Mycorrhiza and Biochar Effects on Carbon Sequestration

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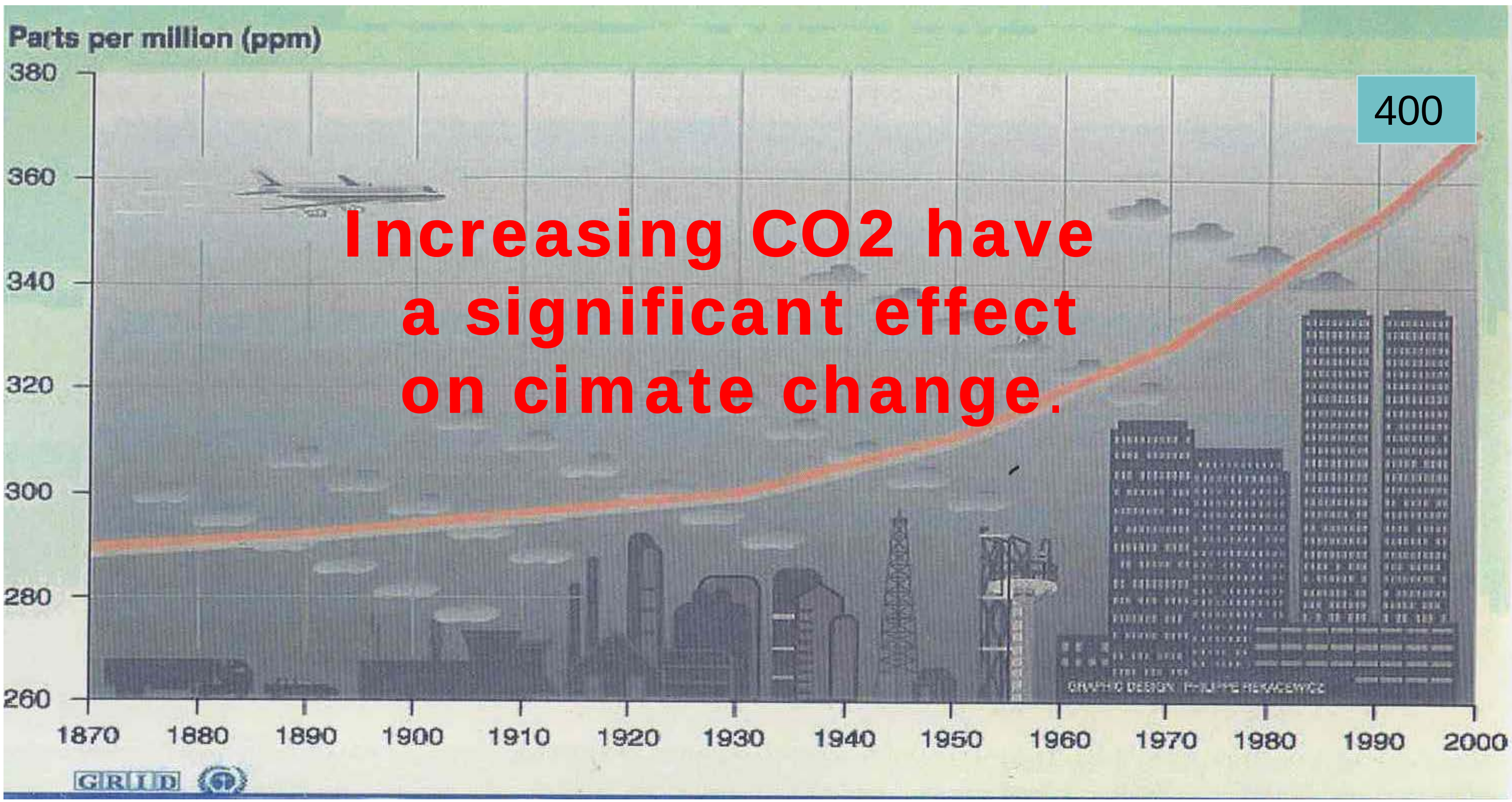
Since the onset of industrial revolution around 1850, the concentration of carbon dioxide (CO2) has increased by 31% from 280 ppm to 380 ppm year in 2005, and is presently increasing at 1.7 ppm year or 0.46% yr−1 (WMO 2006; IPCC 2007), presently is **400 ppm**.



Atmospheric Carbondioxide (CO_2)

- Atmospheric CO_2 concentrations have significant effects on climate change and concequently have effects on sustainability of ecosystem.
- At the same time, soil quality and productivity is decline.

There are several techniques to mitigate atmospheric CO_2

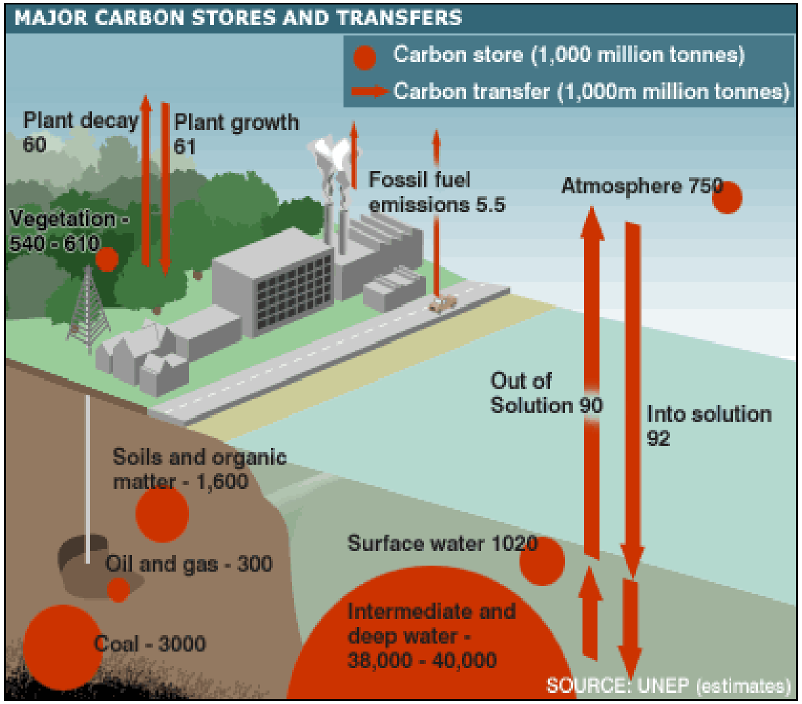
- Soil can be a sink for atmospheric CO_2, thus reducing the net CO_2 emissions normally associated with agricultural ecosystems, and mitigating the ‘greenhouse effect’.

- There are several techniques to mitigate atmospheric CO_2 which can be fixed to terrestrial ecosystems.

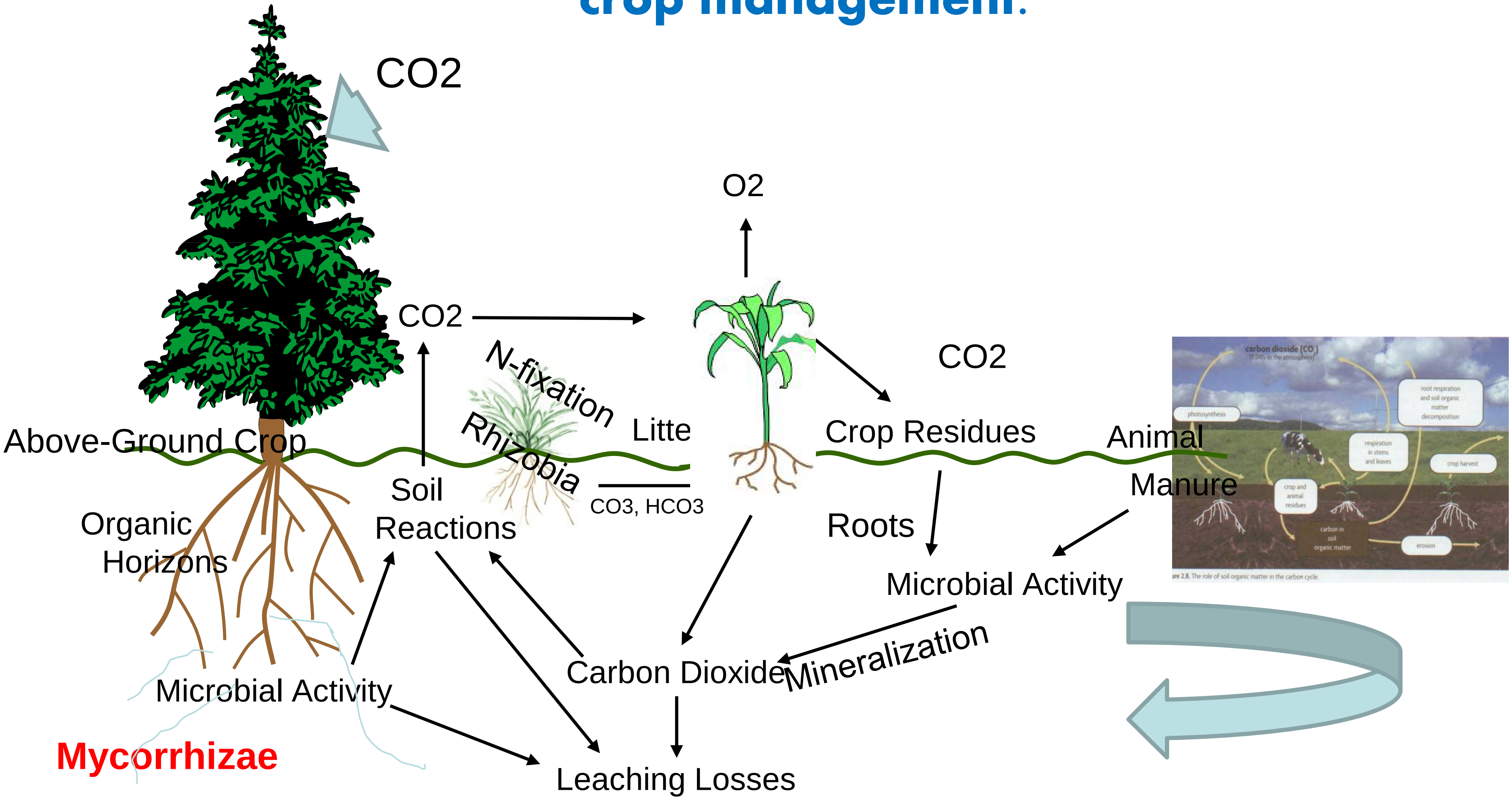
Carbon Strategy

There are three strategies of lowering CO2 emissions to mitigate climate change (Schrag 2007):

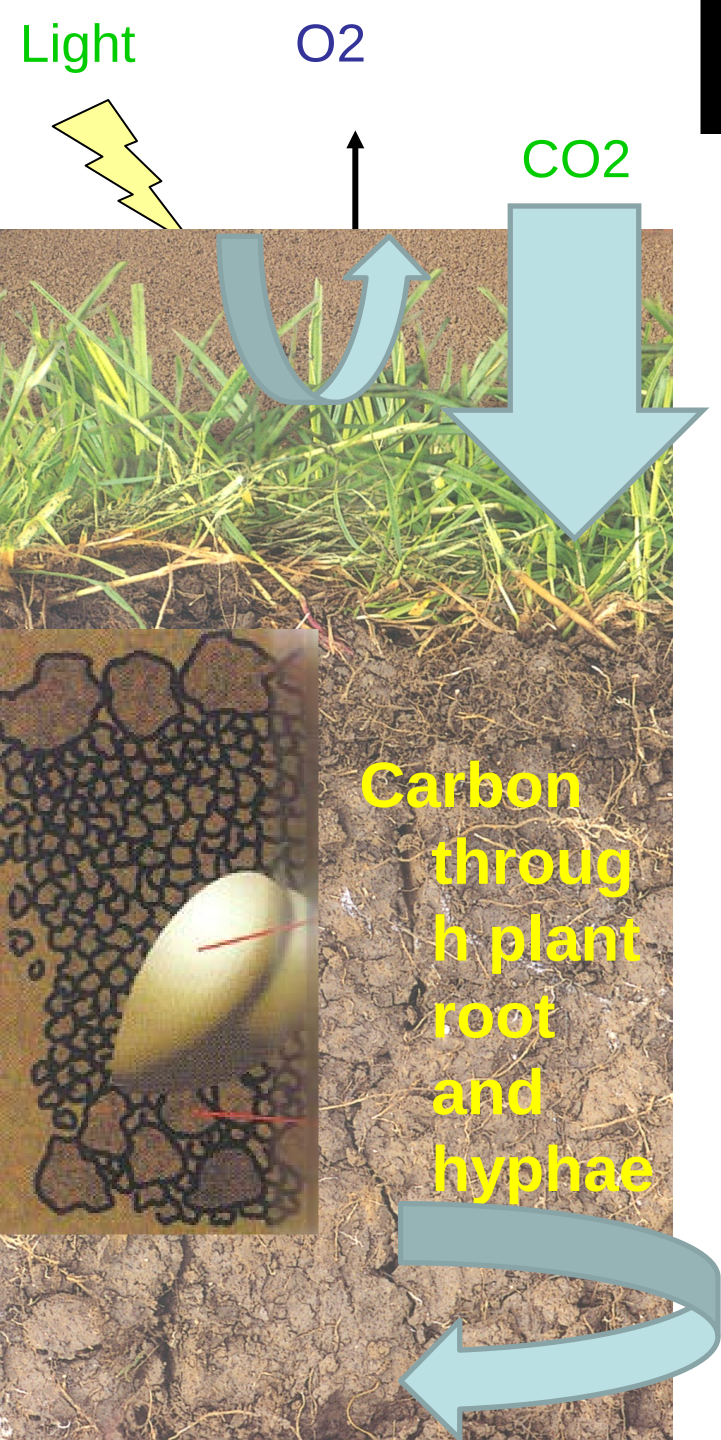
- 1) reducing the global energy use,
- 2) developing low or no-carbon fuel, and
- **3) sequestering CO2 from point sources or atmosphere through natural (photosynthesis) and engineering techniques.**



Carbon Cycle or carbon fluxes between the biosphere and the atmosphere much more related with soil and crop management.



The basic processes of the carbon cycle are: CO2 in through photosynthesis, and CO2 out through decomposition. The net gain of C in the soil is a function of the balance between inputs (i.e., net primary productivity plus any external inputs) and losses (i.e.,decomposition, erosion, leaching).



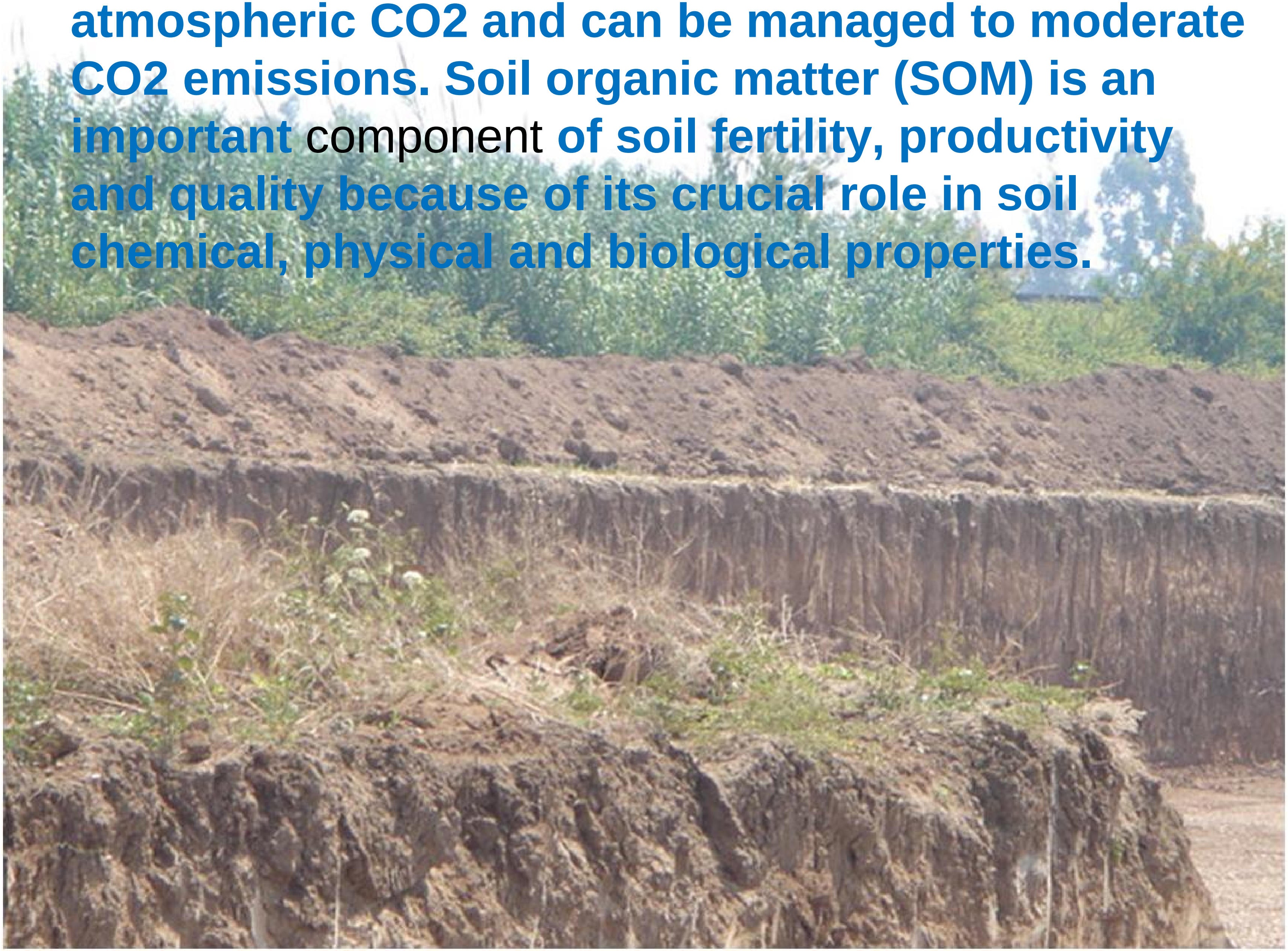
Photosynthesis

Fixing CO_2 from atmospher to soil through **phostosentesis** is one of the powerful natural mechanisms

$$6\,CO_2 + 12\,H_2O + \text{Light} \rightarrow C_6H_{12}O_6 + 6\,O_2 + 6\,H_2O$$

Through the process of photosynthesis, plants absorb CO_2 from the atmosphere, transform it into plant carbon, and sequester it in either above- or below-ground biomass and/or soil carbon.

Agricultural soils can be both a sink and source of **atmospheric CO_2 and can be managed to moderate CO_2 emissions. Soil organic matter (SOM) is an important** component **of soil fertility, productivity and quality because of its crucial role in soil chemical, physical and biological properties.**



Mycorrhiza Can Contribute to The Carbon Sequestration

- Since plant root and mycorrhizal fungi are demanding more carbon, plant are fixing more atmospheric CO2 via natural process of photosynthesis to the soil and biota. **Mycorrhizae also can contribute to the carbon sequestration**.

Mycorrhiza and Carbon

- Both carbon and mycorrhizal associations are pottentially important in ecosystem services provided by soils and hence mitigation of global climate change.

The carbon-limitation hypothesis

- Gehring and Whitham, (2002) predicted the carbon-limitation hypothesis in which removal of above ground biomass by clipping or mowing will reduce AMF growth because there is a reduced amount of photosynthate available for the symbionts.

In generally protected land use and soil management improves soil organic carbon storage and can reduce the carbon emission and soil erosion.

Mycorrhizal fungi have more carbon

- Measurements of plant carbon allocation to mycorrhizal fungi have been estimated to be **5-20% of total plant carbon uptake** (Pearson and Jakobsen, 1993), and in some ecosystems the biomass of mycorrhizal fungi can be comparable to the biomass of fine roots.

Carbon is Drain to Rhizosphere

Greater amounts of carbon are transferred to the roots in mycorrhizal compared with non-mycorrhizal plants.

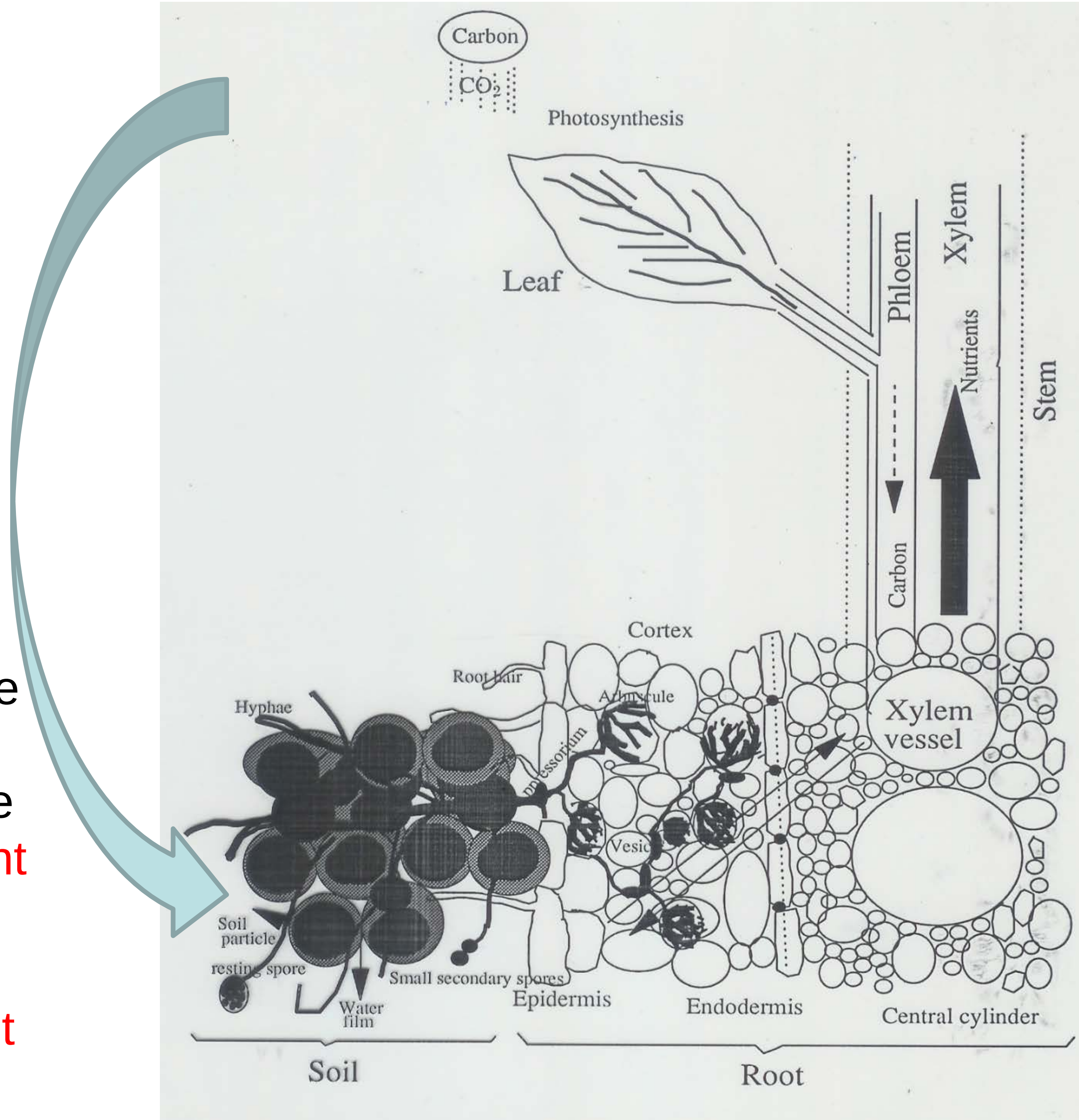
Mycorrhizal fungi of both modulated and non-modulate roots consumed approximately 4 % of C fixed; 1% entered fungal biomass and 3 % is respired.

Nodules consumed approximately 7% of carbon fixed in non-mycorrhizal plants but 12 % in mycorrhizal plants.

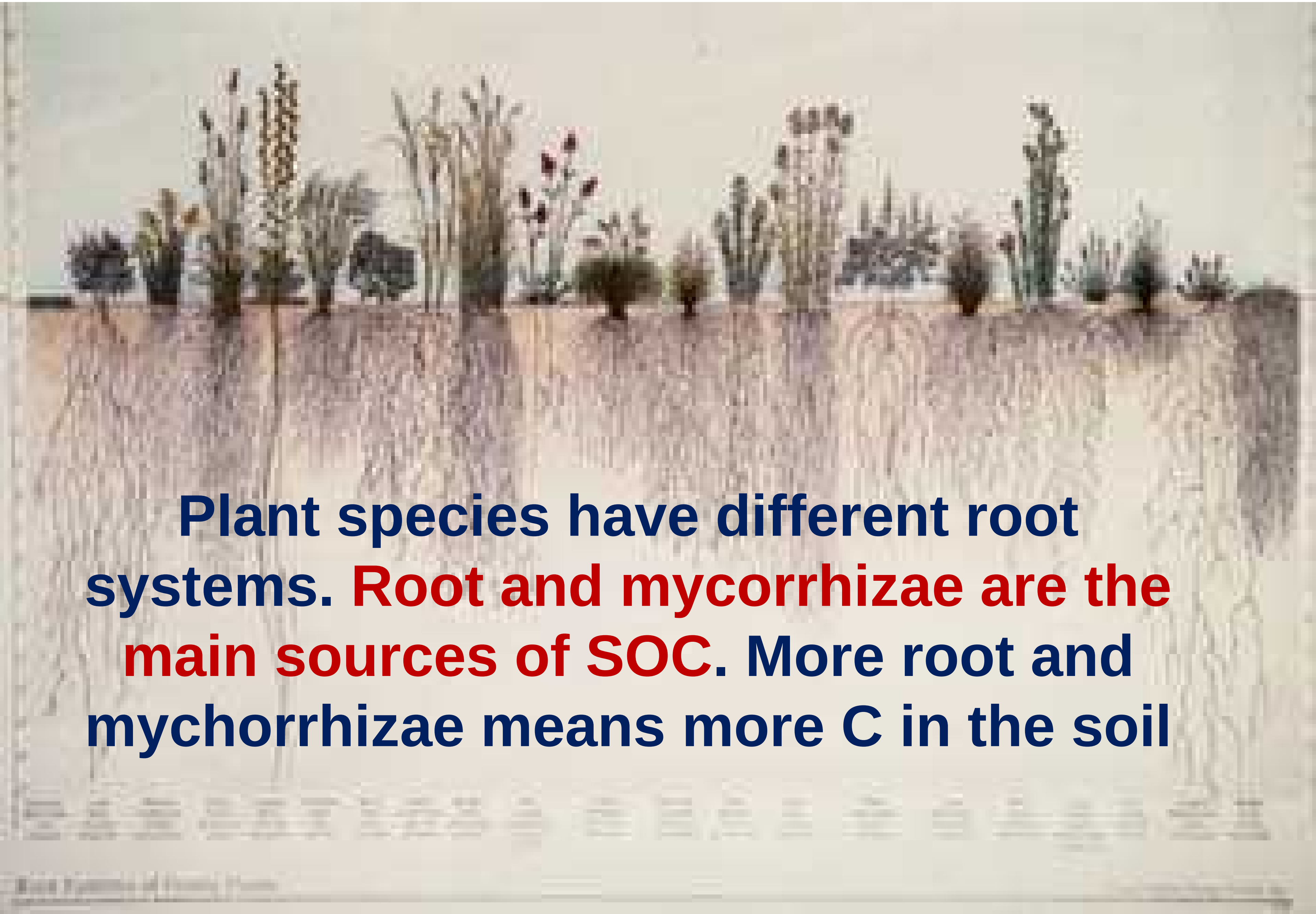
Recent results shown that between 12 and 22 % of photosentate is drain in root area.

Carbon From Leaves To Rhizospher

The most efficient method of carbon mitigation is photosets mechanism which can download the atmospheric carbon to the surface. Plant species and soil management is important.



Flowchart 1 Schematic representation of mycorrhizal presence in soil and relation with plant nutrition

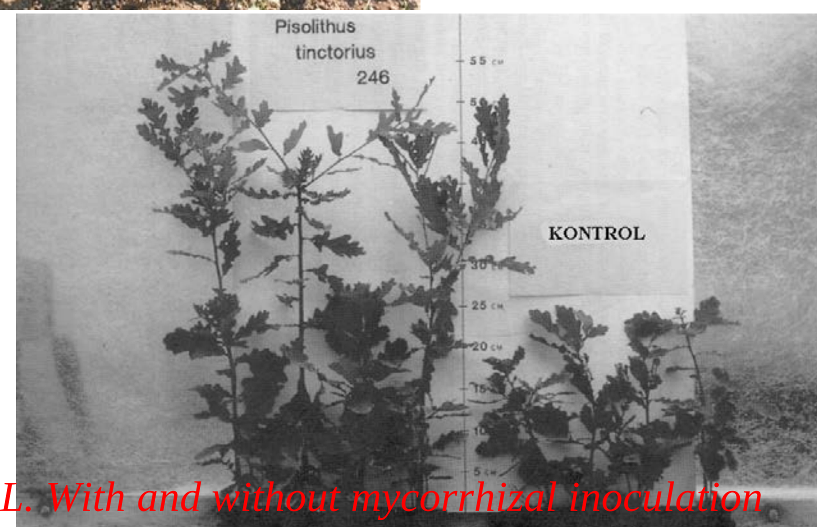


Plant species have different root systems. Root and mycorrhizae are the main sources of SOC. More root and mychorrhizae means more C in the soil

Mycorrhzae Can Increase Net Primary Production

Ortas, 2012

Mycorrhizae fungus mediated effects on plant growth can potentially improve carbon sequestration by increasing net primary production, especially in nutrient-limited environments.



Quercus robur L. With and without mycorrhizal inoculation

The AMF can influence carbon fluxes between the biosphere and the atmosphere through different pathways (Fig. 1).

A key AMF-mediated process involved in the storage of carbon in soils is the transfer of photosynthate from host plants to AMF hyphae.

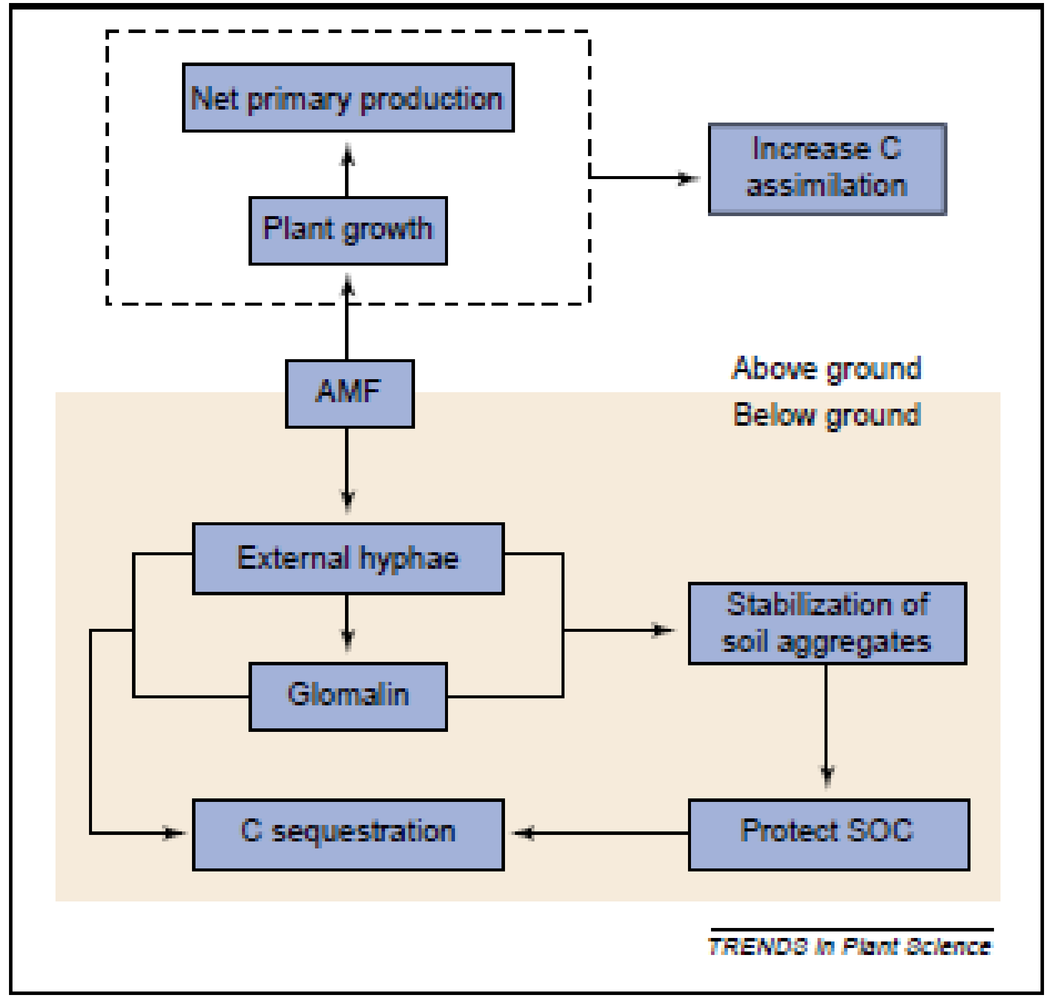


Fig. 1. Role played by arbuscular mycorrhizal fungi (AMF) in regulating carbon fluxes between the biosphere and the atmosphere. Abbreviation: SOC, soil organic carbon.

Zhu and Miller, 2003

Mycorrhiza Help Soil Development

- Mycorrhizae also play a key role in soil aggregate formation and aggregates can keep carbon in soil.
- In order to keep carbon in soil very recently biochar application is used very commonly.
- Without burning organic material producing biochar is very important agricultural strategy.

Mycorrhizae increase C sequestration through aggregate

- Recent research suggests that mycorrhizal fungi might be an important component of **the SOC pool, in addition to facilitating carbon sequestration by stabilizing soil aggregates.**

What is aggregate?

How soil aggregate formed

What is the major component of aggregate?

What is the role of organic carbon on aggregate?

ROLE OF MYCORRHİZAE IS SIGNIFICANT?

Conceptual diagram of soil aggregation

Ortas 2011

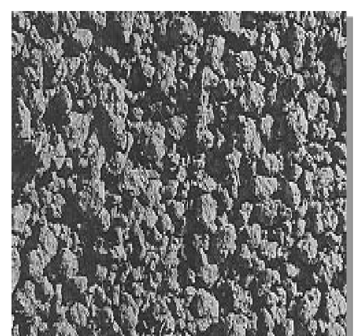
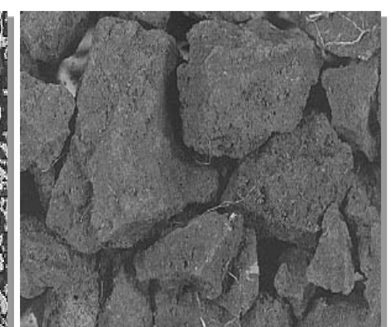
Other important sources of organic compounds on aggregation are polysaccharides, carbohydrates, lignin and lipids.

Extensive soil based mycelium of fungus around roots can help soil aggregation processes.

Macroaggregates OR Microaggregates?

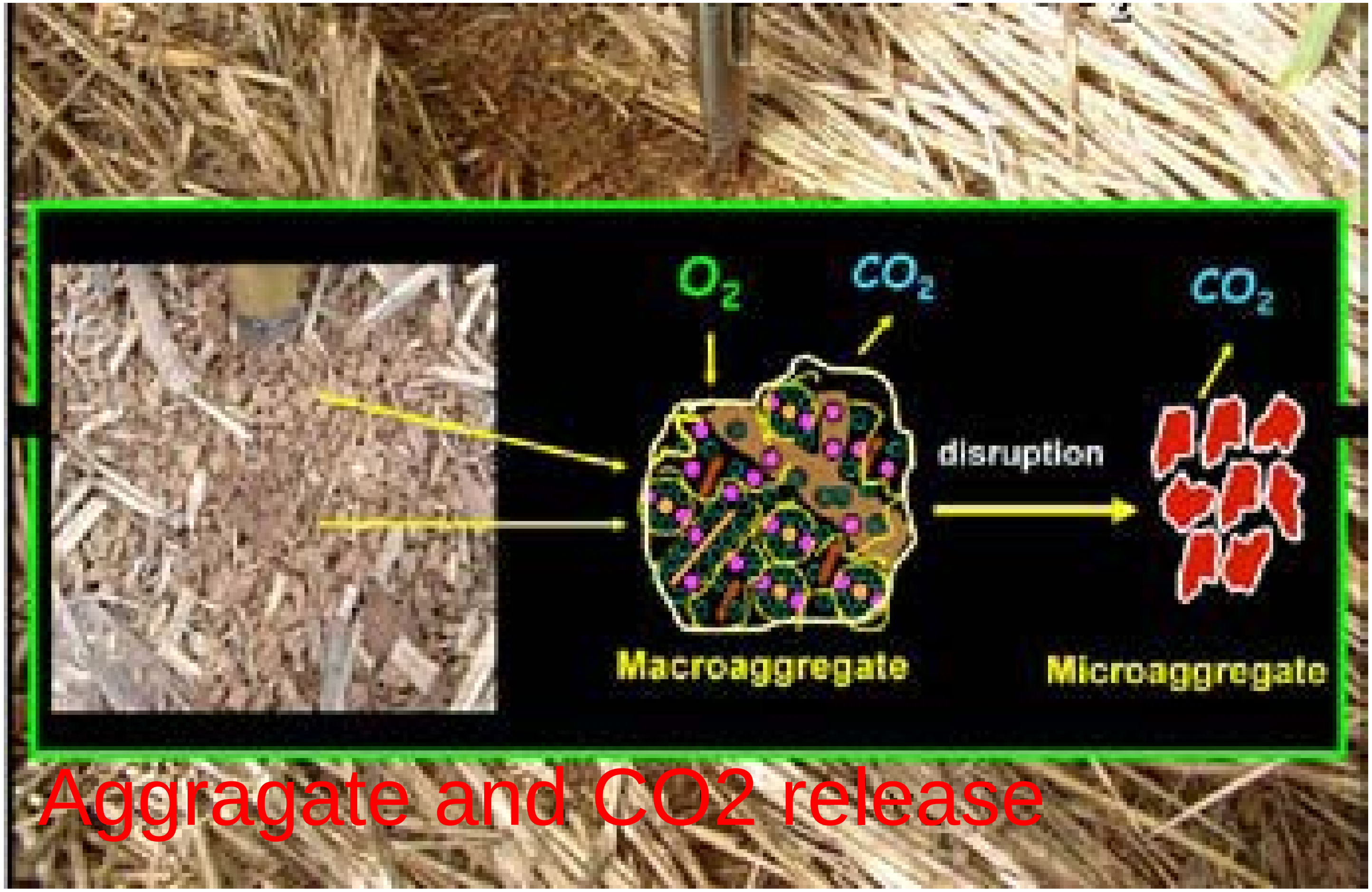
- The results showed that MWD values of soil aggregates were positively correlated with values of **total hyphal length and hyphal density of the AM** fungi utilized. They also showed that the mean weight diameter (MWD) of **macro ggregates of 1-2 mm diameter,** was significantly higher in mycorrhizal soils compared to the non-mycorrhizal soil.



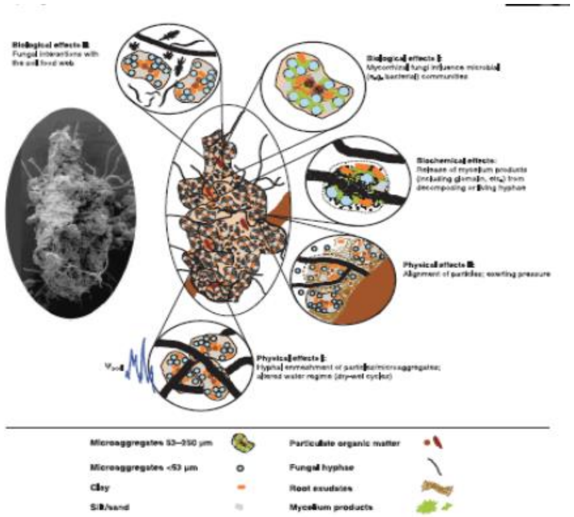

More aggregate formation can result in more soil carbon storage

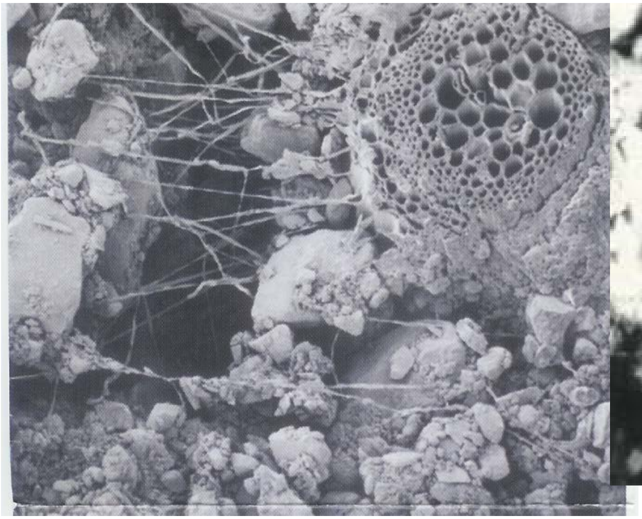
Disrupts of macroaggregates and breaks them into microaggregates by letting in oxygen and releasing carbon dioxide. From Dr. João de Moraes Sá.

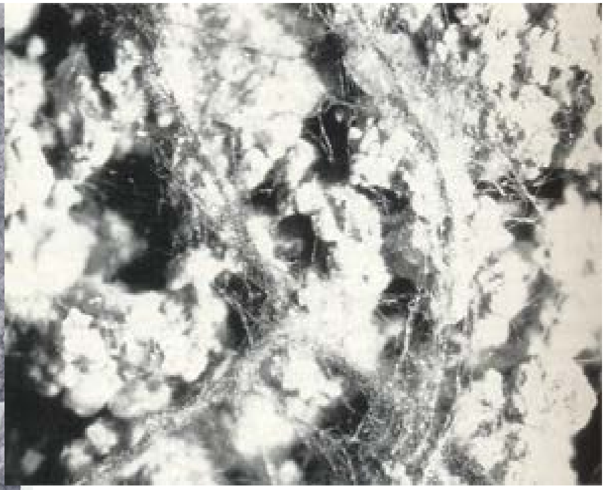


Arbuscular mycorrhizal fungi (AMF) as soil microorganisms appear to play a predominant effect on aggregates formation because the symbiosis significantly changes the root functioning (, Miller and Jastrow, 1990; Rillig 2004a,b).

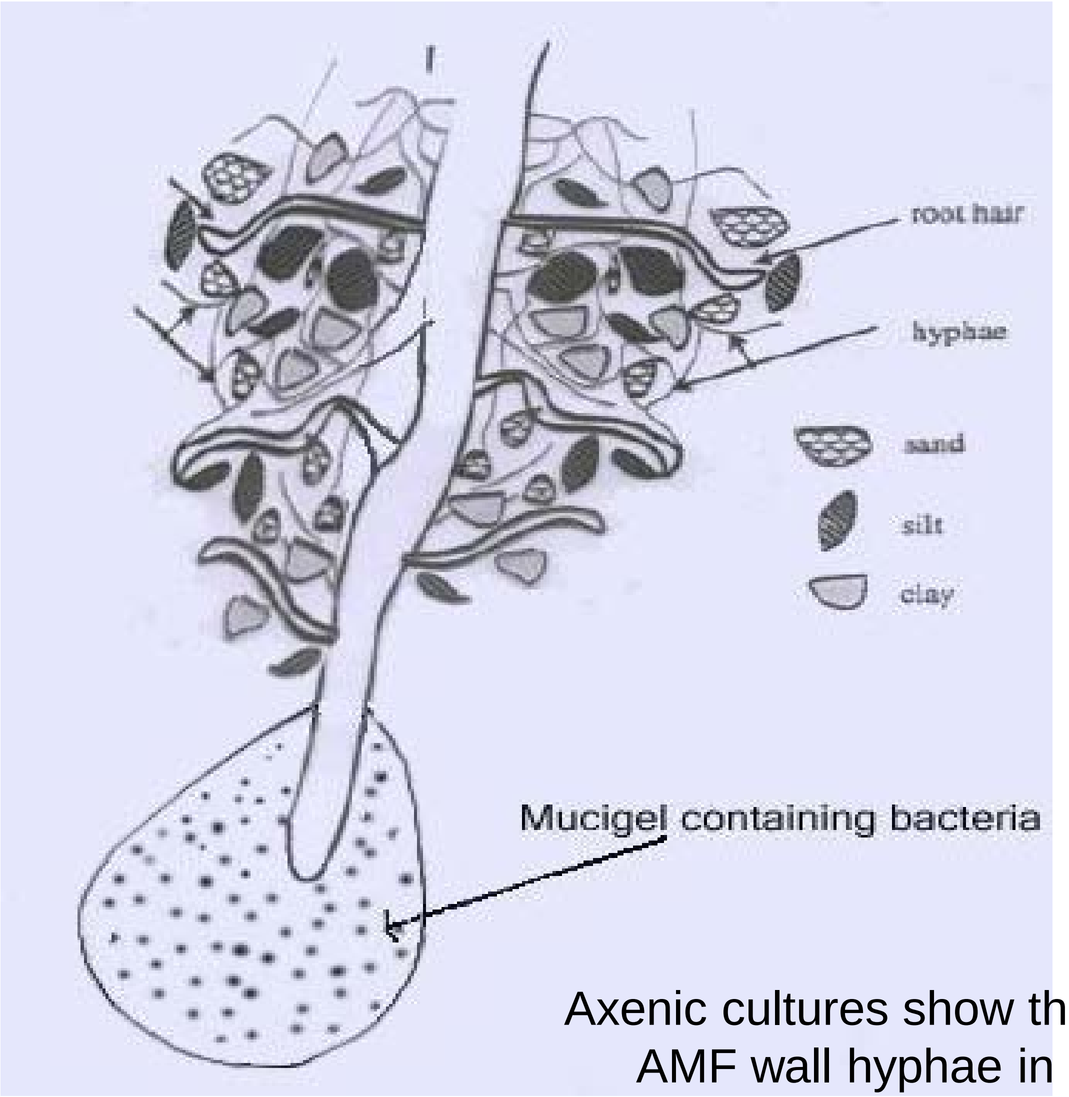
There is much evidence that arbuscular mycorrhizal fungi increase soil aggregate formation, and that aggregate formation may be mediated by the arbuscular mycorrhizal protein glomalin.







A diagrammatic view of mycorrhizosphere

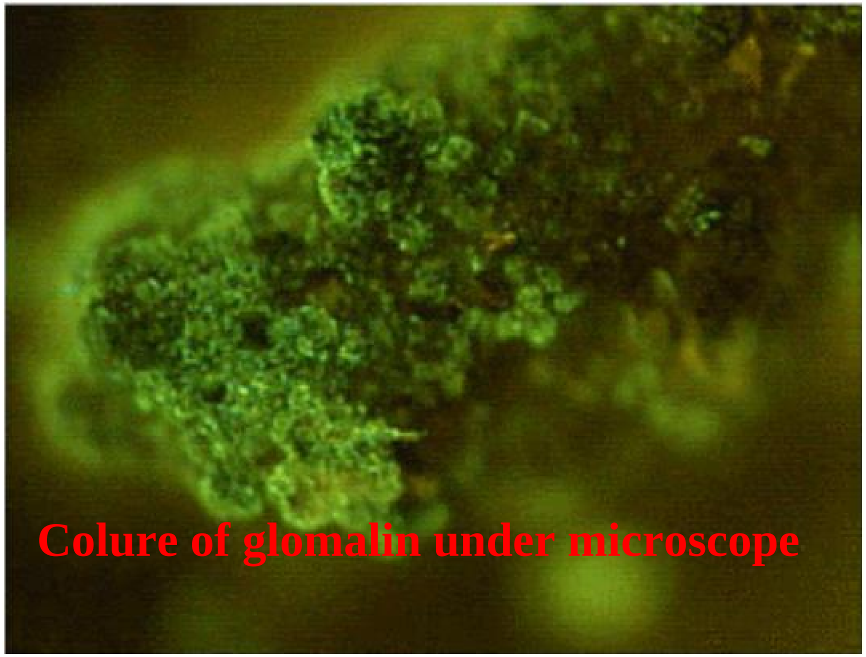


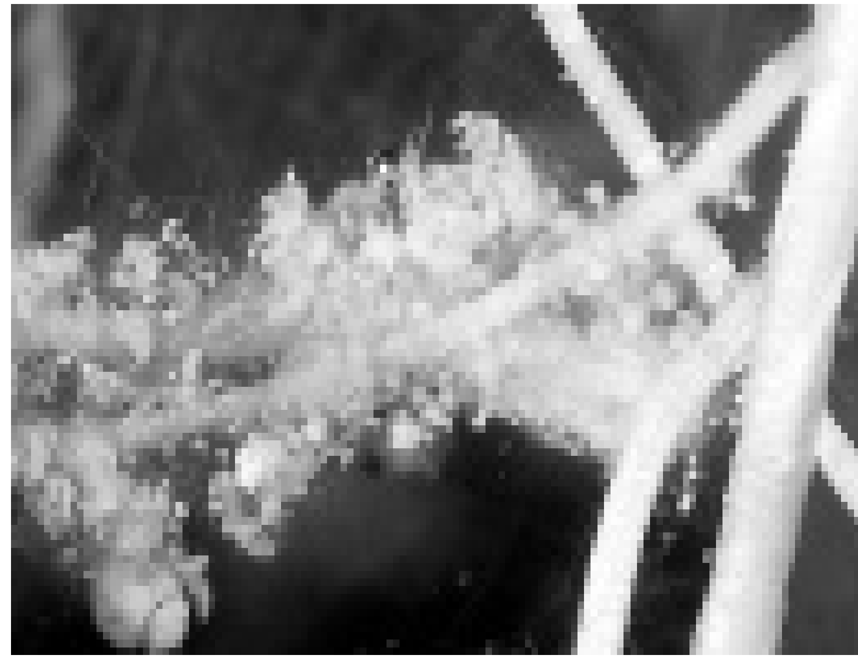
Aggregation tends to increase with increasing root length density, , root turnover, hyphal growth, microbial association and glomalin, among other effects (Rillig *et al., 2002).*

Axenic cultures show that glomalin, originally present in AMF wall hyphae in a 80% *and* secreted into the environment in a minor proportion is accumulated in air-water interface (Haddad and Sarkar, 2003).

How Mycorrhiza Contribute to Soil

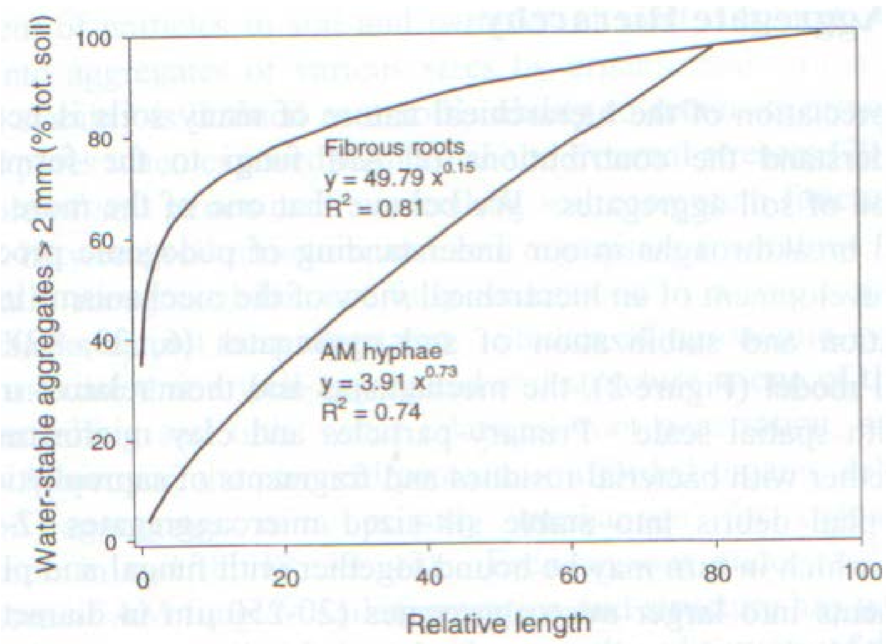
Via the glomales (glomalin)?
What is the role of glomalin on aggragation?





It has been described a glycoprotein produced by AM fungi with a strong cementing capacity of soil particles (Wright and Upadhyaya, 1996;Rillig 2004). Glomalin is very difficult to solubilize and it is resistant to most chemical used.

The studies indicate that hyphae are the primary mechanism for binding sand particles into aggregated units. Hyphae of arbuscular mycorrhizal fungi (AMF) are considered to be primary soil aggregators and there is a positively correlation between AMF hyphae and aggregate stability in natural systems.



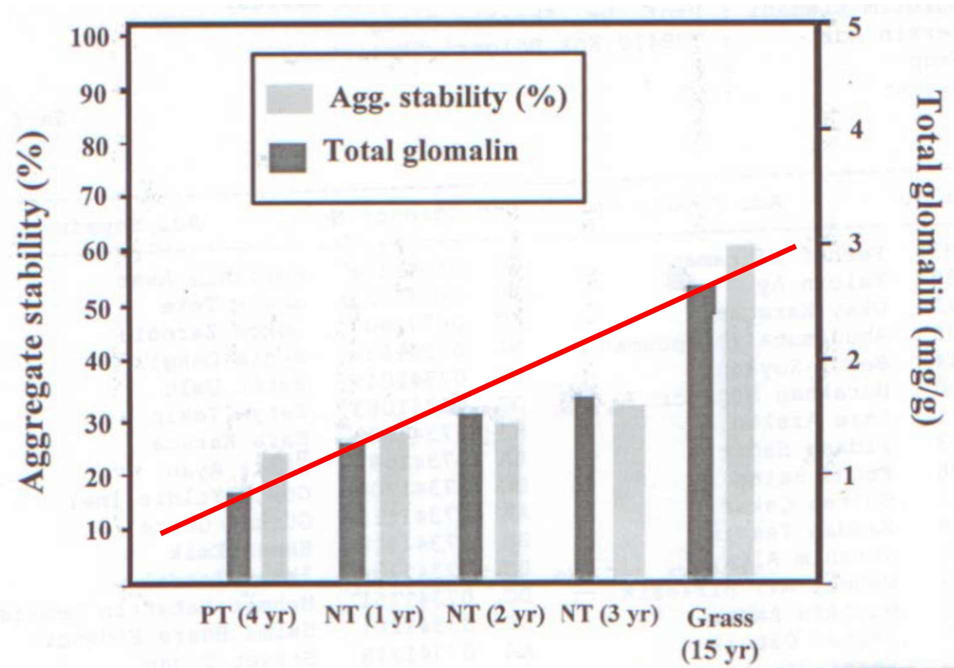


Figure The relationship between water-stable aggregates and relative root and AM hyphal length in a prairie restoration chronosequence

The aggregate keep and protect carbon in soil

- The aggregates are very important soil properties for soil quality and provide physical fertility.
- The aggregates also play an important role in stabilizing SOC and act and play a significant role to storage more carbon in soil.
- Also the aggregates protect SOC against mineralization

What are we doing about carbon studies

Semi-arid Turkish soils have low SOC contents because of high temperatures and decomposition rates. Since climate change is directly related with soil carbon storage and release it is important **to keep more carbon in the soil with several new techniques. Also for sustainable agriculture there is need to keep SOC at certain level**.

A) Effect of on long term soil and crop managements SOC budget and carbon sequestration.

B) Searching soil carbon

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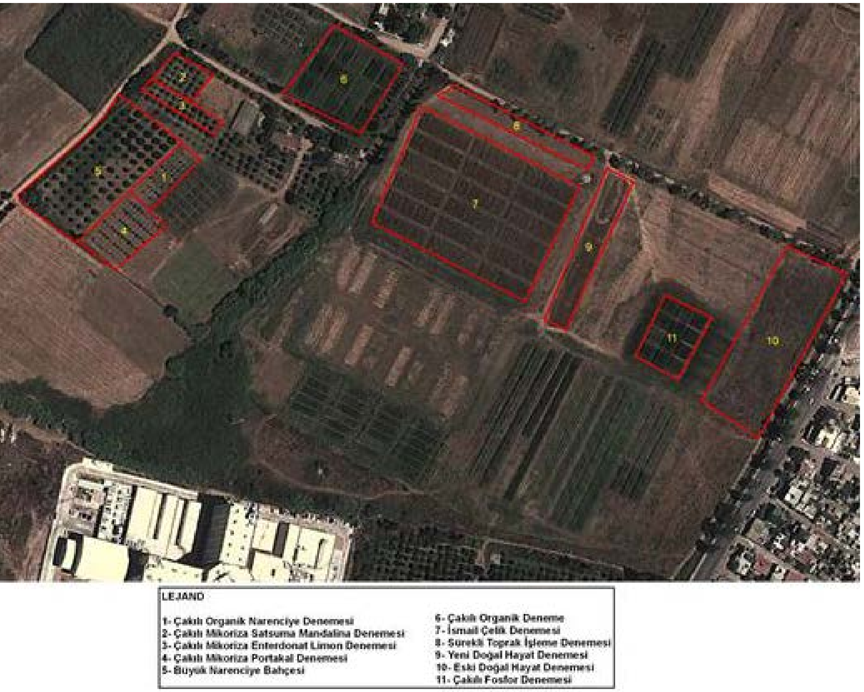


Soil keep carbon for long term

The type of land use and soil cultivation are also important factors controlling **organic carbon storage** in soils.

It is important to keep carbon in soil rather than biomass.

Carbon remain in biomass for 10 years, remain in soil is about 35 years.

So there is a need to give importance to the new techniques for carbon sequestration.

Soil biotechnology can help to keep more carbon in soil rather than p

Carbon Sequastration Works in Turkey

- Since 1996 we have several long term experiments and regularly we measure soil organic C and N.
- We have searched C sequestration of several soil profiles.

Carbon sequestration

Carbon sequestration can be defined as the net removal of CO2 from the atmosphere into long-lived pools of carbon. Still it is not easy to calculate the net C sequastration because of several reasons such as belowground C mesurementes

Include pictures of trees, roots and microbes, recalcitrant SOC

Carbon sequestration rates in the Menzilat soils from 1974 to 2010

	Horizon	Soil depth		Texture g kg-1			pH	Salt	P_2O_5	CEC Cmol+	$CaCO_3$	OM	Organic carbon	Bulk density	Soil OC	Inorganic carbon	Rate of CSQ 1974-2010
		cm		Sand	silt	Clay		%	kg ha^{-1}	kg^{-1}	%	%	%	g cm^{-3}	Mg ha^{-1}	Mg ha^{-1}	Kg C ha^{-1}
2010	Ap	0-30	30	32.5	27	40.5	7.43	0.113	43.6	17.6	21.9	1.51	0.87	1.6	41.9	87.4	997.9
	CA	30-60	30	30	24.5	45.5	7.62	0.123	14.2	17.6	30.4	0.49	0.28	1.3	11.1	98.8	-353.4
	C1	60-94	34	16	30	54	7.50	0.133	10.9	21.2	28.4	0.51	0.30	1.3	13.1	104.6	-534.8
	C2	94-125	31	14.5	31.5	54	7.59	0.131	9.5	18.0	33.6	0.52	0.30	1.35	12.6	117.2	-106.2
	Total														78.7	408.0	3.7
1974	Ap	0-6	6	344	402	254	7.50	0.250	15.4	18.3	51.48	1.59	0.92	1.44	8.0	37.1	
	A12	6-21	15	360	370	270	7.70	0.230		31.7	28.8	1.91	1.11	1.39	23.1	50.0	
	A13	21-47	26	120	594	286	7.80	0.140		29.6	37.22	1.47	0.85	1.41	31.3	113.7	
	C	47-74	27	337	418	246	7.70	0.130		13.1	53.46	0.73	0.42	1.42	16.2	170.8	

Kızıltapır soil series carbon sequestration change from 1974 to 2010 on olive tree

	Soil Horizon	Soil Depth cm	Organic Carbon %	Bulk density G cm^{-3}	SOC Mg ha^{-1}	CSQ NR kg C ha^{-1}	SCQ R kg C ha^{-1}	Differences between R-NR CSQ kg C ha^{-1}
Non-rhizosphere 2010	Ap	0-13	1.45	1.3	24.5	176.7		
	Bt1(BA)	13-28	0.93	1.3	18.1	-636.5		
	Bt2	28-43	0.99	1.4	20.7	153.8		
Rhizospher 2010	Ap	0-20	2.43	1.25	60.8		1183.7	36.3
	Bt1	20-40	1.62	1.3	42.2		33.7	24.2
	B2t	40-60	2.11	1.5	63.3		1338.0	42.6
1974 Non-rhizosphere	Ap	0-11	1.32	1.25	18.1			
	B1	11-38	1.21	1.25	41.0			
	B2t	38-50	1.11	1.15	15.2			

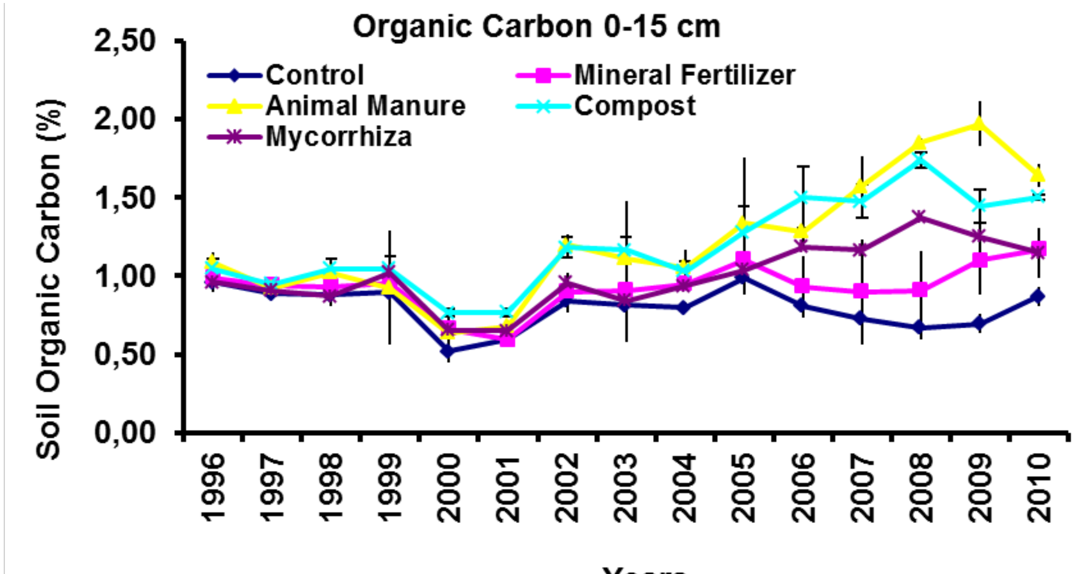
Not: Carbon and nitrogen sequestration was calculated on base of 1974 year's data (Ozbek *et al*., 1974)
Rhizosphere =R Non-Rhizosphere = NR

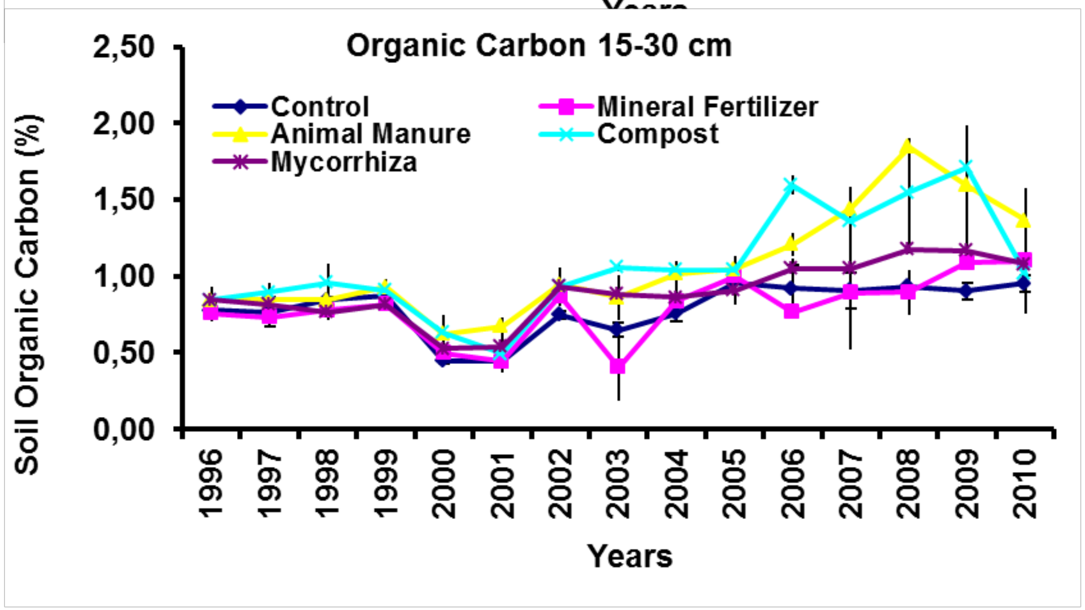
Long-term effect of organic and inorganic fertilizers on carbon sequastration

- Since 1996 we regularly measure the soil organic C and N. And we measure aggregate stability and other soil properties such as MWD diameter and

Effect on mycorrhiza inoculation on C sequastration from 1996 t0 2013 in Menzilat soil

Depth	Treatments			1996 SOC	2013 SOC	Carbon Sequastration 1996-2013
		%C	Bulk density	SOC Mg ha-1	SOC Mg ha-1	SOC 2013- SOC 1996
0-15	**Control**	0,88	1,34	17,59	17,690,10	7,19
	Compost + Mycorrhiza				23,425,83	416,28
	mean				20,552,96	211,74
15-30	**Control**	0,78	1,34	15,70	18,432,73	195,00
	Compost + Mycorrhiza				22,807,10	507,26
	Mean				20,624,92	351,13





Organic and inorganic fertilizer management enhanced soil organic carbon (SOC) pool. Especaily organic fertilizers and mycorrhizae inoculation are significantly accumlate carbon sequastration.

Initial soil inorganic, organic carbon and nitrogen concentration and effects of organic and inorganic fertilizers application on total soil organic carbon and total nitrogen pools 2013.

Depth	Treatments	Total Soil carbon (%)		Inorganic carbon (%)		SOC (%)		N (%)		C:N ratio		SOC pool (Mg ha^{-1})		TSN pool (Mg ha^{-1})	
0-0.15 m	Control	4.61	±0.01b	3.80	±0.01a	0.81	±0.00b	0.08	±0.00b	9.67	±0.42	17.69	±0.27b	1.83	±0.11b
	Min. Ferti.	4.83	±0.10ab	3.86	±0.07a	0.97	±0.05b	0.10	±0.00a	9.32	±0.05	20.99	±1.83ab	2.25	±0.18a
	Animal Manure	5.04	±0.07a	3.74	±0.07a	1.30	±0.11a	0.12	±0.01a	11.09	±0.61	23.08	±2.49a	2.09	±0.27ab
	Compost	5.02	±0.38a	3.76	±0.20a	1.26	±0.20a	0.11	±0.01a	10.91	±0.74	21.40	±3.87ab	1.95	±0.22ab
	Com + Myc.	4.86	±0.05ab	3.75	±0.05a	1.11	±0.10a	0.10	±0.01ab	11.19	±1.21	21.42	±1.01ab	1.92	±0.17ab
0.15-0.30 m	Control	4.65	±0.09b	3.81	±0.06a	0.84	±0.12b	0.08	±0.01b	10.15	±0.84	18.43	±2.69b	1.82	±0.22a
	Min Ferti.	4.86	±0.06b	3.86	±0.12a	1.00	±0.10b	0.10	±0.01ab	10.22	±1.18	21.78	±1.87ab	2.15	±0.30a
	Animal Manure	5.06	±0.15a	3.85	±0.16a	1.21	±0.05a	0.11	±0.00a	10.82	±0.30	23.01	±0.77a	2.13	±0.12a
	Compost	4.99	±0.23a	3.73	±0.15a	1.26	±0.10a	0.11	±0.01a	11.23	±1.85	22.21	±2.68ab	1.99	±0.15a
	Com + Myc.	5.06	±0.21a	3.84	±0.05a	1.22	±0.17a	0.11	±0.01a	11.52	±0.60	23.90	±3.39a	2.07	±0.22a

Carbon and nitrogen sequestration rate between 1996 and 2010

					Carbon Sequestration				Nitrogen Sequestration			
		ρ_b	SOC	N	SOC		Gain in SOC	Rate of CSQ	TSN		Gain in TSN	Rate of NSQ
					1996	2010			1996	2010		
Depth	**Treatments**	**Mg m^{-3}**	**(%)**			**Mg ha^{-1} C**		**Kg ha^{-1} year^{-1}**		**Mg ha^{-1} N**		**Kg ha^{-1} year^{-1}**
0-0.15 m	**Control**	1.34	0.88	0.08	17.6	17.7	0.1	7	1.7	1.8	0.16	11
	Mineral Fertilizer					21.0	3.4	243		2.3	0.57	41
	Animal Manure					23.1	5.5	393		2.1	0.41	29
	Compost					21.4	3.8	272		2.0	0.28	20
	Compost +Mycor.					21.4	3.8	273		1.9	0.25	18
Mean						20.9	3.3	238		2.0	0.33	24
0.15-0.30 m	**Control**	1.34	0.78	0.07	15.7	18.4	2.7	195	1.4	1.8	0.38	27
	Mineral Fertilizer					21.8	6.1	434		2.2	0.71	51
	Animal Manure					23.0	7.3	522		2.1	0.69	49
	Compost					22.2	6.5	465		2.0	0.55	40
	Compost + Mycor.					23.9	8.2	586		2.1	0.63	45
Mean						21.9	6.2	441		2.0	0.60	43
					Carbon and Nitrogen Sequestration of 0-0.30 m							
0-0.30 m	**Control**	1.34	0.83	0.08	33,8	36,2	2,3	166	3,1	3,7	0,53	38
	Mineral Fertilizer					42,8	9,0	642		4,4	1,28	91
	Animal Manure					46,1	12,3	**880**		4,2	1,10	78
	Compost					43,5	9,7	**690**		3,9	0,82	59
	Compost +Mycor.					45,3	11,5	**822**		4,0	0,87	62
Mean						42,8	9,0	**640**		4,0	0,9	66

2002

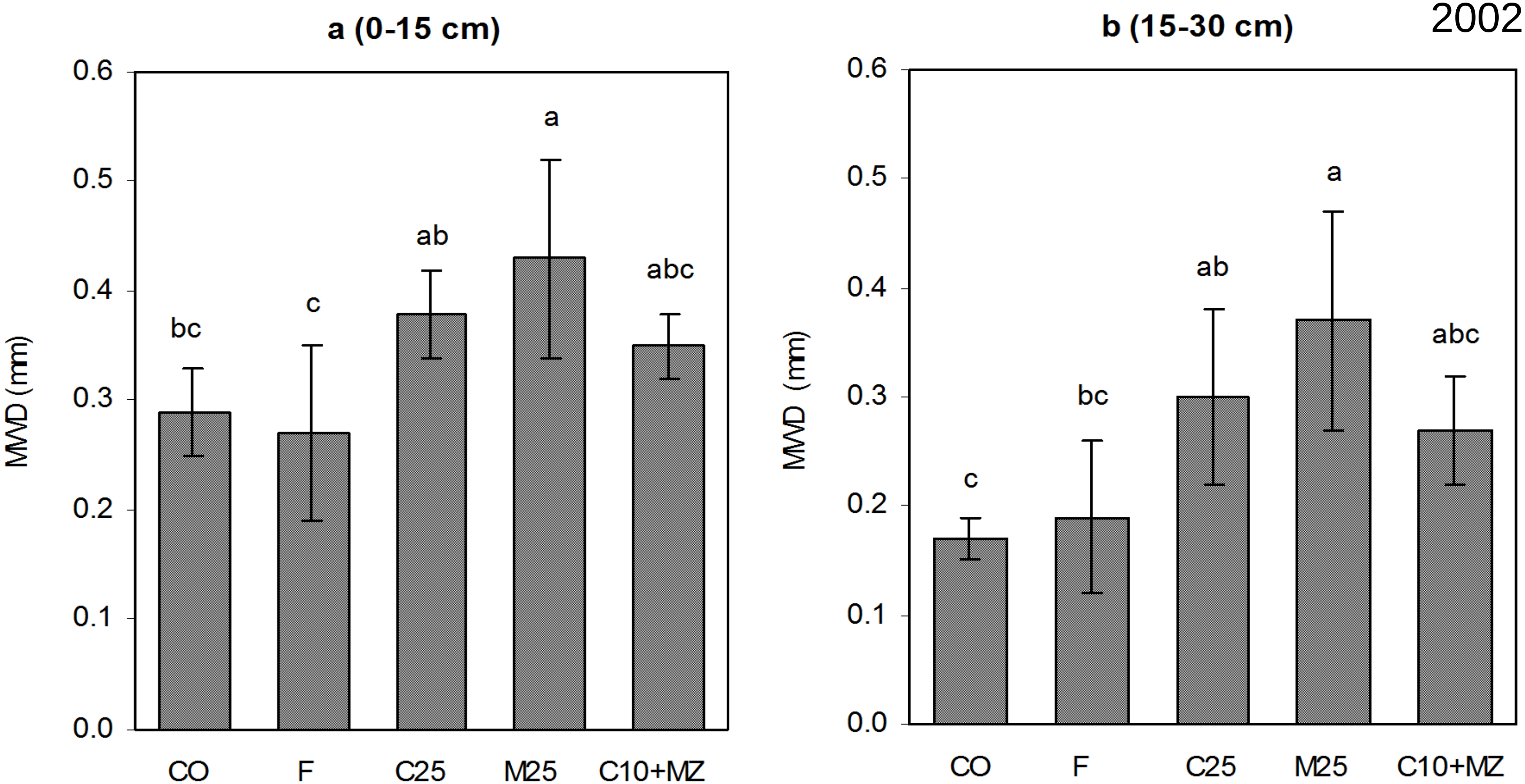
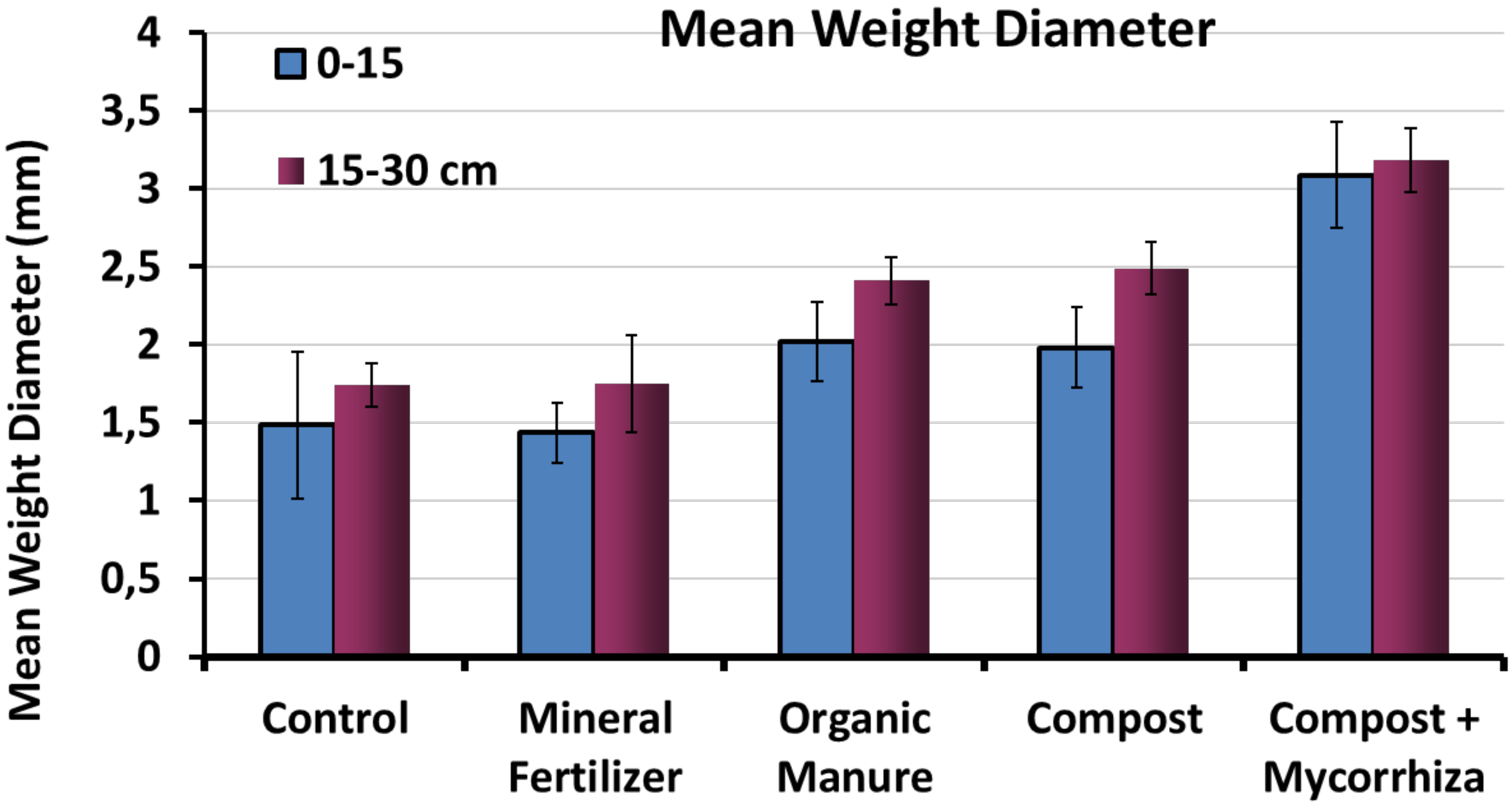
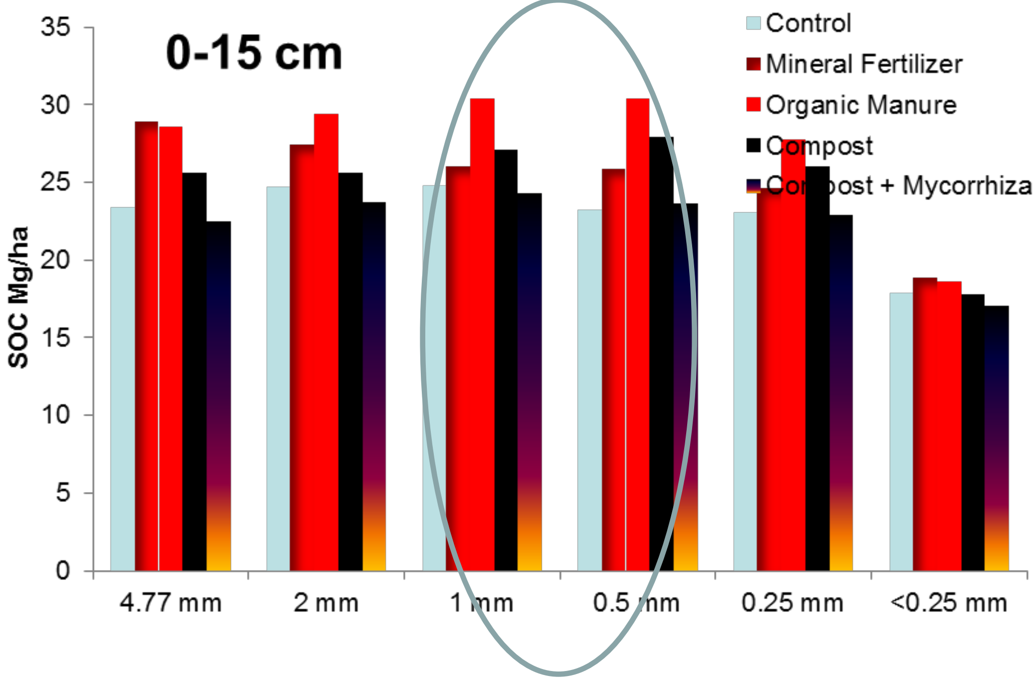


Figure Effect of treatments on soil aggregation as measured by mean weight diameter (MWD) at depth of 0-15 cm (a) and 15-30 cm (b). CO: Control, F: Mineral fertilizer (N-P-K), C25: Compost, F25: Manure, C10+MZ: Compost+Mycorrhizae inoculation. Means for treatments in the same soil depth followed by the same letter are not significantly different (p□0.05).

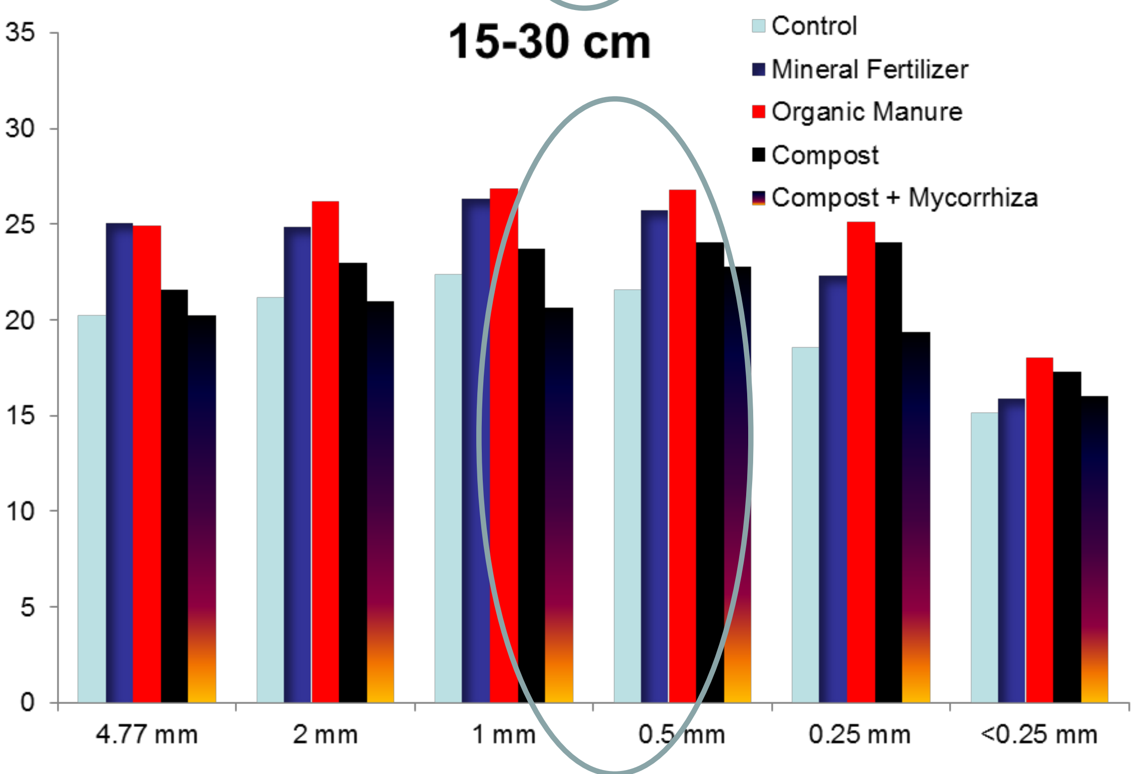
Çelik, Kılıc and Ortaş, 2004



- Soil aggregation, represented by MWD was significantly affected by the **mycorrhizae, compost and manure** treatments.



0-15 cm
Control
Mineral Fertilizer
Organic Manure
Compost
Compost + Mycorrhiza
SOC Mg/ha
35
30
25
20
15
10
5
0
4.77 mm
2 mm
1 mm
0.5 mm
0.25 mm
<0.25 mm

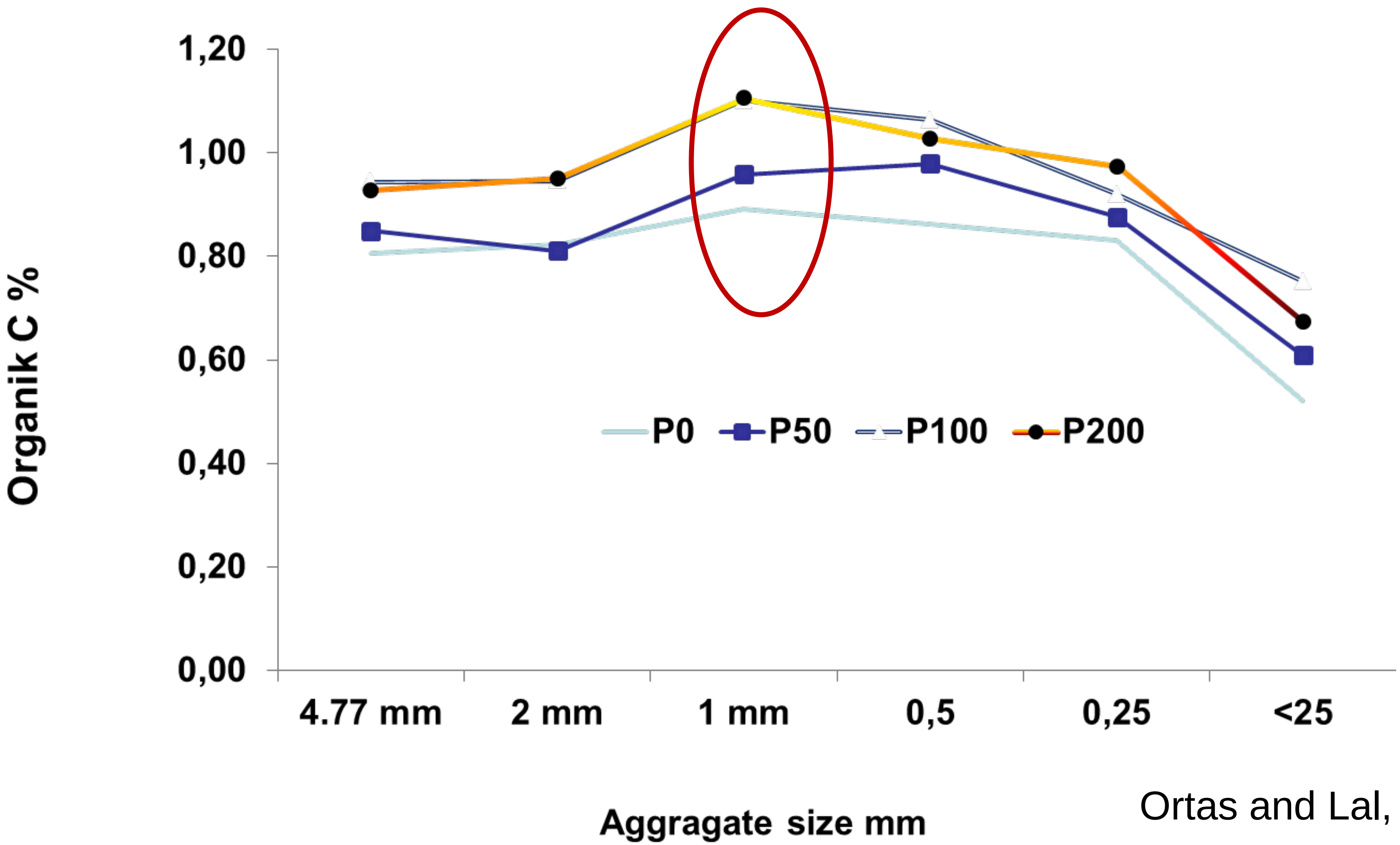


15-30 cm
Control
Mineral Fertilizer
Organic Manure
Compost
Compost + Mycorrhiza
35
30
25
20
15
10
5
0
4.77 mm
2 mm
1 mm
0.5 mm
0.25 mm
<0.25 mm

Mean rate of Carbon and nitrogen sequestration 1998 and 2010

Fertilizer Treatments	Carbon Sequestration							Nitrogen Sequestration			
	ρ_b	SOC	N	SOC Pool		SOC	Rate of C Sequestration	TSN		ΔTSN	Rate of N Sequestration
				1998		2010		1998	2010		
	Mg m^{-3}	(%)		Mg ha^{-1} C			kg C ha^{-1} yr^{-1}	Mg ha^{-1} N			kg N ha^{-1} yr^{-1}
P0	1.32	0.91	0.09	18.1	16.5	-1.6	**-110.9**	1.92	1.7	-0.21	-15.3
P1					20.6	2.5	**179.3**		2.2	0.25	17.9
P2					22.2	4.1	**295.5**		2.4	0.42	30.1
P3					25.9	7.8	**556.9**		2.3	0.40	28.9
Mean					21.3	3.2	**230.2**		2.1	0.22	15.4

There was **more C concentration in 0.5-1 mm aggregate sizes than in <0.25** mm size range. Also soil physical properties MWD were affected with high organic carbon addation.

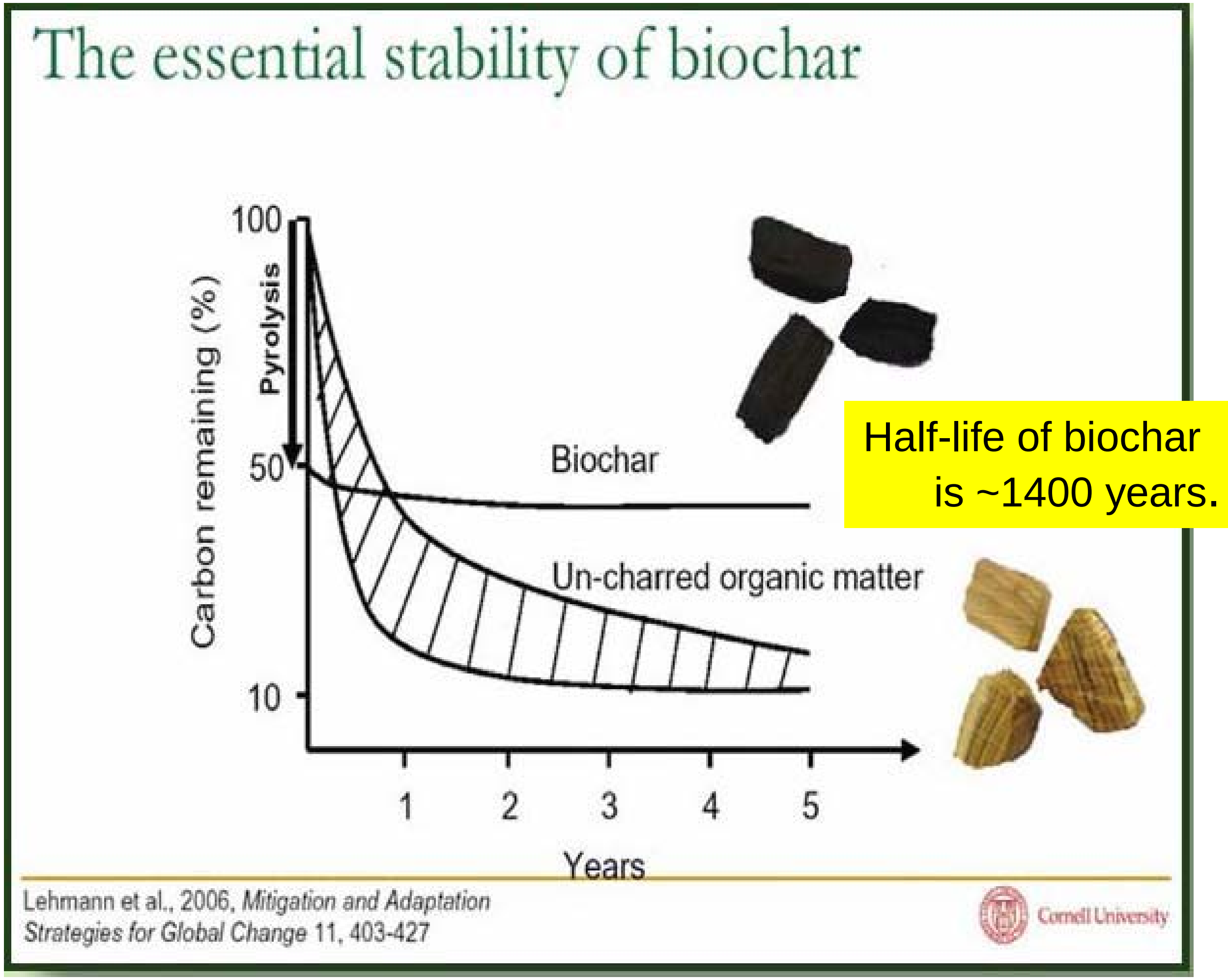


Ortas and Lal, 2012

Why Biochar Rather Than OM Application?

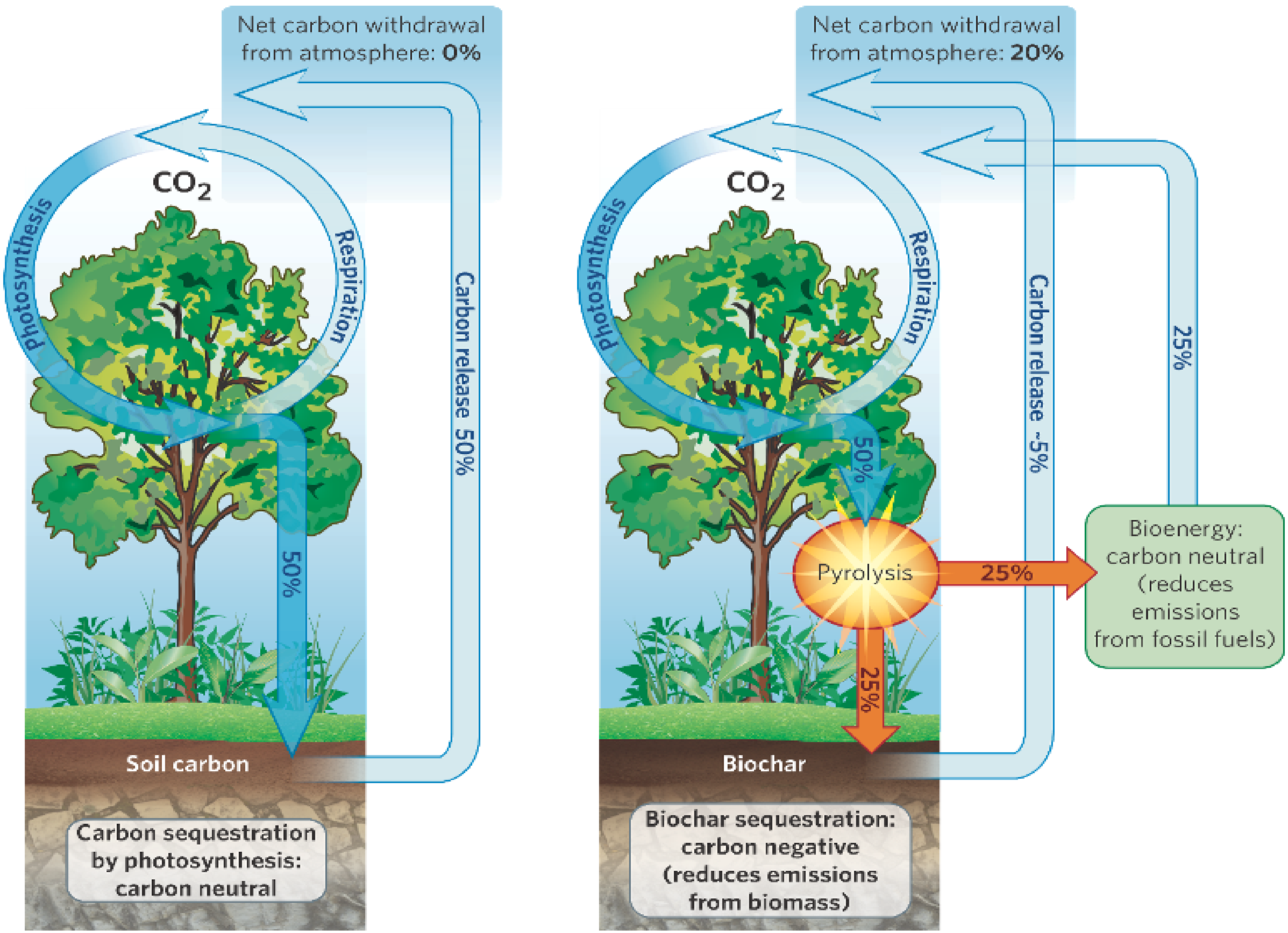
- Since the organic material esealy decomposes and released to the atmosphere as the CO2, new approaches are needed to keep organic carbon in soil.
- Converting OC in to stabel C as a biochar which is logical to keep C in the soil for long term. Biochar is olso a important technique for mitigating atmospheric CO_2

Biochar can be used lor long term



Biochar can hold carbon in the soil for hundreds and even thousands of years.

Additional effects from adding biochar to soil can further reduce greenhouse gas emissions and enhance carbon storage in the soil.



We are working biochar

- Since 2013 we are working on biochar effect on soil amendment and plant growth, nutrient uptake.
- We developed a biochar production unites. Biochar are producing at different temperatures by using several plant materials.

Biochar Can Improve Soil Fertility

- Biochar is a stable, recalcitrant organic carbon (C) compound, created when plant biomass is heated usually in between 300°C and 700°C temperatures, under very low oxygen concentrations.

- Biochar application to **soil can improve soil fertility and long-term C storage,** thus leading to multiple benefits regarding climate-change mitigation and adaptation.

How We Can Produce Biochar

We have developed a biochar production oven

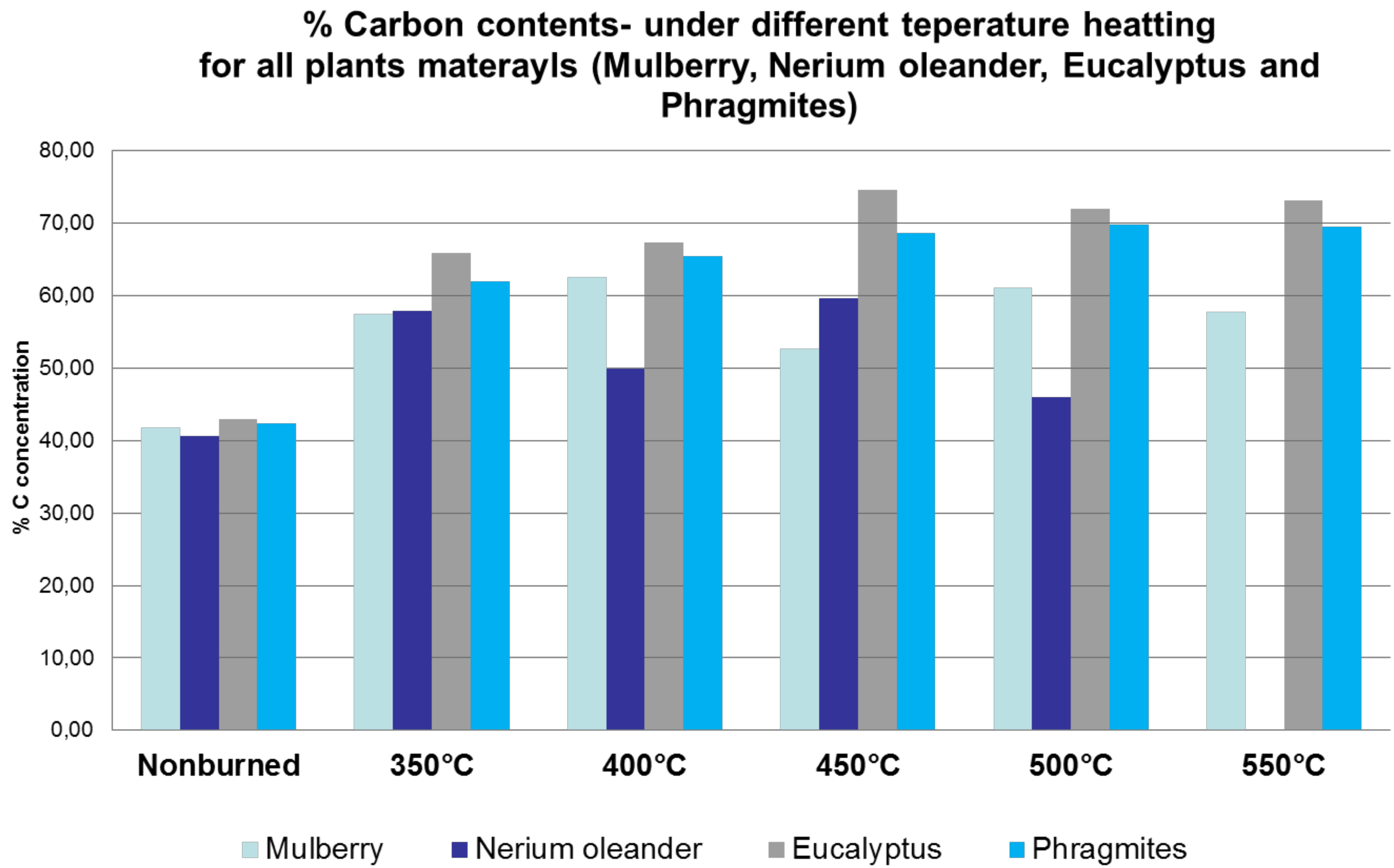
We have Produced Biochar

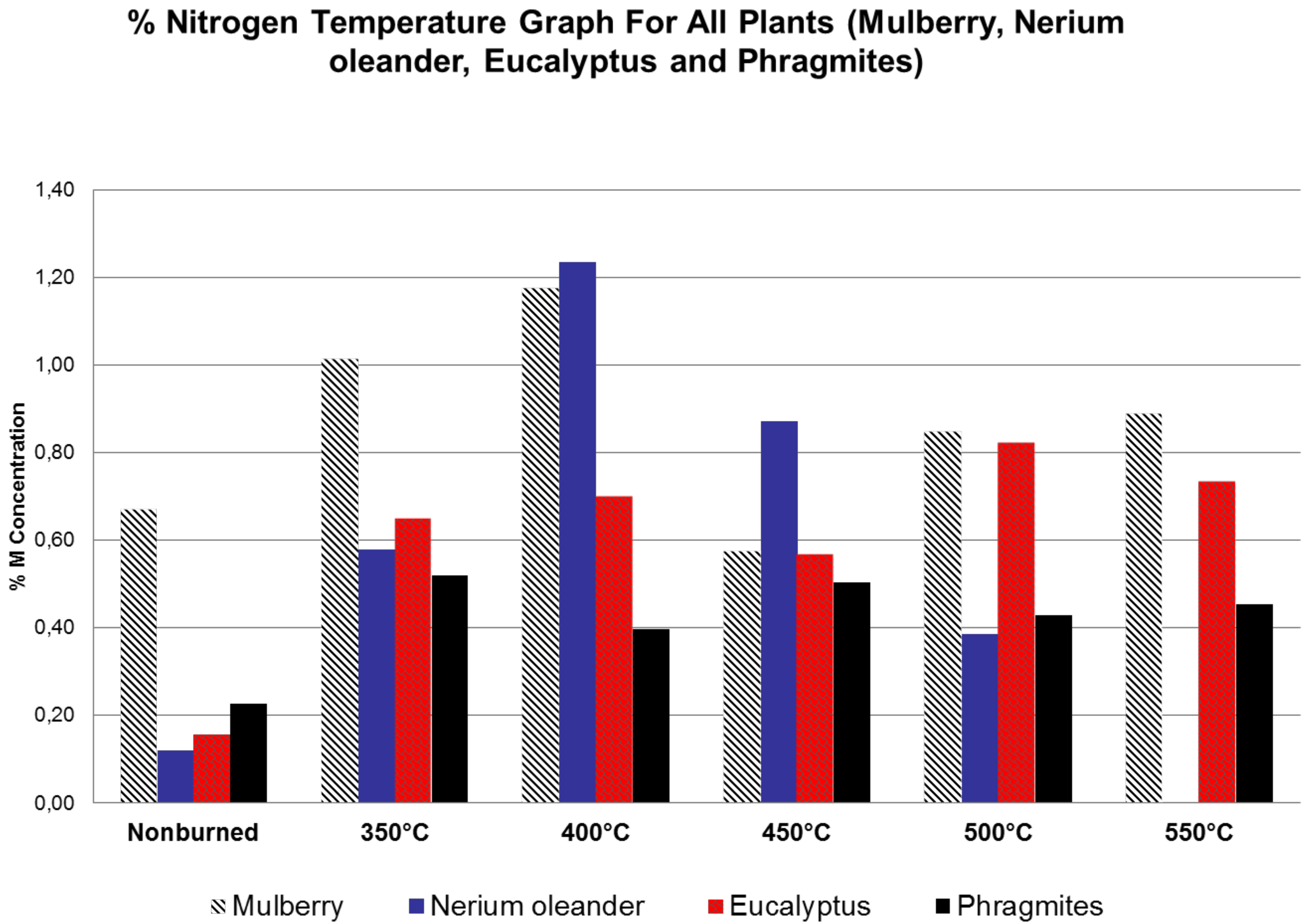
- We have produced biochar from four different plant (Mulberry, Oleander, Eucalyptus and Phragmites) branchs under different temperatures (350**0**C ,4000C, 4500C, 5000C and 5500C).

Biochar Have High C Concentration

- The highest carbon contents of biochar were obtained respectively, at **400°C** for Mulberry at **450°C** for Eucalyptus and Oleander and finally at **500 °C** for Phragmites.

- The highest nitrogen contents of biochar were obtained respectively at **350°C** for Phragmites at **400°C** for Mulberry and Oleander and lastly at **500 °C** for Eucalyptus.


% Carbon contents- under different teperature heatting
for all plants materayls (Mulberry, Nerium oleander, Eucalyptus and Phragmites)
% C concentration
80,00
70,00
60,00
50,00
40,00
30,00
20,00
10,00
0,00
Nonburned
350°C
400°C
450°C
500°C
550°C
Mulberry
Nerium oleander
Eucalyptus
Phragmites


% Nitrogen Temperature Graph For All Plants (Mulberry, Nerium oleander, Eucalyptus and Phragmites)
% M Concentration
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
Nonburned
350°C
400°C
450°C
500°C
550°C
Mulberry
Nerium oleander
Eucalyptus
Phragmites

Effect of Teperature on % of P Concentration

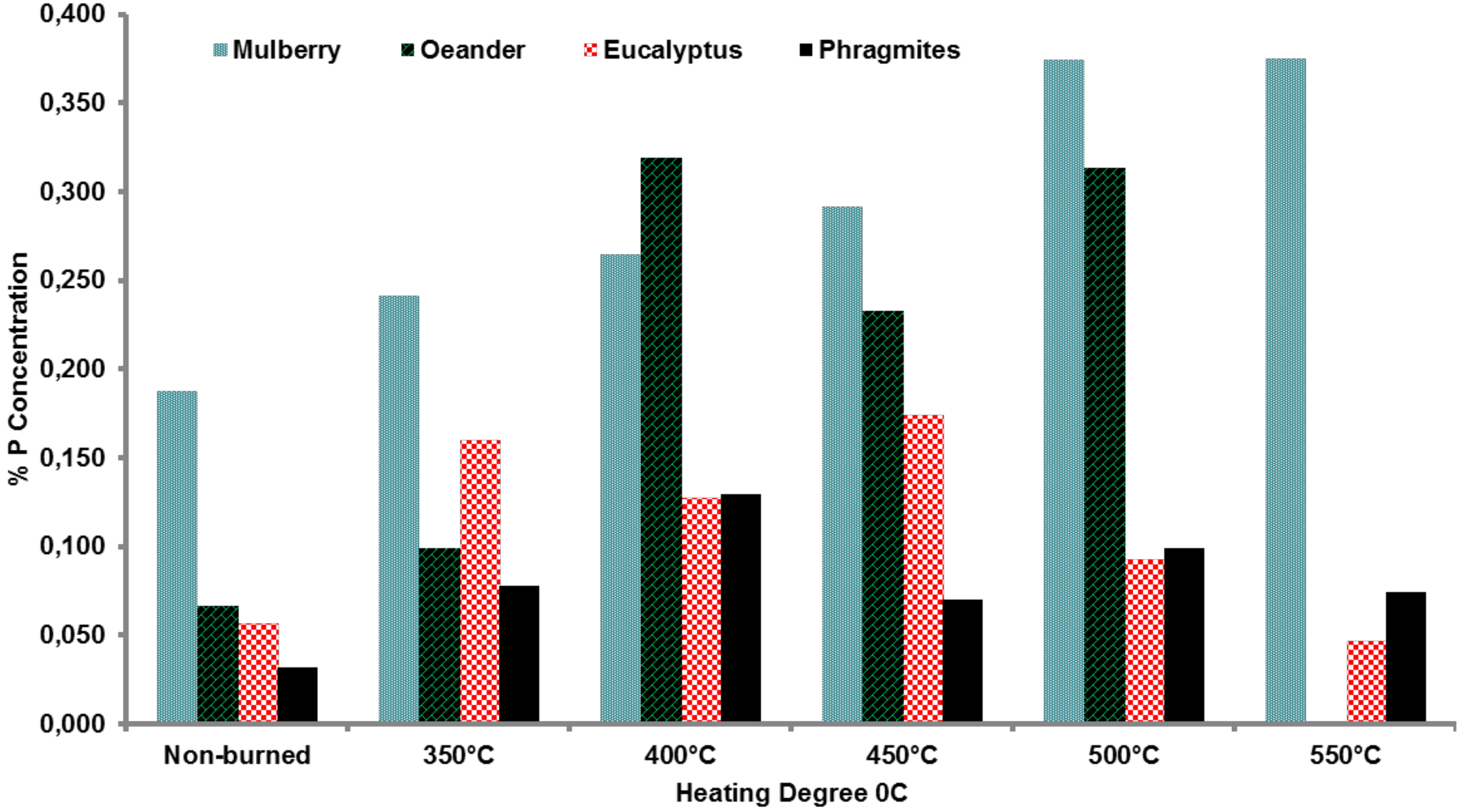


Table. Effect of temperature on nutrients concetration of different biochar Mulberry, Nerium oleander, Eucalyptus and Phragmites

		N	C	P	Fe	Mn	Cu	Zn
		%			mg/kg			
Mulberry	**Non-burned**	0,67	**41,72**	**0,19**	33,49	9,96	2,75	**15,65**
	350	1,01	**57,48**	**0,24**	68,18	18,34	3,72	**17,15**
	400	1,17	**62,51**	**0,27**	64,34	19,67	3,29	**17,85**
	450	0,58	**52,67**	**0,29**	88,70	45,24	6,31	**13,20**
	500	0,85	**61,04**	**0,37**	77,26	20,42	5,13	**29,61**
	550	0,89	**57,69**	**0,38**	79,22	23,64	4,66	**23,84**
	Mean	0,86	**55,52**	**0,29**	68,53	22,88	4,31	**19,55**
Oleander	**Non-burned**	0,12	**40,64**	**0,07**	38,36	20,34	3,36	11,30
	350	0,58	**57,91**	**0,10**	173,30	40,99	11,34	17,30
	400	1,24	**49,89**	**0,32**	257,80	63,27	8,86	13,09
	450	0,87	**59,70**	**0,23**	276,15	21,84	4,15	18,85
	500	0,39	**46,01**	**0,31**	224,60	70,96	11,21	29,70
	550							
	Mean	0,64	**50,83**	**0,21**	194,04	43,48	7,78	18,05
Eucalyptus	**Non-burned**	0,16	**42,87**	**0,06**	26,36	15,10	10,02	39,36
	350	0,65	**65,92**	**0,16**	151,70	91,26	9,37	61,13
	400	0,70	**67,33**	**0,13**	120,30	54,02	10,95	42,13
	450	0,57	**74,53**	**0,17**	59,59	62,66	8,40	44,09
	500	0,82	**71,97**	**0,19**	191,50	9,12	8,23	41,46
	550	0,73	**73,20**	**0,15**	59,83	49,85	8,81	39,64
	Mean	0,61	**65,97**	**0,11**	101,55	47,00	9,30	44,64

RESULTS

- The results showed that MWD values of soil aggregates were positively correlated with values of **total hyphal length and hyphal density of the AM** fungi utilized. They also showed that the mean weight diameter (MWD) of **macro aggregates of 1-2 mm diameter,** was significantly higher in mycorrhizal soils compared to the non-mycorrhizal soil

RESULT

- Mycorrhizal inoculation + compost were more effective in improving soil physical properties than the inorganic treatment.

Soil aggregation, represented by MWD, was significantly affected by the **mycorrhizae, compost and manure** treatments.

RESULT

- Biochar is a very important C source.
- Biochar production depend on plant material and temperature.
- A good biochar can enrich the nutrients concentrations.

CONCLUSIONS

Soil and crop management may affect many soil properties, such as enhancing the soil organic carbon (SOC) pool, the development of the soil structure and the transfer of atmospheric CO2 to soil through photosynthesis is very important. It is also important to manage mycorrhizal fungi which is a powerful tool to fix more CO2 from atmosphere to soil through plant leaves and roots.

CONCLUSIONS

It is important to produce high quality biochar.

Also to use biochar as a soil amendment material which is a **strong carbon sources to keep in soil for long term**.