traditional skills and modern techniques, whatever language you speak, you have a world to offer and every day climb with the ISA."

Dr. Tom Smiley: Welcome to the ISA Science of Arboriculture podcast series. This is Dr. Tom Smiley at the Bartlett Tree Research Laboratory host of this podcast series, which is brought to you by the International society of arboriculture and the FA Bartlett Tree Expert Company.

Today's podcast presentation is by Dr. Alessio Fini. He is a professor of arboriculture in the Department of Agricultural and Environmental Services, Production Landscape, Bioenergy of the University of Milan Italy. He will be speaking on, Does Soil Ceiling Affect Urban Tree Health? An Eight Year Research Project?

Dr. Alessio Fini: Good afternoon, everybody. And welcome to this long-term research evaluating the effects of soil ceiling on health of urban trees. I am Italian, and as all Italians, I'm very proud of the place where I live. I'm in the north of Italy, a region, which unfortunately is entering in a lockdown because of COVID-19 tomorrow.

But I hope It will be soon over and I'll be back ready to visit some beautiful place we have in our region. We got beautiful glaciers, particularly in the Stelvio region. We've got astonishing lakes. This is Lake Maggiore, but [00:02:00] Lake Como is also very popular. In the US. And we had once a wonderful secondary forest covering the whole flood plain, in Lombardia region which was made of [unknown], and was so thick and dense that Romans at times of the Roman empire were calling it a [unknown], the forest of walls.

Actually my region has changed quite a lot over the last thousand years. And it is now one of the most densely populated and built areas in Europe. Before the 2008 economic crisis, about eight square meter of soil were sealed every second in Italy.

And so it really looked like we were going through a future pretty much similar to those the peak that in the movie Blade Runner 2049, where all the earth was covered by impermeable surfaces. Fortunately over the last 10 years, there is growing awareness about the provision in regulation and cultural benefits provided by urban vegetation which can definitely increase the wellbeing of urban dwellers.

So we are starting planting back trees in the cities. We are starting to think cities that integrate trees. Because the urban environment is extremely different from the natural environment where trees have evolved and adapted. One of the most striking difference. Is that in cities, the soil is covered by pavement. That of course facilitate human activities, but it's still largely unknown how [00:04:00] trees can respond of being grown in a paved site, in a site covered with interminable pavement.

What is known is that permeable pavement reduced the amount of rainfall that can infiltrate in the soil. And so the run off increase and that's something we are starting to know more and more frequently because excessive runoff can lead to flash flood problems.

It is also called that because the amount of rainfall that can infiltrate in the soil is decreased. The soil should be drier under pavement, then it would be if it was uncovered. And this may predispose trees to water stress.

To address the issues, related to soil sealing, alternative pavements have been developed. Mainly porous pavement. If they are permeable themselves along the entire structure to water, or permeable pavement, if they are made by impermeable, modular elements, but voids between elements allow the infiltration of water in the soil.

So the aim of this research is to understand what happened to a tree when it is grown under these different pavement types for an eight year period. So this goal we built in 2011 and experimental field, which was made by 24 subplots. Each subplot, which was about 50 square meter large, um, had two unpaved planting bits and plastic cylinder were buried through the pavement to the [00:06:00] soil, to allow access to this soil and the measurement of solid parameters. Each block was divided by the neighboring plots using plastic barrier, very down in the soil, to 70 centimeters. The soil on the experimental side had quite a lot of gravel and it was, uh, a sandy silt top soil with [unknown] PH and an average content of a organic matter.

So in this field, we imposed four different pavement treatments with six replicates. We got, we compared an impermeable design, which was asphalt on a concrete sub grade, a permeable design, which was [unknown] on sub grade, a porous design, which was a a liner bound by epoxy resin on a crushed drop sub grade. And finally the control was bare soil kept free of weed using herbicide.

In March, 2012, plants of [unknown] were planted in the field. We used 24 balled and burlapped plants per species, which are planting with 46 centimeters circumference. We choose these species because they have a quite different rooting pattern and also different mechanisms adopted to tolerate the environmental stress.

[Unknown] is an isohydric water spending species, which bases most of its tolerance on the capacity to explore large volume of soil and absorb a lot of water from large volume of soil and carried efficiently. On the contrary, [00:08:00] [unknown] is anisohydric species, which basis its tolerance on adjustment occurring at the leaf level, mainly it can actively decrease the osmotic potential. And so absorb the water, which is strongly bound to the soil particles.

So, this is how the field look like in March 2012 just after its completion. And these are the environmental conditions that trees had to face over the next years. We got a temperature, which was exactly the same as the 30 year average while rainfall was likely above average. All in 2015 and 2017, we got rainfall, which was slightly below the 30 year average. So the trees could grow healthy. And this is how the field looked like in the early 2020.

Well, over these eight years we carried out a lot of measurement to trees and soil. We measure some above ground, tree attributes that can be related to tree growth. So shoot growth, DBH, plant and canopy height, the area of the drip line, and [unknown] index. Which were measured on all trees. And also we, we focused quite a lot on below ground attributes. We use different methods to estimate the effects of the different pavement on the root system of our trees.

The first method was the use of ground penetrating radar. Actually we use GPR before in 2014. But trees were still [00:10:00] very young and very few roots were grown outside the unpaved planting bit and the measurement was not really successful. We did it again in 2020. And this time we use the, uh, one of the into software specifically designed for marking tree roots.

The tree [unknown] and this measurement was conducted in cooperation with studio plant. Also, we will use sonic tomography as well to assess the density of course roots. This measurement was done using two different arrangement of the transmitter of the sound arrived arrangement, which is the one you can see here in the pictures. And [a unknown] arrangement all around the tree.

We also try to find out which species caused the most damage to pavement and which pavement suffer from higher damage. To do this, we conducted two samplings, one in 2014, uh two years after the construction of the field. And one, 2020, of course, in the first sampling most, uh, of trees still at roots within the planting pit.

And so the damage recorded so far is unlikely to be due to roots. While in 2020 clearly, we try to correlate the damage observed to the presence of roots. To do these measurements all the plots were divided in one per one square. In 51 per one squares and the frequency of squares damaged was counted and recorded.

Several [00:12:00] plant physiological traits that we measured over this experiment. The first is plant water relation. So we measured pre-dawn water potential, sealing water potential, and midday water potential, which are key indexes of the hydration of plant tissues. Also combining water potential data with transpiration data from gas exchange, it is possible to calculate the conductivity of the plant to water because we got the amount of water transpired and the driving force of the process.

So combining transpiration and water potential data, we could calculate the connectivity to water of the whole plant of the root took seal and part of the pathway. And of course the leaf conductivity to water.

[unknown] exchange where extensively measured from 2013 to 2020, four measurements per year were conducted in May, June, July, and September. Measurements were carried out on fully expanded leaves, exposed to full solar, [unknown], and were conducted at 1300 micromoles, [unknown]. So saturating [unknown], 110 PPM.

Very interestingly we could combine gas exchange measurements to light adopted chlorophyll fluorescence measurement. We conducted simultaneous measurements of gas exchange and light adaptive chlorophyll fluorescence, and this allowed the calculation of the conductance of the [unknown] to CO2 usually in gas exchange measurement, where we stop accounting, the CO2 reaching the [00:14:00] [unknown] chamber combining such two measurements it is possible to estimate the amount of CO2 effectively reaching the chloroplast and available for photosynthesis.

Dark adaptive chlorophyll fluorescence parameters were also measured. The [unknown], which is a very popular parameter because of simple interpretation values higher than pointed indicate the absence of stress to the photosynthetic apparatus.

And finally we conducted measurements on soil traits. We measure the CO2 flux from the soil after the plastic cylinders were unsealed for measurement. We measured soil O2 concentration and volumetric soil moisture, which was recorded at 20 and 45 centimeters below grade. So if the temperature was also measured at 25 centimeters below grade using a temperature probe while in July 2018 we measured surface temperature using a thermal camera mounted on a [unknown].

So I'm trying to use all these, huge amount of information we collected over these eight years to understand very, to, to answer a very few questions that might be of our interest as arborist. So what happens when we lay a pavement without planting trees? Well, what we realized is that all types of pavement increased soil moisture compare to control.

These data were [00:16:00] collected in the very first years after planting, where when tree roots were still mostly confined to the unpaid plant impede trees were still small. And the contribution of transpiration to soil water balance was liking negligible . So during these four years, when, when the contribution of tree transpiration to soil water balance was low we found that permeable pavement was the Mo you used the highest moister in the soil.

Under the pavement, you can see that soil under permeable pavement was often partly saturated, so that soil moisture exceeded field capacity. Impermeable pavement showed very little change in soil moisture throughout the year when porous pavement were the ones that more similarly mimic the water dynamics, which normally occur in the unpaved soil.

So analyzing the soil moisture content and the change in soil moisture through the year, we tried to estimate the impact of the different pavement on infiltration of rainfall into the soil, but also on evaporation of water, which is in the soil and can evaporate to the atmosphere.

We found that impermeable pavement greatly restrict both processes, both infiltration and evaporation, while permeable pavement allowed rainwater to infiltrate in the soil, but slow down evaporation, conversely porous pavement, allowed both processes and were very similar as the, in the control.[00:18:00]

When water evaporates it consumes energy. It dissipates, each gram of water, which evaporates dissipates 2.46 kJ/kg as latently it's heat that is subtracted by urban energy balance. So transpiration evaporation make the environment cooler. So it's not surprising that pavement which displayed a higher capacity to allow evaporation of water from the soil, so the control and the porous pavement were significantly cooler a surface temperature compared to treatments, which didn't allow evaporation, so impermeable, impermeable pavement. And these data observed using a thermal camera was confirmed by temperature measurement at 25 centimeters below grade. You can see this graph that soil beneath, impermeable and permeable pavement will significantly warmer when compared to the control in porous pavement.

So every time that we lay down a pavement, which halts the evaporation of soil water. We reduced the amount of heat dissipated as latent heat, and we can trigger a urban heat island which is something that I think we definitely don't want.

So we need to plant trees. Trees can cast shade. Trees can transpire water from the soil. And so they are very effective in cooling down the environment. Over the years, when I was going to this field for taking measurement, it was more and more comfortable as the trees grew because [00:20:00] I could spend more time in this shade then in the early phases of this planting.

However, how will trees respond to pavements will pavement effect tree health. So I start showing you a net photosynthesis, the amount of carbon that trees can assimilate from the atmosphere and convert into carbohydrates to be used for growth, defense, and reproduction. So net photosynthesis this is a key vital parameter for a tree. And this is the grand average of a net photosynthesis, the average of data collected during all the measurement dates. We can see that a [unknown] show no, no impact of pavement on photosynthesis. All the treatments are just assimilating pretty much the same amount of carbon. While in [unknown] plants growing impermeable and porous pavement have the higher photosynthesis then control. In turn, plants growing in asphalt, have lower photosynthesis then the control.

So all pavement in practicing has increased net photosynthesis except for asphault. Differences are significant, but as you can see, they are really mild, is not a big impact of pavements on photosynthesis.

This effect was not due to stomata limitation to photosynthesis. So as it commonly observed in a drought stress of very mild intensity. During drought, for example, plants close stomata, and the amount of CO_2 that can get in the leaf decreases.

And it's [00:22:00] not enough to supply carbon assimilation needed, and this may lead me to photosynthesis. But in this case, I can see that the amount of CO_2 in the stomata chamber. In fractions, plants growing in asphalt, impermeable pavement was even higher than that available to control excluding stomatal limitation.

Conversely, we noticed the high, a higher draw down of CO_2 from the stomata chamber to the site of carboxylase indicating a lower capacity of mass or field of fraction was growing in asphalt to carry CO_2 from the substomatal chamber to the chloroplast. This pathway of CO_2 is an active process, which is largely mediated by proteins that can facilitate the diffusion of CO_2 within the leaf socio porins, carbonic anhydrase are typical proteins involved in these.

The change observed, induced, by pavement infractions for carbon assimilation was not constant throughout the year, but rather become significant at the end of the growing season. In September, you can appreciate the differences between proximus growing in asphalt and control were highly significant.

From this graph, we can also appreciate the different strategy of the two species to carry out efficiently photosynthesis throughout. The fractions had that a more opportunistic behavior, displaying higher rates of photosynthesis. Then [unknown] when conditions were favorable in May. Chaldees instead was more [00:24:00] conservative. Displaying an increase of photosynthesis, going from favorable condition of spring to the warmer and and harsher condition experienced during summer.

What a relation also confirm the different strategy of the two species to tolerate environmental stresses. You can see how the water potential, both [unknown] displayed by the isohydric [unknown] was far less negative compared to that display by the an anisohydric fraxinus.

Again, infractions. We can see that pavement impacted tissue hydration. In particular, a water potential of plants growing impermeable pavement, which was somehow moister compared to other treatments, had more favorable water relation compared to control. Conversely plants growing in asphalt had more negative water potential compared to control, indicating less favorable water relations.

Combining such water potential data to transpiration. We could calculate that conductivity of the plants to order. And interestingly, we found big differences between the leaf conductivities of [unknown] growing in asphalt and that offer in was growing in unpaved soil. And we realized that leaf cognitively was significantly warmer [unknown] plants growing on asphalt. Leaf conductivity has been correlated in a very recent work by [unknown] to massive [00:26:00] conductives to seal to the CO2 diffusion.

And both processes appear to be highly dynamic in the plant. The plant can modify them weekly to respond to environmental perturbation. And one of the plant signaling that trigger such changes in leaf conductivity a of conductance is [unknown] case it's signaling. [unknown] is a key plant [unknown] most related to root to shoot signaling and to control of a stomata opening during stress.

We did not measure up [unknown] directly, but we measured some compounds, volatile, organic compounds, which are from the very same metabolic pathway as [unknown]. And what we found is that bulk emission the emission of such compounds increase when [unknown] plants were grown in impermeable pavement compared to control.

So what may have caused these changes in plant physiology and metabolism?

A perfect candidate can be soil moisture. I said to you before that, before tree establishment, all paved treatments had higher soil moisture compared to control. Clearly after tree establishment transpiration started to impact soil water balance, and we noticed a progressive decline in soil moisture availability, particularly at 20 centimeters below grade in the impermeable treatment.

Probably because the lower [00:28:00] amount of water that can infiltrate the impermeable treatment during rainfall, [unknown] the rehydration of water, which is, which has been transpired. And this resulted in a progressive decline of soil moisture in the shallow soil layer which was observed in the impermeable pavement.

However soil moisture availability remained above the wilting point. And if we look to soil moisture availability at 45 centimeters below grade, we can see that there is not a big difference, a significant difference between impermeable pavements and control. More striking is that measurement, which resulted from the measurement of CO2 flux.

We found that after tree establishment the flux of CO2 from soils covered with impermeable pavement increased steeply. Which did not occur, you know, the treatment. Indicating that the amount of CO2 which is produced by soil root respiration, cannot properly be fused in the atmosphere if the soil discovered we've been permeable pavement and accumulates in the soil.

Well, studies have shown that elevated signs here too. Can feedback impact root metabolism in particularly down regulating the such an aid the hydrogen activity which is the activity of an enzyme highly, uh, related to root respiration activity and growth..

So [00:30:00] did these, can these have practical consequences on tree growth? And this is what my students are asking during a field trip to the experimental field. Well, These are very preliminary results obtained by [unknown]. We still need to work on these data, but this is a root density, heat map update by GPR scanning, which allowed us to reconstruct the root system of the different trees.

Actually we realized that the root plate rate use vary between hundred [unknown] to 240 centimeters depending on the species and the treatment. So in fraxinus the roots extended for about 20 times DBH while in [unknown], some importantly roots expanded, farther, but they reached the plastic barriers, limiting the plots and they started circling.

So [unknown] estimation of a route expansion [unknown] is not possible. What we realized by, by GPS scanning is that it's very difficult to separate roots of different trees, which overlapped in the central part of the plot. However, results from GPR indicates quite consistently in both species.

That the route count by GPR decreased in paved, treatments and the largest decrease was observed for plants growing in asphalt. Also [00:32:00] GPR revealed that roots of threes growing in paved sites were somehow shallower compared to roots of control trees. However, we found some bias in the bias at which the GPR can identify a rooting depth in our experiment.

Really interestingly we found that also finer roots are highly affected by the presence of pavements. This is the case of [unknown] and we can see that in the impermeable treatment [unknown] roots were mostly confined in the Um, paved planting pit. You can see the finer roots are really concentrating. Then you can also see looking at this picture where the planting pit was while in other treatments, fine roots were really spread everywhere under the pavement.

Similarly, [unknown] we realized that, but these are also very preliminary data, which need to be confirmed by further measurement [unknown] was growing on asphalt had less absorbing roots per unit [unknown] roots. So that plant is growing then asphalt had the lower amount of absorbing surface compared to that of the other treatments.

Conversely above ground growth was poorly affected by pavement. Only species affect the DBH growth. As you can see in this picture, [unknown] is growing twice faster [00:34:00] compared to [unknown]. Shoot grow was affected by pavements [unknown]. And in this case, we can see that fraxinus plants growing in permeable pavement had longer shoots compared to other treatments.

Probably because of higher moisture availability. But the overall expansion of the canopy as indicated by the drip line area was not affected by pavement. It's striking however, that [unknown] grew faster compared to[unknown]. Seven year after planting average DBH [unknown] was about 15 centimeters and drip line area was about 12 square meter DBH and [unknown] was half compared [unknown] and its drip line area was one third of [unknown]. [unknown] is really a plastic species capable of adapting and providing high benefit in all paving sites. However [unknown] is also one of this species, which is more likely to damage pavement.

We counted the frequency of damage according to pavements. And we realized that permeable and porous pavement where those displaying the highest occurrence of damage. We have realized that wherever that most of damages, according to porous pavement occurred very early after the construction.

And they are probably not likely due to root conflicts, but rather to water infiltrating in the pavement and freezing. [00:36:00] And icing, de-icing cycles led to cracking of the pavement and the progressive damage. So if, uh, this kind of root independent damage was removed from the calculation, you can see that damage according to porous pavement were pretty much similar to that recorded in in permeable pavement and bought both treatments were consistent to the amount of shallow roots also in control.

So in conclusion, eight years of measurement revealed small and species specific effects on three physiology because of pavement. So in my mind, from the tree perspective, her high quality soil as a much greater importance than the pavement is. However, every time we lay an impermeable pavement, we reduce the evaporation of soil water, and these can trigger the urban heat island.

Above the trees preliminary analysis with GPR ground penetrating radar revealed that plants growing, under asphalt had less roots. And in particular had less finer roots compared to our other pavement types and control.

Conversely above ground growth was very little affected by pavement. So the hypothesis that we have now is that pavement may alter root to shoot ratio thus promoting an ABA signaling to the leaves, which limited carbon assimilation by the imposition of a massive [00:38:00] field limitation to photosynthesis.

We are carrying out more activities. Right now, over the last month we did a lot of root studies to confirm these hypothesis. We use sonic tomography and [unknown] to the detect root density. We use two different arrangement of the transmitter of the sound because we feel that the radio arrangement such as that you see on the left may not allow a very good description of the root system because there are large gaps among, between the direction of sounding. Conversely agreed, arrangement of sense, or look more promising.

Something else we realized from our [unknown] is that pavement or really affect the speed of sound. And so there is a need of calibrating when working on different pavements. To do these, we are conducting a [unknown] measurement before and after removing the pavement.

In mid-October we started the removing the pavement. That was a big work, but allowed us to remove the whole pavement that top and the sub grade and to perform sampling of tree roots. To carry out, their analysis of microrisal associated to roots and to identify how the pavement can affect microrisal colonization.

These activity will be done in cooperation with university of Pisa. And finally in cooperation with [unknown], which is a French research center. Last week, we hired [00:40:00] a suction excavator and we started pulling out the soil from the root system. So to expose the root system in order to allow a scanner with laser lidar scanning to the roots. To identify, with laser all route attributes. Of course, we also come back to the hand measurements, and we measured a lot of attributes about the different root system. And we tried to pull them out of the soil. Unfortunately, this was impossible with[unknown] which could withstand a force about three tons even after all the major routes were severed artificially severed. But we could do with [unknown] so we could see entire root system then of [unknown] plants. And we could scan with laser scanning also after removal. So we will have a lot of new data in the next month to work on.

A lot of work has been done. A lot of work is still waiting to be done, but we are a good team. And yeah, we really want to thank the Tree Fund for the opportunity that it provided us to conduct these long term research with two brands, objective, objective grant, and our research fellow grant. We are doing eight year of such research and really grateful to the Tree Fund and to you all for your attention.

Dr. Tom Smiley: This concludes Dr. Alessio Fini's talk on does Soil Ceiling Affect [00:42:00] Urban Tree Health Results of an Eight Year Study. This talk was originally presented at the 2020 ISA Virtual Conference. The views and information expressed are those of the presenter. Please join us next month for another presentation in the ISA's Science of Arboriculture podcast series.

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