Research projects to improve growth and stress tolerance in the nursery and after transplanting in the urban environment

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My profile:

Department of Agrifood Production and Environmental Sciences
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Teaching:

- **Arboriculture and Urban Forestry** (6 credits, MD in Landscape Architecture)
- **Ornamental Arboriculture, Green areas planting and management** (9 credits, BD in Plant nursery science, green areas planning and management)
- **Methodologies and tools to mitigate climate change effects in the urban environment** (3 credits, MD Management of the agro-environment)

Former member of the Board of Directors of the International Society of Arboriculture (from February 2005 until August 2016)

Research Interests:

- Physiological and growth aspects of different species as affected by the urban environment
- Planning the green city in the global change era: urban tree species function and suitability for predicted future climates

- I have a Facebook page **"Arboriculture and Urban Forestry", with more than 8500 members** which is continuously updated. If you have a FB profile you can click "I like" and you will receive the information almost on a daily basis

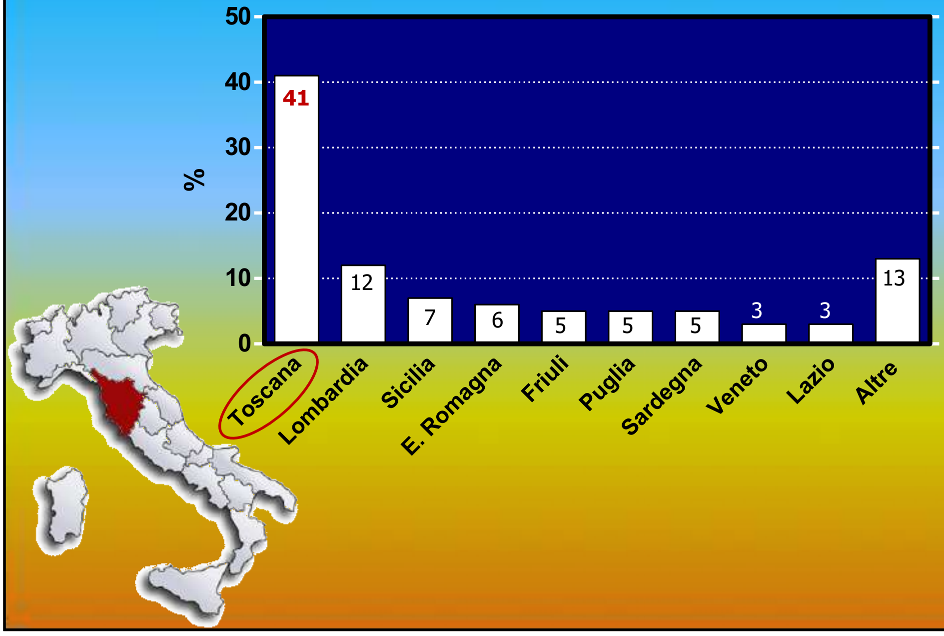
The Ornamental Plant Production District in Pistoia

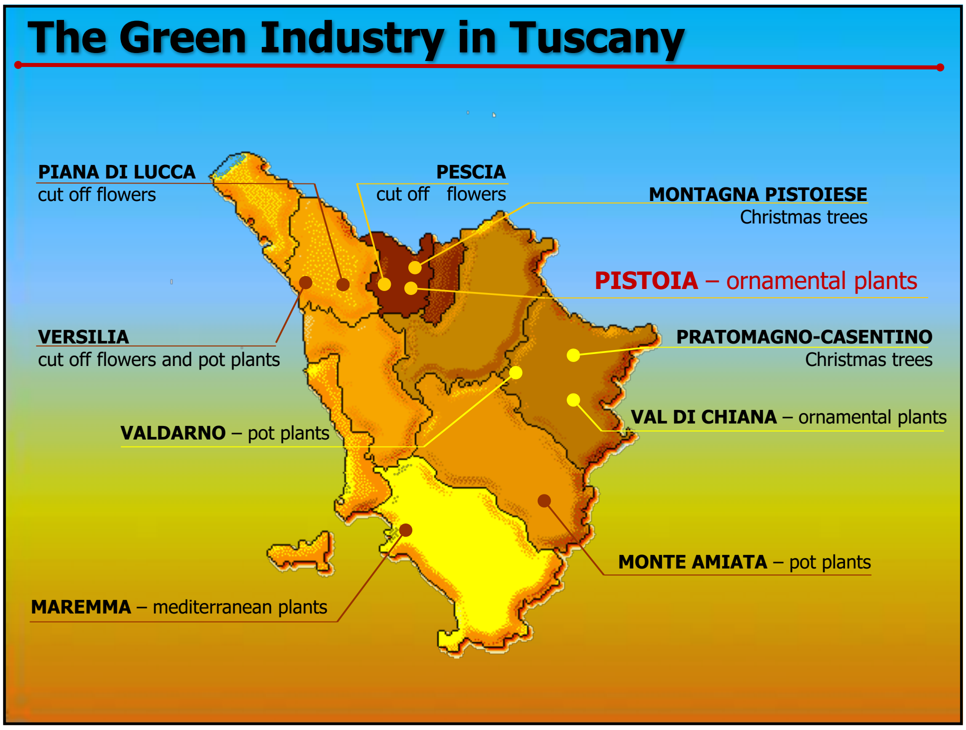
… a long history and tradition

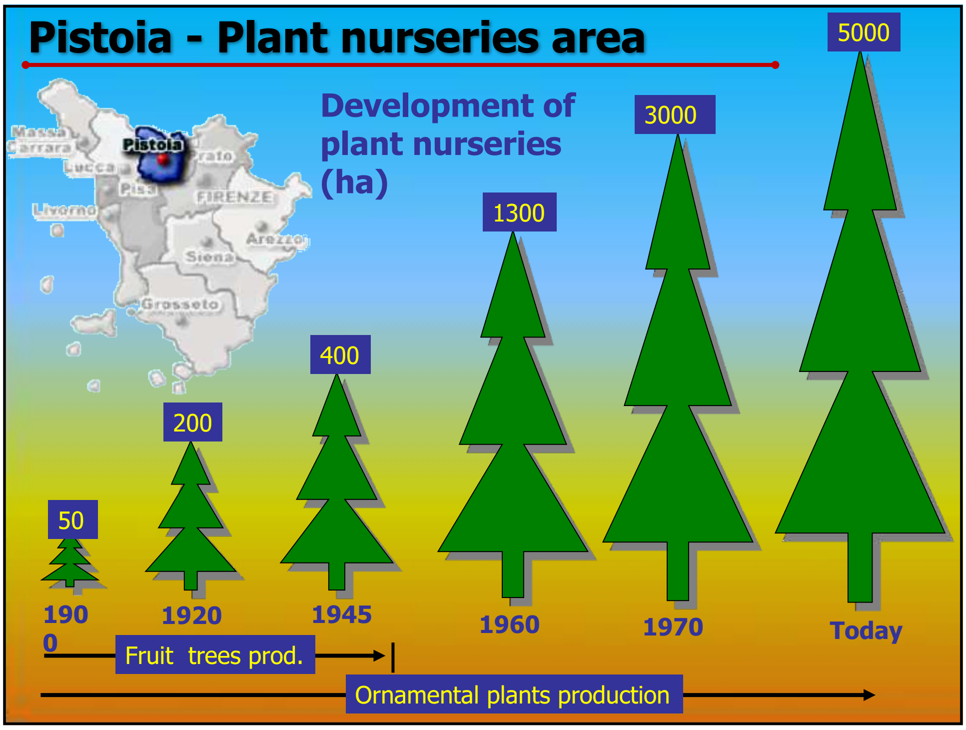
...early '900

...today

Ornamental plant production in Italy



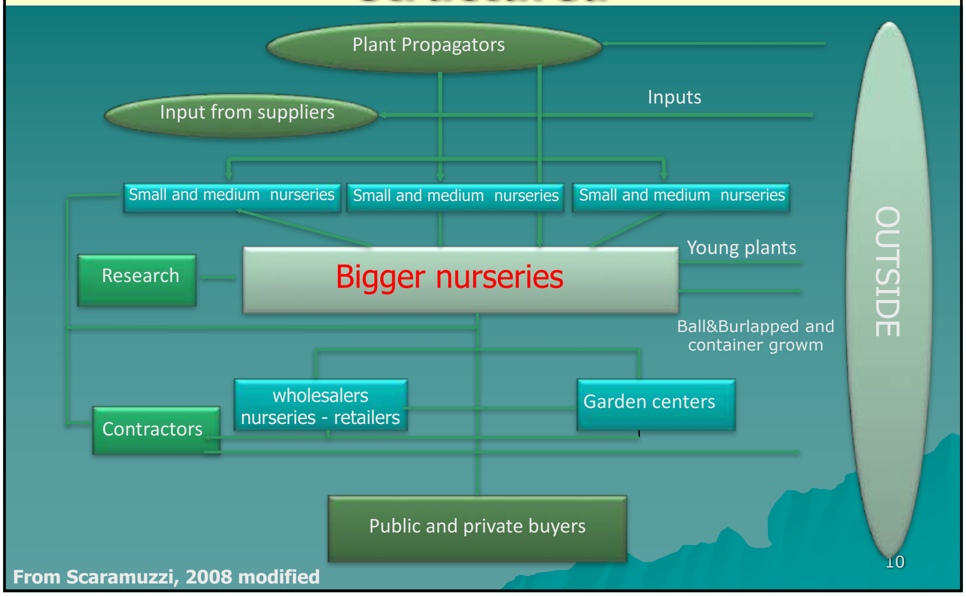

The Green Industry in Tuscany
PIANA DI LUCCA
cut off flowers
PESCIA
cut off flowers
MONTAGNA PISTOIESE
Christmas trees
PISTOIA – ornamental plants
VERSILIA
cut off flowers and pot plants
PRATOMAGNO-CASENTINO
Christmas trees
VALDARNO – pot plants
VAL DI CHIANA – ornamental plants
MONTE AMIATA – pot plants
MAREMMA – mediterranean plants


Pistoia - Plant nurseries area
Development of plant nurseries (ha)
Massa Carrara
Pistoia
Prato
Lucca
Pisa
FIRENZE
Livorno
Arezzo
Siena
Grosseto
50
200
400
1300
3000
5000
1900
1920
1945
1960
1970
Today
Fruit trees prod.
Ornamental plants production

Numbers

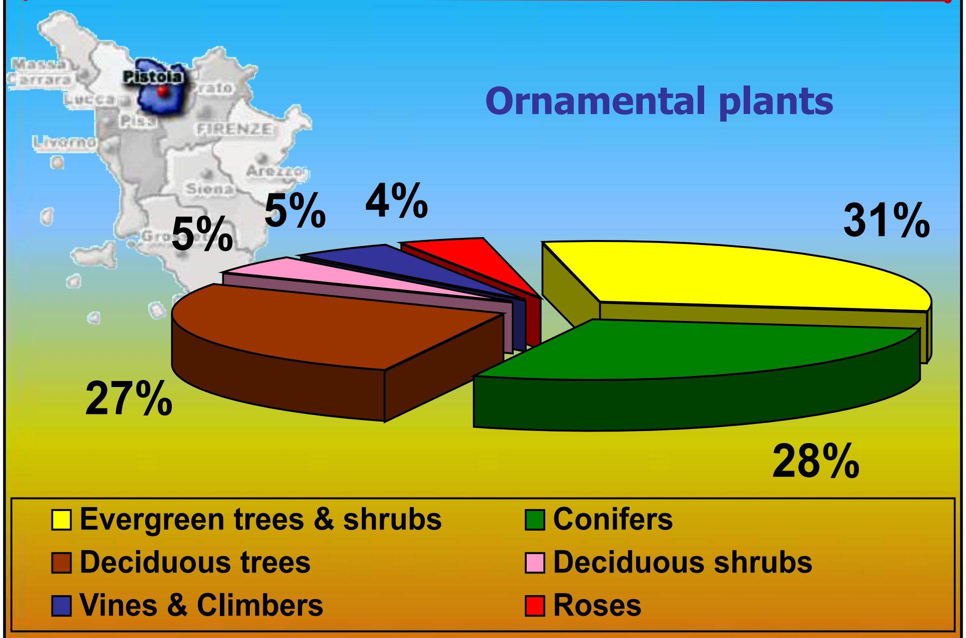
- Total nurseries area >5.000 ha (container grown plants >1.000 ha)
- 1.500 enterprises
- 5.500 workers (2.500 employed)
- Gross Production more than 600 millions € (mostly for export)

How the nursery industry is structured



From Scaramuzzi, 2008 modified

What kind of production in Pistoia?



Ball & burlapped and container plants

Evergreen trees & shrubs

Conifers

Deciduous trees

Deciduous shrubs

Vines, climbers & roses

Palm trees

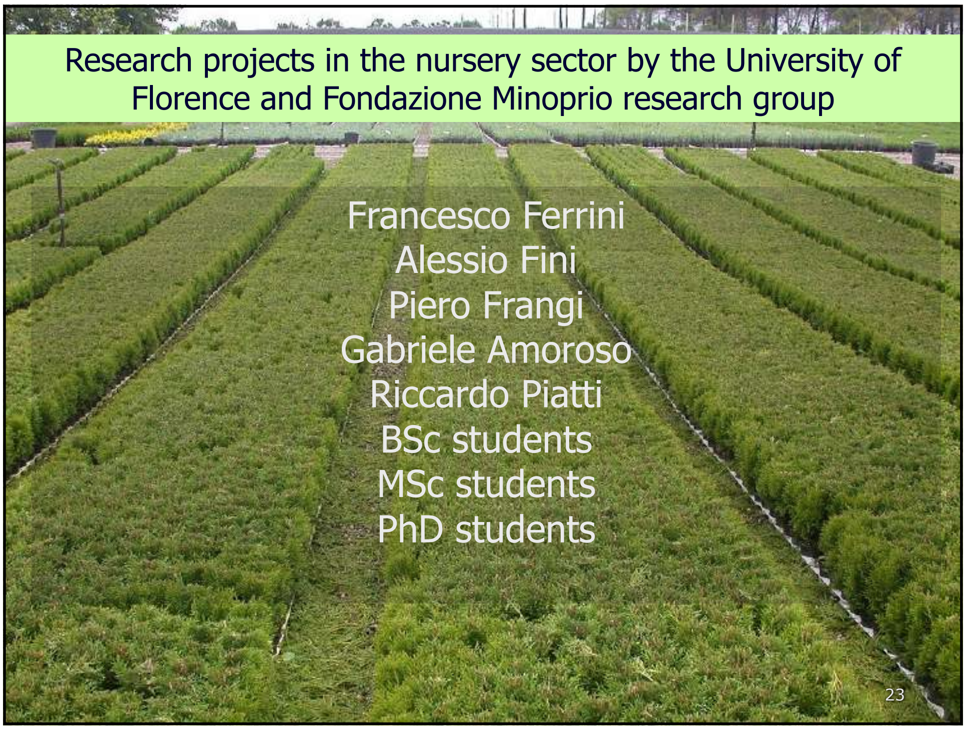
Topiary art

Strength of the Ornamental Plant Production District in Pistoia

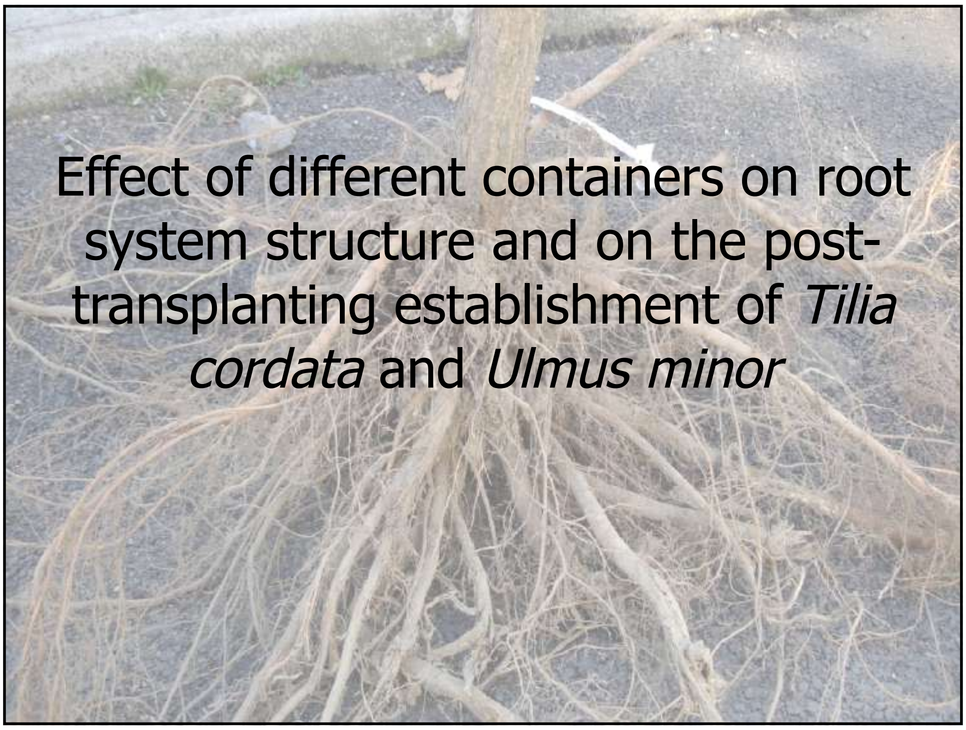
- Productive and commercial capability worldwide known
- Clear entrepreneurial and professional skills
- Favourable climate and soil conditions.
- Strong connections among different economic areas, presence of satellite activities to the nursery industry
- Geographic layout

The present scenario

- Stability of production value
- Economic crisis (investments reduction)
- Trust (Confidence) crisis
- Stagnation or recession?


Research projects in the nursery sector by the University of Florence and Fondazione Minoprio research group
Francesco Ferrini
Alessio Fini
Piero Frangi
Gabriele Amoroso
Riccardo Piatti
BSc students
MSc students
PhD students
23


1st



Effect of different containers on root system structure and on the post-transplanting establishment of *Tilia cordata* and *Ulmus minor*

Aim:
To reduce/avoid root circling

by using

- Different container form (i.e vertical ribs)
- Air pruning

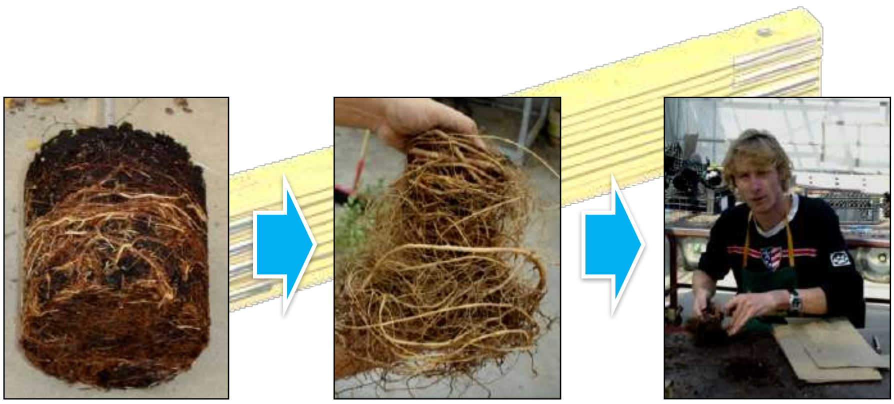
Research plan

- 2 species: littleleaf linden (*Tilia cordata* Mill.) and field elm (*Ulmus minor* Mill.)
- 2008-2009: container trials (Air-Pot®, Quadro Antispiralizzante, traditional smooth-sided) **0,9 liter** container
- 2009-2010: container trials (Air-Pot®, Quadro Antispiralizzante, traditional smooth-sided) **3 liters**

- March 2010: field transplant
- March 2012: harvesting (shoot and root biomass, % deformed roots)
- May 2014: (shoot and root biomass, % deformed roots)

Seasons 2010-2012: leaf greenness index (SPAD), chlorophyll fluorescence, annual shoot growth

At the end of the first and of the second year, plant growth and root circling rate were evaluated on 5 plants/plot



Results of the trial with 0.9 L container

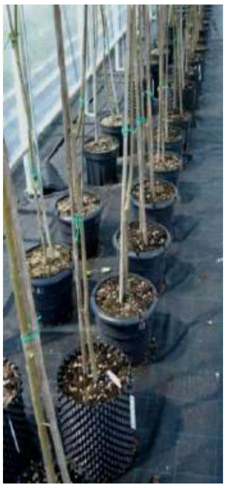
Container type	Aerial Biomass (g) Dry weight	Root Biomass (g) Dry weight	Root Circling (%)
	Tilia cordata		
Superoots® Air-Cell™	12,7	14,6 a	13,2 b
Quadro fondo rete	13,7	11,4 b	15,1 b
Standard container	11,9	14,0 a	26,2 a
Significance	*n.s.*	*	**
	Ulmus minor		
Superoots® Air-Cell™	13,4	9,5	11,3 b
Quadro fondo rete	12,8	9,0	17,1 b
Standard container	12,5	8,8	26,8 a
Significance	*n.s.*	*n.s.*	**

Results of the trial with 3 L container

Container type	Aerial Biomass (g) Dry weight	Root Biomass (g) Dry weight	Root Circling (%)
	Tilia cordata		
Superoots® Air-Cell™	35.9 b	38.7	18.3 b
Quadro fondo rete	47.1 a	40.8	19.3 b
Standard container	41.9 a	40.7	34.6 a
Significance	**	*n.s.*	**
	Ulmus minor		
Superoots® Air-Cell™	66.6	39.4 b	25.0 c
Quadro fondo rete	76.1	50.4 a	48.0 b
Standard container	77.9	44.7 ab	58.9 a
Significance	*n.s.*	*	**

- Plants grown in standard plastic containers for a long time result in **deformed roots**



We know that…..

- Deformed root systems can contribute to long-term **tree growth problems** in the landscape as instability, reduced shoot growth, tree decline and mortality
- In order to reduce the incidence of deformed roots induced during container production many **alternative container types** have been designed

Second part of the project

Objective: evaluate the effect of the different container typology adopted in the nursery on the root growth and conformation after transplanting

Trees were then planted in the open field (Metaverde Project)



2010: field transplanting

4 plots with 8 plants each

Sampling 2010-2012: Chlorophyll content (SPAD) Chlorophyll Fluorescence, Shoot length (Linden)

2012: plants uprooting

Ball reduction to 35 cm in *Tilia*, 50 cm in *Ulmus*
Determination of aerial biomass, root biomass and % of circling roots

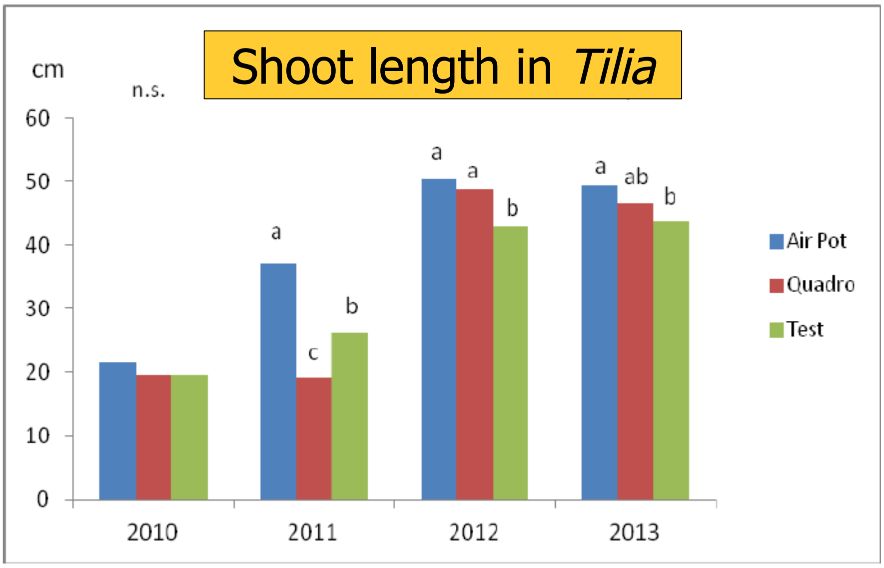
Results after two years of in-field growth

Container type	Aerial biomass dry weight (g)	Root biomass dry weight (g)	Root circling %
		Tilia	
Air-Pot®	366,9	158,7	16,0 c
Quadro antispiralizzante	300,0	173,1	33,0 b
Standard container	306,2	185,8	56,0 a
Significance	*n.s.*	*n.s.*	**
		Ulmus	
Air-Pot®	1595,2	536,1 b	33,0 b
Quadro antispiralizzante	2584,5	969,3 a	77,7 a
Standard	2283,7	863,2 a	90,2 a
Significance	*n.s.*	**	**

2013-2014: data harvest continued

Biomass 2014

Shoot length in *Tilia*



Longer shoots in the "Air-pot" trees

Results after four years of in-field growth

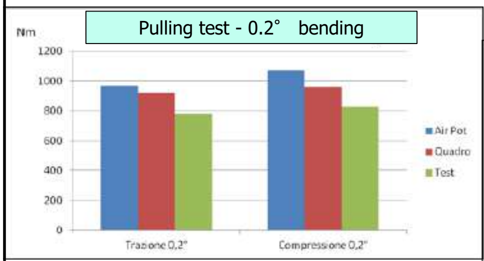
Container type	Aerial biomass (kg) fresh weight	Root biomass (kg) fresh weight	Root circling %
		Tilia	
Air-Pot®	9,8	1,6	43,3 c
Quadro antispiralizzante	11,1	2,0	60,4 b
Standard container	9,0	1,9	81,4 a
Significance	*n.s.*	*n.s.*	**
		Ulmus	
Air-Pot®	67,0	13,1	34,9
Quadro antispiralizzante	64,9	13,2	54,0
Standard container	52,6	11,1	56,0
Significance	*n.s.*	*n.s.*	*n.s.*

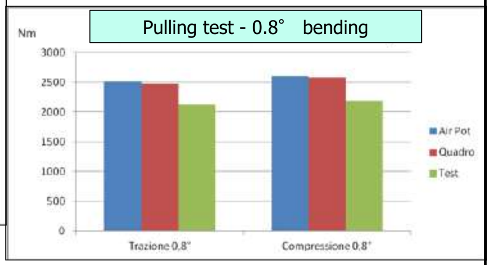
After 4 years in the field, root circling was still much higher in the trees grown in standard container during the nursery phase. This was statistically significant in *Tilia*

Pulling test

April 2014 on Elm (Studio Gifor – Florence)
Wind-force simulation on trees

Pulling test





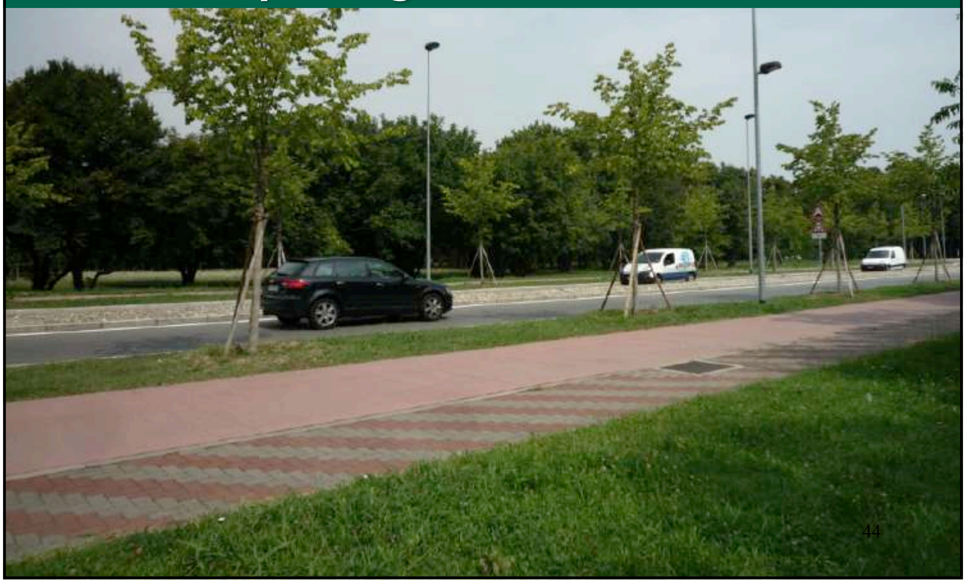
April 2014 on Elm (Studio Gifor – Florence)
Wind-force simulation on trees

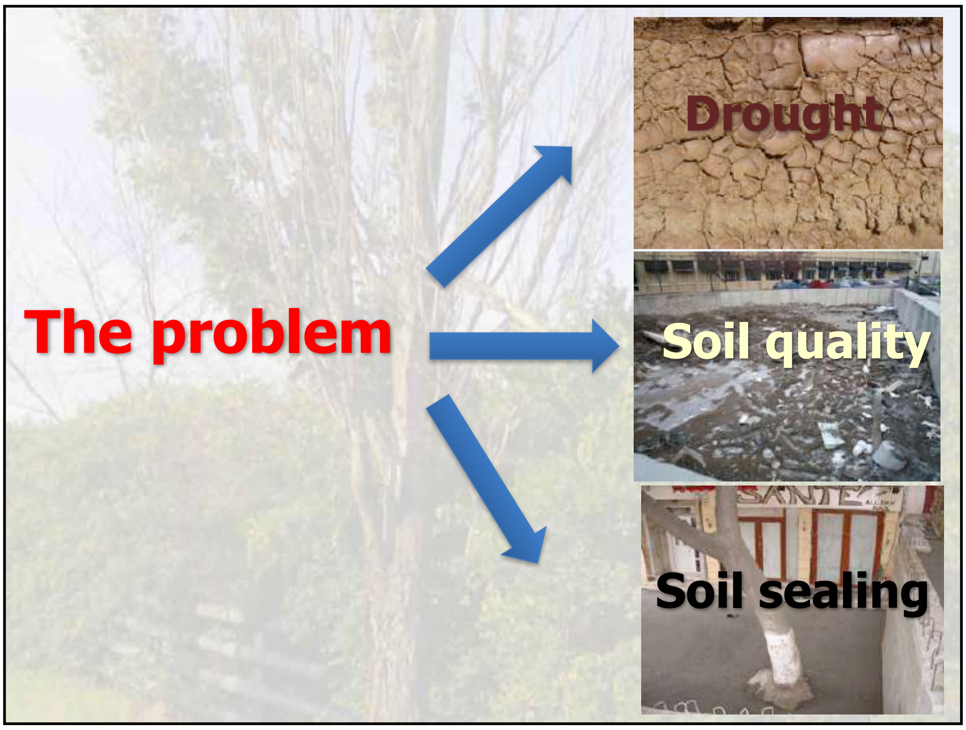
Final considerations

- Container form strongly affects root system quality in trees
- A malformed root system in the initial growth stages keeps on being malformed in the following years, unless drastic pruning is applied
- Root defects (girdling, circling, structural weakness) often show even several years after transplanting
- Best results have been obtained with Air-Pot containers but cultivation techniques must be adjusted (substrate, irrigation)

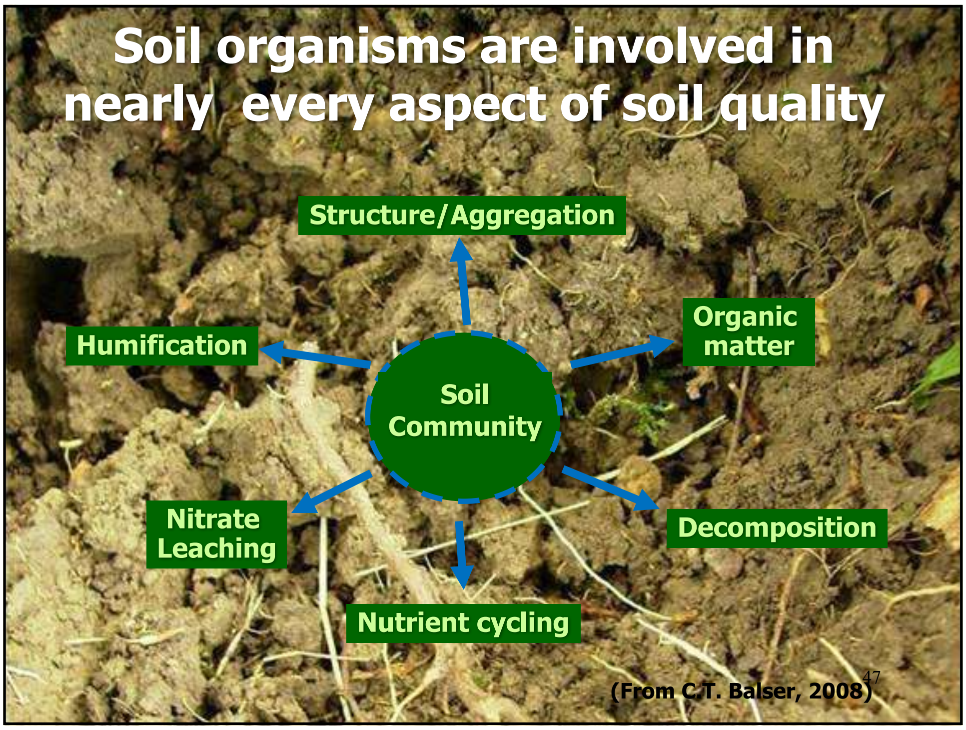



Effect of mycorrhizal inoculation in the nursery and at planting on tree growth and physiology after transplanting in the urban environment




The problem
Drought
Soil quality
Soil sealing


Quality of urban soils
Do you expect to find microorganisms in this type of junky soil??


Soil organisms are involved in nearly every aspect of soil quality
Structure/Aggregation
Humification
Organic matter
Soil Community
Nitrate Leaching
Decomposition
Nutrient cycling
(From C.T. Balser, 2008)
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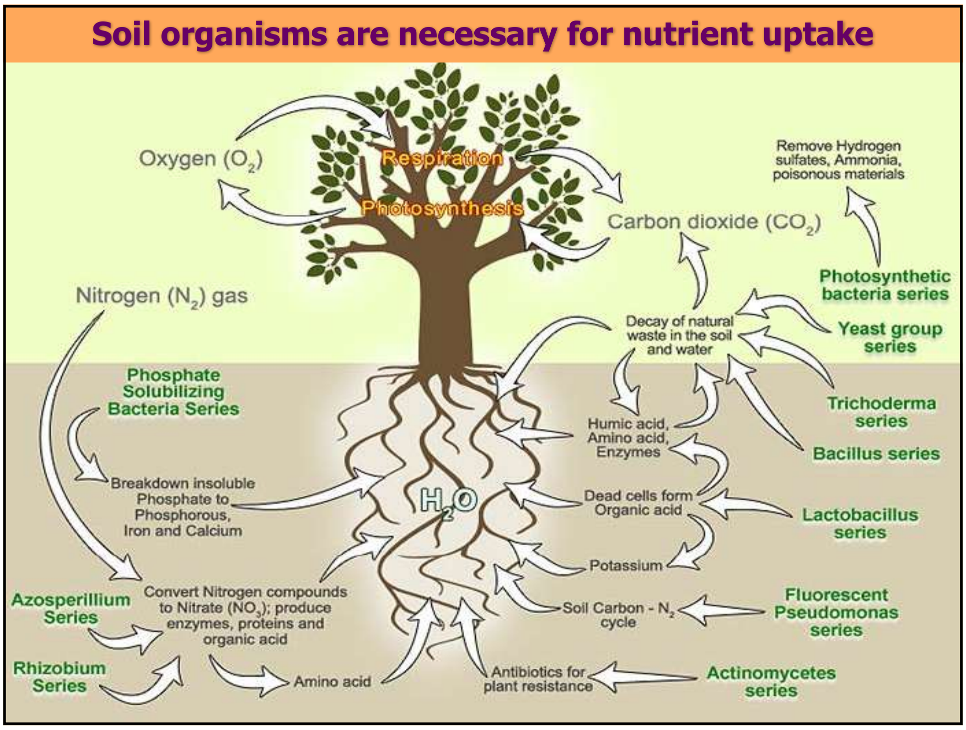

Soil organisms are necessary for nutrient uptake
Oxygen (O_2)
Respiration
Photosynthesis
Carbon dioxide (CO_2)
Remove Hydrogen sulfates, Ammonia, poisonous materials
Photosynthetic bacteria series
Yeast group series
Nitrogen (N_2) gas
Decay of natural waste in the soil and water
Phosphate Solubilizing Bacteria Series
Trichoderma series
Humic acid, Amino acid, Enzymes
Bacillus series
Breakdown insoluble Phosphate to Phosphorous, Iron and Calcium
H_2O
Dead cells form Organic acid
Lactobacillus series
Potassium
Azosperillium Series
Convert Nitrogen compounds to Nitrate (NO_3); produce enzymes, proteins and organic acid
Soil Carbon - N_2 cycle
Fluorescent Pseudomonas series
Rhizobium Series
Amino acid
Antibiotics for plant resistance
Actinomycetes series

Plant Nutrient Uptake

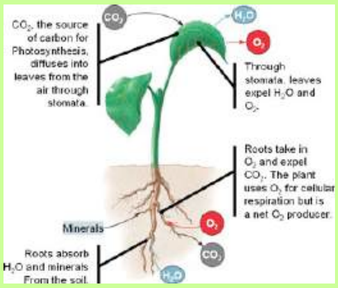
What influences rates of nutrient uptake by vegetation?

1) Nutrient supply rate from the soil (e.g., mineralization rate) is the most important

2) Root length

- the major plant trait determining uptake
- high specific root length maximizes root surface area (SRL = length per mass)

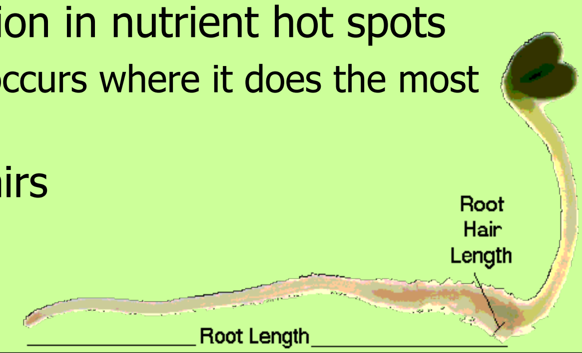
3) Root activity (uptake capacity per unit root length, density of ion carriers) secondary to root length, but important during phases of rapid expansion, like after disturbance



From Hungate, 2008

Root elongation is the main way plants can increase nutrient uptake

- Increased root:shoot ratio
  - Increased investment in roots
- Root proliferation in nutrient hot spots
  - Root growth occurs where it does the most good
- Longer root hairs



From Hungate, 2008, redrawn

Is there any other solution to increase nutrient uptake?

Something natural that is able:

- To increase root absorbing surface;
- To induce positive alterations in the **rhizosphere** (the narrow region of soil that is directly influenced by root secretions and associated soil microorganisms);
- To render available forms of phosphorus otherwise not available by plants;
- To generally improve the nutrient absorption (ammonium, nitrates, K, Ca, Fe,….);
- To compete against pathogens

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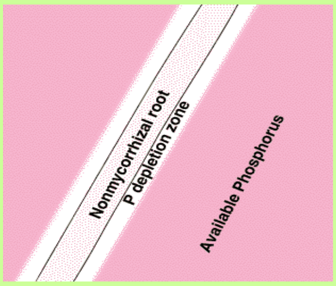
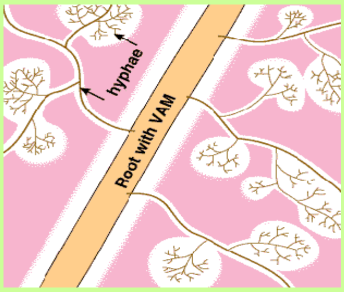
Why mycorrhiza?

Not inculated with mycorrhizae



Inoculated with mycorrhizae



- Roots and root hairs cannot enter the smallest pores
- because Hyphae size is 1/10th of root hair……
- …..and this increased surface area
- Extension beyond depletion zone

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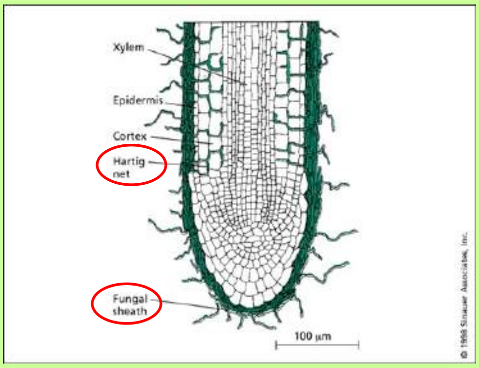
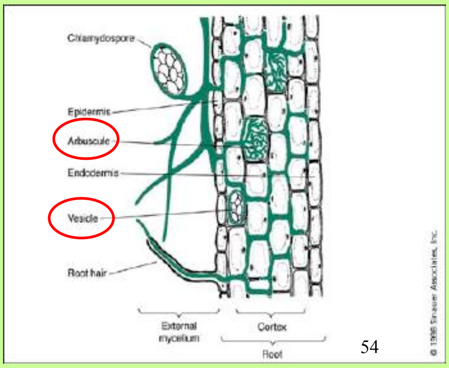
Comparison of Arbuscular mycorrhizae and Ectomycorrhizae, the two major types of mycorrhizae globally

Structure of ectomycorrhizae, showing fungal sheath encasing root and penetration between cortical cells



Fungal hyphae penetrate walls of cortical cells (but not plasma membrane); they produce highly branched "arbuscules" in close association with plant cell plasma membrane, forming the point of transfer of nutrients and carbon;



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Benefits of ectomycorrhiza for the tree?

- improved water uptake
- improved nutrient uptake
- storage of nutrients
- increased production of biomass
- protection of toxic elements
- protection of soil-borne pathogenes
- higher stress-tolerance



Benefit of mycorrhizal symbiosis for the fungus?

- The fungus gets 15 – 30 % of the products of the plant-photosynthesis

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Kutscheidt, 2007

Water Uptake

Mycorrhizal plants may better tolerate drought because of :

- Increased root branching and fineness (Kothari et al.,1990)
- Reduced resistance to water flow in the soil to root interface (Cowan, 1965)
- Greater capacity to adjust osmotically (Schellenbaum et al., 1998)
- Greater capacity to avoid drought (Augè et al., 1992)
- Increased Water Use Efficiency (Simpson and Daft, 1990)
- Increased P nutrition (Koide, 1993)

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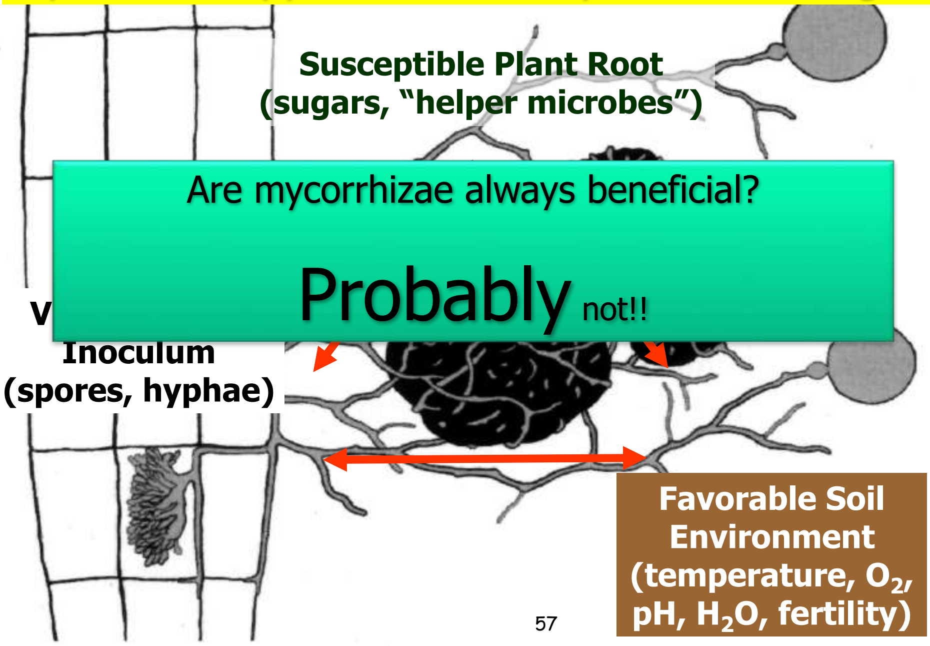
Mycorrhizal application: the mycorrhizal triangle



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RESEARCH BACKGROUND

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Urbanization acts as a heavy disturbance, altering soil microbial community and reducing biodiversity

↓

Reduced or altered mycorrhizal fungi species. Some studies demonstrated that, despite of similar frequency of colonization, healthy lindens growing in city areas were associated to different mycorrhizal fungi if compared to unhealthy lindens growing in the same environment

↓

Urban trees rarely thrive (average life span 10 to 15 years)

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Results of Mycorrhization

A large number of commercial products is available

Several experiences in the literature with constranting results

Using „generalists" products may cause reduced or even no benefit to the trees

•Low specificity with species to be inoculated

•Low specificity with environmental conditions

• Ecto- or endomycorrhizal components of the inoculum are sometimes redundant

•Some negative interactions are possible, though they are not common (often caused by *Pisolitus tinctorius*)

•Sometimes commercial products are used a long after their production and this might cause loss of vitality

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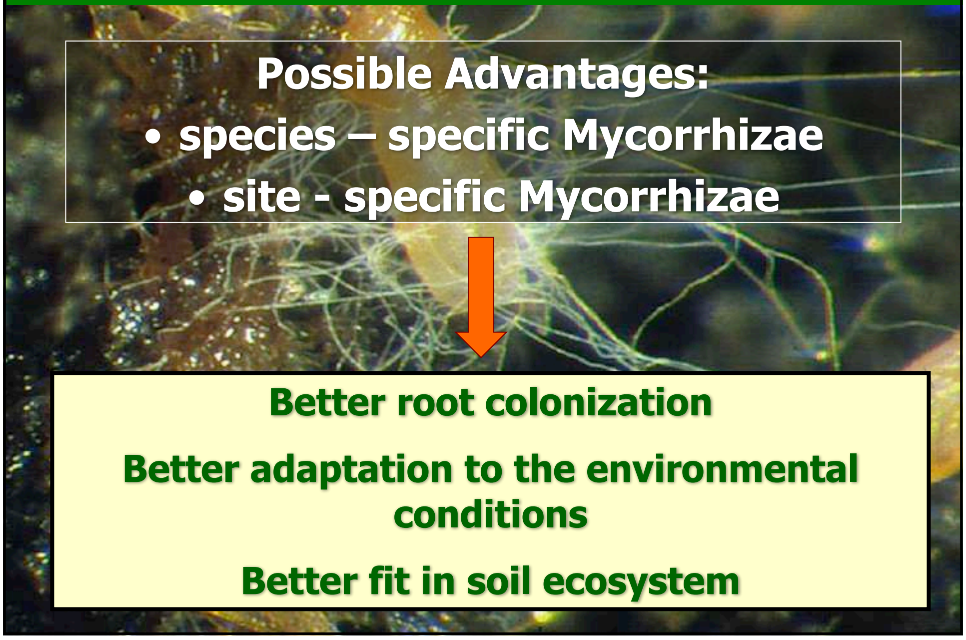
Use of autochtonous strains of mycorrhizae



Possible Advantages:

- species – specific Mycorrhizae
- site - specific Mycorrhizae

Better root colonization

Better adaptation to the environmental conditions

Better fit in soil ecosystem

Material and Methods

PROJECT: Acclimation through controlled mycorrhization in the nursery

STEP 1: looking for healthy hedge maples, pedunculate oaks and littleleaf lindens in Milan urban and peri-urban areas (we also looked for other species inside this project)

METHODS: building up the inoculum..

STEP 2: assessing soil characteristics (pH, texture, phosphorus-content).
Are they similar to those of site where mycorrhizal trees will have to be planted?

YES… proceed to root harvesting

NO… keep searching

METHODS: building up the inoculum..

STEP 3: analysis and identification of fungal strains

ECM

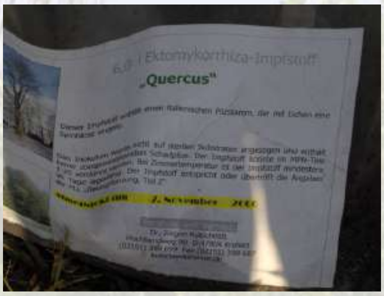
- Frequency of mycorrhizal root tips (*Newton and Pigott 1991, New Phytol*)
- Fungus-host compatibility was evaluated on the basis of the structure of the Hartig net (*Brundrett et al., 1996, New Phytol*)

VAM

- Roots were stained with 0.05% Trypan blue in lactoglycerol (*Koske and Gemma, 1989, Mycol Res; Klingeman et al., 2002, HortScience*)
- Percentage of root colonization was assessed by the magnified intersection method (*McGonigle et al., 1990, New Phytol*)
- Vitality of the mycelium was determined by the succinate dehydrogenase reaction (*Gianinazzi and Gianinazzi-Pearson, 1992*)
- Alkaline phosphatase activity was measured after staining with staining with an ALP staining solution (*Janoušková et al., 2009, Mycorrhiza*)

METHODS: building up the inoculum..

STEP 4: To propagate the selected fungal strains, single fungus pot cultures of the selected fungal strains were established with one-year-old seedlings of maple, linden and oak in a greenhouse and in non-sterile conditions



STEP 5: After 8 months, fine roots were harvested from the seedlings, cut into small pieces and used to produce the inoculum. The inoculum was composed by infected root pieces, fungal mycelium, montmorillonite and a hydrogel to avoid dehydration

METHODS: building up the inoculum..

STEP 6: INOCULATION

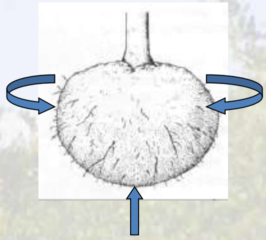
- Every 10 cm of stem diameter correspond to 450 -500 ml of inoculum

i.e: Beech Ø 80 cm = 3 l (price is 45 $/1 l)

Inoculation of mature trees for health restoration can be quite expensive!!!!!!!!!!!

Controlled mycorrhization of young nursery plants requires much less inoculum (25-50 ml) but:

1) the selected strains are able to survive in the nursery conditions; 2) mycorrhizae survive transplant in the outplanting site



- **2/3 spreading on the sides**
- **1/3 putting into bottom**

Use of autochtonous strains of mycorrhizae

Our research project, instead of using commercial products, is based on a 4-steps approach

1a) Excavation around healthy trees in a selected environment

4) Distribution*

1b) Roots+soil samples harvest

3) Preparation

2) Analysis and multiplication

* The inoculum was composed by colonized root pieces, fungal mycelium, montorillonite and a hydrogel to avoid dehydration

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MAIN PARAMETERS MEASURED

INOCULATION % (measured one year after inoculation)

SHOOT GROWTH (measured at the end of each growing season)

TRUNK DIAMETER AND PLANT HEIGHT (Measured each winter on all plants; diameter was measured at 1,3m)

LEAF GAS EXCHANGE (A, E, Gs, WUE=A/E) (Measured using a portable infrared gas analyser, Ciras-2, PP-System).

CHLOROPHYLL CONTENT (Measured with a SPAD-meter, Konica Minolta)

CHLOROPHYLL FLUORESCENCE (F_0, F_V/F_m)
Measured with a portable fluorimeter, Handy Pea, Hansatech Ins., after 30 min. dark adaption).
Fv = Variable fluorescence Fm = Maximum fluorescence
F_0 = Basal Fluorescence

LEAF WATER POTENTIAL measured at predawn with a pressure bomb

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PROJECT #1: Effect of controlled inoculation with specific mycorrhizal fungi from the urban environment on growth and physiology of containerized shade tree species growing under different water regimes

Fini A., Frangi P., Amoroso G., Piatti R., Faoro M., Bellasio C., Ferrini F., 2011. Mycorrhiza (2011) 21:703–7119 (I.F. 2,65)

The aims of this work were:

- To evaluate if inoculation with specific mycorrhiza obtained in the urban environment can increase mycorrhizal frequency, growth, leaf gas exchange and drought tolerance of container-grown plants in the nursery
- To study the effects of deficit irrigation on some morphological and physiological parameters in three widely-use shade tree species
- To detect if there are interactions between mycorrhization and drought tolerance

METHODS: treatments

MYCORRHIZA:

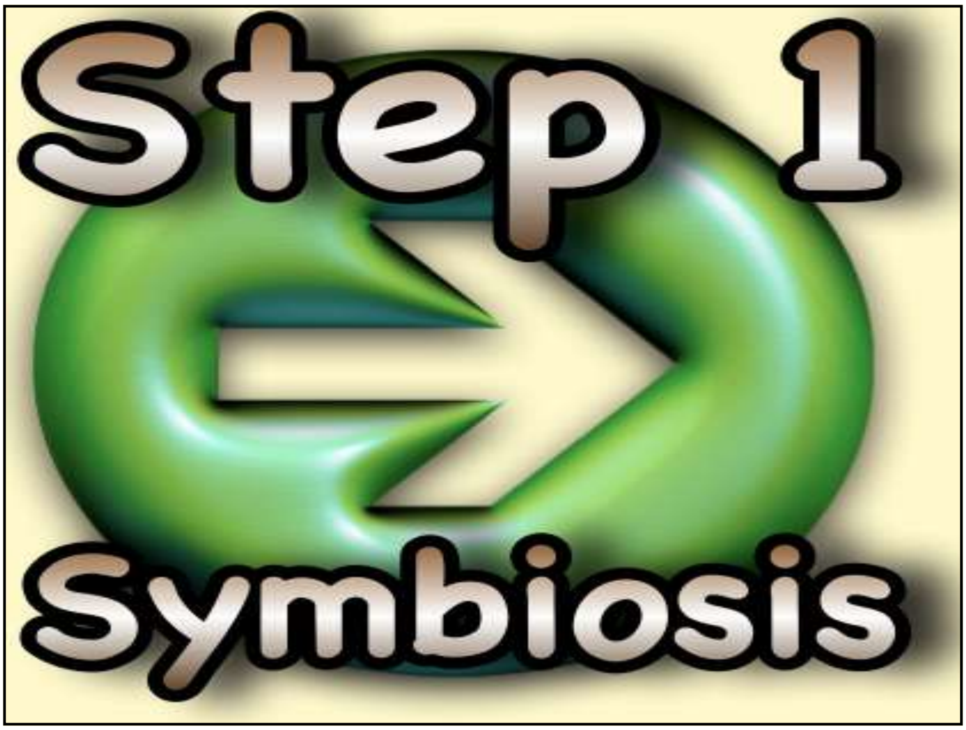
1) 50% of the plants were inoculated with native, specific mycorrhizae at potting (**+M**)
2) 50% of the plants were not inoculated (**-M**)

Inoculation was carried out at trasplant by mixing 25 ml of specific inoculum to the substrate. Maple was inoculated with VAM, oak with ECM, and linden with both VAM and ECM, having care not to mix the two products

WATER REGIME:

1) 50% of the plants were daily irrigated to container-capacity (**WW**)
2) 50% of the plants were daily irrigated to 30% of container water holding capacity (**WS**)

Container Capacity, Wilting Point and Effective Water Holding Capacity of the substrate was determined with a gravimetric method using the method described by Sammons and Struve (2008)



Mycorrhizal frequency (one year after inoculation)

Species	Inoculation (I)		Water regime(W)		Significance		
	+M	-M	WW	WS	I	W	I xW
Acer	53%	24%	33%	44%	**	**	ns
Tilia (ECM)	81%	59%	68%	72%	**	ns	ns
Tilia (AMF)	17%	10%	14%	14%	*	ns	ns
Quercus	80%	41%	54%	61%	**	**	ns

• As found by others, control plants had some degree of mycorrhization, but inoculation increased mycorrhizal frequency in all species (*Appleton, 2003, J Arboric; Wiseman and Wells, 2009, J Env Hort*)

• Water shortage increased mycorrhizal frequency in maple and oak but not in linden (*Augè, 2001, Mycorrhiza; Entry et al., 2002, Adv Environ Res*)

•No interactions were found between mycorrhisation and water regime

STEP 2: GROWTH

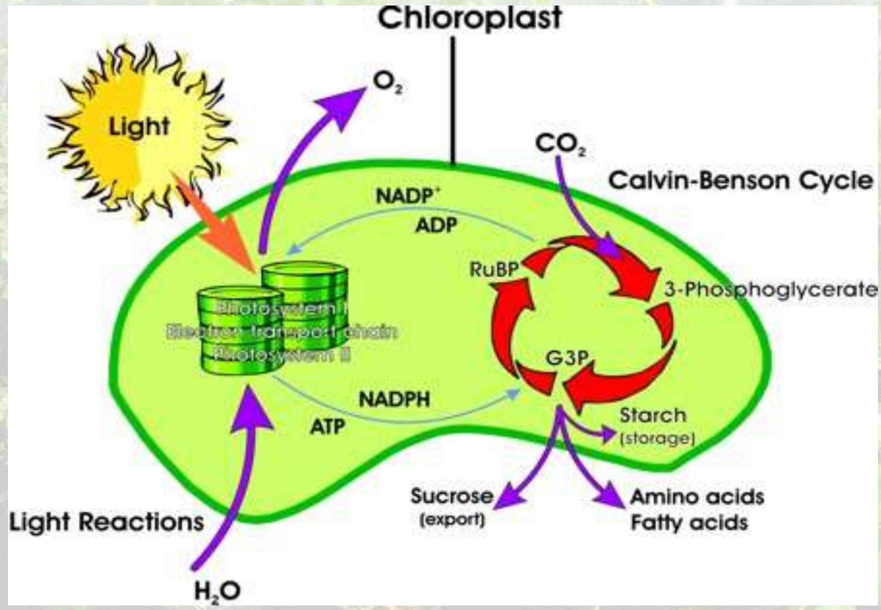
Biomass

Species	Parameter	Inoculation (I)		Water regime (W)		Significance		
		+M	-M	WW	WS	I	W	I xW
Acer	Plant DW 2009 (g)	248.2	238.2	292.2	195.2	ns	**	ns
	Root:shoot 2009	0.9	1.0	1.0	0.9	ns	ns	ns
	Leaf area 2009 (cm^2)	5398.3	4964.9	5859.5	4503.7	ns	*	ns
Tilia	Plant DW 2009 (g)	160.4	153.3	190.3	123.4	ns	**	ns
	Root:shoot 2009	0.9	0.9	0.9	0.9	ns	ns	ns
	Leaf area 2009 (cm^2)	4428.0	4036.9	4833.4	3631.5	*	**	ns
Quercus	Plant DW 2009 (g)	187.5	201.8	233.6	155.8	ns	**	ns
	Root:shoot 2009	0.7	0.8	0.6	1.0	ns	**	ns
	Leaf area 2009 (cm^2)	5092.9	3875.9	5715.4	3253.4	**	**	ns

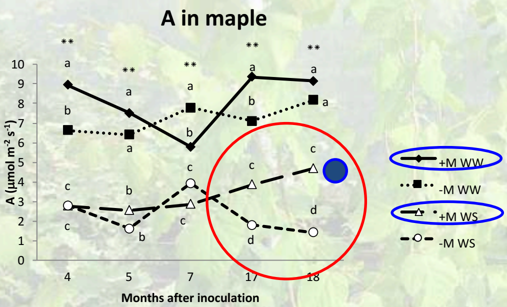
Inoculation with specific mycorrhizae **did not enhance biomass accumulation** of maple, linden and oak saplings growing in container. Plants growing in **water stressing conditions had lower leaf, stem and root** (except for oak) dry weights than well watered plants of the same species, regardless if being inoculated or not.

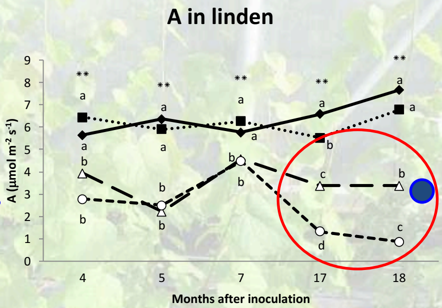
No interactions were found between mycorrhization and water regime

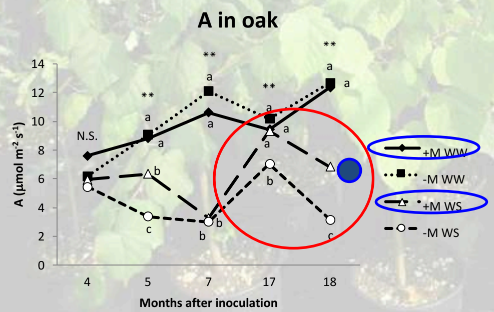
STEP 3: PHYSIOLOGY



Leaf gas exchange: photosynthesis

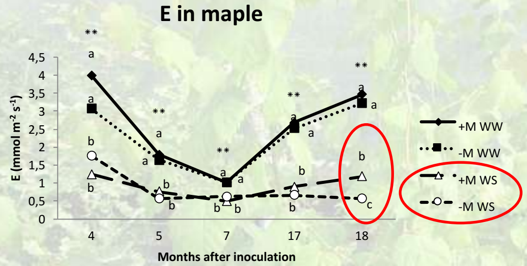


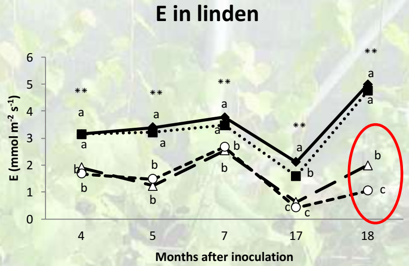


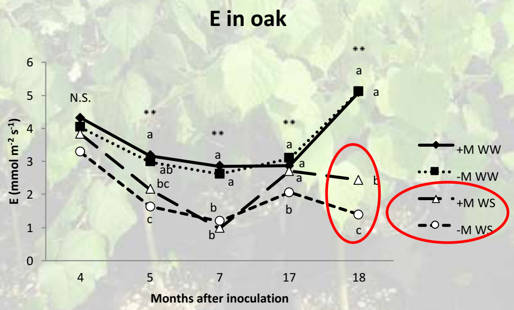


Regardless to the species, Net photosynthesis was always higher in inoculated plants especially when water stress was induced

What about transpiration, water uptake and transport?





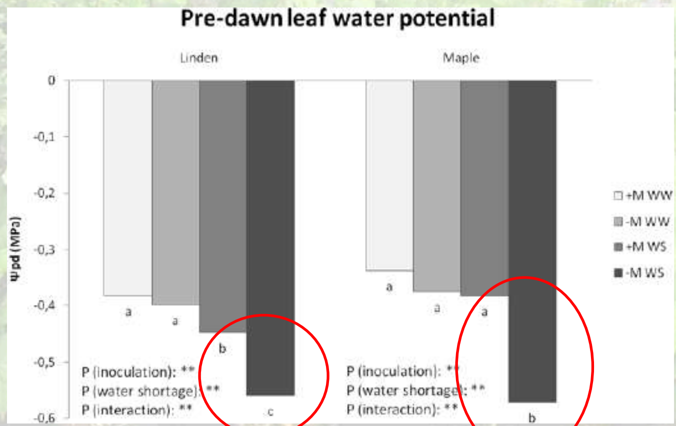


Regardless to the species, transpiration was higher in the inoculated plants when water stress was induced

Possible reasons for higher transpiration

(*Allen 1982, New Phytol; Augé et al., 1986, Plant Physiol; Ebel et al., 1996, Mycorrhiza*)

- Increased water uptake by mycorrhizal root system
- Delayed stomatal closure
- Increased soil to plant hydraulic conductance



Conclusions

- Controlled mycorrhization in the nursery didn't enhance growth of container-grown maples, lindens and oak.

- Anyway, inoculation provided several physiological benefits as the maintenance of less negative leaf water potential, higher apparent carboxylation rate, higher RuBP regeneration and higher quantum yield of PSII under water shortage

- **The overall data suggest that inoculated plants were better able to maintain physiological activity of shade tree species during water stress if compared to non-inoculated plants, and thus can be considered more drought-tolerant**

One question remains to be answered: what about the effect of deficit irrigation on post-transplant growth and physiology?

In March 2010 trees from the research where planted in the field
(without any fertilisation and irrigation)

From the container to the open environment

Results on plant growth: first season after planting

Species	Parameter	Inoculation (I)		Water regime (W)		Significance		
		+M	-M	WW	WS	I	W	I xW
Acer	Shoot length (cm)	16.2	19.1	14.4 b	20.9 a	ns	*	ns
	Diameter (mm)	22.7	22.4	23	22	ns	ns	ns
	Leaf area (cm^2)	15.36	12.71	14.24	14.83	ns	ns	ns
	Leaf Mass per Area	0.032	0.036	0.036	0.033	ns	ns	ns
Tilia	Shoot length (cm)	16.4	15.8	19.1 a	13.1 b	ns	*	ns
	Diameter (mm)	21.5 b	23.2 a	23.5 a	21.2 b	*	*	ns
	Leaf area (cm^2)	34.62	33.39	38.87 a	29.84 b	ns	*	ns
	Leaf Mass per Area	0.028	0.029	0.025 b	0.031 a	ns	*	ns
Quercus	Shoot length (cm)	20.9	20.1	16.86 b	24.4 a	*		ns
	Diameter (mm)	20.7	19.9	21.9 a	18.8 b	*		ns
	Leaf area (cm^2)	16.3 a	13.57 b	15.47	14.4	ns		ns
	Leaf Mass per Area	0.03	0.034	0.032	0.033	ns		ns

WW = well watered plants during container-phase
WS = water stressed plants during container-phase
+M = Inoculated at potting in the nursery
-M = non inoculated
LMA Leaf Mass per Area (g/m^2)

Water-stressed plants had higher growth except in *Tilia*.
Mycorrhization was, in general, not effective

Results on leaf gas exchange: first season after planting

Species		Inoculation (I)		Water regime (W)		Significance		
		+M	-M	WW	WS	Inoc.	Water	I x W
Acer	A	10,33	7,4	8,0	9,7	**	*	ns
	E	3,3	2,6	2,7	3,1	**	*	ns
	WUE	3,2	2,9	2,9	3.1	**	*	ns
Tilia	A	11,05	9,92	9,65	11,32	*	**	ns
	E	2,94	2,85	2,68	3,11	ns	**	ns
	WUE	3,84	3,53	3,59	3,79	*	ns	
Quercus	A	15,64	14,68	14,29	16,03	ns	*	ns
	E	3,44	3,44	3,3	3,58	ns	*	ns
	WUE	4,58	4,26	4,33	4,51	*	ns	ns

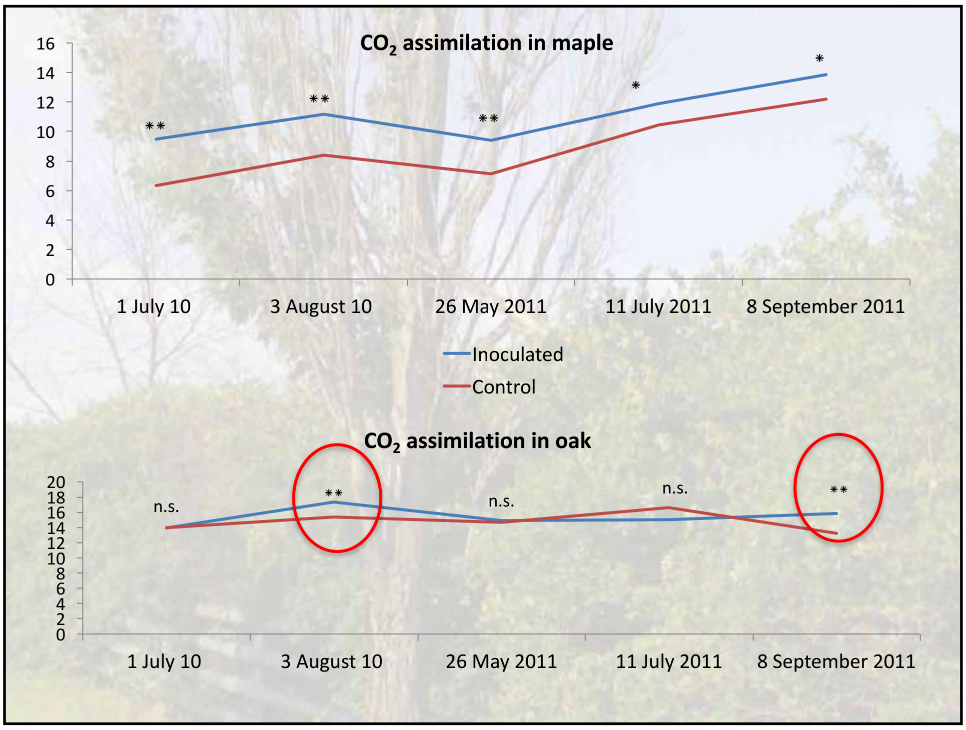
Photosynthesis (A) is in μmol m^{-2} s^{-1}
Transpiration (E) is in mmol m^{-2} s^{-1}

WW = well watered plants during container-phase
WS = water stressed plants during container-phase

Water-stressed plants had higher leaf gas exchange. Mycorrhization was effective especially on maple

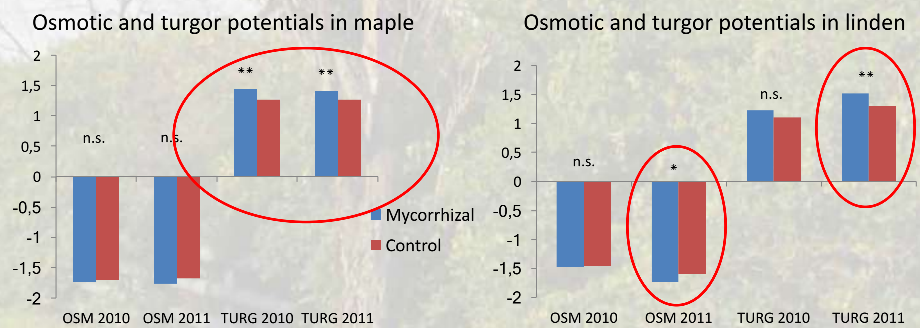
Diameter and shoot growth

Linden	Shoot growth (cm)		Diameter growth (mm)
	2010	*2011*	*2010-2011*
Acer campestre			
Inoculated	16,2	64,8 a	13,7
Non inoculated	19,1	56,8 b	14,6
P	n.s.	*	n.s.
Tilia cordata			
Inoculated	16,4	78,5 a	18,6
Non inoculated	15,8	69,4 b	17,1
P	n.s.	*	n.s.
Quercus robur			
Inoculated	20,9	90,5 a	16,0
Non inoculated	20,1	68,6 b	15,3
P	n.s.	*	n.s.



Average Fv/Fm (maximal quantum yield of PSII), pre-dawn water potential, and Water Use Efficiency over the whole experiment

	Fv/Fm	Ψw	WUE	Fv/Fm	Ψw	WUE	Fv/Fm	Ψw	WUE
	Acer campestre			*Tilia cordata*			*Quercus robur*		
Inoculated	0.750 a	-0.32 a	3.17 a	0.804 a	-0.23 a	3.84 a	0.787	-0.29	4.58 a
Control	0.737 b	-0.41 b	2.86 b	0.792 b	-0.29 b	3.53 b	0.786	-0.32	4.26 b
P	*	**	**	*	*	*	n.s.	n.s.	*



Project # 2. From the Nursery to the Urban environment

SPECIES INOCULATED:
Tilia x europaea 'Pallida' Typ. Lappen

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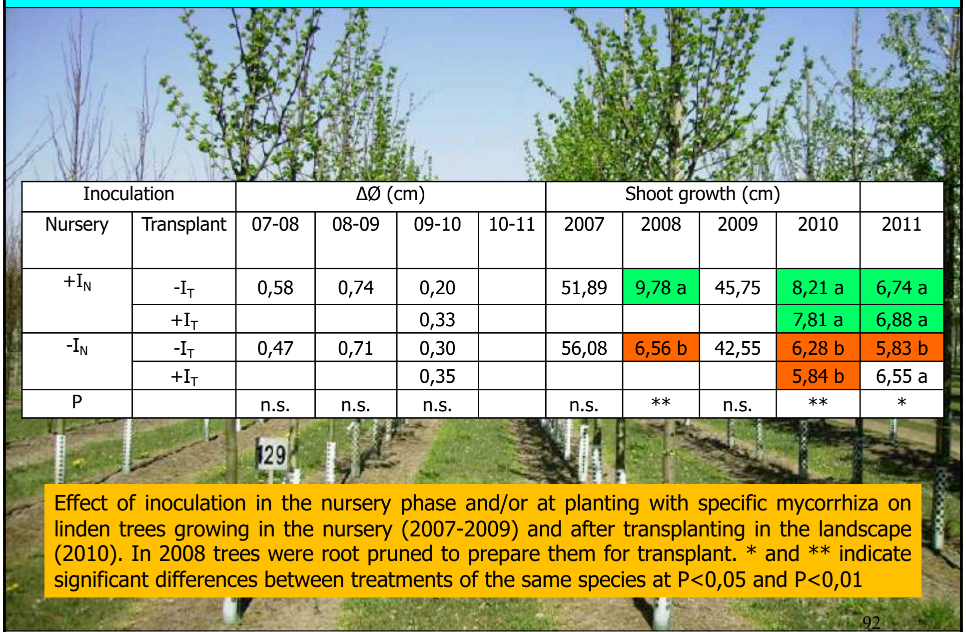
From the Nursery to the Urban environment

From the Nursery to the Urban environment

From the Nursery to the Urban environment



Inoculation		ΔØ (cm)				Shoot growth (cm)				
Nursery	Transplant	07-08	08-09	09-10	10-11	2007	2008	2009	2010	2011
$+I_N$	$-I_T$	0,58	0,74	0,20		51,89	9,78 a	45,75	8,21 a	6,74 a
	$+I_T$			0,33					7,81 a	6,88 a
$-I_N$	$-I_T$	0,47	0,71	0,30		56,08	6,56 b	42,55	6,28 b	5,83 b
	$+I_T$			0,35					5,84 b	6,55 a
P		n.s.	n.s.	n.s.		n.s.	**	n.s.	**	*

Effect of inoculation in the nursery phase and/or at planting with specific mycorrhiza on linden trees growing in the nursery (2007-2009) and after transplanting in the landscape (2010). In 2008 trees were root pruned to prepare them for transplant. * and ** indicate significant differences between treatments of the same species at P<0,05 and P<0,01

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***Tilia x europaea* 'Pallida' Typ. Lappen**

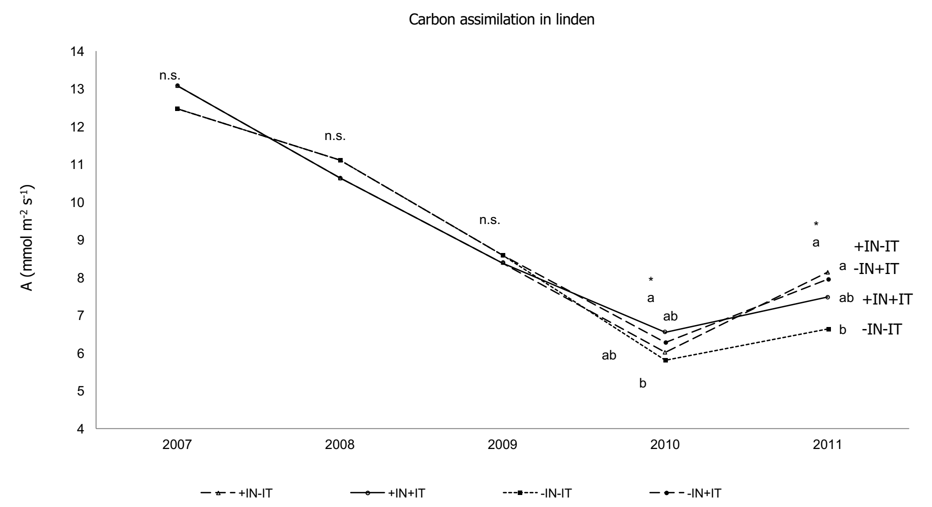
From the Nursery to the Urban environment

Inoculation		Chlorophyll (SPAD Value)				Chlor. Fluorescence (Fv/Fm)					Ψw
Nursery	Transplant	2007	2008	2009	2010	2007	2008	2009	2010	2011	2011
$+I_N$	$-I_T$	42.37	38.24 a	27.43	26.72	0.79	0.762 a	0.814 a	0.769 ab	0,815	- 0.413 b
	$+I_T$	-	-	-	26.72	-	-	-	0.778 a	0,824	- 0.306 a
$-I_N$	$-I_T$	40.5	35.78 b	27.32	24.13	0.77	0.735 b	0.802 b	0.769 ab	0,824	- 0.413 b
	$+I_T$	-	-	-	24.92	-	-	-	0.762 b	0,822	- 0.391 b
P		n.s.	**	n.s.	n.s.	n.s.	**	**	**	n.s.	*

Effect of inoculation in the nursery phase and/or at planting with specific mycorrhiza on linden trees chlorophyll content (SPAD Units), chlorophyll fluorescence in the nursery (2007-2009) and after transplant in the landscape (2010-2011 when also leaf water potential was measured). In 2008 trees were root pruned to prepare them for transplant. * and ** indicate significant differences between treatments of the same species at P<0,05 and P<0,01

***Tilia x europaea* 'Pallida' Typ. Lappen**

From the Nursery to the Urban environment



Carbon assimilation (A, µmol m^{-2} s^{-1}) in linden inoculated in the nursery ($+I_N$-I_T), in the nursery and at transplanting ($+I_N$+I_T), not inoculated ($-I_N$-I_T) and inoculated only at transplant ($-I_N$+I_T). Different letters within the same sampling date indicate significant differences at p < 0,05. * data still to be processed

***Tilia x europaea* 'Pallida' Typ. Lappen**

Thesis	WUE 2007	WUE 2008	WUE 2009	WUE 2010	WUE 2011
+IN-IT	10.35	6.53	8.1	5.15	4.94 a
+IN+IT				5.55	5.03 a
-IN-IT	10.55	6.24	8.6	5.33	3.81 b
-IN+IT				6.04	4.64 ab
sig.	n.s.	n.s.	n.s.	n.s.	*

Effect of inoculation after planting with specific mycorrhiza on linden trees on water use efficiency in the nursery (2007-2009) and after transplant in the landscape (2010-2011). In 2008 trees were root pruned to prepare them for transplant. * indicates significant differences between treatments of the same species at P<0,05

From the Nursery to the Urban environment

Lesson learnt

✓When stress occurred, an inoculation-induced increase in shoot growth was found. Particularly, shoot growth was higher in plants inoculated in the nursery and both in the nursery and at planting if compared to control and plants inoculated only at planting

✓Inoculating plants both in the nursery and/or at transplanting have probably contributed to a greater root colonization by mycorrhizal fungi, which determined higher photosynthesis

✓We can speculate that trees inoculated had a higher photosynthesis on a plant-scale basis (higher Pn and longer shoots)

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***Tilia x europaea* 'Pallida' Typ. Lappen**

2) Street trees and trees growing in a parking lot

Celtis australis (European hackberry) and Fraxinus excelsior

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Street trees and trees growing in a parking lot

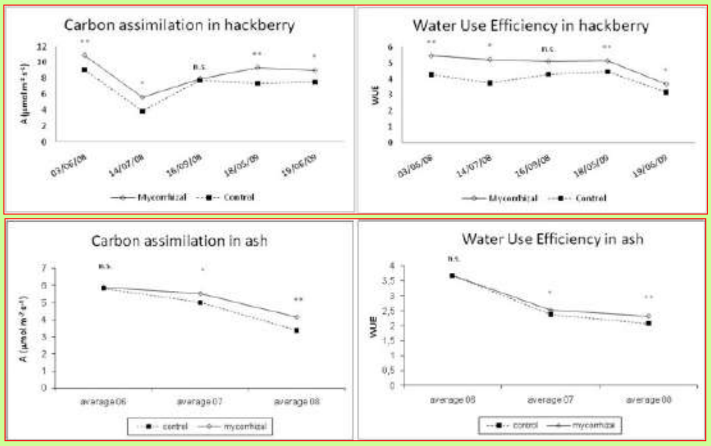
Celtis australis (European hackberry) and Fraxinus excelsior (European ash)

	ΔØ (cm)			Shoot growth (cm)			Chlorophyll content (SPAD)	
Celtis australis	06/07	07/08	08/09	2007	2008	2009	June 2008	Sept. 2008
Mycorrhiza	0,57	1,26	0.45	23,86	30,33	36,55	45,37	48,77
Control	0,3	1,07	0.37	15,4	15,25	20.25	39,06	35,68
P	**	*	n.s.	**	**	**	**	**
Fraxinus excelsior	06/07	07/08	08/09	2007	2008	2009	2007	2008
Mycorrhiza	N.D.	0,71	N.D.	7,05	10,12	N.D.	29,04	30,1
Control	N.D.	0,88	N.D.	4,76	7,11	N.D.	30,03	30,4
P	-	n.s.	-	**	**	-	n.s.	n.s.

Effects of inoculation with selected mycorrhiza on diameter and shoot growth and on chlorophyll content of *Celtis autralis* and *Fraxinus excelsior* planted in a parking lot and along a street, respectively. * and ** indicate significant differences between mycorrhizal and control trees of the same species at $P<0,05$ and $P<0,01$. N.D. = not determined.

Street trees and trees growing in a parking lot

Celtis australis **(European hackberry) and** ***Fraxinus excelsior*** **(European ash)**



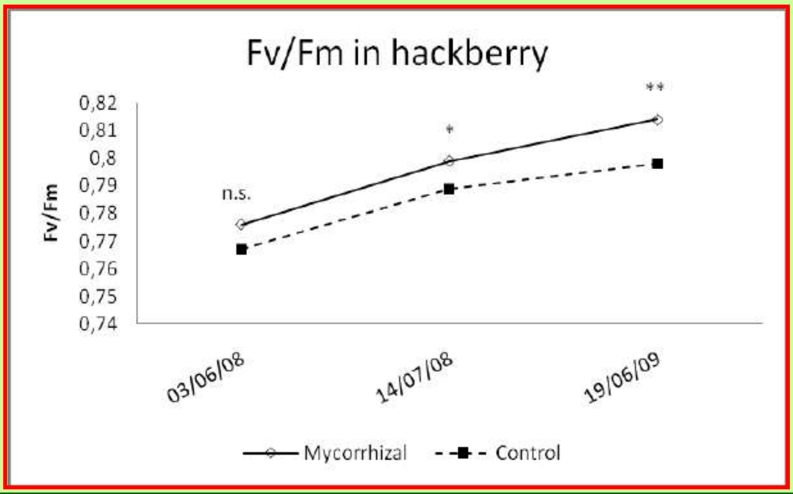
Carbon assimilation (A, mmol m-2 s-1, left) and Water Use Efficiency (WUE, mmol CO_2/mmol H_2O, right) in inoculated and non-inoculated hackberry (Above) amd ash trees (below) planted in a parking lot and as street trees. * and ** indicate significant differences between mycorrhizal and control trees within the same sampling date at P<0,05 and P<0,01

Higher growth ⟷ **Higher photosynthesis** ⟷ **Higher WUE**

Isn'it sustainable??

Street trees and trees growing in a parking lot

Celtis australis **(European hackberry)**



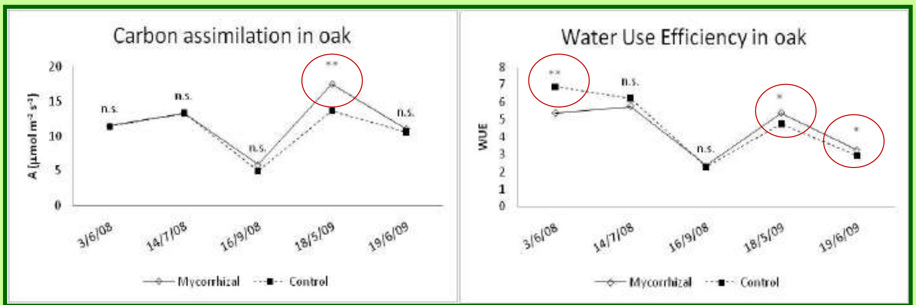
Maximal quantum yield of photosystem II (Fv/Fm) in inoculated and non-inoculated hackberry planted in a parking lot. * and ** indicate significant differences between mycorrhizal and control trees of the same species at P<0,05 and P<0,01

3) Trees planted in a Urban Park

Urban Park: English oak

	ΔØ (cm)			Shoot growth (cm)			Chlorophyll content (SPAD)	
Quercus robur	06/07	07/08	08/09	2007	2008	2009	June 2008	Sept. 2008
Mycorrhiza	0,7	1,3	1,43	13,52	68,22	71,4	43,2	43,6
Control	0,52	1,27	1,27	4,13	41,38	48,8	39,1	39,8
P	n.s.	n.s.	n.s.	**	**	**	*	**

Effects of inoculation with selected ecto-mycorrhiza on diameter and shoot growth and on chlorophyll content of *Quercus robur* planted in an urban park. * and ** indicate significant differences between mycorrhizal and control trees of the same species at P<0,05 and P<0,01.

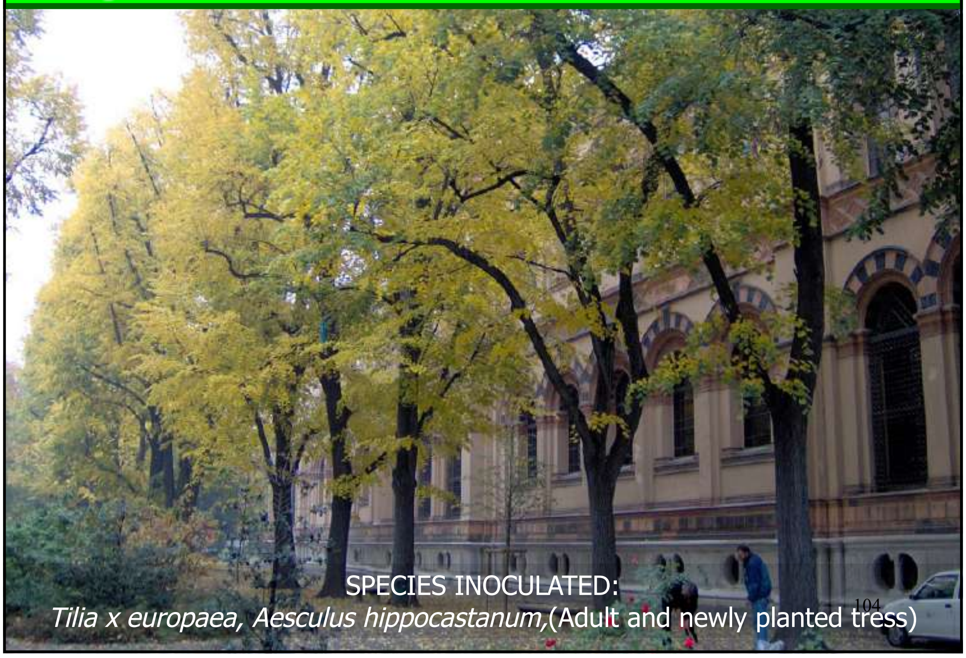


Carbon assimilation (A, mmol m^{-2} s^{-1}, left) and Water Use Efficiency (WUE, mmol CO_2/mmol H_2O, right) in inoculated and non-inoculated pedunculate oaks planted in and urban park. * and ** indicate significant differences between mycorrhizal and control trees within the same sampling date at P<0,05 and P<0,01.

Urban Park: English oak

Take home message: Though the photosynthesis only rarely showed significant differences on single-leaf basis, plants had higher growth and they sequestered a much higher Carbon amount on the whole-plant-basis

4) Trees in a Historical Urban Park



SPECIES INOCULATED:
Tilia x europaea, Aesculus hippocastanum,(Adult and newly planted tress)

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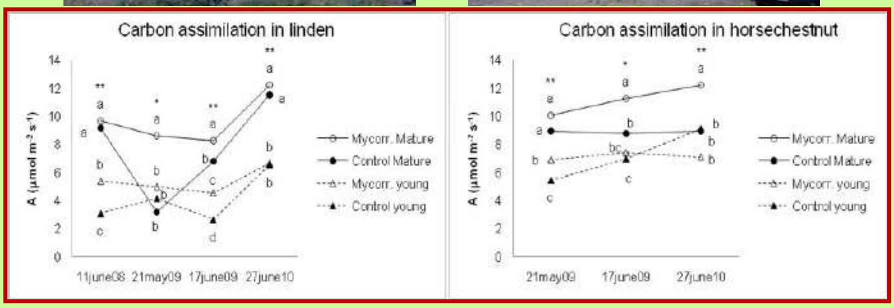
Historical Urban Park

	ΔØ 06/07 (cm)	ΔØ 07/08 (cm)	ΔØ 08/09 (cm)	shoot growth 2008 (cm)	shoot growth 2009 (cm)	Chl. Content 2008 (SPAD)
Tilia						
Mature mycorrhizal	2,74 a	1,38 a	0,8	14,5 a	21,5 a	52,4 a
Mature control	1,71 a	0,33 b	1,3	12,1 b	14,8 b	47,6 b
Young mycorrhizal	0,63 b	0,24 b	0,6	9,7 c	8,6 c	42,0 c
Young control	0,81 b	0,18 b	1,2	12,6 b	7,7 c	39,8 c
P (inoculation)	n.s.	n.s.	n.s.	n.s.	**	*
P (age)	**	**	n.s.	**	**	**
P (IxA)	n.s.	*	n.s.	*	*	*
Aesculus						
Mature mycorrhizal	1,8 a	0,61	0,4 b	8,8 c	9,5 c	N.D.
Mature control	1,1 ab	0,71	0,4 b	5,7 d	6,1 d	N.D.
Young mycorrhizal	0,6 b	0,33	0,7 ab	13,7 a	15,4 a	43,4 a
Young control	0,9 ab	0,48	1,1 a	12,1 b	10,9 b	40,3 b
P (inoculation)	n.s.	n.s.	n.s.	**	**	*
P (age)	*	n.s.	*	**	**	-
P (IxA)	n.s.	n.s.	n.s.	n.s.	n.s.	-

Effects of selected mycorrhiza on diameter and shoot growth and on chlorophyll content of newly planted (young) and mature *Tilia* and *Aesculus* planted in an historical garden in the centre of Milan. * and ** indicate significant differences between mycorrhizal and control trees of the same species at P<0,05 and P<0,01. N.D. = not determined.

Historical Urban Park



Effects of selected mycorrhiza on carbon assimilation of young and mature *Tilia* (left) and *Aesculus* (right) planted in an historical garden in the centre of Milan. * and ** indicate significant differences between treatments within the same sampling date at P<0,05 and P<0,01

Summary of the whole research project

Green areas typologies	Site	Species	Age	Plant number	Mycorrhizal group	Inoculum per plant (ml)
Nursery (container) then transplating in the open field	Como	*Acer campestre, Quercus robur, Tilia cordata*	Young (2 years)	240	Endo, Ecto, and Ecto+Endo	50
Nursery (open field) then transplating in the urban environment	Nettetal (Germany) then Milan	*Tilia x europaea 'Pallida'*	Young (trunk girth 14-16 cm, 5-6")	48	Ecto+Endo	180
Tree Avenue	Florence	*Fraxinus excelsior*	Young (trunk girth 20-25 cm, 8-10")	20	Endo	280
Parking lot	Milan	*Celtis australis*	Young (trunk girth 14-16 cm, 5-6")	24	Endo	180
Urban park	Milan	*Quercus robur*	Young (trunk girth 14-16 cm, 5-6")	64	Ecto	125
Historical park	Milan	*Tilia x europaea, Aesculus hippocastanum*	Young (trunk girth 20-25 cm, 8-10") and mature (170-220 cm, 70-85")	56	*Ecto+Endo (Tilia)*, Endo (*Aesculus*)	280 (young plants), 1600-2000 (old plants)

Results of the whole research project

Typology	Species	Effect on Growth	Effect on Photosynthesis	Effect on Water use efficiency	Effect on chlorophyll fluorescence	Effect on chlorophyll content	Effect on Water potential
Nursery (container) then transplating in the open field	*Acer campestre*	Not significant	Increase, esp. in the 2° year +46%	+41%	+5%	n.s	+31%
	Quercus robur			+15%	+5%	+6%	Not determined
	Tilia cordata	n.s.	Increase, esp. in the 2° year +45%	+49%	+3%	n.s.	+15%
Nursery (open field) then transplating in the urban environment	*Tilia x europaea* 'Pallida'	variable	n.s. in the nursery. +8% after transplanting	n.s. in the nursery+58% after transplanting	Increase in the nursery (+3%). N.S. after transplanting	Increase in the nursery (+3%). N.S. after transplanting	+35%
Tree Avenue	*Fraxinus excelsior* 'Westhof's Glorie'	n.s. for trunk diameter, shoot growth +45%	Increase, esp. in the 2° year +23%	Increase, esp. in the 2° year +12%	n.s.	+26%	Not determined
Parking lot	*Celtis australis*	Trunk diameter (+43%) and shoot growth (78%)	Increase, esp. in the 2° year +21%	+17%	+2%	+26%	Not determined
Urban park	*Quercus robur*	n.s. for trunk diameter, shoot growth +212%	n.s.	Increase, esp. in the 2° year +13%	Increase, esp. In the 2nd year 3%	+10%	Not determined
Historical park	*Tilia x europaea* (young)	n.s. (except for leaf area shoot growth +31%	n.s.	+37%	not determined	n.s.	Not determined
	Tilia x europaea (mature)	n.s. for trunk diameter, shoot growth +45%	Increase, esp. in the 2° year +26%	+19%	not determined	+10%	Not determined
	Aesculus hippocastanum	n.s. for trunk diameter, shoot growth +27%	n.s.	+14%	Not determined	+8%	Not determined
	Aesculus hippocastanum	n.s. for trunk diameter, shoot growth +55%	Increase, esp. in the 2° year +26%	+8%	Not determined	Not determined	Not determined

Conclusions

- Inoculation with selected, native mycorrhiza improved, in general, plant growth and physiology.

ANYWAY:

- The time of response depends on the inoculated species
- The effect of mycorrhiza on host growth is dependent on environmental conditions

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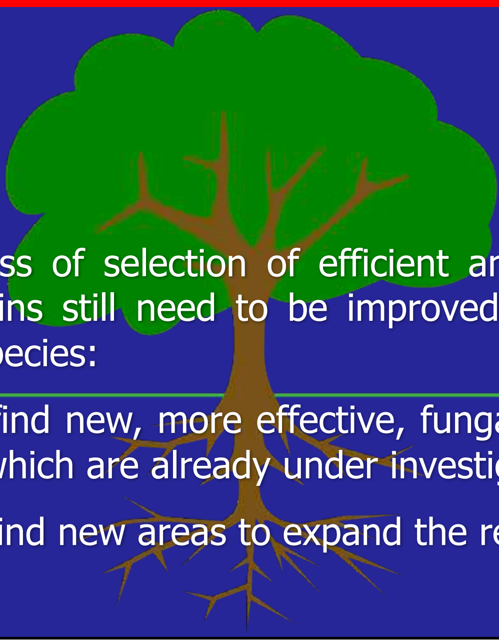
Conclusions



The process of selection of efficient and effective fungal strains still need to be improved, especially on some species:

- Need to find new, more effective, fungal strains in the areas which are already under investigation
- Need to find new areas to expand the research

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Many thanks to our sponsor which funded the research with 26.000 €

www.granditrapianti.it

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Mulching and amending with compost: results of a long term project on some woody ornamentals in different environments

Use of Compost in the urban environment

Amendment

Mulching


Mulching with Compost
115


Why mulching?
116

Benefits of organic mulches

Physical:
- Improve soil structure (long-term effect)
- Reduce compaction
- Reduce erosion
- Conserve soil moisture
- Reduce soil temperature annual fluctuations

Chemical:
- Modify and stabilize pH
- Increase CEC
- Supply nutrients over time

Biological:
- Supply soil biota
- Suppress weeds
- Suppress pathogens

Aesthetical
- Gives a finished look, improving aesthetic quality

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The disadvantages of mulching

Mainly from excessive mulch
- Reduced gaseous exchange…suffocation
- Rodent damage and root disease
- Evaporation of excess water is hindered

Sometimes mulching can be ineffective accordingly to environmental conditions

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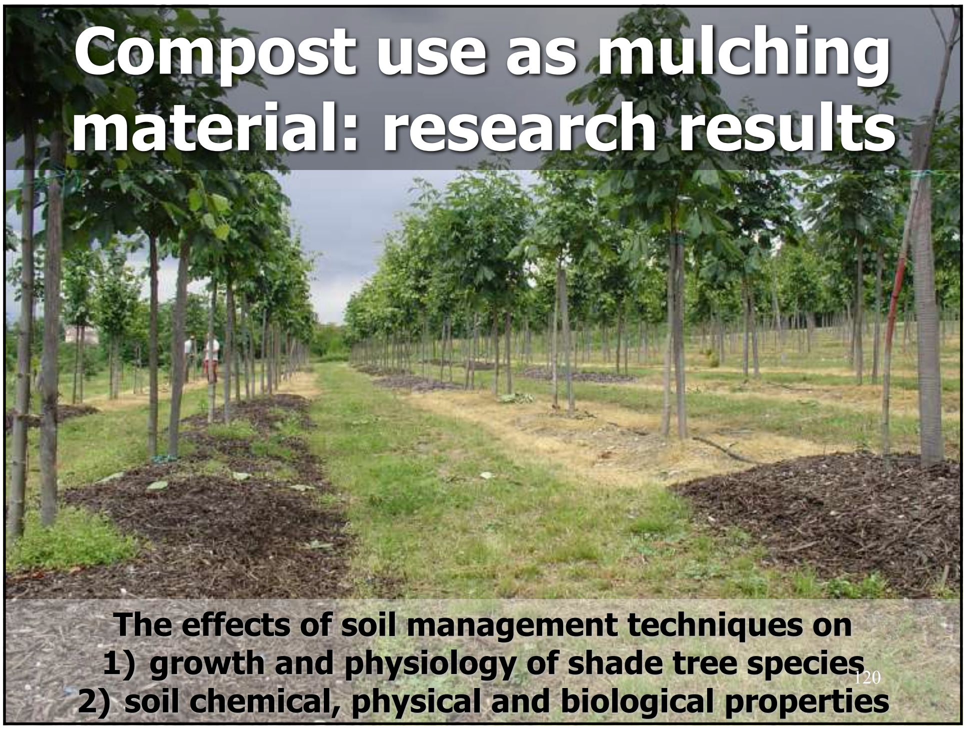
What's he doing?


Compost use as mulching material: research results
The effects of soil management techniques on
1) growth and physiology of shade tree species
2) soil chemical, physical and biological properties
120

Mulching material characteristics

Pine bark	Compost
	

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Effect of soil management techniques on plant height trunk diameter and shoot growth of *Aesculus x carnea*

Parameter	Year	Pine bark	Compost	Control	p
Height (cm)	*Year 1*	285,21	305,83	299,37	n.s.
	Year 2	288,49 b	311,59 a	300,91 ab	*
	Year 3	320 b	348,57 a	332,75 ab	**
Diameter (mm)	*Year 1*	25,33	24,71	25,58	n.s.
	Year 2	37,22 b	42,82 a	38,27 b	**
	Year 3	52,86 b	60,19 a	54,55 b	*
	Year 4	66,68 a	76 a	68,25 b	*
Shoot length (cm)	*Year 1*	9.57 b	13.94 a	13.72 a	**
	Year 2	47.37	46.98	45.34	n.s.
	Year 3	54.72 b	62.6 a	55.34 b	**

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Effect of soil management techniques on plant height, trunk diameter and shoot length of *Tilia x europaea*

Parameter	Year	Pine bark	compost	control	p
Height (cm)	*Year 1*	337,08 b	330,83 a	360,83 a	*
	Year 2	355,8	353,5	370	n.s.
	Year 3	421,09	431,3	421,08	n.s.
Diameter (mm)	*Year 1*	26,04	26,62	26,62	n.s.
	Year 2	35,54	35,35	37,03	n.s.
	Year 3	50,91	54,52	51,39	n.s.
	Year 4	67,96 b	72,7 a	67,78 b	*
Shoot length (cm)	*Year 1*	20.02 b	25.97 a	18.14 b	**
	Year 2	75.45 b	83.57 a	58.83 c	**
	Year 3	82.94 a	79.8 a	63.67 b	**

Concluding remarks about the effects shown on trees

(Ferrini F., A. Fini, G. Amoroso, P. Frangi, 2008. Mulching of ornamental trees: effects on growth and physiology. Arboriculture and Urban Forestry, 34(3): 157-162)

☞ Mulching showed to be an efficient and sustainable management technique in terms of weed control and costs

☞ Also compost mulching had strong positive effects on tree growth and on plant physiology though results were variable according to the species (*Tilia* responded more slowly)

(Ferrini F., A. Fini, G. Amoroso, P. Frangi, 2008. Mulching of ornamental trees: effects on growth and physiology. Arboriculture and Urban Forestry, 34(3): 157-162)

Effect of soil management techniques on some soil physical properties (at the end of the research).

Lower bulk density

Higher soil moisture

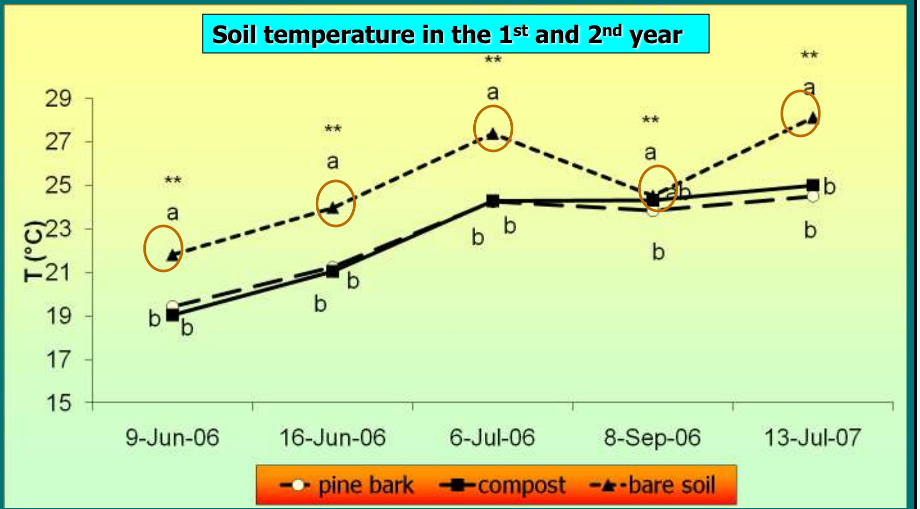
Parameter	Pine bark	Compost	Control	P
Bulk density (g cm^{-3})	1.23 ab	1.18 b	1.26 a	*
Soil moisture (% v/v)	17.2 b	19.8 a	6.7 c	*
Wilting point (% v/v)	7.9	8.7	8.1	NS
Field capacity (% v/v)	22.1 b	26.7 a	25.3 ab	*
AWC (% v/v)	14.2 b	18.0 a	17.2 ab	*

Higher field capacity

Higher AWC

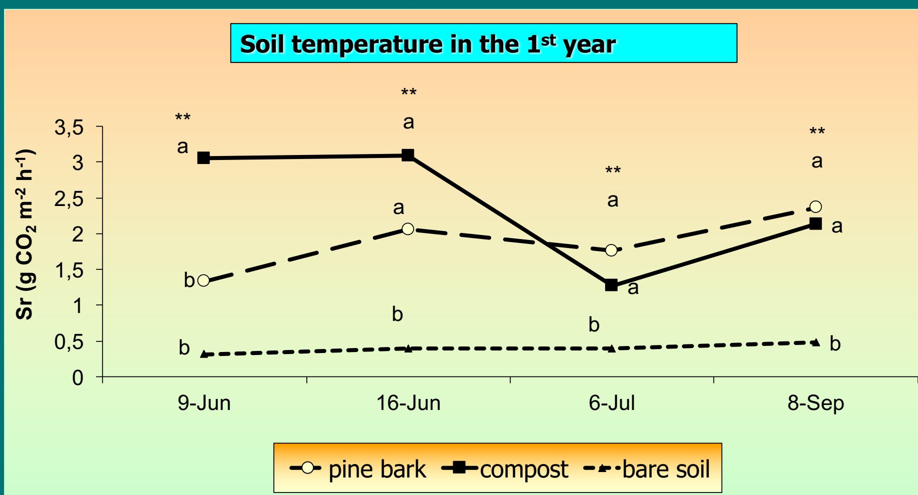
Different letters within the same row indicate statistical differences at P≤0.05 (*) using HSD Tukey test. NS = not significant.

Effects of mulching on soil temperature



Soil temperature measured at 10 cm below soil surface in 2006 and 2007. Different letters indicate statistical differences using HSD Tukey test.

Effects of mulching on soil respiration



Soil respiration measured at 5 cm below soil surface from June to September. Different letters indicate statistical differences using HSD Tukey test.

Effect of soil management techniques on soil chemical and biological properties

Parameter	Pine bark	Compost	Control	P
TOC (g $100g^{-1}$)	1.62 ab	1.82 a	1.49 b	**
Total N (g kg^{-1})	1.11 b	1.32 a	1.18 b	**
C/N ratio	14.6 a	13.8 ab	12.6 b	*
N_2O emission (mg m^{-2} d^{-1})	2.8 b	6.2 a	3.1 b	**
Biomass C (mg $100g^{-1}$ dry soil)	75.4 a	82.5 a	48.0 b	**

Different letters within the same row indicate statistical differences at P≤0.05 (*) or P≤0.01 (**) using HSD Tukey test.

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Conclusions

(FERRINI. F., A. Fini, S. Pellegrini, A. Agnelli M. Platinetti, P. Frangi, G. Amoroso, 2008. Effects of two organic mulches on soil chemical, physical and biological properties. Proceedings of the 3rd Symposium "The Landscape Below Ground", Morton Arboretum, Lisle-IL, USA)

Soil temperature under both mulches was significantly lower than in bare soil.

Soil biological activity was also enhanced by mulches.

No difference in soil oxygen content was found among the treatments.

Soil bulk density was significantly lower under compost mulch.

Soil moisture, TOC, C/N ratio and microbial biomass resulted significantly higher.

Still to consider in depth the N_2O production (greenhouse gas)

In conclusion, mulch affected soil properties and created a more favorable environment for roots, which resulted in enhanced plant growth.

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Effects of mulching with compost on growth and physiology of *Acer campestre* L. and *Carpinus betulus* L.

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PLANTING MATERIAL

Carpinus betulus L.

Acer campestre L.

360 trees were planted in the field in 2003 following a randomized block design with 3 replicates and 4 treatments:

1- Total weeding by herbicides

2- Chemical weeding in the row and natural grass cover between the rows

3- Chemical weeding in the row and tillage between the rows

4- Mulching with compost in the row and natural grass cover between the rows

Acer campestre

	Shoot growth (cm)		Stem Diameter (cm)		Chl content
Treatment	*2006*	*2007*	*2006*	*2007*	*2007*
Total weeding	70,2 b	58,3 b	6,5 a	7,3	41,1 b
Tillage + herbicides	70 b	57,5 b	6,3 a	7,8	43,9 ab
Grass cover	69,6 b	45,5 c	5,4 b	6,7	41,5 b
Mulch + Grass cover	86 a	72 a	6,1 ab	7,7	45,6 a
P	**	**	*	*N.S.*	**

Acer campestre

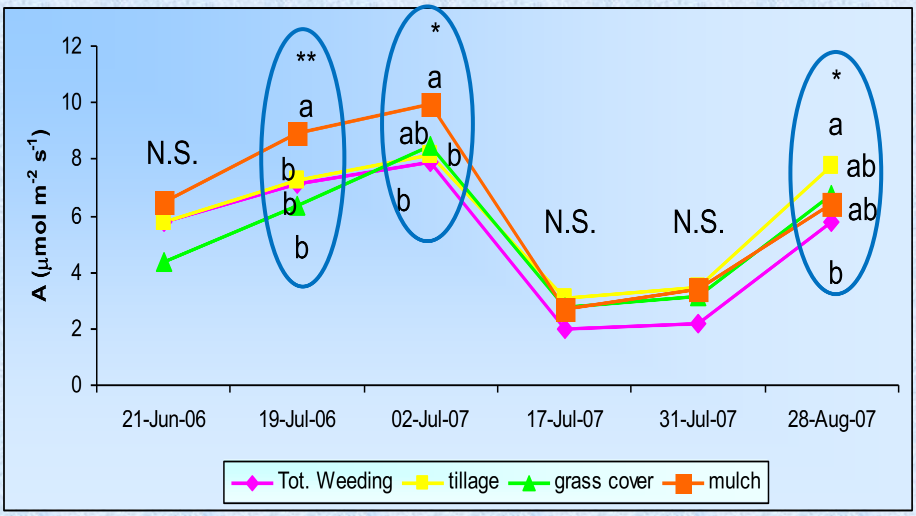
	A (μmol m^{-2} s^{-1})		E (mmol m^{-2} s^{-1})		WUE (A/E)	
Treatment	2006	2007	2006	2007	2006	2007
Total weeding	9,8	7,9 ab	3,1	2,4 b	3,4	3,7 b
Tillage + herbicides	10,4	8,9 a	2,9	2,9 a	3,9	3,1 c
Grass cover	10,1	7,3 b	2,7	2,3 b	4,1	3,3 bc
Mulch + Grass cover	10,9	9 a	3	2,1 b	3,9	4,3 a
P	N.S.	**	N.S.	**	N.S.	**

Carpinus betulus

	Shoot growth (cm)		Stem Diameter (cm)		Chl content	Fv/Fm
Treatment	***2006***	***2007***	***2006***	***2007***	***2007***	***2007***
Total weeding	70 b	44,7 b	6,5 a	7,7 a	38,7 b	0,72
Tillage + herbicides	67 b	53,4 a	5,9 ab	7,4 ab	40,2 ab	0,73
Grass cover	57,1 c	35,6 c	5,7 b	6,7 b	38,8 b	0,7
Mulch + Grass cover	74 a	54,4 a	6,3 a	8 a	42,3 a	0,73
P	**	**	*	*	**	N.S.

Carpinus betulus

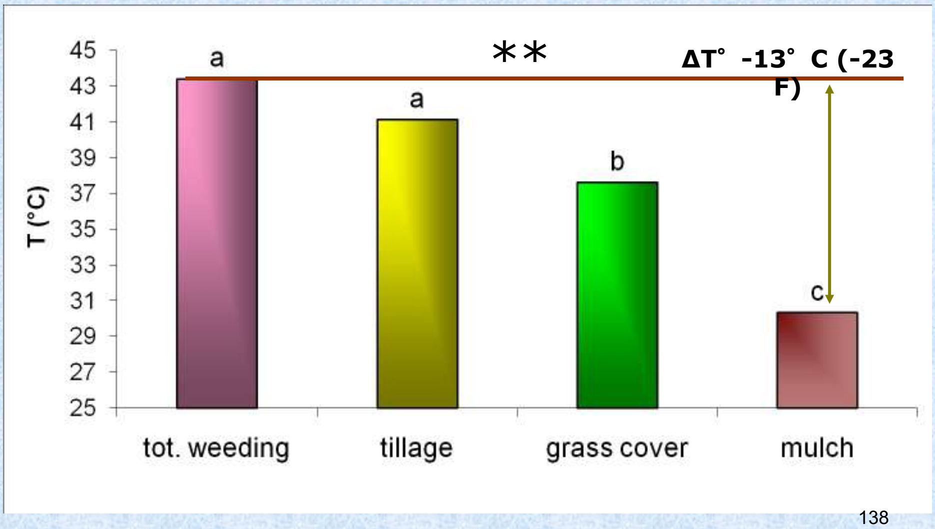
Net Photosynthesis in 2006 and 2007



Carpinus betulus

	E (mmol m^{-2} s^{-1})		WUE		Fv/Fm
Treatment	***2006***	***2007***	***2006***	***2007***	***2007***
Total weeding	1,9	1,6 b	3,8	3,4	0,72
Tillage + herbicides	2	2,2 a	3,6	2,7	0,73
Grass cover	1,6	1,9 a	3,4	2,9	0,7
Mulch + Grass cover	2	1,9 a	4,1	3,2	0,73
P	N.S.	**	N.S.	N.S.	N.S.

Effects on soil temperature



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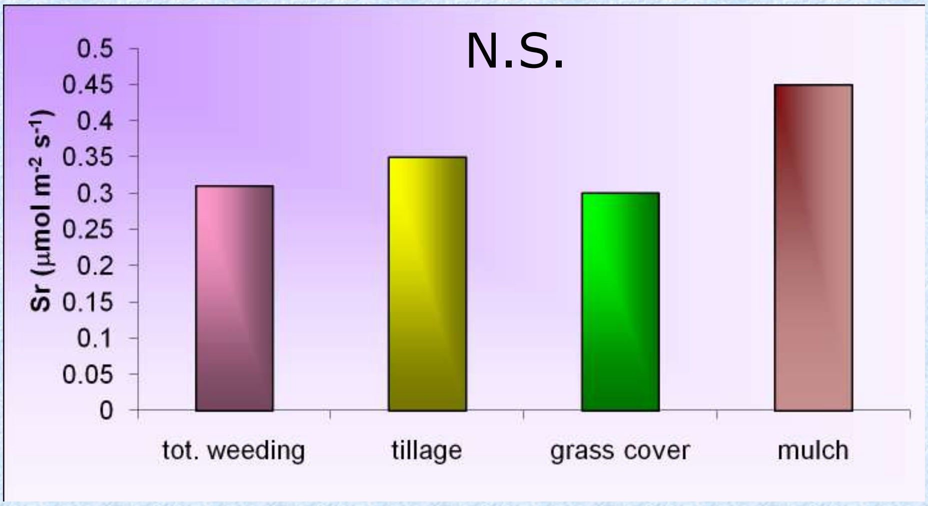
Effects on soil respiration



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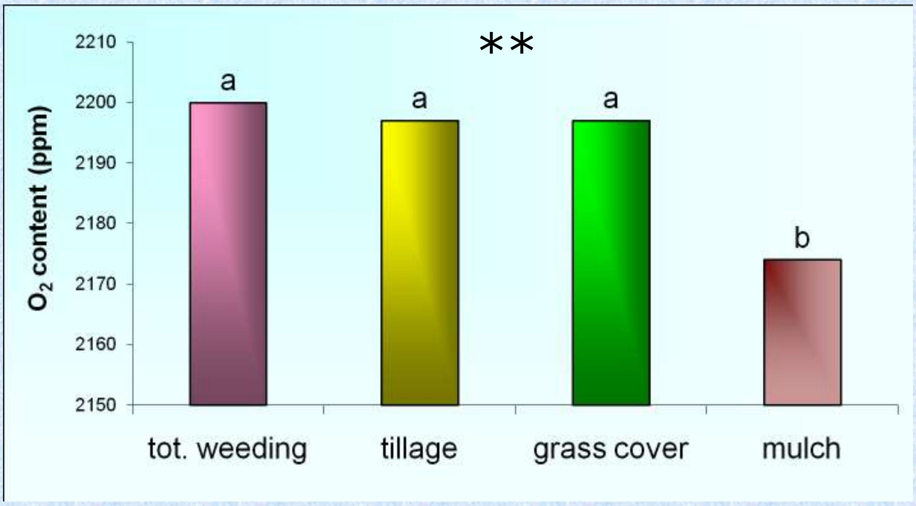
Effects on soil oxygen content



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LESSON LEARNT

(Fini A., Ferrini F., 2011. Effects of mulching with compost on growth and physiology of *Acer campestre* L. and *Carpinus betulus* L. Adv. Hort. Sci., 25(4): 232-238)

- Mulching on the row and natural grass cover between the rows increased plant growth, leaf gas exchanges and chlorophyll content.
- Mulching significantly reduced soil temperature in the upper 10 cm of soil
- Contrary to previous experiments, no change in soil respiration was observed
- A decrease in O_2 availability to roots can occur, especially if mulches are distributed in thick layers or if the mulching material is not sufficiently stable and mature

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Other results (project funded by Tuscany region):

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Effects of mulching with mixed compost (green compost+organic waste) on growth and physiology of two widely grown shrubs: *Hypericum x moseranum* and *Prunus laurocerasus. (80 plants x species). 40 per treatment*

Results

Thesis	Stems dry weight (g)	Leaves (dry weight (g)	Total dry weight (g)	Chlor. (SPAD value)
Hypericum x moseranum				
Compost	835.42 a	229.54 a	1064.97 a	55,65 a
Control	396.11 b	95.07 b	491.18 b	40,10 b
Prunus laurocerasus				
Compost	866.43 a	477.77 a	1344.2 a	64,60 a
Control	521.5 b	317.38 b	838.88 b	55,65 b

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In the first year after planting just the chlorophyll content was measured and it was statistically higher in the compost treatment

Effects of mulching with mixed compost (green compost+organic waste) on growth and physiology of European Elm *Ulmus minor* (Smoothleaf elm).
13 plants/mulching treatments – Urban park, bad soil)

Results 2009

Compost layer (cm)	Shoot length (cm)	Pn (µmol m^{-2} s^{-1})	Pn on whole plant basis (µmol m^{-2} s^{-1})	Chlorophyll Content (SPAD)
Control	52,5 b	2,7 n.s.	2,66 b	39,8 b
5	80,8 a	2,6	2,82 b	44,4 a
10	82,9 a	2,3	4,21 a	45,7 a

Compost layer (cm)	Single leaf area (cm^2)	Leaf number/plant	Total leaf area/plant (m^2)	Leaf Mass per Area (LMA) g/m^2
Control	28,61 n.s.	344,82 b	0,98 b	84,9 n.s.
5	28,72	376,96 b	1,08 b	94,7
10	31,96	586,58 a	1,87 a	99,9

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Results 2010

Compost layer (cm)	Pn (μmol m^{-2} s^{-1})	WUE	Chlorophyll Content (SPAD)	Leaf area (cm^2)	LMA ($g*m^2$)
Control	**17,84 n.s**	**7,49 b**	**47.2 b**	**31,07 n.s.**	**79 ns**
5	**16,84**	**7,44 b**	**50.0 a**	**31,34**	**75**
10	**18,13**	**8,30 a**	**50.1 a**	**33,23**	**77**

Compost layer (cm)	Pruning weight (g)	Shoot elongation (cm)	Ø 20 cm	Ø 130 cm	Plant height
Control	**228,77 b**	**44,11 b**	**3,84 c**	**3,42 b**	**5,24 c**
5	**467,62 a**	**67,77 a**	**4,56 b**	**3,91 b**	**5,77 b**
10	**484,68 a**	**71,02 a**	**4,97 a**	**4,42 a**	**6,23 a**

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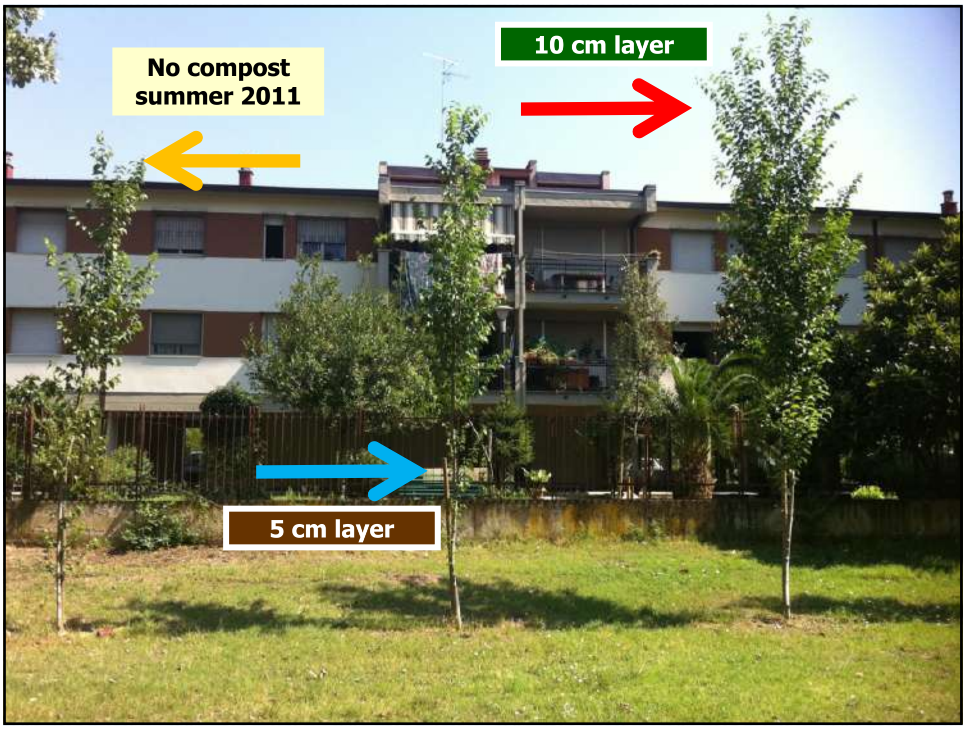
Results 2011

Compost layer (cm)	Pn (μmol m^{-2} s^{-1})	WUE	Chlorophyll Content (SPAD)	Leaf area (cm^2)	LMA ($g*m^2$)
Control	**3,59 n.s.**	**5,13 b**	**49,7 n.s.**	**28,46 ns**	**113,69 n.s.**
5	**4,32**	**5,70 b**	**48,4**	**30,39**	**113,97**
10	**4,4**	**7,29 a**	**50,0**	**31,53**	**115,57**

Compost layer (cm)	Shoot elongation (cm)	Ø 130 cm	ΔØ cm
Control	**31,37 b**	**4,95 c**	**1,3 b**
5	**38,83 ab**	**5,59 b**	**1,53 b**
10	**45,37 a**	**6,37 a**	**1,88 a**



EFFECT ON PLANT GROWTH AND PHYSIOLOGY - SUMMARY

Species	Effect on growth	Effect on photosynthesys	Effect on water use efficiency	Effect on chlorophyll fluorescence	Effect on chlorophyll content
Aesculus hippocastanum	+	+	+	=	+
Tilia cordata	+	+	+	=	+
Ulmus campestris	+	+	+	=	+
Carpinus betulus	+	+	+	=	+
Acer campestre	+	+	+	=	+
Hypericum x moseranum	+	N.D.	N.D.	N.D.	+
Prunus laurocerasus	+	N.D.	N.D.	N.D.	+

EFFECT ON SOIL CHARACTERISTICS SUMMARY

Species	T°	Humidity	Available water	Density	Respiration	O_2 content
Aesculus hippocastanum	-	+	+	+	+/=	=
Tilia cordata	-	+	+	+	+/=	=
Carpinus betulus	-	+	N.D.	N.D.	=	-
Acer campestre	-	+	N.D.	N.D.	=	-

Improper mulching

http://www.bartstreeservice.com

http://springhillatcanfield.com/

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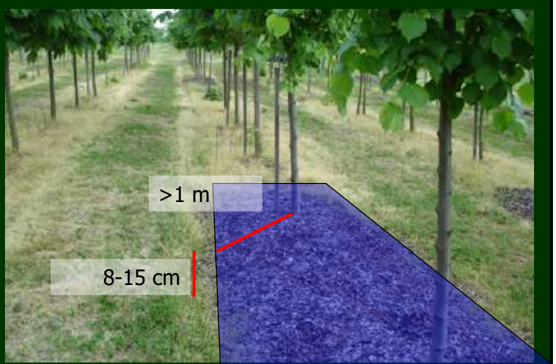
How to mulch properly



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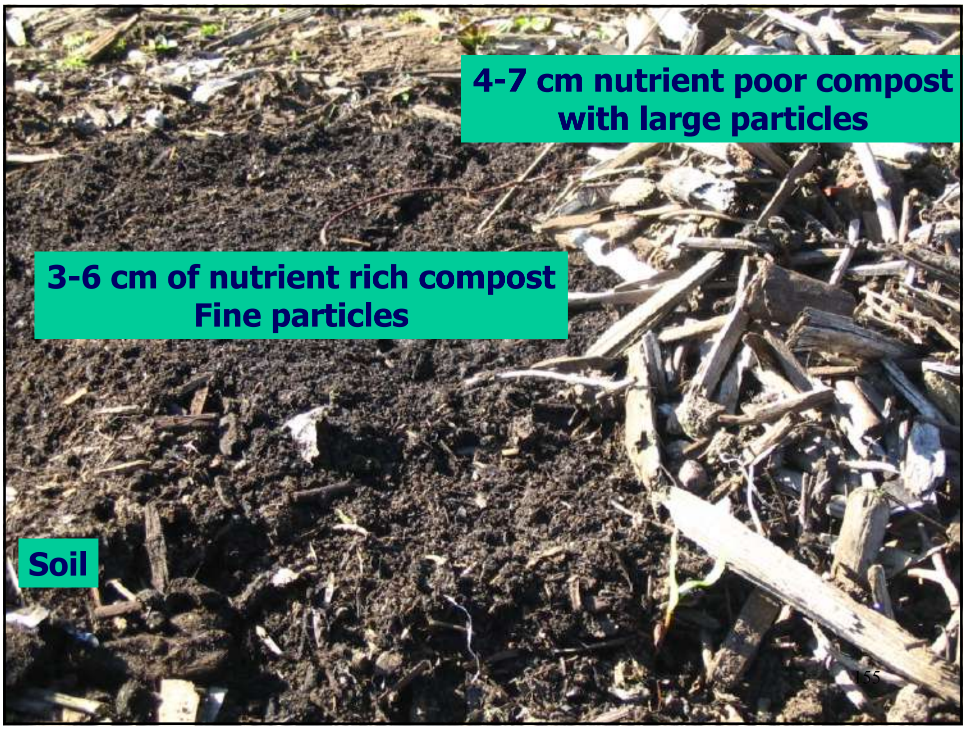
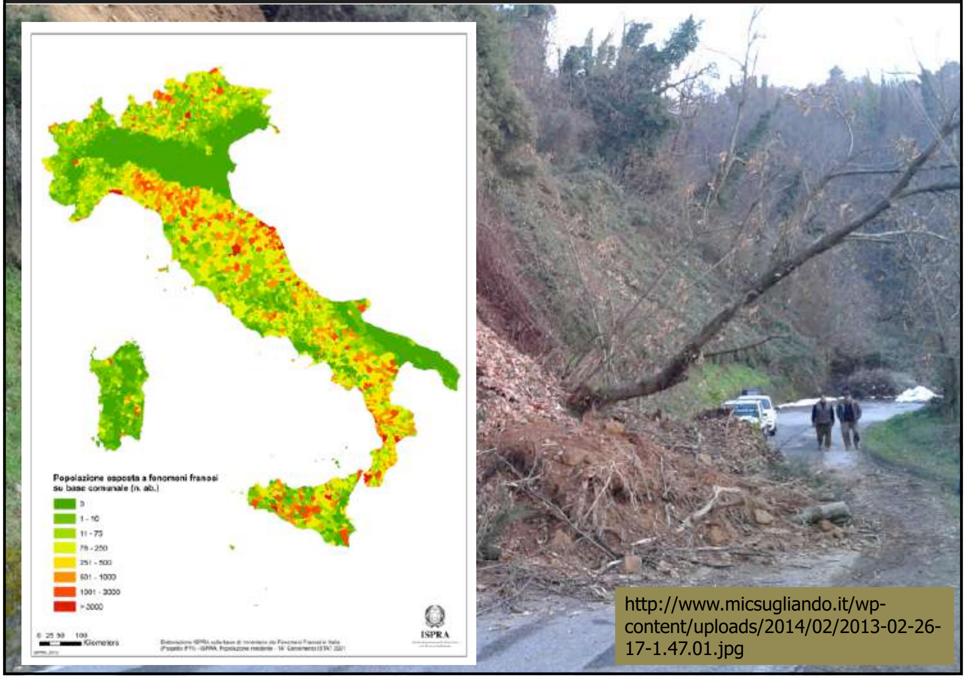

4-7 cm nutrient poor compost
with large particles
3-6 cm of nutrient rich compost
Fine particles
Soil


Future research
• Methodology to predict N-availability
• Deeper research on NO_2 production
• Compost and tree biochemistry and physiology
• The specific use of compost fractions
• Designed compost products


4th


Evaluation of shrubs for slope
consolidation in urban landscape

Problem: to control erosion and landslide risk along main roads



http://www.micsugliando.it/wp-content/uploads/2014/02/2013-02-26-17-1.47.01.jpg

Problem: to control erosion and landslide risk along main roads

http://4.bp.blogspot.com/-IXfBkts01FU/Tqke_LfOkHI/AAAAAAAADE0/i-mm-KkjDGU/s1600/2.jpg

Species selection

The use of shrubs instead of grasses is advisable because they need less care, they don't need pruning, they limit soil erosion more than grass they can increase biodiversity and the improve landscape visual quality (Hill, 1965)

Characteristics of the species best suited for slope greening :

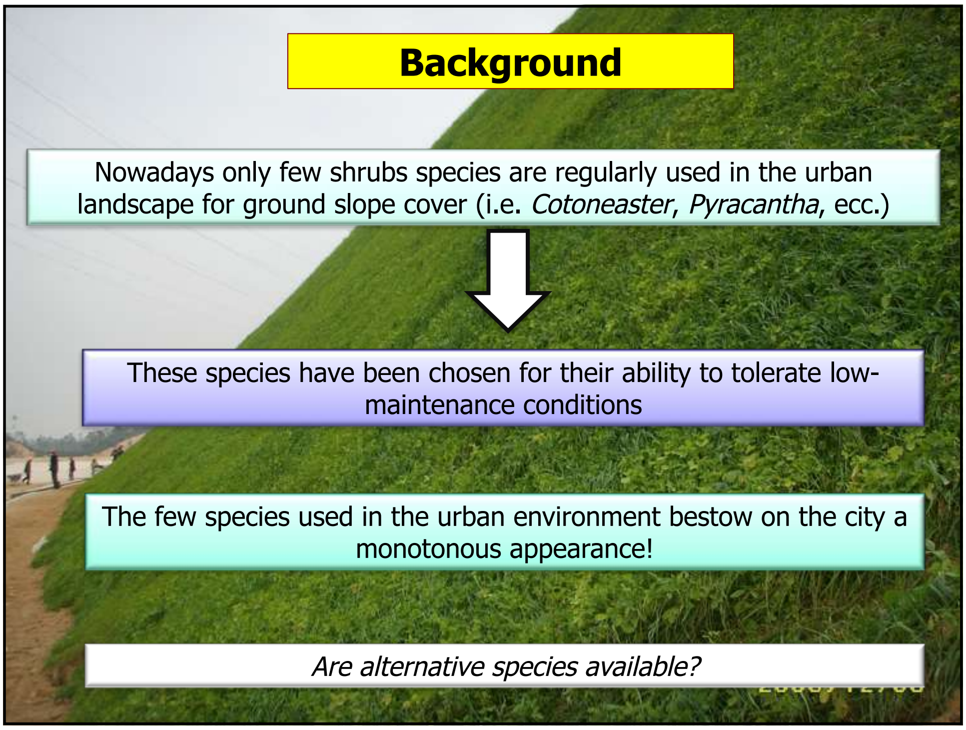
- Aesthetic quality
- Rapidity of soil coverage
- Wide and largely branched root system
- Drought tolerance
- De-icing salt tolerance (colder locations)
- Capacity to survive and thrive in poor soils
- Torelance to soil and air pollution
- Pest resistance
- Low-management requirement

(Conaway e Thayler, 1981)

On this base an old American study compared more than 100 species, ramking them on their performance

Research: Evaluation of shrubs for slope consolidation in urban landscape

The aim of this trial was to collect data about the performance of 25 shrubs species (or cultivar) growth in a slope over three years



Background

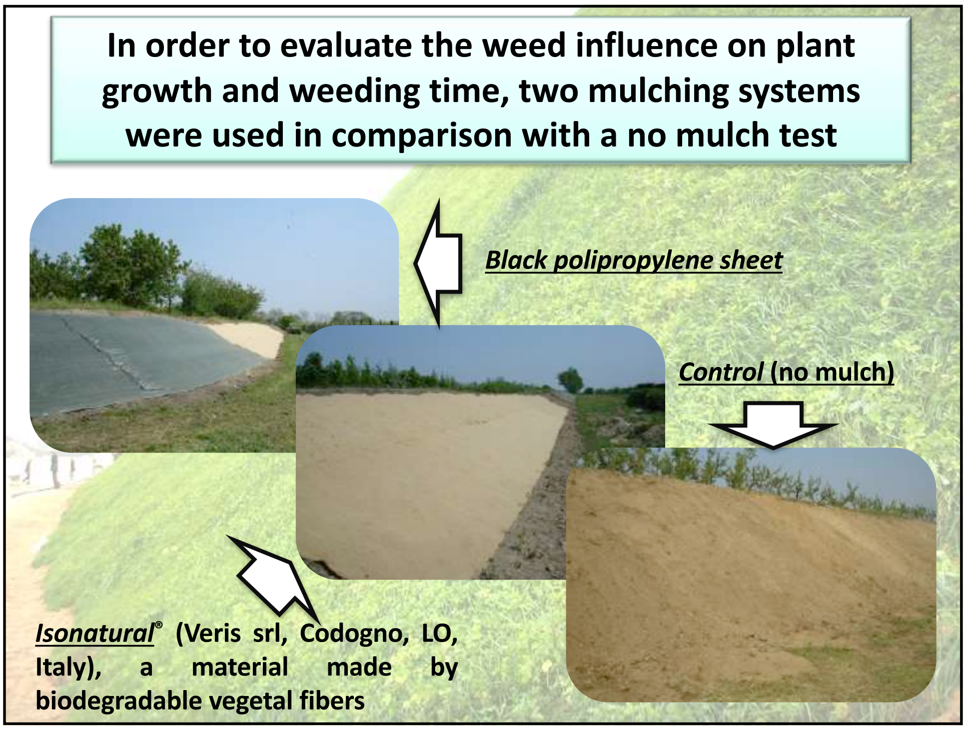
Nowadays only few shrubs species are regularly used in the urban landscape for ground slope cover (i.e. *Cotoneaster*, *Pyracantha*, ecc.)

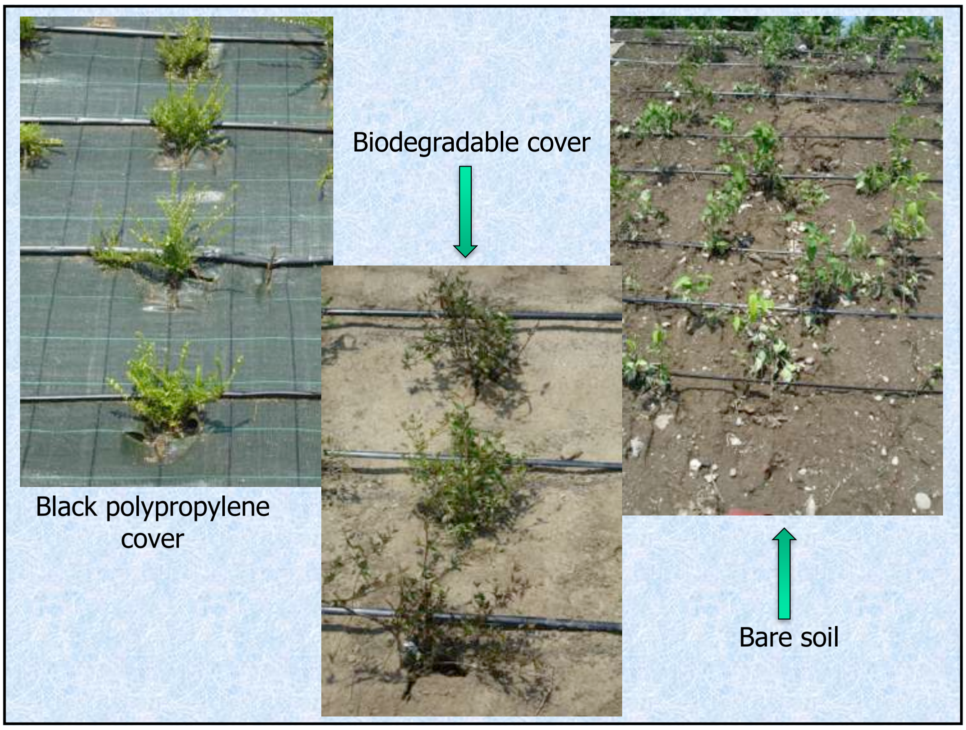
↓

These species have been chosen for their ability to tolerate low-maintenance conditions

The few species used in the urban environment bestow on the city a monotonous appearance!

Are alternative species available?


In order to evaluate the weed influence on plant growth and weeding time, two mulching systems were used in comparison with a no mulch test
Black polipropylene sheet
Control (no mulch)
Isonatural® (Veris srl, Codogno, LO, Italy), a material made by biodegradable vegetal fibers


Biodegradable cover
Black polypropylene cover
Bare soil

For this trial 1800 m^2 (2152 yd^2) of slope area and 7200 plants were used (288 x 25 per species)

Species were arranged in completely randomized blocks with three replicates. Each block was formed by 75 plots

Species List (25 total)

Abelia x grandiflora
Caryopteris x clandonensis
Cornus sericea
Coronilla emerus
Corylopsis pauciflora
Deutzia gracilis
Deutzia hybr.
Deutzia scabra
Forsythia x intermedia
Genista lydia
Hedera helix
Hibiscus syriacus
Hipericum 'Hidcote'
Hippophae rhamnoides
Kerria japonica
Lonicera nitida
Lonicera pileata
Philadelphus x virginalis
Physocarpus opulifolius
Potentilla fruticosa
Salix purpurea
Spartium junceum
Spiraea japonica
Viburnum farreri
Viburnum plicatum

To evaluate the adaptability of the cultivar tested in the urban environment no pruning or pest management were carried out

Plants were irrigated only in the first year during the driest periods of summer using a drip irrigation system

Chemical weeding in 2007 (before planting) using Gallery T-DG (trifluralin + isoxaben) (45 kg/ha) and Ronstar® (oxadiazon) both in granular formulation (180 kg/ha). No chemical weeding was done after that. Hand weeding was carried out twice in the first year and three times in the second and third year. Time needed for weed removal was recorded for each plot

Data Harvest

Hand weeding was carried out twice in the first year and three times in the second year Gallery T-DG (trifluralin + isoxaben) (45 kg/ha) and Ronstar® (oxadiazon) in granular formulation. Time needed for weed removal was recorded for each plot

In every plot, plant height and ground cover percentage were measured bimonthly during the growing seasons

1	<25%
2	25-50 %
3	50-75 %
4	>75%

At the end of the trial we measured root and crown biomass

Root growth:

<u>Root density</u>: m of roots/d^3 of soil

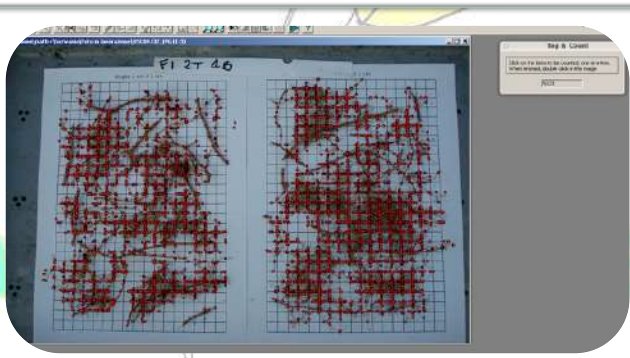
<u>Specific length</u>: meters of roots/g of root dry matter

Methodology:

400 soil sample (probes) were dug and divided in two parts (0-10 cm) and (10-25 cm)…

…samples were then sieved and roots separated from the soil

…finally, before drying root length of any single sample was measured and the total length was estimated following the method proposed by Tennant (1975).



EVENT TIMING

Results

LLC.

Weed removal time sec/m² over three years among species

Salix purpurea **'Nana'**
136 sec/m² over three years

Purple willow was the species that needed the least time for weeding

No statistical differences in the three growing seasons from *S. purpurea* 'Nana' were observed in:

Abelia x grandiflora

Caryopteris x cland.

Cornus sericea

Coronilla emerus

Deutzia x hybrida

Deutzia scabra

No statistical differences in the three growing seasons from *S. purpurea* 'Nana' were observed in:

Forsythia x intermedia

Hypericum

Philadelphus x virg.

Physocarpus 'Diablo'

Spartium junceum

Spiraea japonica

Weed removal time/m² over three years and total growth

	Weeding time/m² (s)				Height increment after 3 years (cm)
	2007	2008	2009	total	
Polipropylene	47 b	109 b	14 b	170 b	83.5 a
Isonatural®	44 b	121 b	24 b	189 b	85,0 a
Test	174 a	301 a	106 a	581 a	64,8 b
Significance	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

BIOMASS PRODUCTION

Species with the higher vertical length (at the end of the trial) :

Coronilla emerus

Deutzia x hybrida

Forsythia x intermedia

Physocarpus 'Diablo'

Spartium junceum

Height increment: 1.0 – 1.2 m

Final height: 1.8 – 2.0 m

Species with the higher aerial biomass productio (g/plant) at the end of the trial


3135 g/pt

Spartium Junceum


2007 g/pt

Coronilla emerus

Species with the lower aerial biomass (g/plant) at the end of the trial


580 g/pt

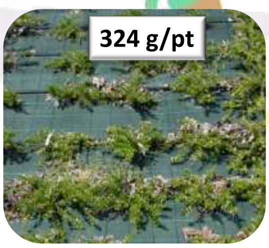
Caryopteris x cland.


276 g/pt

Cornus sericea


543 g/pt

Corylopsis pauciflora


324 g/pt

Lonicera pileata

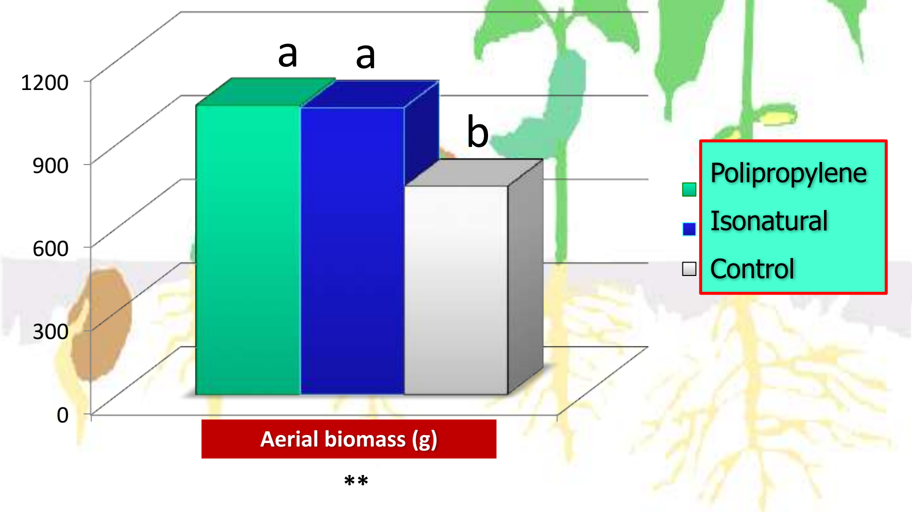

379 g/pt

Genista lydia


314 g/pt

Potentilla fruticosa

Aerial biomass (g) according to the different mulching material at the end of the trial



Root density (m of roots/d^3 (l) of soil) (estimated at the end of the trial)

Soil depth
0 – 10 cm

↑ ***Deutzia scabra***
'Pride of Roch.'
(28.7 m/l)

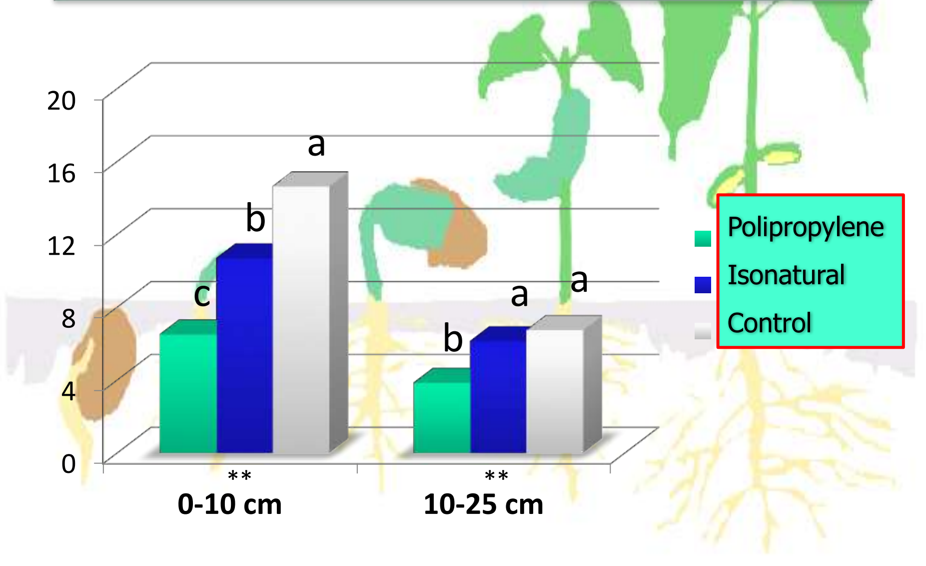
↓ ***Caryopteris x clandonensis***
'Heavenly Blue'
(3.0 m/l)

Soil depth
10-25 cm

↑ ***Forsythia x intermedia***
(14.8 m/l)
Deutzia scabra
'Pride of Roch.'
(12.2 m/l)

↓ ***Caryopteris x clandonensis***
'Heavenly Blue'
(1.4 m/l)

Root density (m of roots/d^3 (l) of soil)
(estimated at the end of the trial)



Specific root length (m of roots/g dry matter)
(at the end of the trial)

depth
<u>0 – 10 cm</u>

↑ ***Lonicera pileata***
(28.8 m/g)

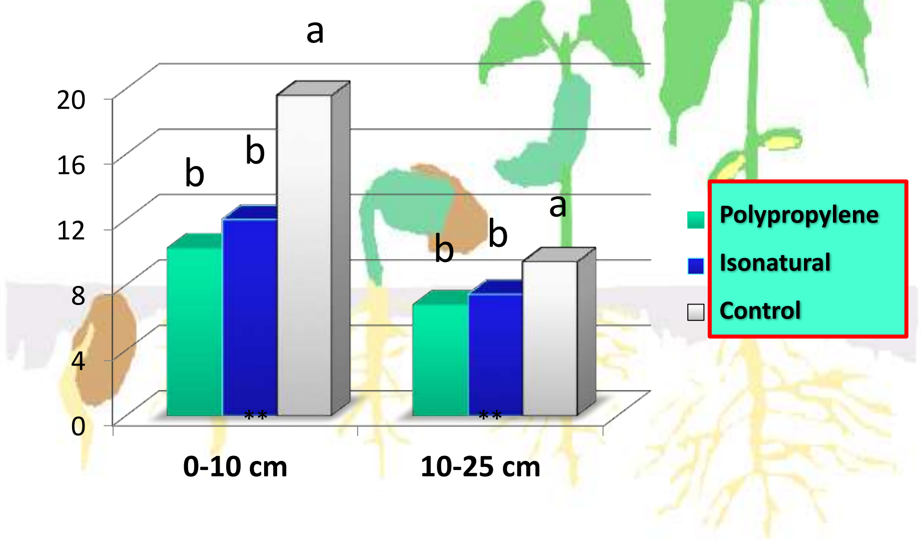
↓ ***Caryopteris x clandonensis***
'Heavenly Blue'
(5.7 m/g)

depth
<u>10-25 cm</u>

↑ ***Deutzia gracilis***
(15.1 m/g)

↓ ***Spartium junceum***
(5.0 m/g)
Hibiscus syriacus
(5.3 m/g)
Caryopteris x clandonensis **'H. B.'**
(5.5 m/g)
…

Specific root length (m roots/g dry matter)
(at the end of the trial)

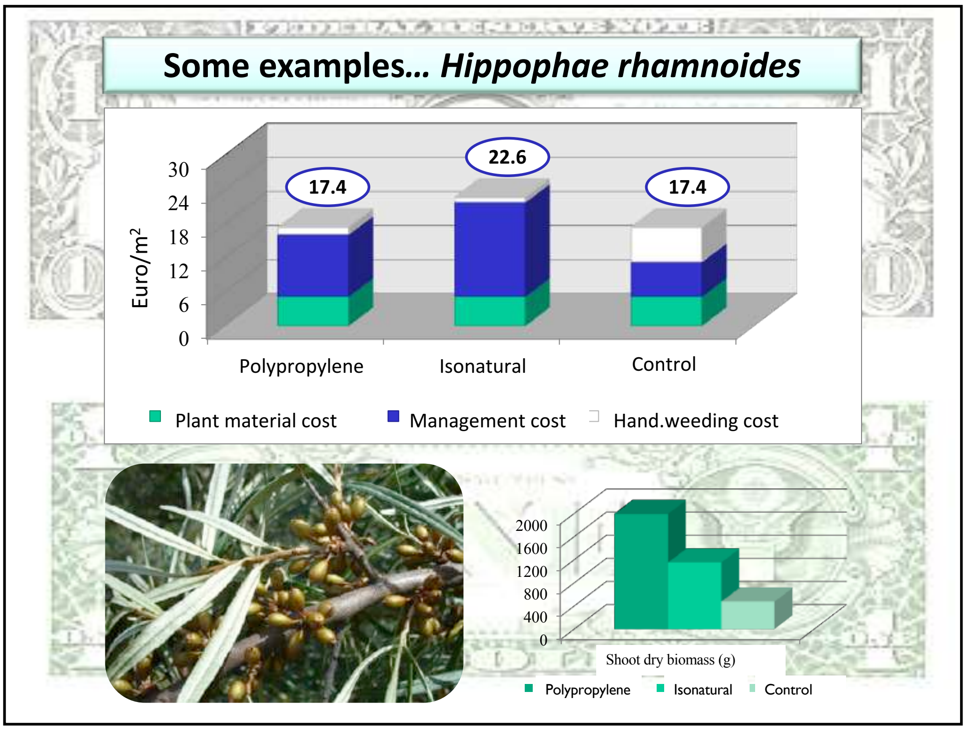


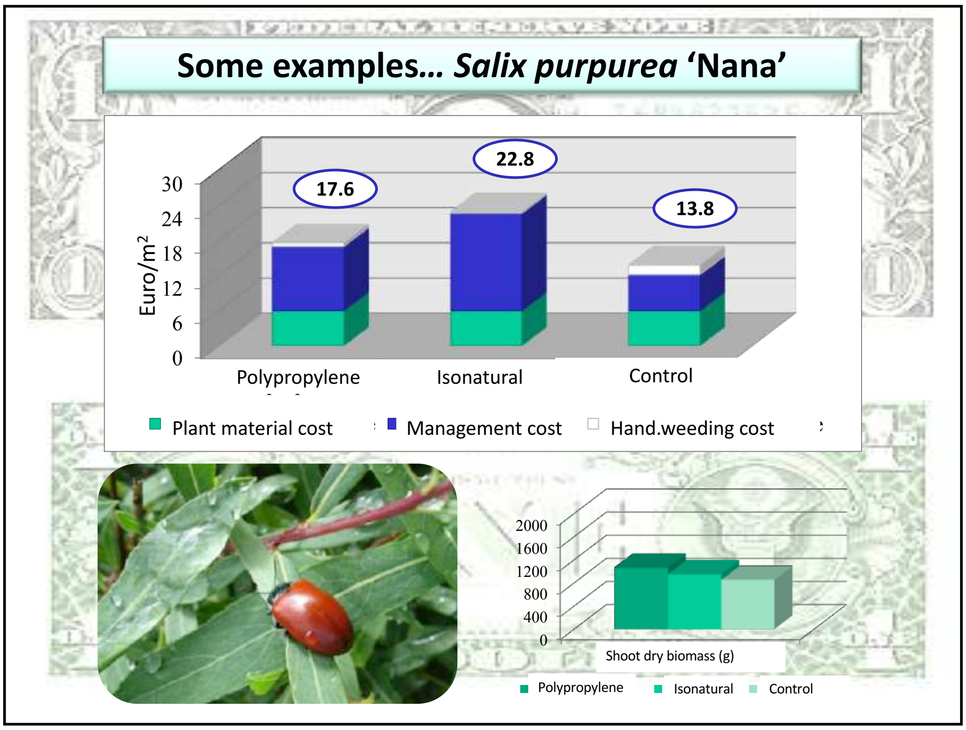
Cost of planting and managing

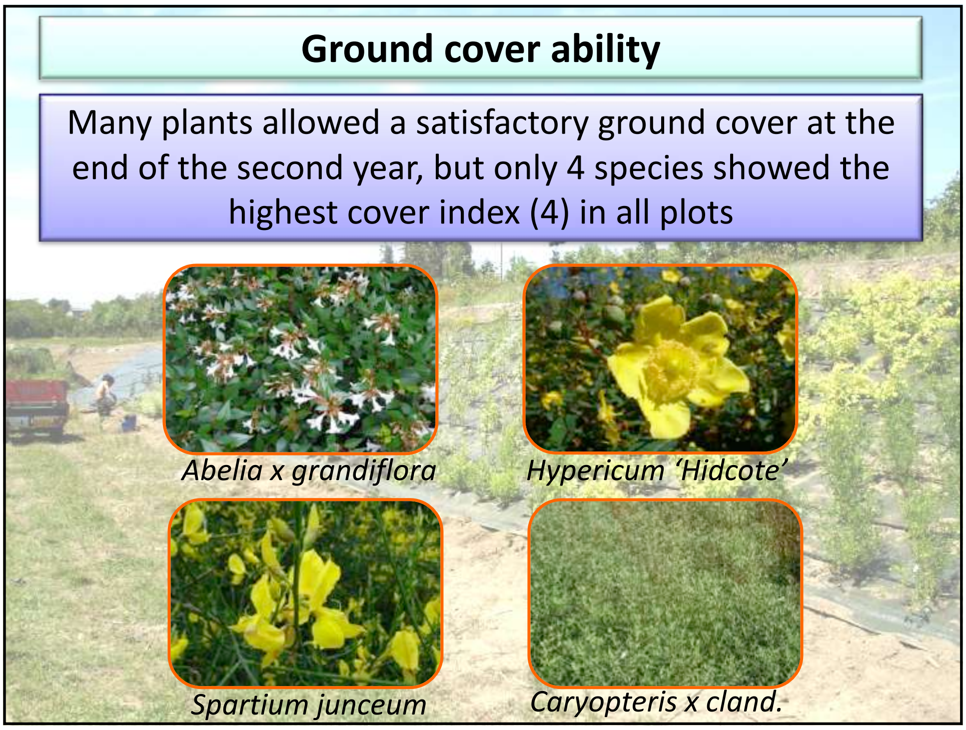
Material and hand labour cost for planting:
-Polypropylene sheet: 10.9 euro/m^2
- biodegradable fabric. (Isonatural): 16.6 euro/m^2
- Control: 6.1 euro/m^2

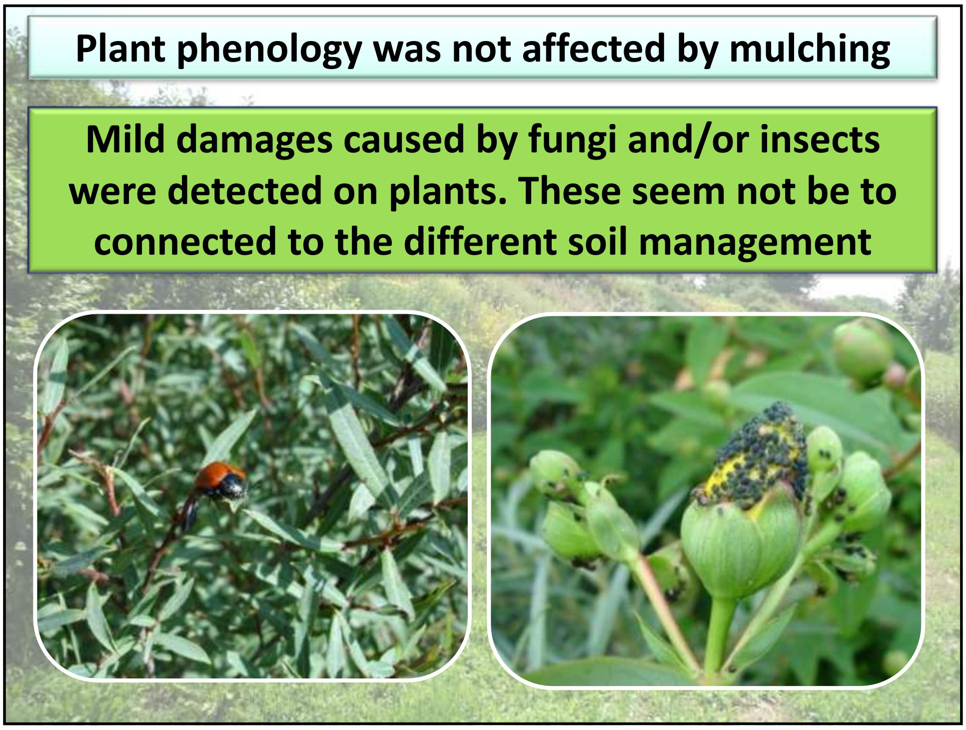
Cost of planting material

Managing cost (manual weeding and chemical weeding during the first year)


Some examples… Hippophae rhamnoides
17.4
22.6
17.4
30
24
18
12
6
0
Euro/m²
Polypropylene
Isonatural
Control
Plant material cost
Management cost
Hand.weeding cost
2000
1600
1200
800
400
0
Shoot dry biomass (g)
Polypropylene
Isonatural
Control


Some examples… Salix purpurea 'Nana'
17.6
22.8
13.8
30
24
18
12
6
0
Euro/m²
Polypropylene
Isonatural
Control
Plant material cost
Management cost
Hand.weeding cost
2000
1600
1200
800
400
0
Shoot dry biomass (g)
Polypropylene
Isonatural
Control


Ground cover ability
Many plants allowed a satisfactory ground cover at the end of the second year, but only 4 species showed the highest cover index (4) in all plots
Abelia x grandiflora
Hypericum 'Hidcote'
Spartium junceum
Caryopteris x cland.


Plant phenology was not affected by mulching
Mild damages caused by fungi and/or insects were detected on plants. These seem not be to connected to the different soil management

Conclusions

Not all the species tested were found suitable for growing on slopes. Time need for ground covering, disease resistance, limited height increase and good appearance are the main factors to consider to choose a shrub

Conclusions

Mulching has allowed a reduction of weeding time. This is very important to reduce management costs especially in slopes

Due to both limited evaporation and reduced weed competition, mulched plants showed a greater growth than unmulched plants

No differences in both growth and weeding time were observed between the two mulching fabrics

Conclusions

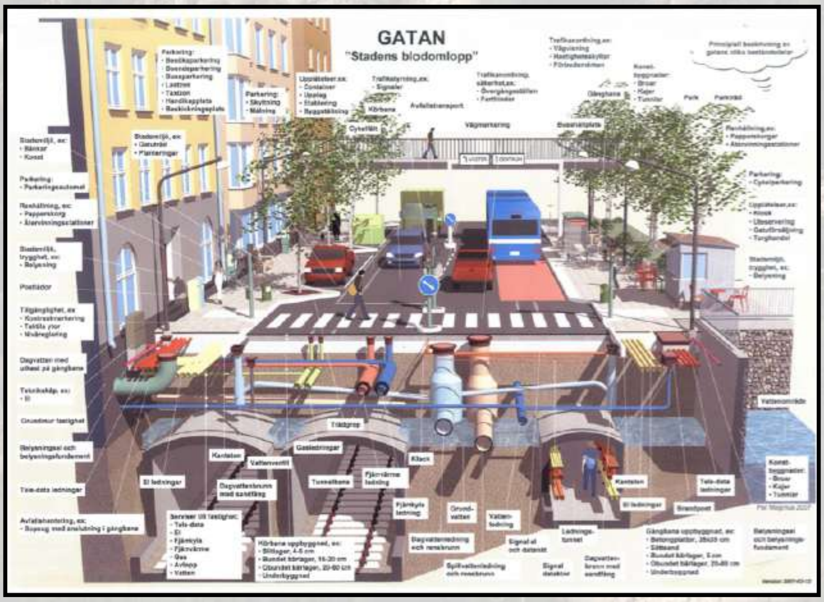
Mulching generally root growth (both root density and specific length).
Soil is more humid when covered and this limits root elongation in search of water

The ideal plant doesn't not exist

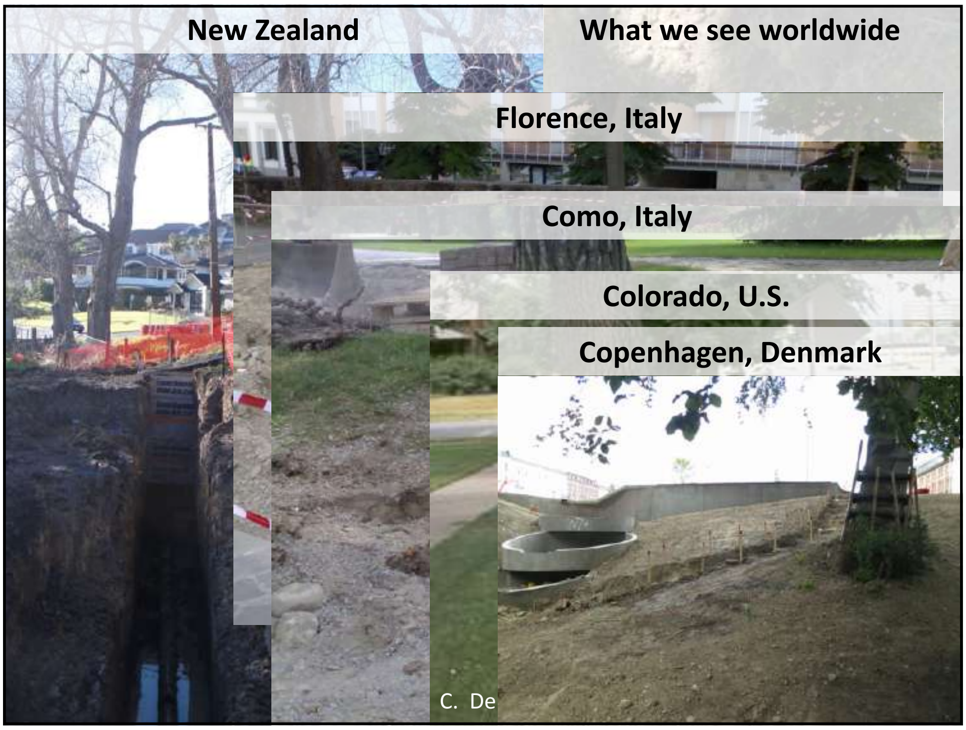
…The right plant in the right place does exist!

Effects of root severance by excavation on growth, physiology and stability of two urban tree species: results from a long-term experiment

Trees in cities are subject to intense conflicts with buildings, roads and utility installations, and engineering requirements often take precedence over tree conservation (Jim, 2003).



O. Stal



- Construction activities and trenching near trees commonly cause extensive root damage (Hauer, 1994; Matheny and Clark, 1998; Jim, 2003)
- A single trench can remove 18% to about 50% of a tree root system, (Watson, 1998; Wajja-Musukwe et al., 2008)
- Root damage increased mortality over the next 8 years by 18-22% (Hauer et al., 1994)
- Visible symptoms may not occur until years after the damage (Watson, 1998; Despot and Gerhold, 2003; Wajja-Musuke et al., 2008)
- However, little attention has been given to the physiological reasons of tree decline

Cutting roots can lead to tree failure

The aims of this work were:

1. to evaluate the long-term effects of two different levels of root severance on growth and physiology of two tree species supposed to differ in tolerance to root manipulation

2. to evaluate the consequences of root severance on both theoretical (calculated) and measured (by pulling test) resistance to uprooting.

Methods: plant material

48 uniform European limes (*Tilia x europaea*) and 48 horsechestnuts (*Aesculus hippocastanum*) were planted in 2004 in a loam sandy soil and allowed to establish undisturbed for five years.

Tilia is supposed to better tolerate root manipulation than *Aesculus* (Matheny, 2005)

2004

2009

Methods: treatments

Control - **C**

Trenching on 1 side of the tree - **MD**

Trenching on 2 sides of the tree - **SD**

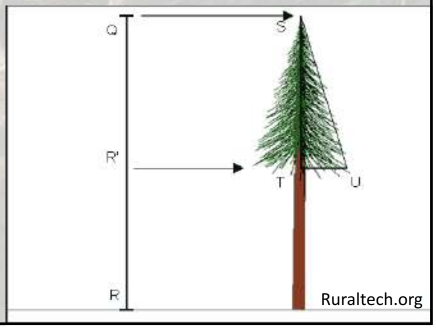
Trenches (70 cm deep) were excavated 40 cm from the root flare in June 2009.

The experimental design was a randomized complete block with 4 blocks

Methods: measurements

GROWTH:

- **Shoot growth** was measured on 10 shoots per species, treatment and block (480 shoots) before trenching and at the end of the four growing seasons after trenching
- **Stem diameter growth**: measured at 1.3 m on all trees before trenching and at the end of each growing season after trenching
- **Tree height and canopy size**: measured on all trees. Canopy height and lateral spread were measured at the end of the four growing seasons after trenching



Methods: measurements

PHYSIOLOGY:

- **Leaf gas exchange:** CO_2 assimilation (A, μmol m^{-2} s^{-1}), transpiration (E, mmol m^{-2} s^{-1}), stomatal conductance (g_s, mmol m^{-2} s^{-1}), intercellular CO_2 concentration (Ci, ppm) and water use efficiency (WUE, μmol CO_2/mmol H_2O) were measured during the growing season on 4 fully expanded leaves leaves per species, treatment and block (96 leaves in total)
- **Maximal quantum yield of PSII photochemistry (Fv/Fm):** measured during the growing season on the same leaves as gas exchange after 30' dark adaption.
- **Pre-dawn water potential (Ψ_w, MPa):** measured between 3:00 and 5:00 A.M. on 4 leaves per species, treatment, side and block (96 leaves in total)

Methods: the Uprooting Resistance Index

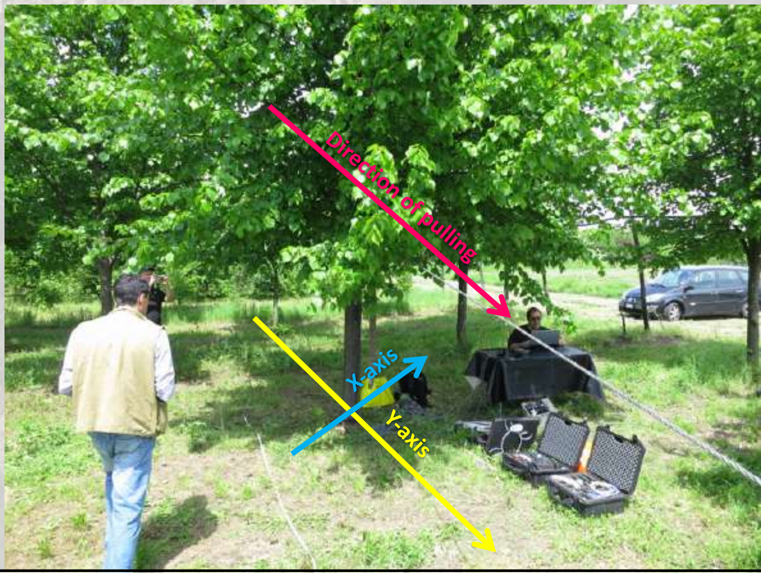
The size of the root system was determined by excavating roots with Airspade®

Methods: the pulling test

Pulling test was performed 3 weeks and 4 years after root severance as described in Sani et al. (2012). Two inclinometers were used to evaluate tree response to pulling in both tension and compression

Methods: the pulling test

The test was carried out by progressively and constantly applying the force created by the 56 mm advancement of the Tirfor cable and instantly recording the variation of the instrumental stress values.



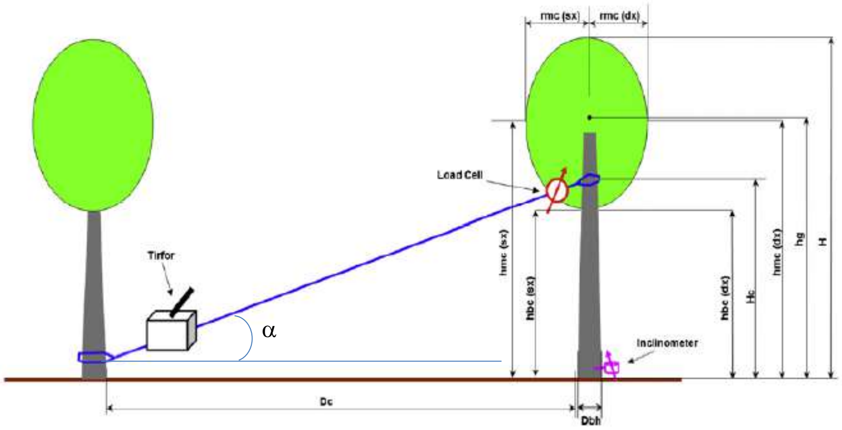
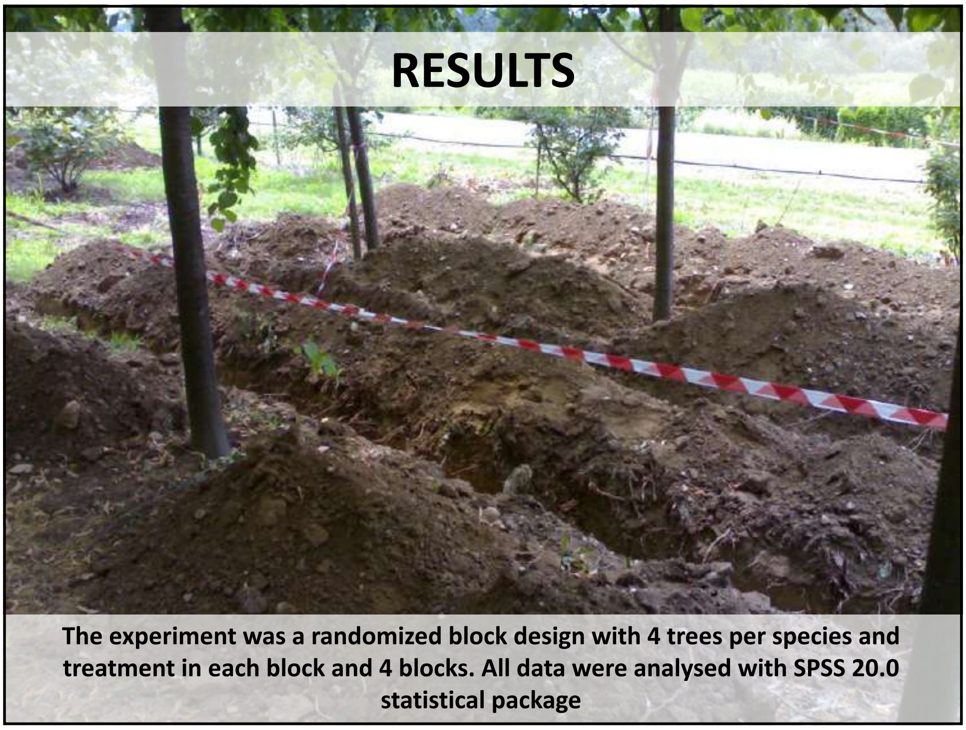


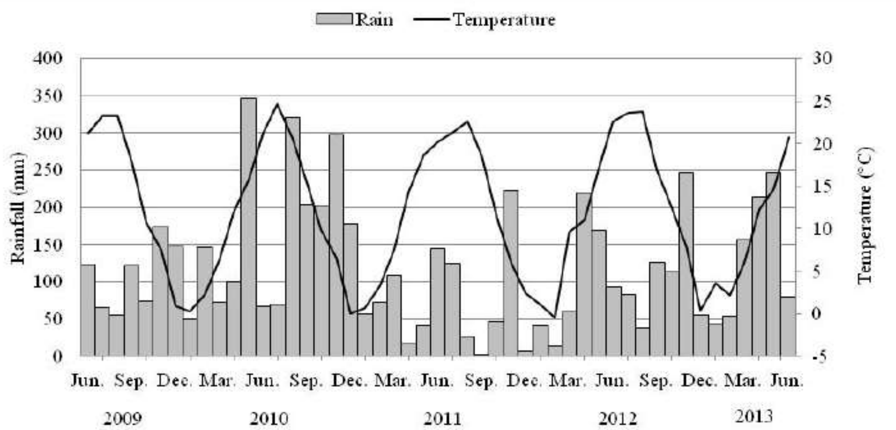
Fig. 1 – Diagram of controlled pulling test.

Bending moment was calculated as: **Force x Hc x cos** α
Where:
Force is the force recorded by the load cell (N); **Hc** is the height of the attachment (m); α is the angle between the direction of pulling and the parallel to soil


In a few cases, we actually pulled a little more…
In order to avoid damaging the plants, an attempt was always made to carry out the test within the elastic field, thus interrupting the pulling when the bending of the plate reached a value of 0.20°


RESULTS
The experiment was a randomized block design with 4 trees per species and treatment in each block and 4 blocks. All data were analysed with SPSS 20.0 statistical package

Will severed trees survive?



Total rainfall year^{-1} (mm)					
Year 1 (2009)	*Year 2 (2010)*	*Year 3 (2011)*	*Year 4 (2012)*	*Year 5 (Jan-Jul 2013)*	***Avg (30 years)***
1450	1806	867	1259	794	**1086**

STEM DIAMETER

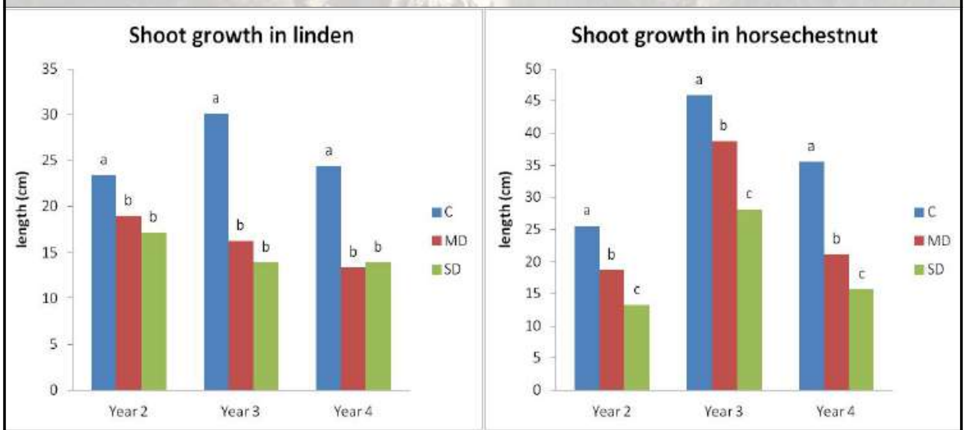
	$Ø_{stem}$ before trenching (cm)	ΔØ year 1 (cm)	ΔØ year 2 (cm)	ΔØ year 3 (cm)	ΔØ year 4 (cm)
Effect of root severance					
Control	9.7 a	1.4 a	1.3 a	1.1 a	1.8 a
MD	10.0 a	1.5 a	1.0 b	0.8 b	1.3 b
SD	8.9 a	0.9 b	0.9 b	0.8 b	1.3 b
P	n.s.	**	**	*	*
Effect of species					
Tilia	10.0 a	1.5 a	1.1 a	0.9	1.5
Aesculus	9.0 b	1.0 b	1.2 a	1.0	1.4
P	**	**	n.s.	n.s.	n.s.
Root severance x Species					
P	n.s.	n.s.	n.s.	*	n.s.

Control - **C**

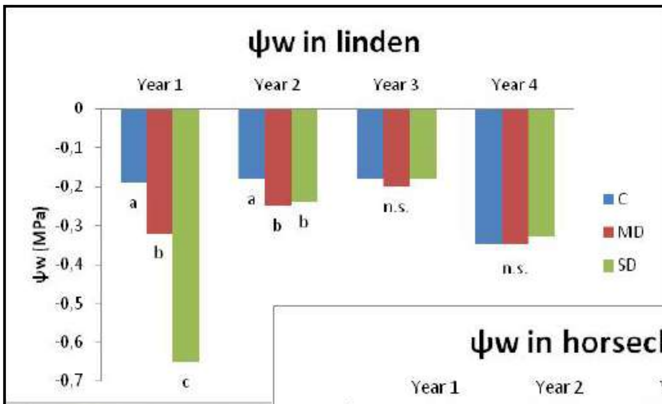
Trenching on 1 side of the tree - **MD**

Trenching on 2 sides of the tree - **SD**

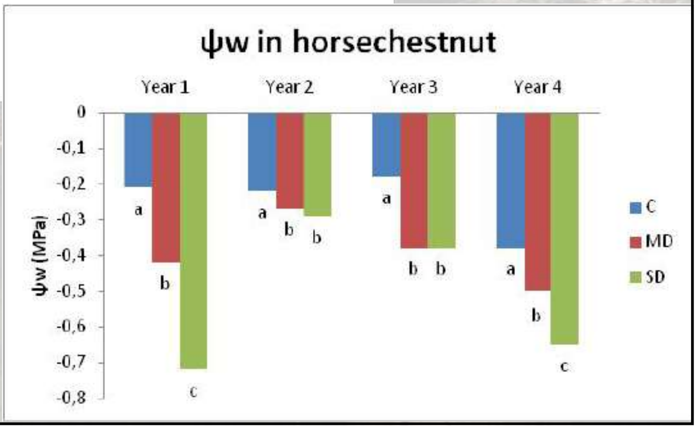
SHOOT GROWTH



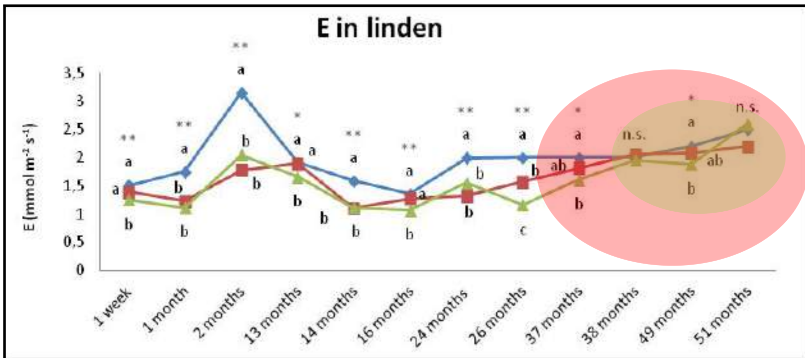
Root severance x Species				
P	n.s.	*	*	*

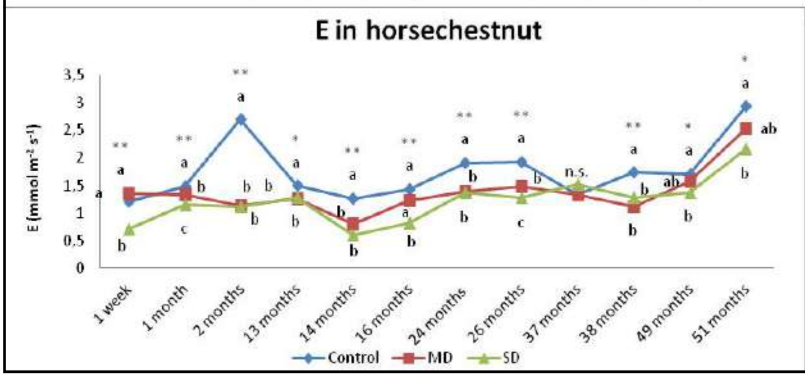


Pre-dawn water potential indicates the tension required to extract water from plant tissues. The less negative it is, the more hydrated are tissues

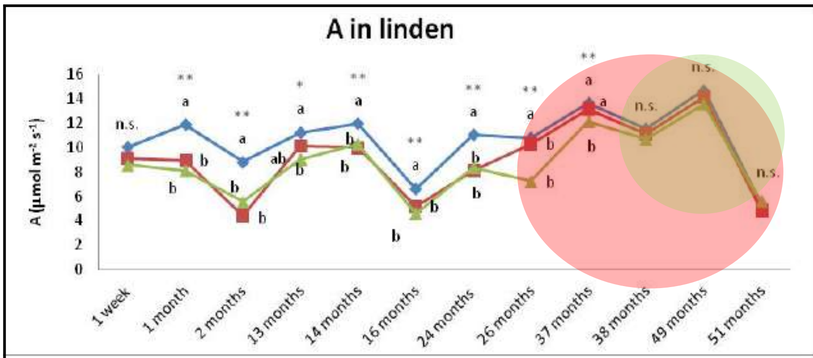


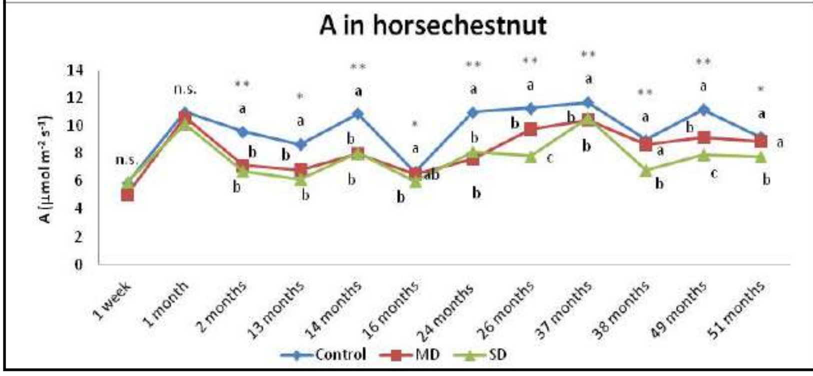
$P_{timeXsevXsp}$: **





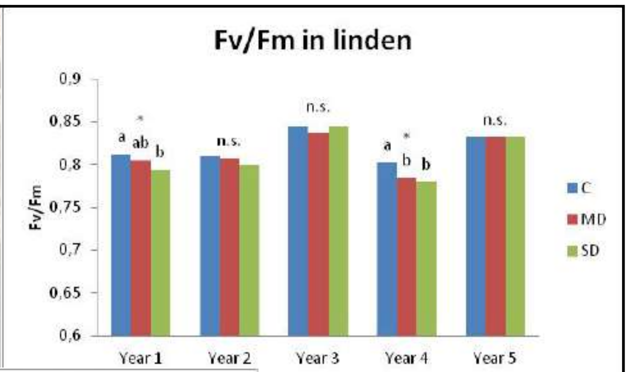
Transpiration is the amount of water evaporated from 1 m^2 of leaf area per unit time

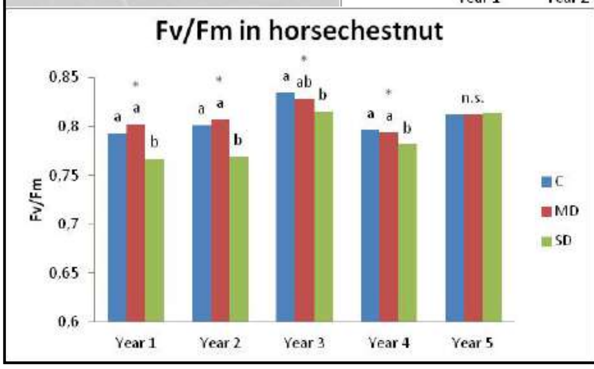




CO_2 assimilation is the amount of CO_2 assimilated from 1 m^2 of leaf area per unit time

MAXIMUM QUANTUM YIELD OF PSII





Healthy leaves usually display values greater than 0.8. Photoinhibition occurs at values lower than 0.75

Physiological effects of root damage on young trees: take home message

•From a physiological point of view, root severance on young trees induced similar effects as a mild water stress, characterized by diffusive limitation to photosynthesis (metabolic limitation, typical of more severe stress, rarely occurred) and a moderate change in pre-dawn water relation.

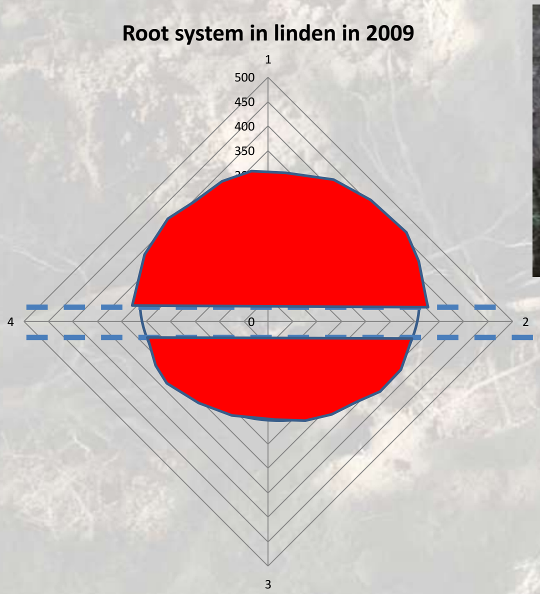
• However, recovery is slower than most abiotic (mild) stresses, particularly in sensitive species such as horsechestnut

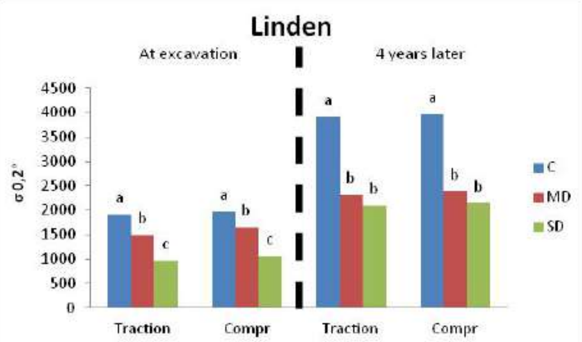
•Linden displayed greater physiological tolerance to root loss than horsechestnut

•It must be considered that experiment was performed during quite rainy years

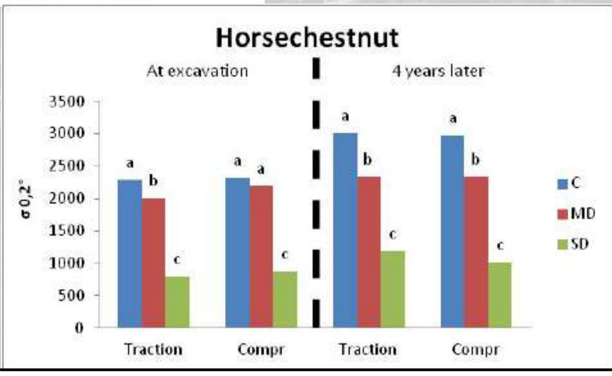
Will severed trees stand up?

What about roots?





Bending moment (both traction and compression) to reach 0.2° change in inclination of the root plate, determined by pulling test



CALCULATED UPROOTING RESISTANCE

Species	Treatment	Root contribution to stability (m³)		Moment Factor (m³)		Uprooting Resistance Index	
		2009	2013	2009	2013	2009	2013
Linden	C	7,5 a	21,0 a	74,4	145,6 a	0,10 a	0,15 a
	MD	2,4 b	7,7 b	77,6	116,1 b	0,03 b	0,07 b
	SD	0,6 c	6,8 b	70,0	105,4 b	0,01 c	0,06 b
	p	**	*	n.s.	*	**	**
Horsechestnut	C	2,5 a	6,8 a	36,9	59,1 a	0,07 a	0,12 a
	MD	1,11 b	4,6 b	36,6	54,3 a	0,03 b	0,08 b
	SD	0,25 c	4,4 b	27,7	30,4 b	0,01 c	0,04 a
	p	**	*	n.s.	*	**	**

The theoretical (calculated) resistance to uprooting was reduced in most of severed treatments. Only SD horsechestnut underwent greater reduction in MF than in GR, 4 years after trenching, resulting in similar URI than control.

CONCLUSIONS

- The change in absorbing root surface caused by root loss induced a chronic mild water stress to trees, even in very rainy years, when water stress is very unlikely to happen on undamaged trees
- Recovery from this stress is extremely slow, because it depends on root regeneration, rather than on resource (water) supply
- Thus, root damage may act as a predisposing factor, which may lead to tree decline as secondary stressors occurs
- The uprooting resistance, both measured and calculated, was reduced by excavation, and recovery was very slow and incomplete in both species
- The sensitive species regenerated displayed little root regeneration, but undewent large above-ground growth reductions, thus URI appeared to be recovered

LIMITATION TO THIS STUDY

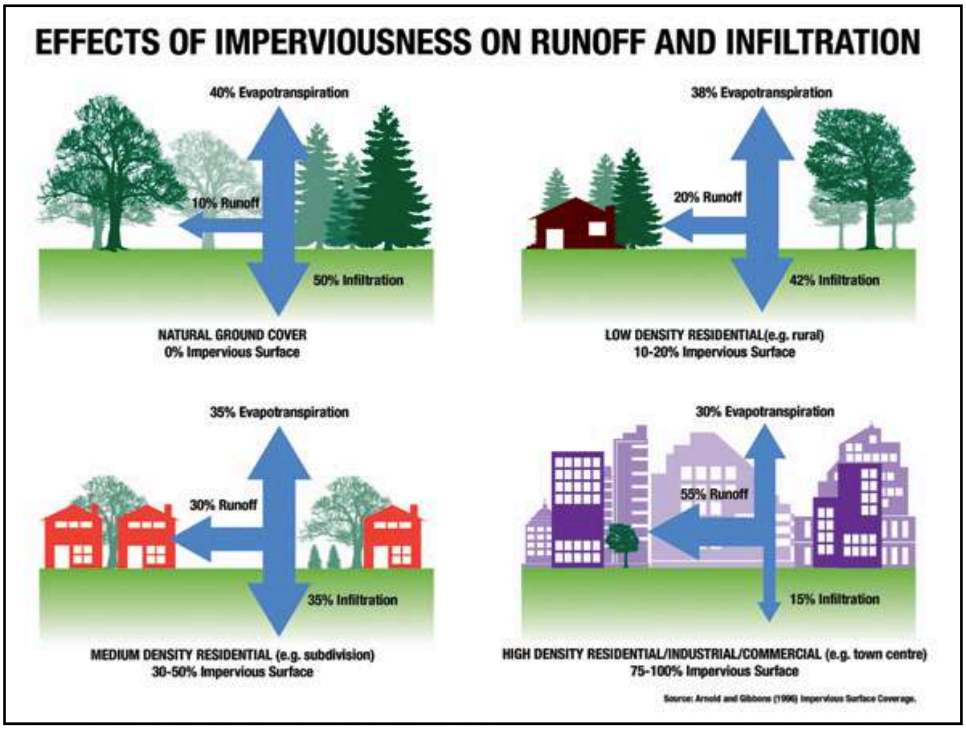
Results of this study show the response of linden and horsechestnut to root damage. However, when extrapolating these findings to urban conditions, it must be considered that **trees were young (25-30 cm circumference at the beginning of the experiment)**. Older trees may show a different response and further research should be aimed at investigating the effects of trenching on mature and senescent trees.

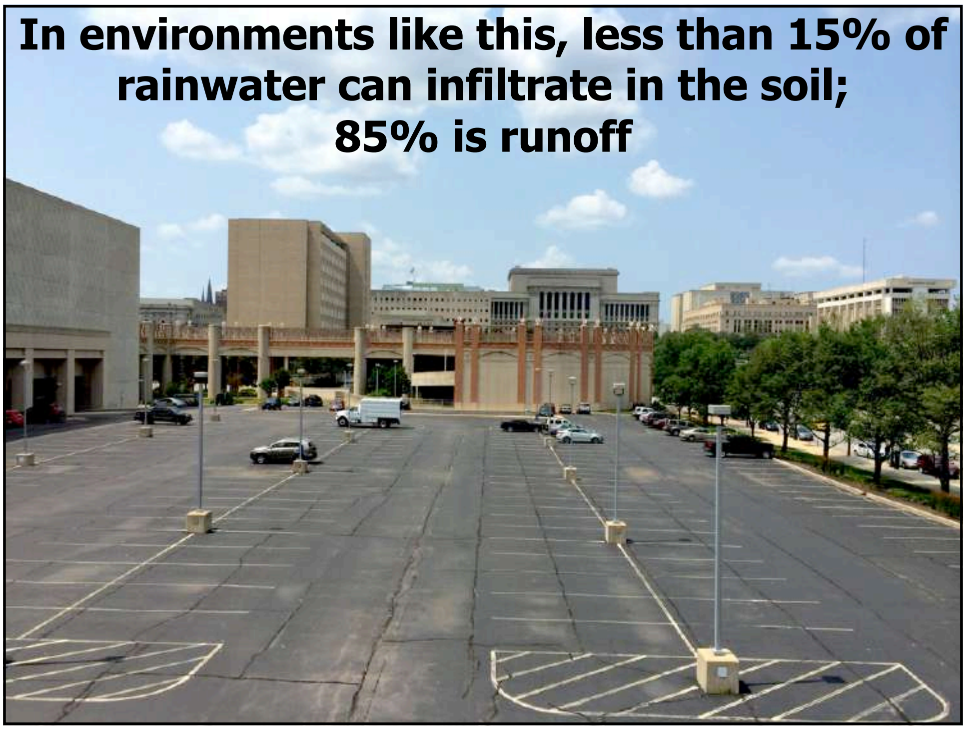
A 3-year-study evaluating the effects of soil sealing on newly planted trees

Soil sealing, “the covering of soil by buildings, constructions, and layers of completely or partly impermeable artificial materials” is the most pervasive form of land take and it is essentially an irreversible process (*Alberti, 2005*)

In Italy, about 8 m^2 (86.11 ft^2) soil are sealed every second (*European Commission, 2012*).

In Europe about 250 km^2 are sealed every day, and the detrimental effects of soil sealing and subsequent soil degradation have been estimated to cost up to 45 billion euro per year (*European Commission, 2012*).


EFFECTS OF IMPERVIOUSNESS ON RUNOFF AND INFILTRATION
40% Evapotranspiration
10% Runoff
50% Infiltration
NATURAL GROUND COVER
0% Impervious Surface
38% Evapotranspiration
20% Runoff
42% Infiltration
LOW DENSITY RESIDENTIAL(e.g. rural)
10-20% Impervious Surface
35% Evapotranspiration
30% Runoff
35% Infiltration
MEDIUM DENSITY RESIDENTIAL (e.g. subdivision)
30-50% Impervious Surface
30% Evapotranspiration
55% Runoff
15% Infiltration
HIGH DENSITY RESIDENTIAL/INDUSTRIAL/COMMERCIAL (e.g. town centre)
75-100% Impervious Surface
Source: Arnold and Gibbons (1996) Impervious Surface Coverage.


In environments like this, less than 15% of
rainwater can infiltrate in the soil;
85% is runoff

FREQUENCY OF EXTEME EVENTS IS INCREASING DUE TO CLIMATE CHANGE. THERE IS AN URGENT NEED TO MITIGATE THE DELETERIOUS EFFECTS OF SOIL SEALING

AIM 1:

Understand what happens to a soil when it is sealed

- Temperature
- Water cycle
- Gas exchange with atmosphere

Hypothesis 1:
Consequences of soil sealing may be mitigated by alternative street designs

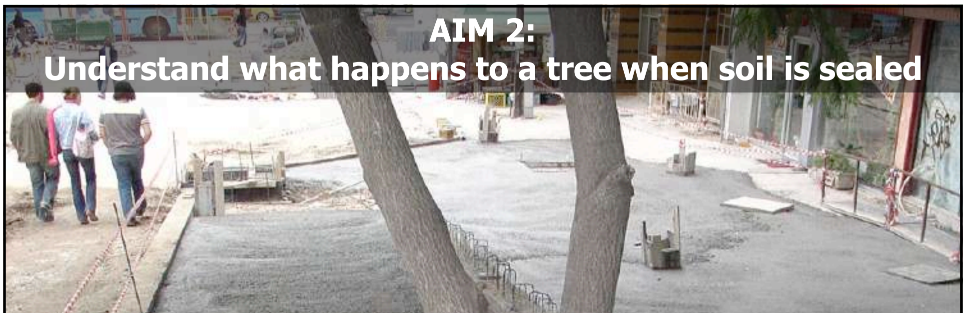
livinglandscapes.uk.com

POROUS PAVEMENTS:
The pavements itself is permeable to water across its entire structure

PERMEABLE PAVEMENTS:
Pavements made by impervious modular elements, but voids between elements allow water infiltration

These pavements have infiltration coefficients = 0.5-0.7, compared to 0.15 of asphalt

AIM 2:
Understand what happens to a tree when soil is sealed



Some authors have identified drought as the major cause of decline of trees in sealed areas (*Depietri et al., 2012; Savi et al., 2015*)
Other works, on the contrary, found higher soil water content under pavements than in unpaved soil (*Morgenroth and Burchan, 2009; Viswanathan et al., 2011; Morgenroth et al., 2013*).

Soil hypoxia and soil CO_2 accumulation under pavements are other possible causes leading to tree decline, through a reduction of root growth and activity (*Viswanathan et al., 2011; Volder et al., 2014*).
Other works, however, found similar or even greater root growth under pavements than under bare soil (*Morgenroth, 2011*).

Hypothesis 2:

Reduction of infiltration and soil moisture

↓

Drought stress

Reduction of gas exchange between soil and atmosphere

↓

Root hypoxia

Despite of pavements are widespread in the urban environment, there is still a very limited amount of knowledge about the soil-tree-pavement interaction in urban sites. Also, still very limited research has been carried out to evaluate the effect of pervious and porous street designs compared to traditional, impervious pavements.



Methods – Building the plots

- 24 plots (50 m^2 area) were built in November 2011
- Each plot was separated from the surrounding ones by polypropylene barriers, buried in the soil down to 70 cm.
- Two planting pits (1 m^2 area) were left unpaved in each plot
- Plastic cylinder were put through the pavements, to allow direct soil measurements. Some cylinders are near the planting pit, some other are buried 5 m away
- Pavement thickness was about 15 cm, including sub-grade, in all treatments

Methods - treatments

Impervious design: asphalt on a concrete sub-grade

Permeable desing: curb on a crushed rock sub-grade

Porous desing: epoxy resin + even-graded inert on a crushed rock sub-grade

Control: unpaved soil (chemical weeding used for weed control)

Methods - species

Celtis australis L. - hackberry
Fraxinus ornus L. – manna ash

• 24 plants per species (14-16 cm circumference; 2'' caliper) were planted in March 2012, according to a randomized block design with 6 blocks

• Each tree was planted in a 1 m^2 planting hole, surrounded by 25 m^2 paved soil

Measurements: soil traits

• Soil moisture (v/v), measured weekly at 20 cm (5 cm below sub-grade) and 45 cm (30 cm below sub-grade) depth, measured with FDR soil moisture probes
• Soil temperature, measured monthly at 25 cm depth using a temperature probe
• Soil oxygen content and soil CO_2 efflux, measured monthly using a soil respiration chamber

These parameters were measured both in the paved soil next to the planting pits and in the paved soil in the middle of the paved plot, not colonized by roots yet.

Measurements: plant traits

GROWTH:

• Shoot growth (10 shoots per plant), measured at the end of the growing season in 2012, 2013, and 2014

• DBH, measured at the end of the growing season in 2012, 2013, and 2014

PHYSIOLOGY:

• Leaf gas exchange (photosynthesis and transpiration) **measured monthly** during the growing season on 12 leaves per treatment and species using a IRGA

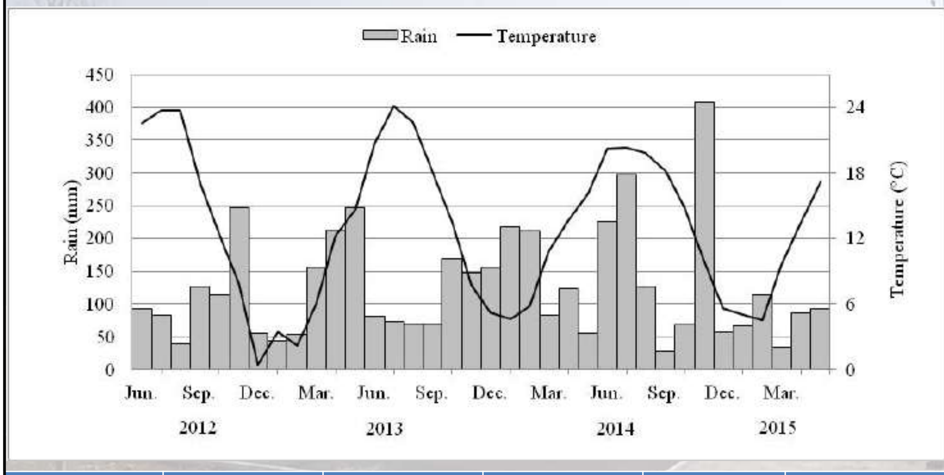
•Fv/Fm, **measured on the same leaves** as gas exchange using a portable fluorometer

• **Pre-dawn and midday water potentials,** measured using a Scholander-type pressure bomb

Results

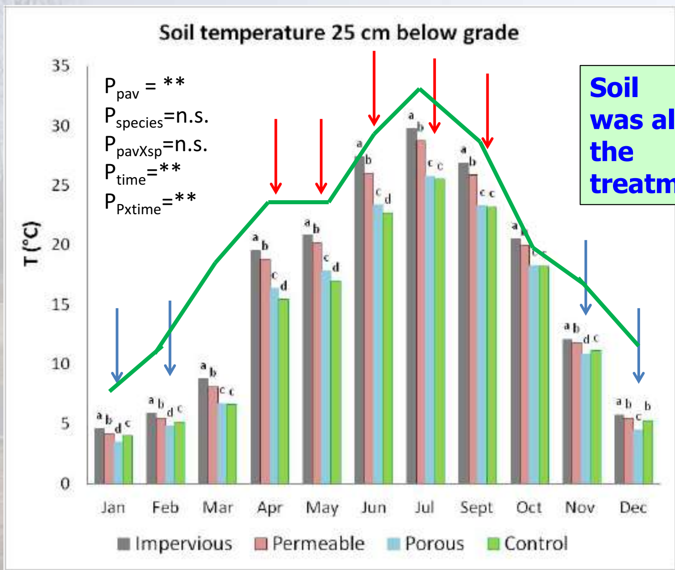
Data were analysed using two-way ANOVA with SPSS statistical package (IBM)

Climate at the experimental site



Year	2012	2013	2014	2015	Avg 1981-2011
Period	June-Dec	Jan-Dec	Jan-Dec	Jan-May	Jan-Dec
Rainfall (mm)	757	1480	1899	394	1086

Effects on soil - Temperature



Soil temperature was always higher in the impermeable treatment

Data are the average of monthly measurements conducted from June 2012 to May 2015.

Line indicates air temperature

During a snowfall, plots paved with asphalt are probably warmer

Effects on soil – soil CO_2 efflux

Potential effects of soil CO_2 accumulation

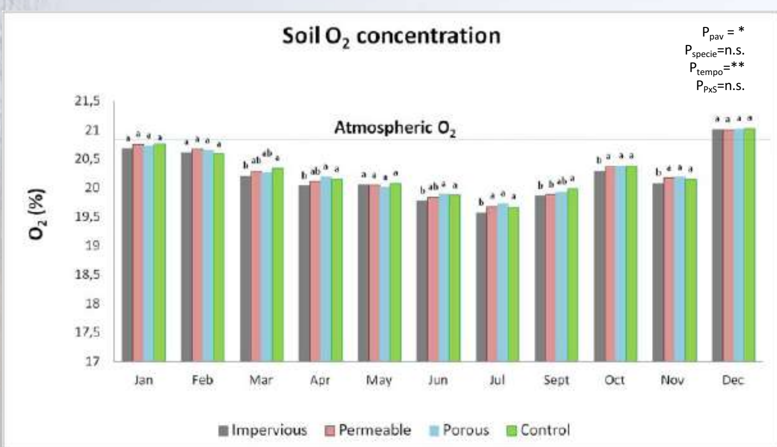
- Inhibition of root respiration and root activity
- Reduction of root growth
- pH of root cells decreases

Reversible
3000 – 4000 ppm

Irreversible
Over 10000 ppm

Research is already going on to check these effects, thanks to the Jack Kimmel and the Research Fellowship Grants by Tree Fund

Effects on soil – oxygen content



- When significant differences were found, soil covered by asphalt had lower O_2 content when compared to unpaved soil, which did not occur using permable or porous pavements
- The reduction is little and not likely to have a biological significance for establishing trees

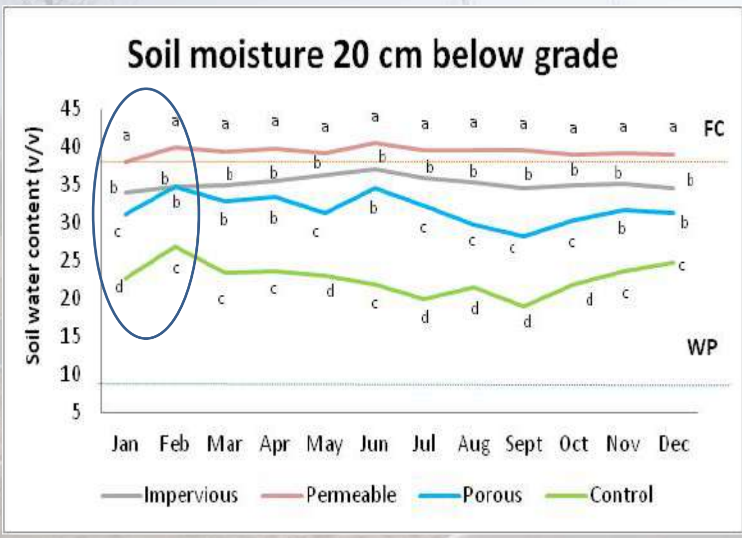
Effects on soil - moisture

Frequency domain reflectometry (FDR) moisture probes

20 cm deep

45 cm deep

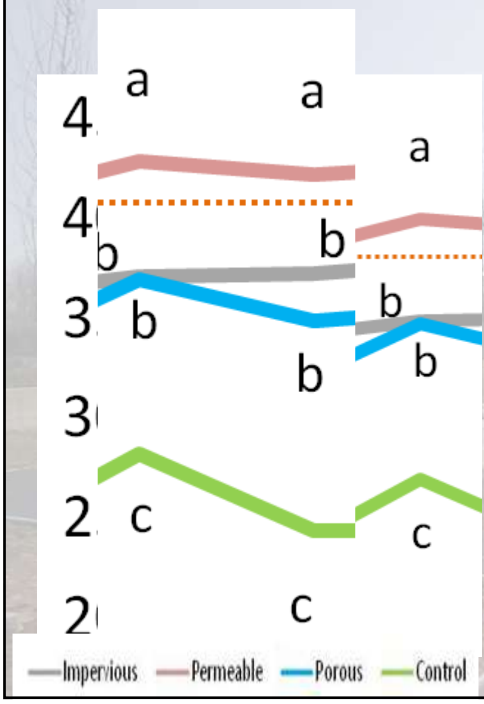
Effects on soil - Moisture in paved soils with no tree roots



WP and FC denote wilting point and field capacity

Variation in moisture through the year:

Asphalt: 8%
Permeable: 7%
Porous: 18%
Control: 29%



During soil rehydration, slope decreases with increasing pavament imperviousness

During soil dehydration, soils covered by impervious layers do not lose water as much as control

Water evaporation converts sensible heat in latent heat: 1 gram of water dissipates 2272 J

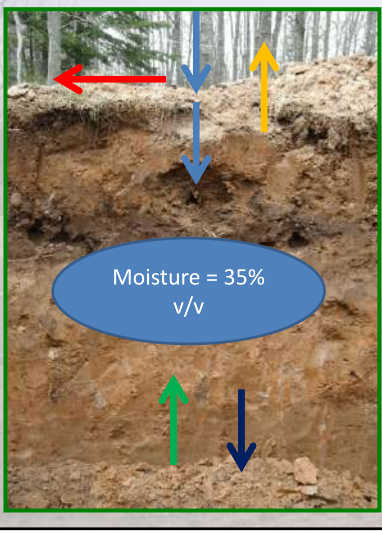
Reduction of evaporation from shallow soil layers because of soil sealing may be a major determinant of soil warming and urban heat island

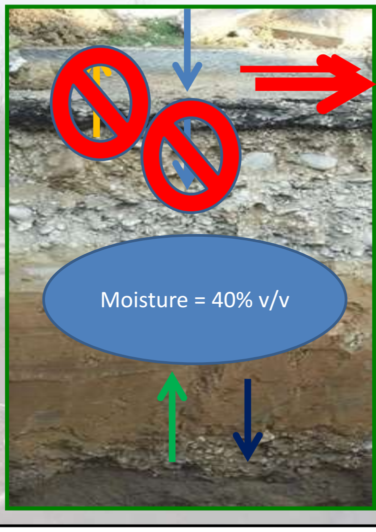
Soil moisture a little deeper – soil without tree roots

TAKE HOME MESSAGE:

soil water balance – soils without tree roots

Soil moisture = **Rainfall** + **Capillary rise** – **Runoff** – **Deep percolation** – **Evaporation**





TAKE HOME MESSAGE:
differences among pavement types, no trees

PAVEMENT	INFILTRATION	EVAPORATION	WATER CONTENT at 20 cm	WATER CONTENT at 45 cm
Impervious	Low	Very Low	Slightly below FC	Slightly above FC
Permeable	Medium*	Low	Saturated	Saturated
Porous	High	Medium	75% available water	Saturated
Control	High	High	40% available water	At or slightly below FC

* May become clogged in about 3 years, decreasing infiltration rate by up to 83%

(Asaeda and Ka, 2000; Abbott et al., 2003; Collins et al., 2008; Morgenroth et al., 2013)

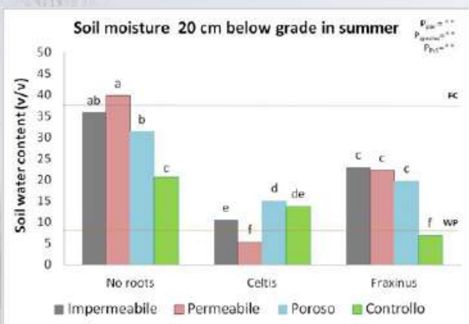
Then, we plant a tree…

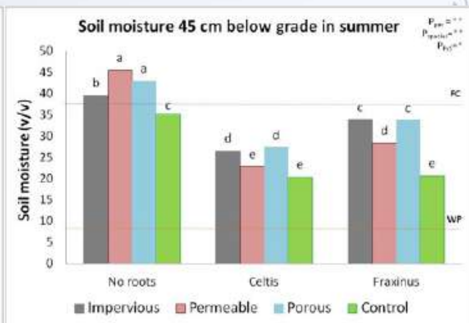
Will higher moisture below pavements be beneficial to urban trees?

OR…

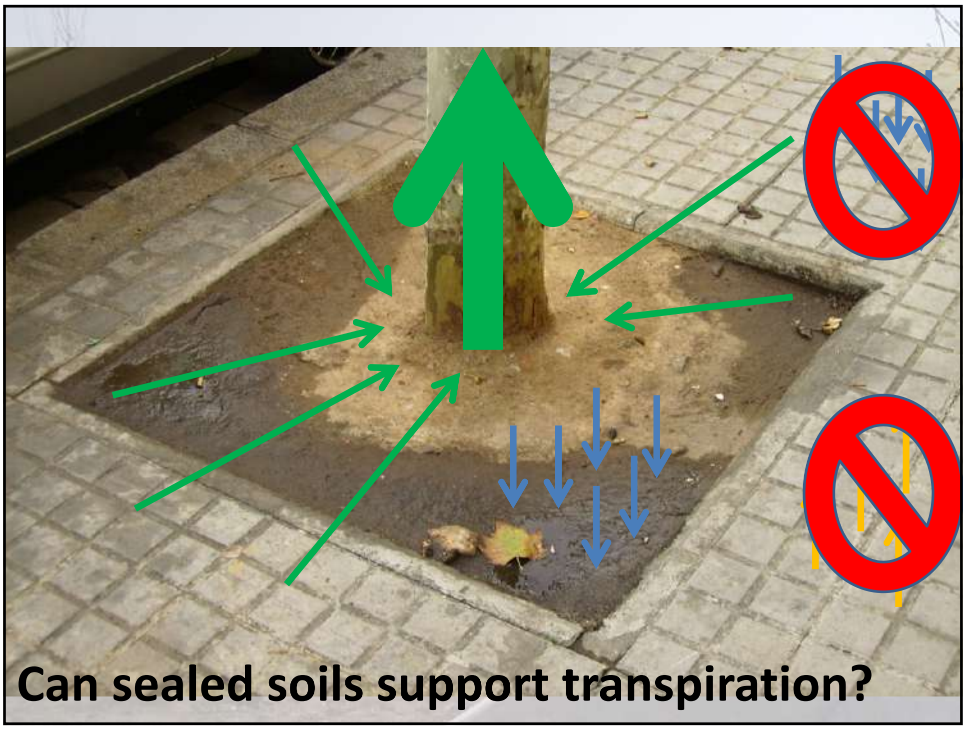
Soil moisture in summer – with tree roots

(values are the average of JJAS measurements conducted from 2012 to 2015)

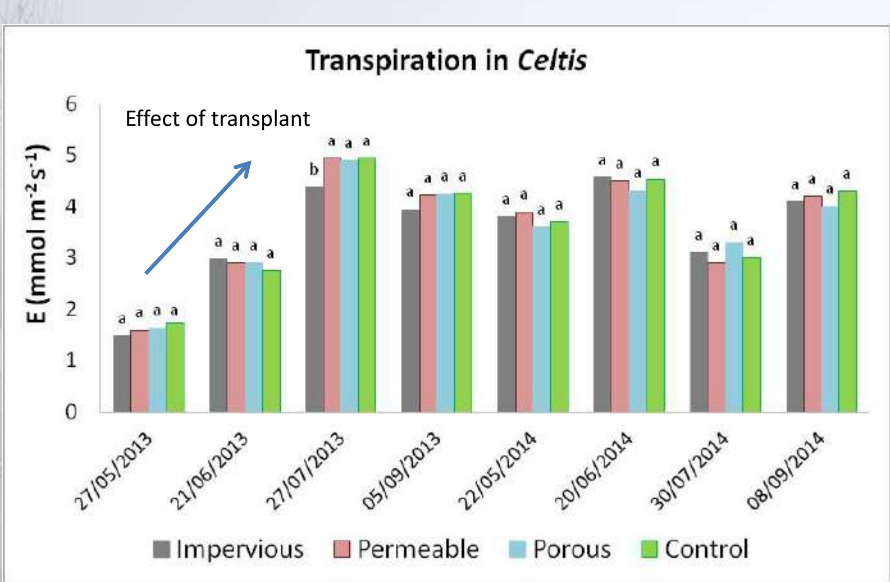




- Transpiration consumes far more water than evaporation
- With trees, soil water content decreased steeply in both paved and unpaved soils
- Soil water content reached wilting point, in some cases, at 20 cm depth, depending on species ability to develop roots in paved/unpaved soils
- Good water availability at 45 cm in all treatments



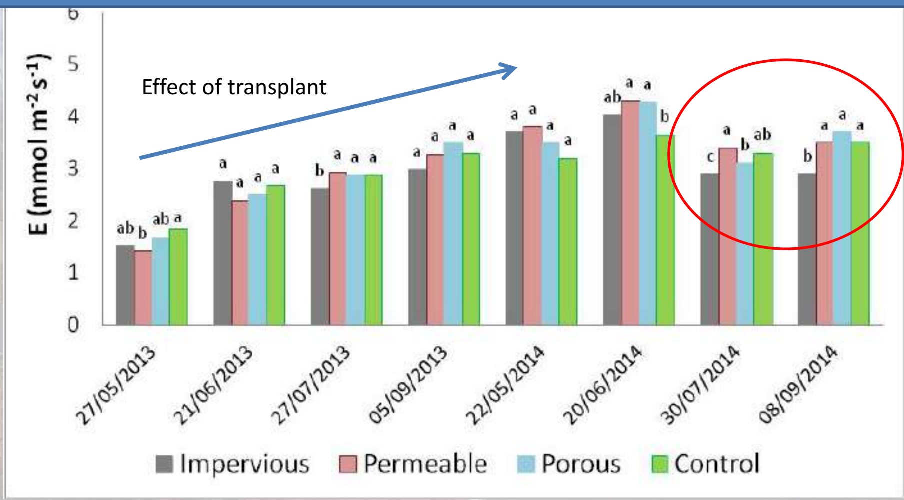
Effects on trees - transpiration



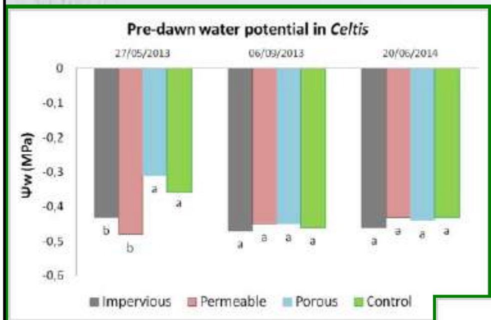
Different letters indicate significant differences at $P<0.05$ using Duncan's MRT

Effects on trees - transpiration

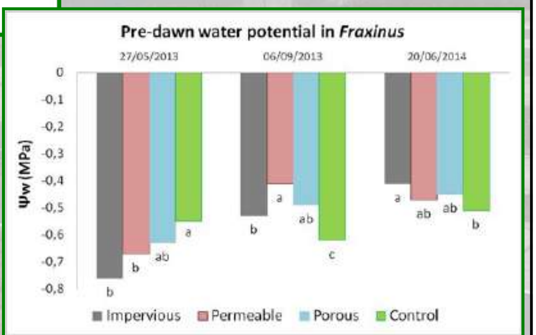
Lower transpiration with higher soil water availability. Signs of hydraulic deterioration or lower root activity in ashes surrounded by asphalt?



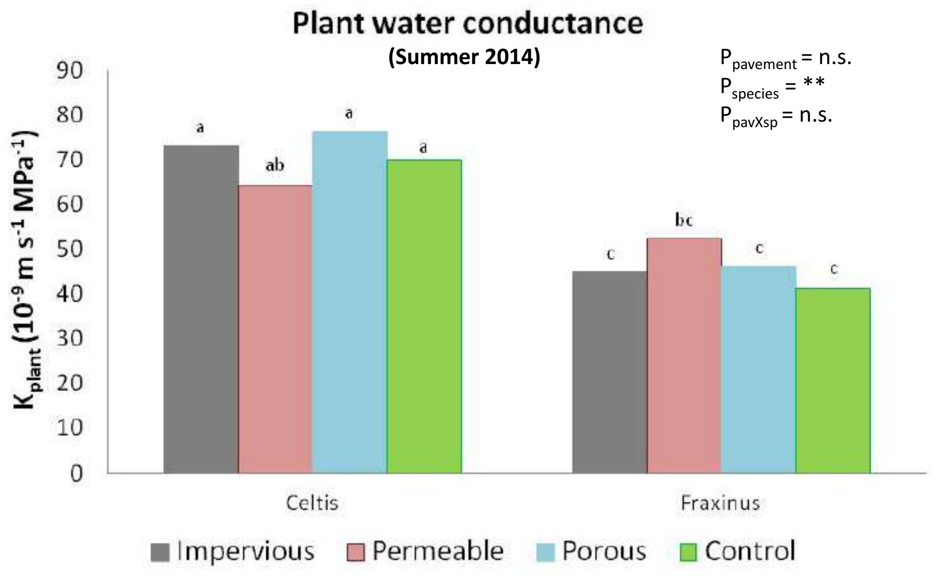
Effects on trees – water relations



Pre-dawn water potential is well representative of plant water status, because, in the absence of transpiration, water potential equilibrates among plant organ and with the soil



$K_{plant} = E/(\Psi_{predawn} - \Psi_{midday})$



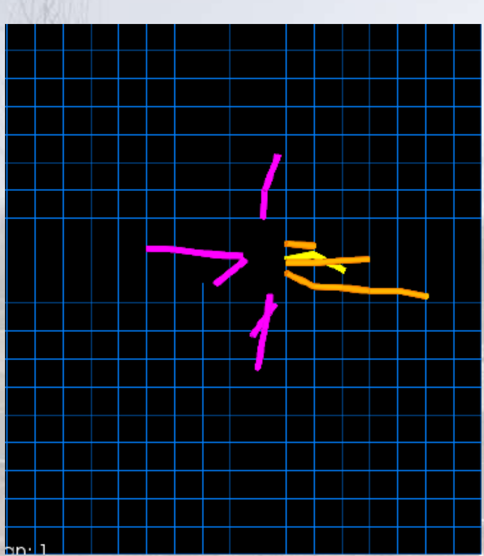
Lower transpiration because of reduced root growth in sealed soils?

Preliminary trials to evaluate root expansion by the use of Ground Penetrating Radar

Frequency: 900 MHz

Grid: 20 x 20 cm (not optimal, denser grids work better)

In cooperation with Boviar (info@boviar.com) using IDS georadar



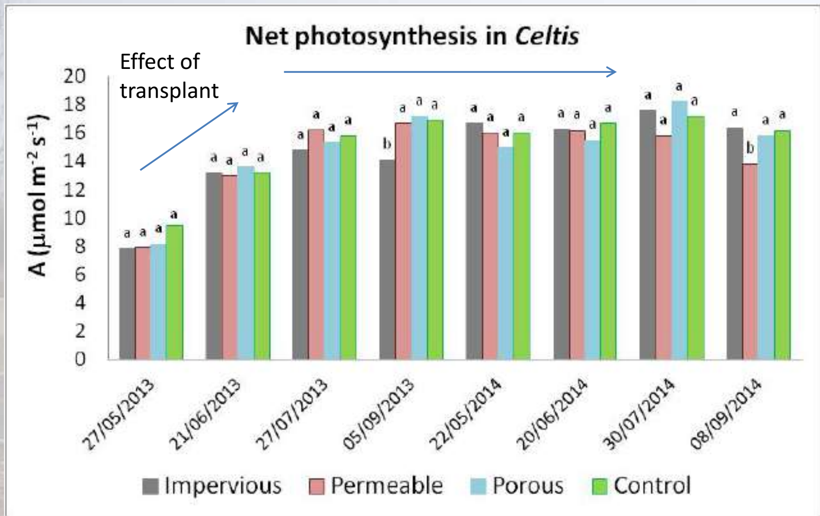
Purple = roots in the top 25 cm of soil

Orange = roots at 25-45 cm depth

Yellow = roots deeper than 45 cm

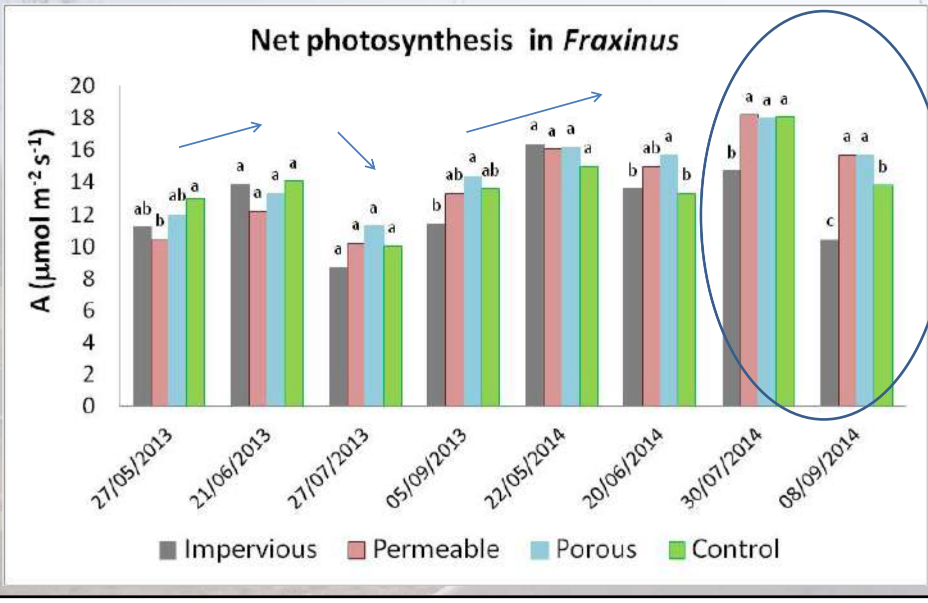
GPR image of hackberry roots in upaved soil. Done In cooperation with Boviar (info@boviar.com) using IDS georadar

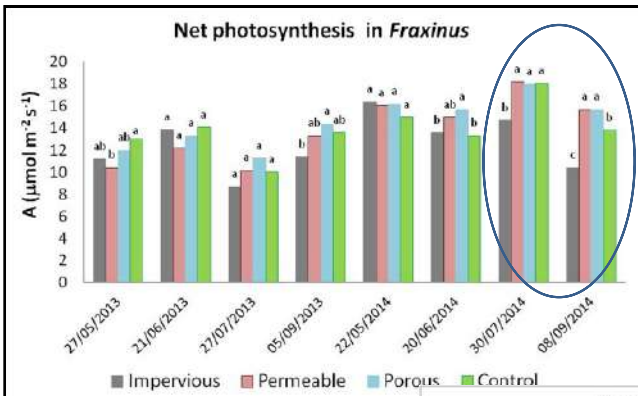
Effects on trees – photosynthesis



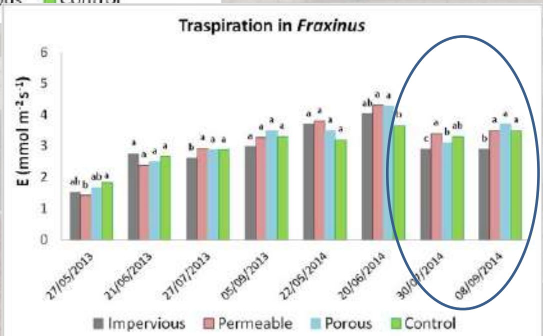
Different letters within the same sampling date indicate significant differences among treatments at P<0.05 using Duncan's MRT

Effects on trees – photosynthesis





PHOTOSYNTHESIS VS. TRANSPIRATION in manna ash

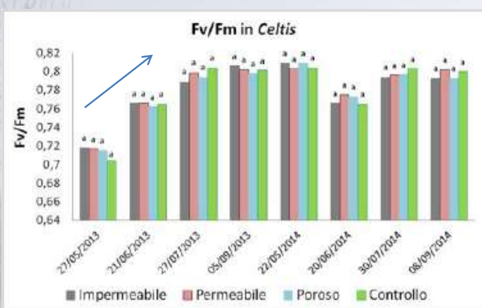


Greater decline in A than E (lower water use efficiency) in “impervious ashes”.

Uncommon when photosynthesis is limited by stomatal closure

Evidence for biochemical limitations?

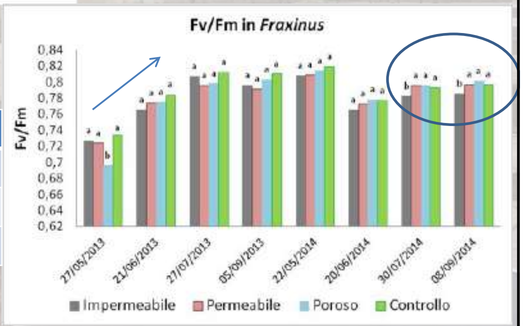
Evidence for metabolic stress on PSII?



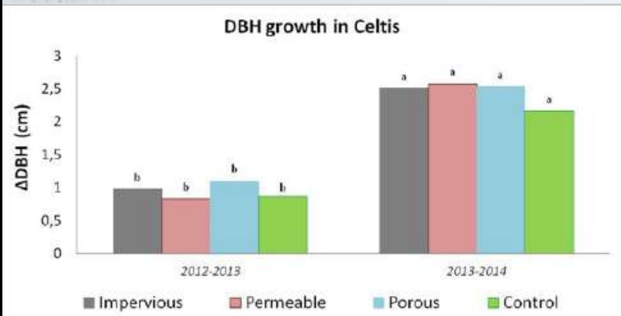
- No evidence of photoinhibition in hackberry

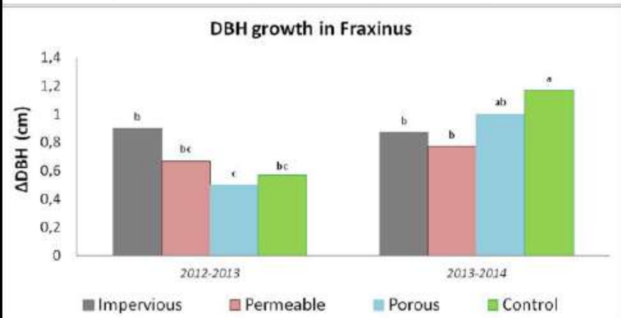
- Some in ashes growing in the impervious treatment, but only very mild stress and in the last two samplings

Fv/Fm	Plant health
> 0,80	Healthy
0,70 – 0,80	Slightly stressed
< 0,7	Severely stressed



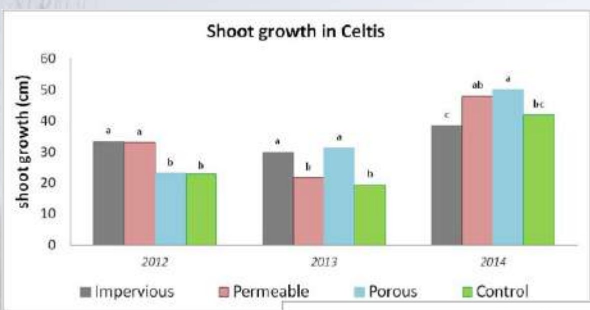
Effects on trees - DBH



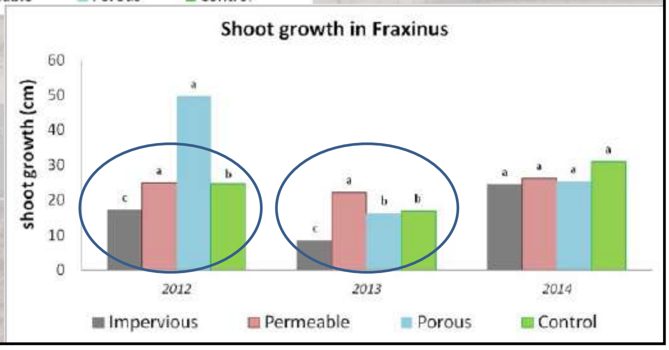


$P_{pavement}$: n.s.
$P_{species}$: **
P_{pavXsp}: *
P_{time}: **
using repeated measures ANOVA

Effects on trees – Shoot growth



Different letters within the same sampling date indicate significant differences at P<0.01 using Duncan's MRT



Conclusions – Effects on soil

- Soil sealing induces 3-5 °C warming in the soil. The effect is likely due to impaired evaporation and can be mitigated using porous pavements.

- Because evaporation is reduced, soil moisture increases with soil sealing, being often above field capacity in soils not planted with trees. This was found in all paved soils. Trees can "bridge" the pavement and transpiration restores water cycle in urban areas.

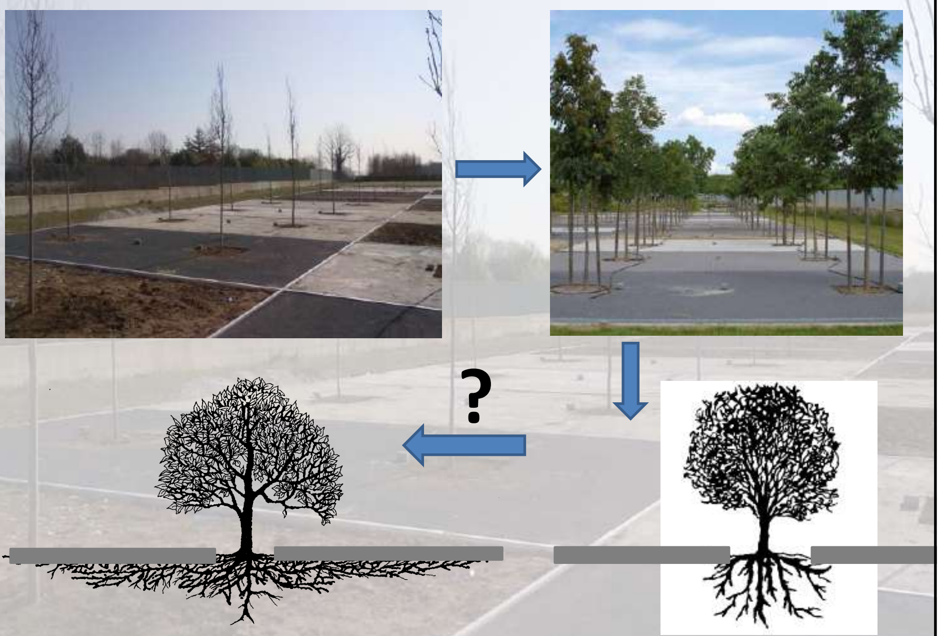
- CO_2 accumulates below impervious pavements, potentially reducing root activity and growth. Porous and, to a lesser extent, permeable pavements can mitigate this effect

- Oxygen slightly declines below impervious pavements. Both porous and permeable pavements can be used to avoid such decline.

Conclusions – Effects on establishing trees

- Planting trees in paved soils is essential to maintain evapotranspiration in urban areas
- Pavements had limited effects on growth and physiology of newly planted trees
- *Celtis* is very tolerant to all types of soil cover, during establishment
- *Fraxinus* in impervious pavements displayed some signs of (very mild) stress since the third year from planting

Limitations



Future perspective

Jack Kimmel Award: 10000 $
Research Fellowship Grant: 100000 $

The Research Project will continue until 2021 to evaluate the plant – soil – pavement interaction once trees are established:

- Root growth by multiple means (GPR, geoelectric, sismic waves, airspade)
- VOC emission as affected by soil sealing
- Plant physiology and biochemistry, with particular emphasis on root signaling (i.e. ABA) affecting photosynthetic yield
- Long term effects of pavements on soil physical, chemical and biological characteristics

Effects of different pruning methods on
***Acer pseudoplatanus*:**
a four-year-experiment scaling down from the whole tree to the chloroplasts

We all know topping is bad….

…..sometimes even destructive!

Why people top trees?

- No national legislation governing the best practices for pruning
- Privates top trees because of lack of information
- Fear of injury
- Topping seems quicker and cheaper
- Despite best pruning being is hardy noticeable, people want to see trees pruned



What do we really know about pruning?

- **Pruning severity and timing** *(Mierowska et al., 2002, Sci. Hortic.;Gilman and Grabosky, 2009, AUF; Fini et al., 2013, Acta Hortic.)*
- **Tree response to wounding** *(Solomon and Blum, 1977; Neely, 1979; Schwarze,2008)*
- **Compartmentalization of wood decay fungi** *(Shigo andMarx, 1977; Schwarze, 2001; O'Hara, 2007; Schwarze et al., 2007)*
- **Tree response in the wind** *(Gilman et al., 2008a, 2008b; Pavliset al., 2008)*

What don't we know?

Little information on pruning methods on the long-term structure and physiology of urban trees (Clark and Matheny, 2010).

Let's try to immedesimate in a tree

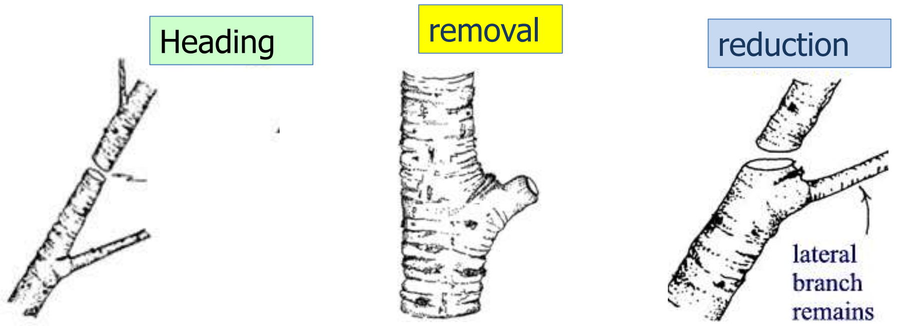
Gilman

Which types of pruning exist?

Topping/heading:
cuts are done in the middle of the internode

Removal:
branches were cut at their insertion with the stem, having care not to damage branch collar

Reduction:
branches were cut back to a lateral with sufficient size to become a new leader



(modified from Gilman, hort.ufl.edu)

Aim

To evaluate the morpho-physiological response to different pruning methods, but similar severity, in maple trees

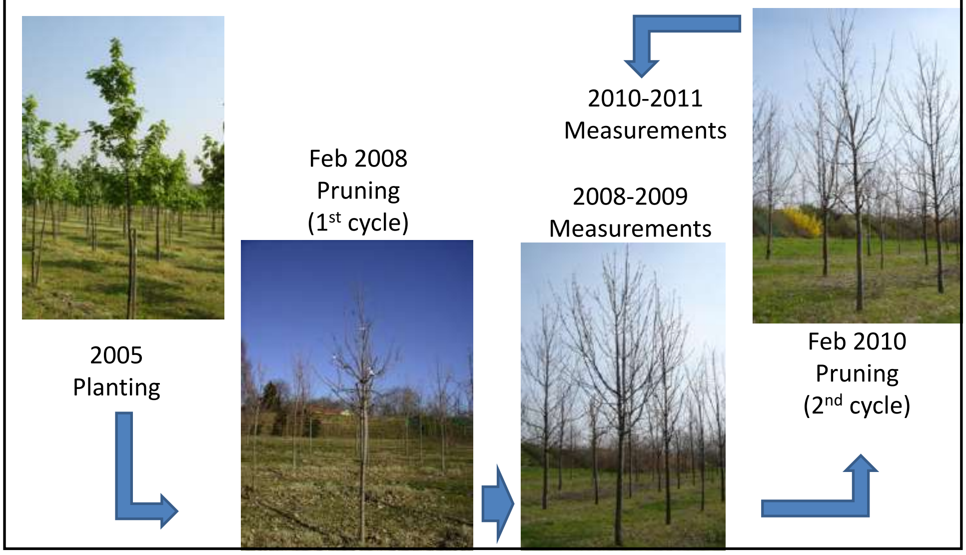
Materials and methods
Plant material and treatments

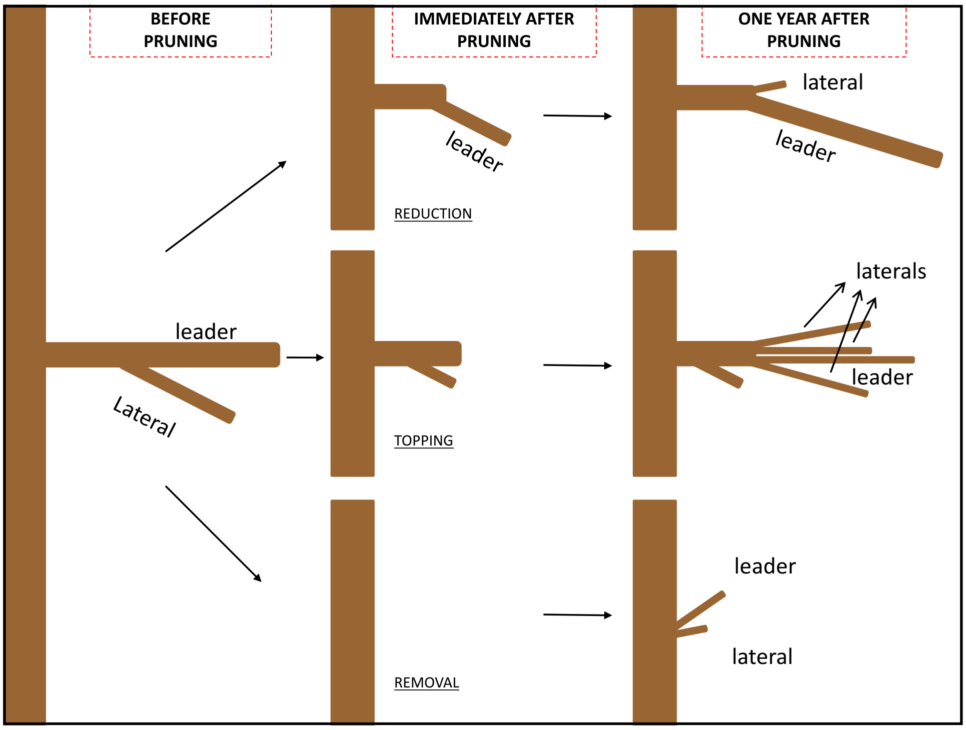
In spring 2005, 28 uniform (10-12 cm circumference) maples were planted in an experimental plot at the Fondazione Minoprio (CO, Italy).
Trees were allowed to establish and grow undisturbed for 3 years.
In February 2008, plants were pruned in order to reduce leaf area by 1/3 according to the following treatments:

- **Topping** (**T**, 7 plants)
- **Removal cut** (**RM**, 7 plants)
- **Reduction cut** (**RD**, 7 plants)
- **Control** (**C**, 7 plants)

Plant material and treatments

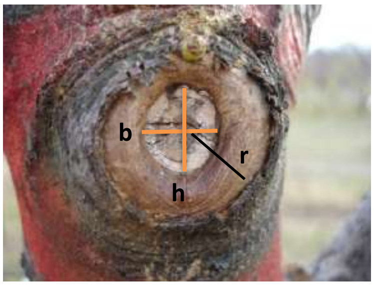
…and in February 2010 they were pruned again with the same treatments as in 2008





Materials and methods
Measurements

- **Length and diameter** of the whole branch, of the leader shoot and of lateral shoots developed after pruning within 20 cm from cut were measured in Feb. 2008, Dec. 2008, Dec. 2009 and Dec. 2010 on all pruned branches.
- **Stem diameter** was measured on all trees at 1,3 m in Feb. 2008, Dec. 2008, Dec. 2009 and Dec. 2010. **Stem RGR** was then calculated as **$(\ln Ø_{t1} - \ln Ø_{t0})/(t_1 - t_0)$**
- **The number of suckers** developed/released after pruning was counted every year
- **Wound closure** was measured in Dec. 2008, Dec. 2009, and Dec. 2010 using the Woundwood Coefficient (Schwarze, 2008)



$$100 - \frac{\pi/4 * b_{t1} * h_{t1}}{\pi/2 * r_{t0}^2}$$

Materials and methods
Measurements

The stress required to cause the failing of the attachment between the primary branch and the new leader shoot (or lateral shoot in control) was measured 2 years after pruning using the methods proposed by Kane et al. (2008).

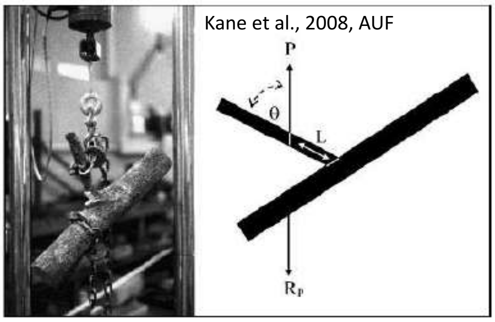


Figure 2. Image showing an attachment being pulled apart in the testing machine (left) and a free body diagram of the setup, where P is the applied load; R_P is the reaction force; L is the distance from the point of applied load to the attachment, measured parallel to the longitudinal axis of the branch; and θ is the angle between the longitudinal axis of the branch and the applied load.

$$\sigma = 32PL\sin\theta/(\pi d^3)$$

Materials and methods
Measurements

- In July 2008 and 2009, ten leaves per tree (70 per treatment), were scanned with A-3 scanner to determine **average leaf area**.

- **Leaf Mass per Area (LMA)**

LMA = leaf dry mass (g) / leaf area (m^2)

- **Leaf greenness index**, which has been related to chlorophyll and nitrogen content (Percival et al., 2008), was calculated using a SPAD-meter (Minolta)

Significance of LMA

(*Bussotti, 2008, Global Change Biol.; Poorter et al., 2009, New Phytol.; Fini, 2011, PhD Thesis*)

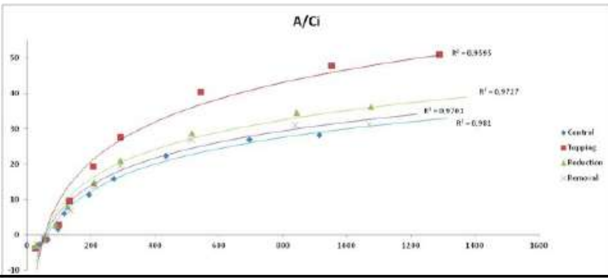
- LMA is an important indicator of plant strategies
- LMA is determined by leaf thickness and leaf density
- LMA usually increases from herbaceous, to woody deciduous and to woody evergreen species
- Within a species, LMA can be affected by environmental conditions and cultural practices
- Leaves with high LMA have high metabolic cost, are build to persist and are better able to tolerate stress than those with lower LMA
- Leaves with low LMA have low metabolic cost, low stress tolerance and are often shed or die in response to stress

Materials and methods
Measurements

- **Carbon assimilation** (A, μmol m^{-2} s^{-1}), **transpiration** (E, mmol m^{-2} s^{-1}), **stomatal conductance** (gs, mmol m^{-2} s^{-1}), and **Water Use Efficiency** (WUE) were measured using an infrared gas analyser (CIRAS 2, PP-System).

Materials and methods
Measurements

- **Response curves of A to leaf internal CO_2 concentration (A/Ci)** were drawn in May and September
- **Stomatal and non-stomatal limitations to photosynthesis** were calculated from A/Ci curves as described by previous works (Lawlor, 2002, Ann Bot; Long and Bernacchi, 2003, J. Exp. Bot)
- **Apparent rate of carboxylation** (V_{cmax}, μmol m^{-2} s^{-1}) and apparant contribution of the electron transport to **ribulose regeneration** (J_{max}, μmol m^{-2} s^{-1}) were measured from A/Ci curves in 2010)



Climate at the experimental site

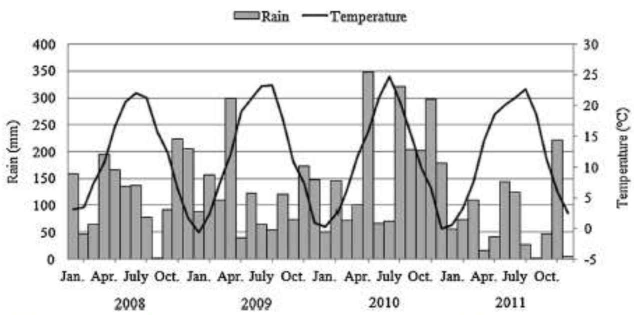


Fig. 1. Monthly average temperature (°C) and rainfall (mm) at the experimental site (Vertemate con Minoprio, CO, Italy, 45°44′ N, 9°04′ E, 250 m above sea level) during the experimental period (2008–2011).

Averages over the last 20 years:

RAINFALL = 1086 mm/y
TEMPERATURE (avg) = 12.3 °C

Wound size and closure (1st cycle)

Treatment	Wound area at pruning (cm²)	Wound closure after 12 months (%)	Wound closure after 24 months (%)
Topping	2,5 b	0 c	1 c
Removal	4,2 a	65 a	93 a
Reduction	2,7 b	44 b	72 b
Control	-	-	-
P	**	**	**


topping


removal


reduction

Wound size and closure (2nd cycle)

Treatment	Wound area at pruning (cm²)	Wound closure after 12 months (%)	Wound closure after 24 months (%)
Topping	3.29 b	4 b	24 b
Removal	7.11 a	17 a	50 a
Reduction	4.11 b	19 a	43 a
Control	-	-	-
P	**	**	**

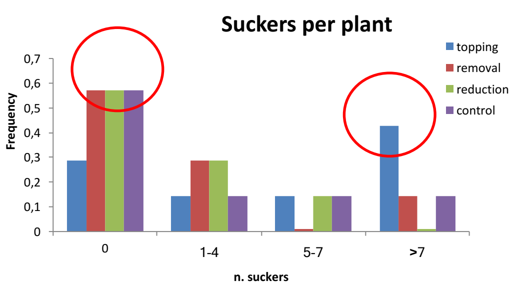
- Results confirmed that removal lead to larger wounds than the other treatment
- Wounds created with topping cuts heal slower than using other pruning methods
- One year after pruning, wound healing occurred at a similar rate in reduction and removal.

Can this finding be upscaled to mature trees?

Maximum recommended wound diamter is 5 and 10 cm for weak and good compartimentalizers, respectively

Effects at the whole-tree level

Treatment	Ø$_{stem}$ Before pruning (cm)	RGR$_{stem}$ 0-24 months, cycle 1 (µm cm^{-1} day^{-1})	RGR$_{stem}$ 0-24 months, cycle 2 (µm cm^{-1} day^{-1})	Dieback 17 months, cycle 1 (%)	Dieback 17 months, cycle 2 (%)
Topping	6,0	8.1 b	6.2 b	26 a	37 a
Removal	6.7	10.0 a	8.8 a	0 b	6 b
Reduction	6.2	10.8 a	8.5 a	3 b	18 b
Control	6.3	10.3 a	9.4 a	0 b	9 b
P	n.s.	**	**	**	**



Effects at the whole-tree level

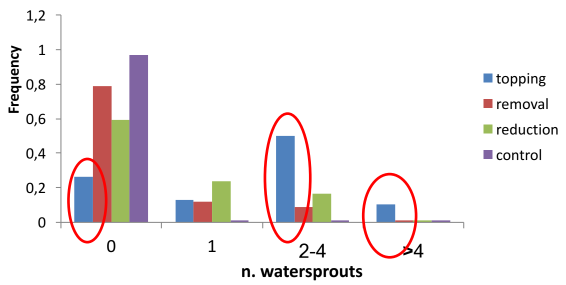
Effects at the whole-branch level

Treatment	L/D_{branch} at pruning, cycle 1	L/D_{branch} 24 months, cycle 1	L/D_{branch} at pruning, cycle 2	L/D_{branch} 24 months, cycle 2
Topping	24.2 c	75.8 b	18.3 c	69.9 b
Removal	-	-	-	-
Reduction	35.4 b	75.9 b	57.2 b	71.0 b
Control	63.7 a	85.9 a	88.4 a	89.1 a
P	**	**	**	**

- Topping and reduction cut reduced branch length and slenderness if compared to control
- Despite a greater reduction in slenderness immediately after pruning, L/D of topped branches increased more than in other treatments in the growing seasons after pruning
- **L/D was lower than 125 in all treatments: if branch union is stable, pruning is not likely to affect whole branch stability in the short-run**

Effects at the shoot level (1st cycle)

Watersprout developed within 20 cm from pruning cuts

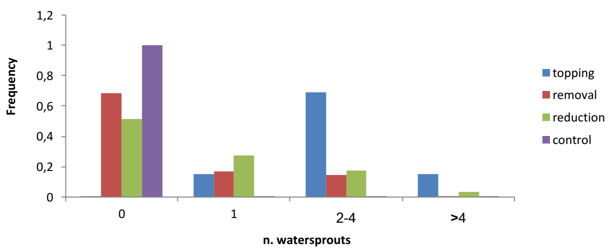


May "lateral" watersprouts become codominant?

	Aspect ratio after 12 months	Aspect ratio after 24 months	L/D_{leader} 24 months
Topping	0.87 a	0.73 a	94,2 a
Removal	0.82 a	0.75 a	60.5 c
Reduction	0.35 b	0.32 b	79,4 b
Control	0.32 b	0.41 b	89,9 a

Effects at the shoot level (2nd cycle)

Watersprout originated within 20 cm from pruning cuts



AGAIN…. WHAT ABOUT CODOMINANCE?

	Aspect ratio after 12 months	Aspect ratio after 24 months	L/D_{leader} 24 months
Topping	0.77 a	0.78 a	95.0 a
Removal	0.91 a	0.76 a	60.3 c
Reduction	0.29 c	0.30 b	80.6 b
Control	0.47 b	0.46 b	75.5 b

Why does topping enhance sprouting?

We hypothesized that different pruning methods may differently disturb apical dominance and control, thereby affecting subsequent growth pattern.

Substituting the apical bud of the branch with the one of a properly sized lateral branch through reduction cut may, at least in part, avoid the complete release of apical dominance which occurs after chopping off (i.e. topping).

Results of this study clearly confirm this hypothesis.

At pruning

Next spring

After 24 months

Why doesn’t reduction cut enhance sprouting?

We hypothesized that different pruning methods may differently disturb apical dominance and control, thereby affecting subsequent growth pattern.

Substituting the apical bud of the branch with the one of a properly sized lateral branch through reduction cut may, at least in part, avoid the complete release of apical dominance which occurs after chopping off (i.e. topping).

Results of this study clearly confirm this hypothesis.

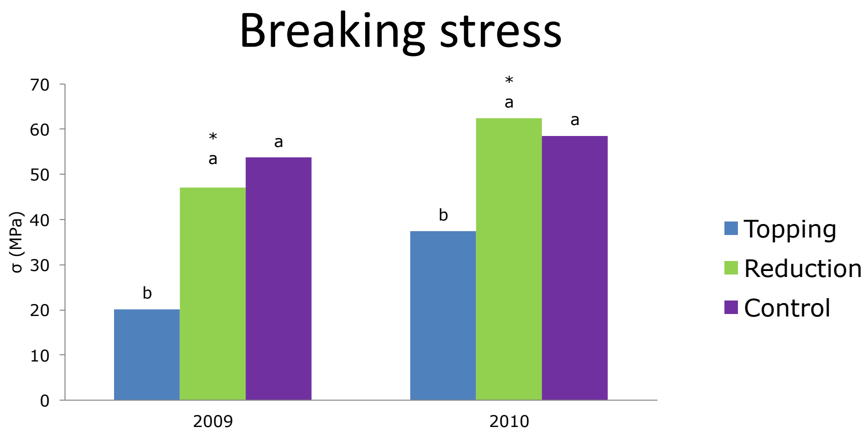
Before pruning

After pruning

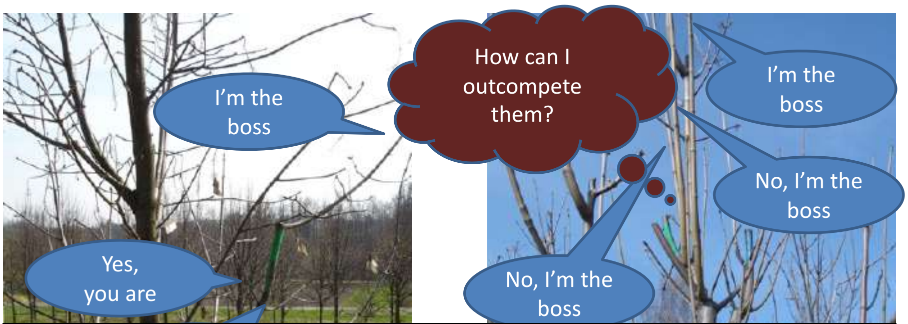
After 8 years

Effects at the shoot level

It has been recently found that well attached branches can be considered safe when **slenderness is lower than 125** (Dahle and Grabosky, 2010). However, **if branch attachment is weak** or if the branch presents signs of structural damage or dacay, failing can occur **when slenderness is higher than 40** (Mattheck, 2007).



Effects at the shoot level



Treatment	Primary growth of shoots on pruned branched 24 months after cycle 1 (cm)	Primary growth of shoots on pruned branched 24 months after cycle 2 (cm)
Topping	92.30 a	84.65 a
Removal	34.40 c	41.82 b
Reduction	69.57 b	33.44 b
Control	52.41 d	26.18 b
P	**	**

How can I grow faster?

Effects at the leaf level (1st cycle)

Effects at the leaf level (2nd cycle)

Treatment	Leaf greenness index 10 (SPAD)	Leaf greenness index 11 (SPAD)	Average leaf area 2010 (cm^2)	Average leaf area 2011 (cm^2)	Leaf Mass per Area 2010 (mg/cm^2)	Leaf Mass per Area 2011 (mg/cm^2)
Topping	42.65 a	39.55 a	279.91 a	183.51 a	8.35 c	6.85 b
Removal	35.00 c	35.71 b	155.32 b	155.91 b	9.90 b	8.37 a
Reduction	39.05 b	38.33 a	165.22 b	165.95 b	11.65 a	8.58 a
Control	36.85 bc	37.34 ab	147.76 b	131.56 c	10.90 ab	8.44 a
P	**	**	*	**	*	**

- As in the 1st cycle, topping resulted in **leaves with more chlorophyll** in the first growing season after pruning.
- **Average leaf area was higher in topped trees** than in the other treatments both in the first and in the second growing season after pruning
- Higher leaf area may result in a less efficient dissipation of heat through convection and may result in higher leaf temperature
- **Leaf mass per area was lower in topped trees** than in the other treatments both in the first and in the second growing season after pruning

Effects at the leaf level

Treatment	V_{cmax} May 2011	J_{max} May 2011	V_{cmax} Sept 2011	J_{max} Sept 2011	Leaf T (°C) 2010	Leaf T (°C) 2011
Topping	124.0 a	226.3 a	133.6 a	198.0 a	27.7 a	29.2 a
Removal	93.4 b	141.4 b	93.0 b	152.6 b	26.0 c	28.7 b
Reduction	103.2 ab	165.5 b	98.0 b	156.0 b	27.1 b	28.4 b
Control	89.5 b	130.2 b	96.0 b	146.3 b	25.7 c	28.3 b
P	*	**	**	**	**	**

•Leaves of topped trees had higher apparent rate of carboxylation and apparent contribution of electron transport to ribulose regeneration if compared to the other treatments

• If considering the activity of enzymes related to photosynthesis, their activity was higher in topping than in the other treatments, and, without other limitations, this should lead to higher carbon assimilation.

•When significant differences were found, **leaves in topped trees were about 1-2°C warmer than control**

Effects at the leaf level

A temporary increase in carbon assimilation was found in the first months after pruning in topped trees. Thereafter**, despite a greater investment in chlorophyll and photosynthetic enzymes** by topped plants if compared to control, **differences among treatments disappeared.**

WHAT DID LIMIT PHOTOSYNTHESIS IN TOPPED MAPLES?

Metabolic impairment? (Rubisco breakdown, impairment in RuBP regeneration)

Heat stress due to larger leaves?

Lack of CO_2 due because stomatal conductance is not infinite?

Effects at the leaf level

Treatment	Ls (%) May 2011	Lm (%) May 2011	Ls (%) Sept 2011	Lm (%) Sept 2011
Was A higher in topping?	Yes	Yes	No	No
Topping	10 b	-52 b	41 a	-11
Removal	11 b	-3 a	21 b	4
Reduction	10 b	-17 a	22 b	-2
Control	17 a	-	18 b	-
P	*	*	*	n.s.

CO_2 DIFFUSION THROUGH STOMATA WAS THE MAIN LIMITATION TO CARBON ASSIMILATION IN TOPPING!!

In other words, it was useless to invest so much resources in chlorophyll and enzymes related to photosynthesis, because carbon assimilation became limited by CO_2 availability in the leaf

Ls: Stomatal limitation Lm Mesophyll limitation (non-stomatal)

Stomatal vs. mesophyll limitations…. It sounds confusing to me!!!!

The powerful engine of a Ferrari is useless if speed limit (imposed by stomatal conductance) is at 50 km/h!!!

Conclusions

We provide here new evidence supporting old knowledge:

Myth: topping will make trees easier to maintain

FAKE: topped branches grew faster, more slender and codominance often occurred

Myth: topping invigorates trees

FAKE: topping altered tree physiology, providing a shift to a more pioneer behavior, but at expenses of stress tolerance. Moreover, topping increase plant investment to leaves, but that is useless because stomatal factors prevent the increase of photosynthesis when environmental conditions are sub-optimal

Conclusions

- Pruning method, not only its severity, modulates the morpho-physiological response of trees.
- Maintenance of apical control and dominance are key issues to preserve a structurally sound trees and the long-term efficiency of the photosynthetic apparatus
- Removal cut provides minimal disturbance to tree physiology
- Reduction cut preserved normal branching pattern and had little effects on leaf structure and photosynthetic performance
- Topping affected branch structure by promoting competition among sprouts of the same branch and by determining a shift towards a more pioneer (fast growing) behavior, but at the expense of tolerance to environmental stresses

Full text available at UFUG journal

Urban Forestry & Urban Greening 14 (2015) 664–674

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ELSEVIER

Effects of different pruning methods on an urban tree species: A four-year-experiment scaling down from the whole tree to the chloroplasts

A. Fini[a,d,*], P. Frangi[b], M. Faoro[b], R. Piatti[b], G. Amoroso[b], F. Ferrini[a,c,d,e]

Evaluation of the ability of shrub and tree species sequester CO_2 in the urban and periurban environment

The aim of this work was to compare carbon assimilation and carbon storage in several widely-used, low-maintenance shrub species

Carbon assimilation and storage were compared:

1) Under non-limiting water availability (Experiment 1);

2) Under water stress (Experiment 2)







METHODS: plant material

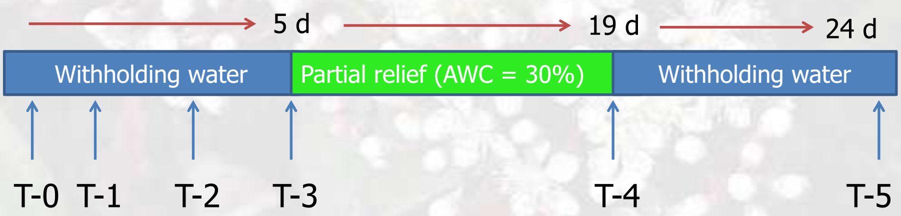
- *Arbutus unedo*
- *Elaeagnus x ebbingei*
- *Ligustrum japonicum*
- *Photinia x fraseri*
- *Viburnum lucidum*
- *Viburnum tinus*
- *Laurus nobilis (only exp. 1)*

20 two-year-old plants per species (2 plants per block and 10 blocks) were potted in 2.5 L containers and grown outdoor under typical Mediterranean conditions (avg. PAR = 1800 mmol m-2 s-1; T > 30 °C during summer) from May to September 2010

Plants were grown in a peat:pumice substrate (3:1) added with 3 kg/m^3 of a controlled-release fertiliser (Osmocote®, 6 months, 10-10-17, Scotts International)

(Exp. 1) Plants were watered daily to maintain the moisture of the substrate near the container capacity

(Exp. 2) Treatments were: 1) **WW**: plants were irrigated daily to container capacity 2) **WS**: plants were exposed to a 24-day water stress scheduled as follows:

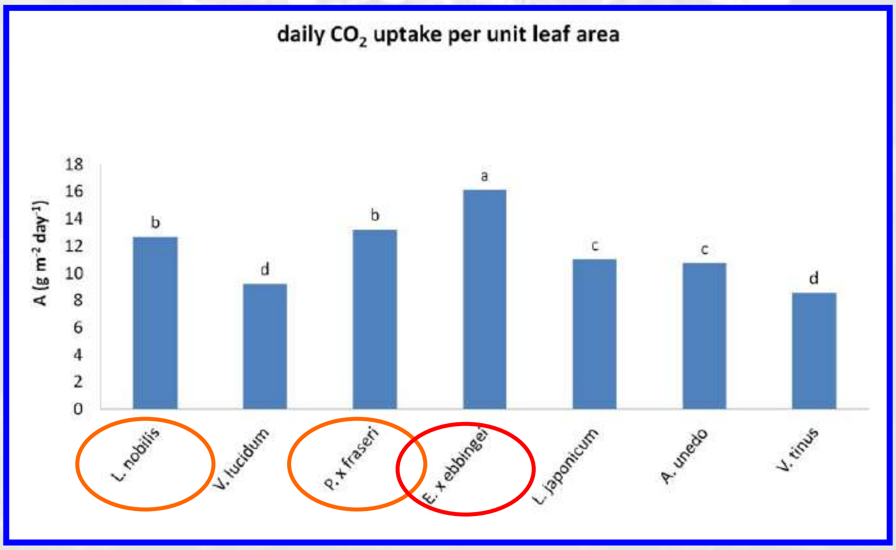


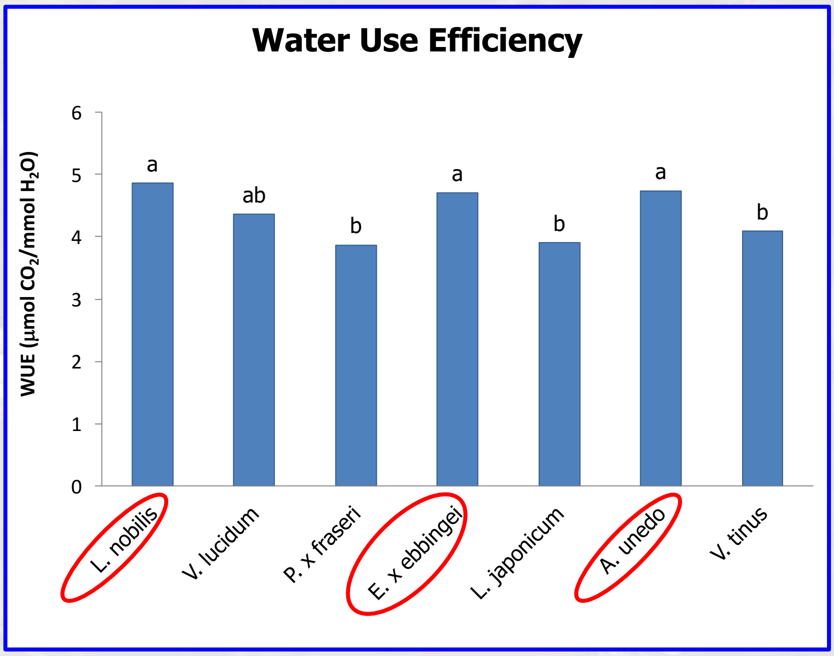
During partial relief, WS plants were watered in order to maintain substrate moisture near 30% of water holding capacity. That amound of water has usually been associated with a mild to moderate drought (*Brilli et al., 2007;Fini et al., 2013*)

RESULTS

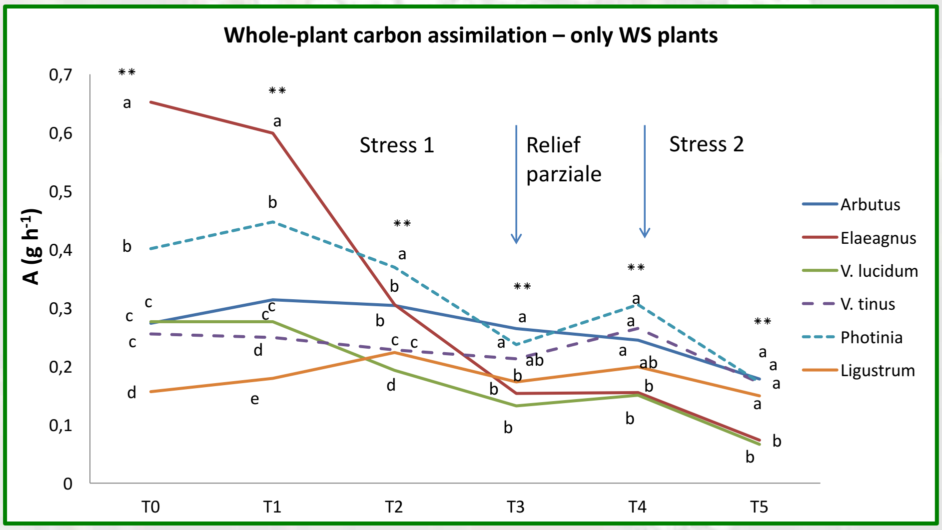
WHICH SPECIES DO DISPLAY HIGHER CARBON ASSIMILATION AND STORAGE IF WATER IS NOT LIMITING?

By integrating daily curve of carbon assimilation, it is possible to calculate the amount of CO2 assimilated (per unit leaf area) by the different species during a typical summer day, under non-limiting water availability





Drought reduced whole-plant CO_2 uptake



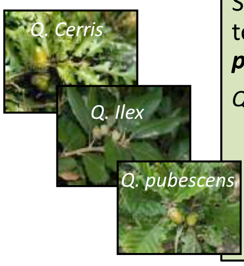
Conclusions – CO_2 sequestration

- If water availability in the planting site is not limiting, *E. x ebbingei* and *L. nobilis* assimilate and store more atomospheric carbon than the other species investigated.

- Drought stress differently affected carbon assimilation in the species investigated.

- Mediterranean species, as *A. unedo* and *V. tinus*, and, among mesic species, *P. x fraseri* are the species which better tolerated drought, and maintained the highest assimilation rate during water shortage.

Our recent lines of research



Study of the response mechanisms of three *Quercus* species to drought and heat stress: ***Quercus ilex*****,** ***Q. cerris*** **e** ***Q. pubescens.***

Quercus species widely employed or potentially to be employed in urban forestry

to evaluate the most suitable species to use in our cities in a scenario of climate changes

Mediterranean seashore dunes

Secondary metabolism in Mediterranean evergreen species with high tolerance to osmotic stress: what's the role for these plants as biofactories?

Isoprenoids and phenylpropanoids are key players in drought stress resistance in the isoprene-emitting *Platanus x acerifolia* - in cooperation with IPSP-CNR

Secondary metabolism in Mediterranean evergreen species with high tolerance to osmotic stress:

What's the role for these plants as biofactories?

Antonella Gori, PhD student in Agricultural and Environmental Sciences- XXIX cycle
Tutor: Francesco Ferrini (DISPAA, University of Florence)
Co-tutor: Mauro Centritto (CNR-IVALSA, Florence)

Effect of topping on microclimate condition and human comfort

supported by Tree FUND

Evergreen shrubs: a barrier against air pollution an open door for the nuresy business

Characterisation of 9 evergreen plant species for their **:**

A. Air pollution mitigation capacity **B**. Carbon storage capacity

UNIVERSITÀ DEGLI STUDI FIRENZE
DISPAA

Paper I – Shrub species

Elaeagnus x ebbingei

Photinia x fraseri

Laurus nobilis

Viburnum lucidum

Arbutus unedo

Ligustrum japonicum

Viburnum tinus

Paper I - Structure

Experiment 1: Carbon uptake and storage under optimal water availability

Experiment 2: Carbon uptake and storage under drought stress

Experiment 3: Leaf surface accumulation of trace metals

Paper I

Conclusions

E. x ebbingei showed the highest carbon storage under optimal water availability, but not under drought conditions. ***P. x fraseri*** represents a compromise between carbon storage capacity and drought resistance.

E. x ebbingei, L. japonicum and ***V. lucidum*** showed the highest unitary leaf accumulation of Pb.

E. x ebbingei, had the highest whole plant leaf accumulation of almost all the measured metals mainly due to the faster and higher growth.

Rain and **Wind speed** were found to influence the metal deposition (PLSR).

Paper II

Conclusions

- ***E. x ebbingei, V. lucidum*** and ***P. x fraseri*** showed an higher capacity in element accumulation per unit leaf surface probably due to their higher growth parameters
- ***E. x ebbingei*** had the highest quantities of elements per whole plant surface
- ***E. x ebbingei*** showed the highest quantity of PM per leaf surface
- Elements and PM showed a similar trend probably influenced by meteorological parameters
- Multivariate methods were effective in the identification of possible sources of pollution

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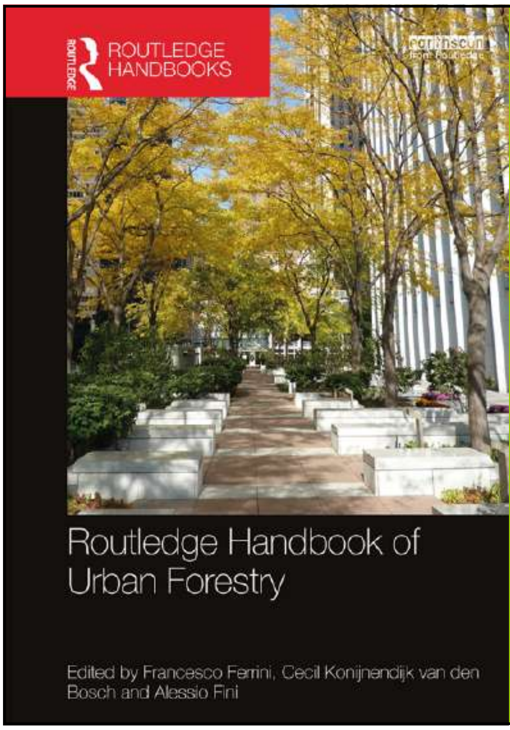

Part I: Urban forestry

Part II: Roles and benefits of urban forests and urban trees

Part III: Urban forest landscapes – a strategic perspective

Part IV: Trees in the urban environment

Part V: Planting sites analysis and modification

Part VI: Selection of planting material, planting techniques and establishment

Part VII: Urban forest and tree management

Robert Miller, Justin Morgenroth, Cynnamon Dobbs

Matilda Van Den Bosch Fabio Salbitano, David Nowak

Lyttimäki Jari, Raffaele Lafortezza, Alan Simson, C.Y. Jim

Stephen Sheppard, Henrik Sjöman, Arne Sæbø

Simone Orlandini, Emilio Padoa Schioppa, Peter Duinker

Carlo Calfapietra, Glynn Percival, Paolo Gonthier

Nina Bassuk, Jason Grabosky, Roger Harris, Daniel Struve

Susan Day, Andrew Koeser, Brian Kane

Karl Niklas, Frank Telewski, Tom Smiley, Steffen Rust

Neville Fay, Michael Raupp, Kathleen Wolf, Cecilia Brunetti

Francesco Ferrini, Cecil Konijnendijk, Alessio Fini
....and MANY OTHERS!!!

Save the date:

ADVANCED COURSE ON BIOMECHANICS OF THE TREES
Pistoia (ITALY), 5-9 June 2017

Speakers (English with simaltenuous translation in Italian=
All details within mid-february
BARRY GARDINER Emeritus Silviculturist (Research Fellow)
BRUNO MOULIA - Ressearch Director at INRA, 20 years experience in research on Plant Bio-Mechanics and Plant Developmental Biology
DUNCAN SLATER - Lecturer in Arboriculture, Myerscough College, Lancashire and a Chartered Forester.
BRIAN KANE Associate Professor of Commercial Arboriculture at the University of Amherst Massachusetts
FRANK TELEWSKI – Michigan State University
GILMAN, EDWARD F., University of Florida, Gainesville, United States

Topics

The dynamics of wind-tree interactions, mechanosensing, thigmomorphogenesis and wind acclimation, posture control vs gravity and growth (gravisensing, proprioception, mechanics and control of the bending movement, reaction woods.
Anatomy of branch junctions (to include bark-included junctions), Natural bracing in trees, UK arboriculture's assessment and treatment of branch junctions in trees, Thigmomorphogenesis in relation to branch junction and tree form
Basic tree biology- types of wood (juvenile vs mature; normal vs reaction (tension, compression, flexure); early vs latewood; non-porous vs porous; diffuse porous vs ring porous).
Introduction to tree biomechanics and hazard trees. Thigmomorphogenesis: Wind loading in trees, perception and acclimation.
Measuring young tree stability and lodging. Growing high quality root systems.
Can pruning reduce tree damage in storms. Pruning strategies leading to enhanced stability.

in cooperation with:
SOI Italian Society of Horticulture
SIA – Società Italiana di Arboricoltura


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Impostazioni
Mi sento più vivo in mezzo agli alberi
I feel more alive among trees
Me siento más vivo en los árboles
Eu me sinto mais vivo
Arboricoltura Urbana-Arboriculture and Urban Forestry di Francesco Ferrini
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Arboricoltura Urbana-Arboriculture and Urban Forestry di Francesco Ferrini
9 h
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THAT'S ALL FOLKS !