CO_2 storage in the soil

Cristos Xiloyannis
University of Basilicata Italy

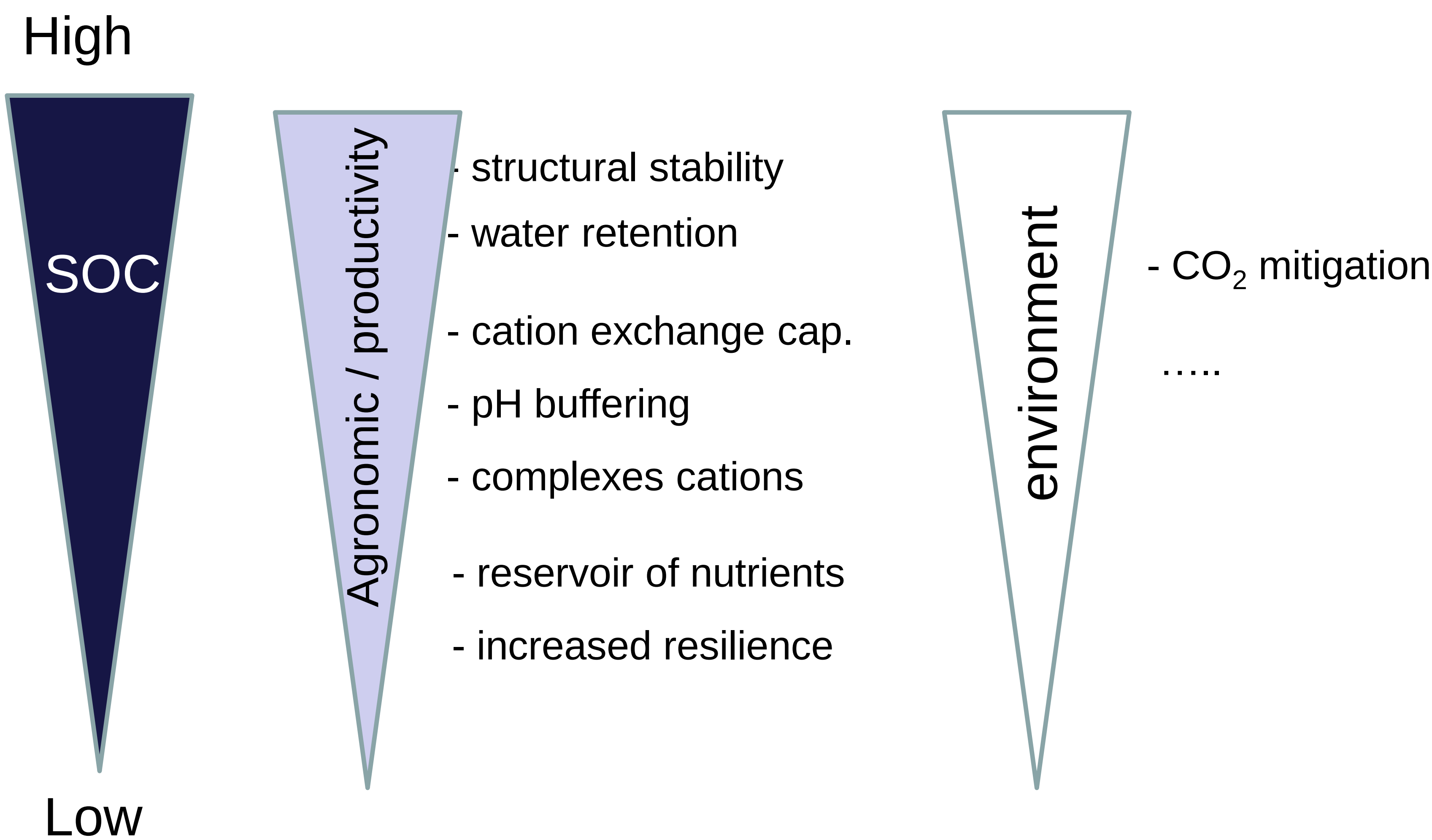
INTERNATIONAL COURSE ON THE CARBON FOOTPRINT OF OLIVE GROWING

MADRID, 26th October 2015

SUMMARY

- Orchard management options to improve SOC
- Predicting models of SOC variations
- Integrating approach to LCA
- Certification procedures

The need for increased SOC



Soils with organic matter less than 1% are desert from microbiological point of view.

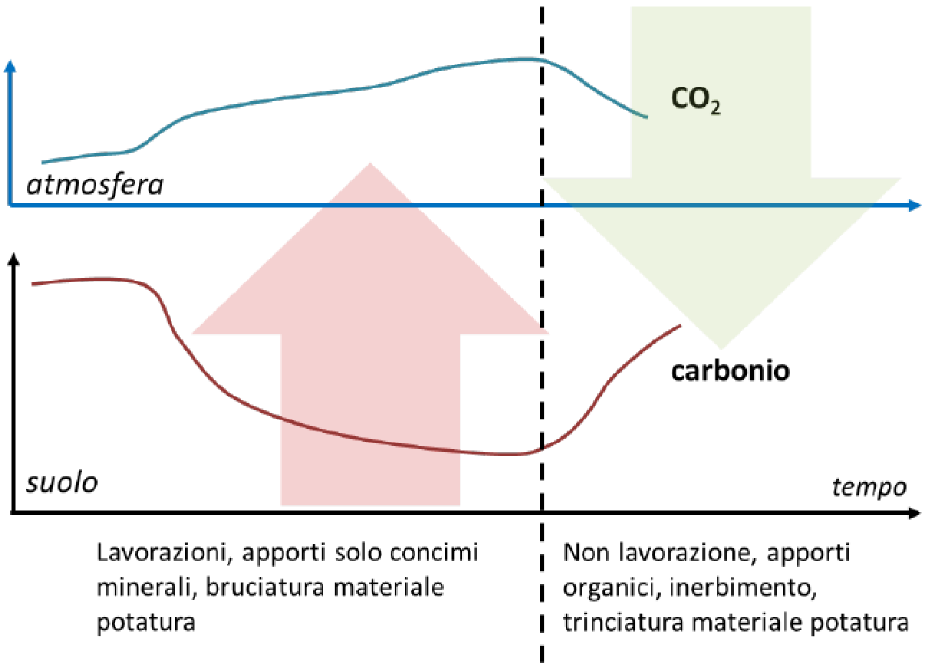
…in Southern Italy the mean soil organic matter is 0.8 – 1.3%

Source: Metapontum Agrobios e Regione Basilicata

Role of orchards

Improve Sink C

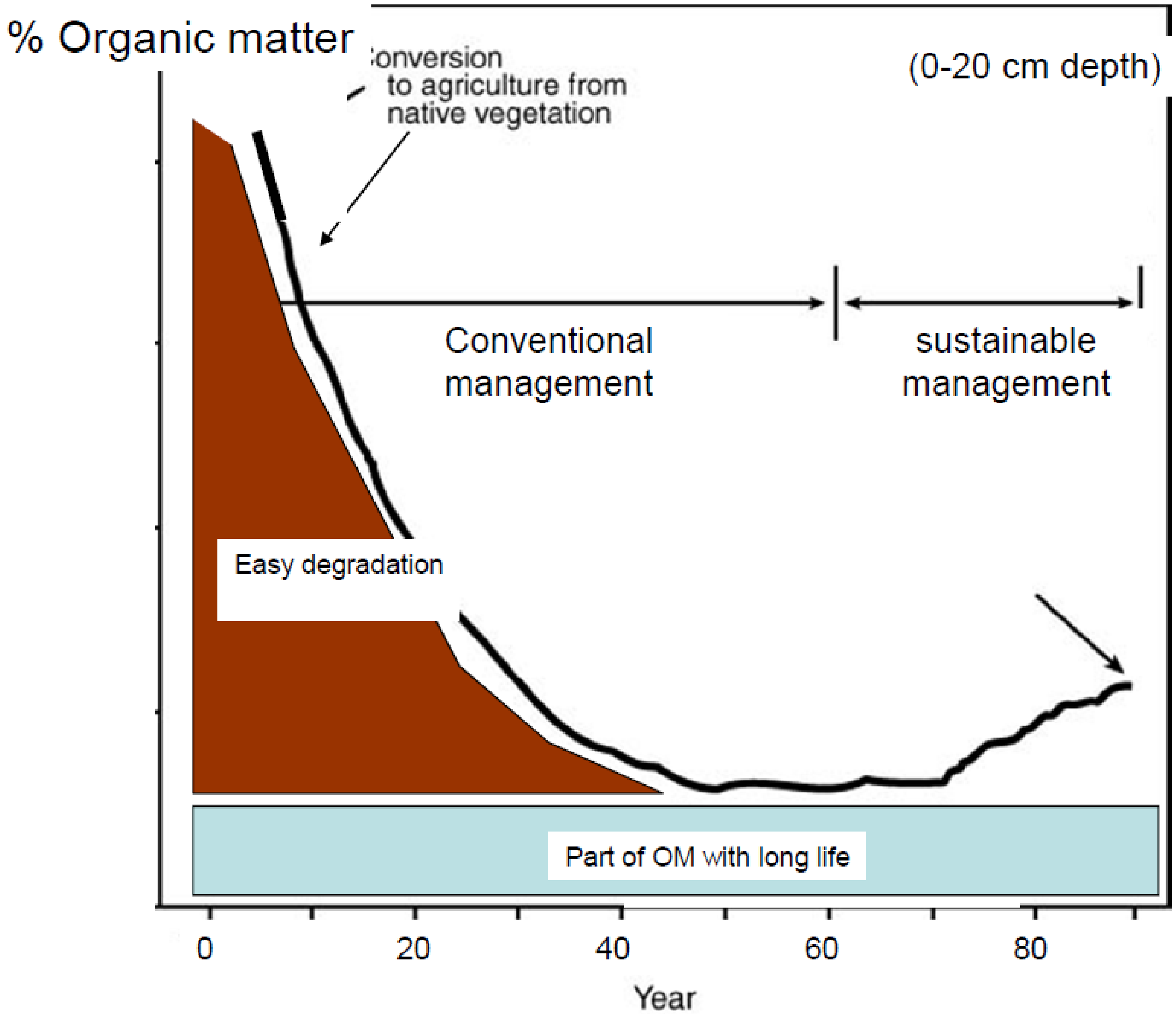
Reduce CO_2 emissions



Atmospheric CO_2 absorbed through photosynthesis

1% soil C increase corresponds to 260 t/ha CO_2 stored

(50 cm depth, 1.4 t/m3 soil bulk density)



Rielaborato da WBGU Special Report:
The Accounting of Biological Sinks and Sources Under the Kyoto Protocol

- increase soil C input

- limit soil C output

- increase soil C input

carbon sources

internal

cover crops
pruning material
senescent leaves

external

stabilised manure
compost
Biochar, others

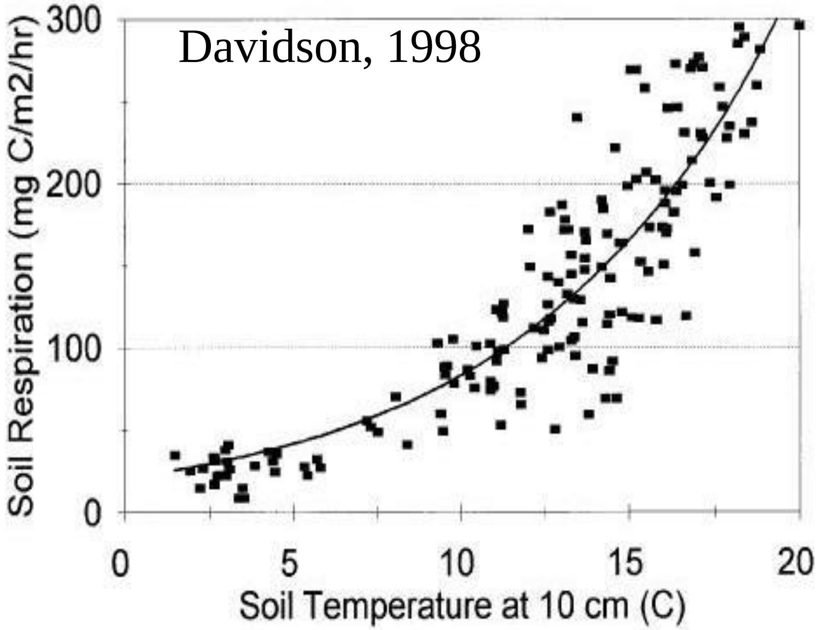
■limit C output

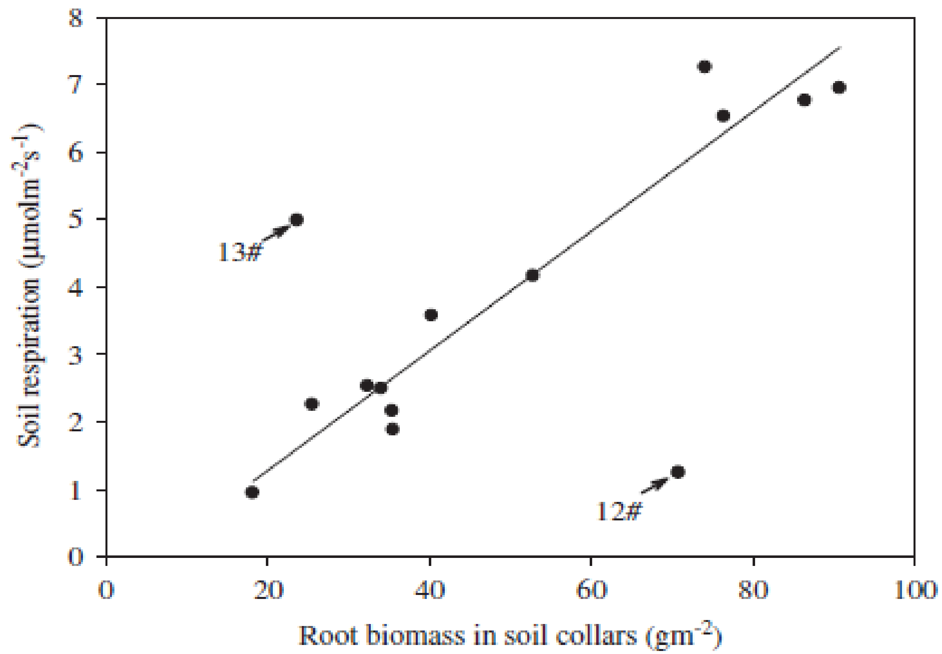
✖Reduction of natural CO_2 emissions from soil

heterotrophic and autotrophic soil respiration

soil water availability
soil temperatures
soil microbiological fertility

factors which affect soil respiration





Hanson *et al*., 2000; Raich *et al*., 2000; Smith *et al*., 2003; Ryan *et al*., 2005; Huang *et al*., 2005; Cook *et al*., 2008; Longdoz *et al*., 2000; Qiao *et al*., 2009; Granli e Steinkamp *et al*., 2001.

Water Content

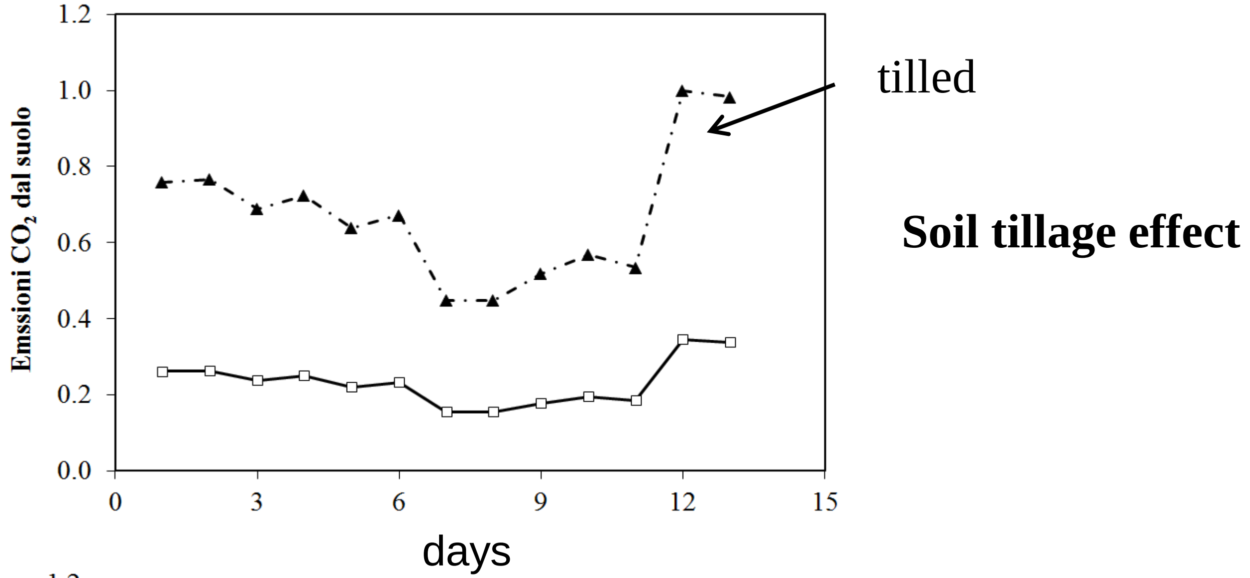
Temperature

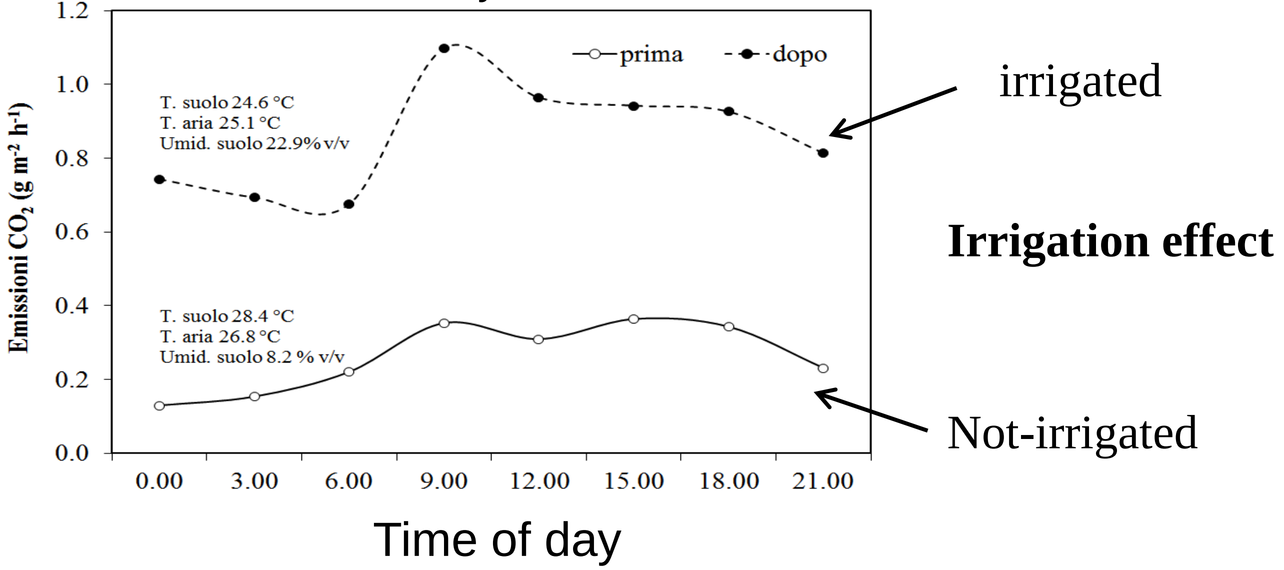
Root Density

Growing Season

Microbial biomass

Impact of soil tillage and moisture (irrigation) on CO_2 soil emissions





Soil respiration chambers portable system

Benefits

- Field variability assessment
- Fast measurements
- High precision

Disadvantages

- Low temporal scale representativeness
- Operator presence

Soil respiration chambers stationary system

Benefits

- Field variability assessment
- Automated system for long term measurements
- Fast data communications by GPS, wireless net

Disadvantages

- Weekly assistance
- Lower precision respect to portable systems
- Influences of climatic variables (rain, fog)

SOSTEN.

AZIENDALE

ato

Gestione del suolo

Nutrizione minerale

minerali,
dosi calcolate
empiricamente

t

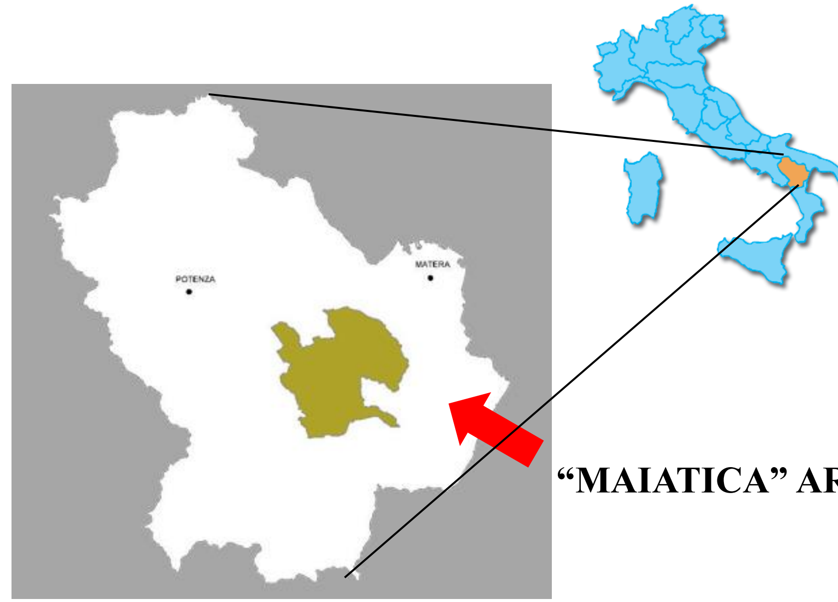
Residui potatura

CASE STUDY

Ferrandina (Matera, Italy)

- Olive orchard
- Lat: 40°29’ 13’’ N;
- Long: 16°27’ 53’’ E.
- Elevation: 320 m a.s.l.
- Cultivar: Maiatica of Ferrandina,

> 50 years old



“MAIATICA” AREA

- Plant density: 156 trees ha^{-1}
- Irrigated with wastewater 3000 m^{3} ha^{-1} y^{-1}
- Soil texture: 73% sand, 15% silt, 13% clay
- Soil Organic Carbon: 1.2 %

FROM 2000 TO 2009

TEN YEARS OF MEASUREMENTS AND STUDIES

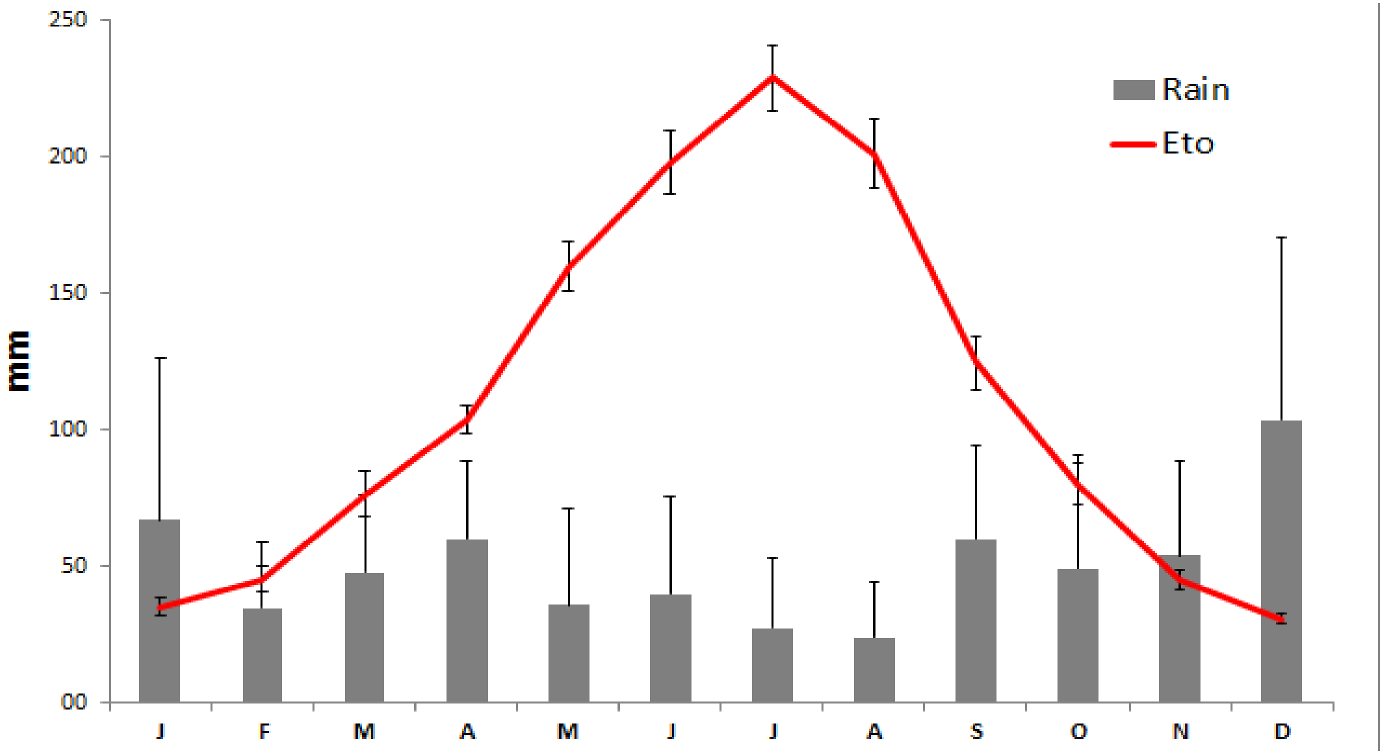
CLIMATE IN FERRANDINA

Avg of 10 years

Avg yearly temperature: **15 - 17 °**C

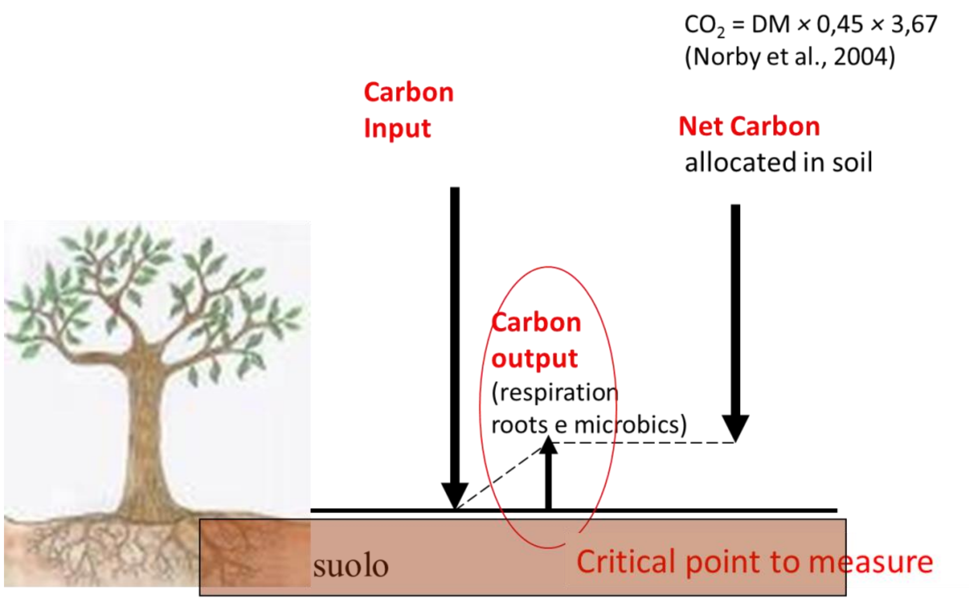
Avg yearly precipitation: **400** a **800** mm

Avg yearly ET_o : **1200 - 1500** mm



Accounting carbon fluxes at orchard scale

..... Carbon balance in the orchard



SOIL RESPIRATION
The critical point

portable

fixed

CARBON STORED IN BIOMASS

DM SAMPLING

PRUNING RESIDUES

YIELD

GRASS COVER

ESTIMATED BASED ON LITERATURE

LEAVES
(Ĉermák et al. 2007; Connor e Fereres , 2005)

TREE ROOTS
(Cannell, 1985).

ROOT OF GRASS COVER
(Celano et al., 2003) .

Mean (2001-2008) Annual Net Primary Productivity (CO_2eq, t ha^{-1} year^{-1})

Net Primary Productivity (NPP)	Sustainable System	Conventional System
	CO_2eq (t ha^{-1} year^{-1})	
Above Ground NPP	28.38	11.03
Yield	9.06	3.99
Olive permanent structures [1]	0.60	0.60
Pruning material	6.11	4.84
Senescent leaves [2]	1.60	1.60
Spontaneous vegetation epigean biomass	11.01	-
Below Ground NPP	10.43	5.51
Olive root biomass [3]	7.68	5.51
Spontaneous vegetation root biomass [4]	2.75	-
Total NPP	-38.81	-16.55

1 calculated according to Almagro et al. (2010).

2 estimated according to Sofo et al. (2005).

3 estimated as the 50% of the annual biomass production of olive trees (Cannell, 1985).

4 estimated as 20% of the above-ground part (Celano et al., 2003).

CO_2eq emissions and stock variations in the 2 systems

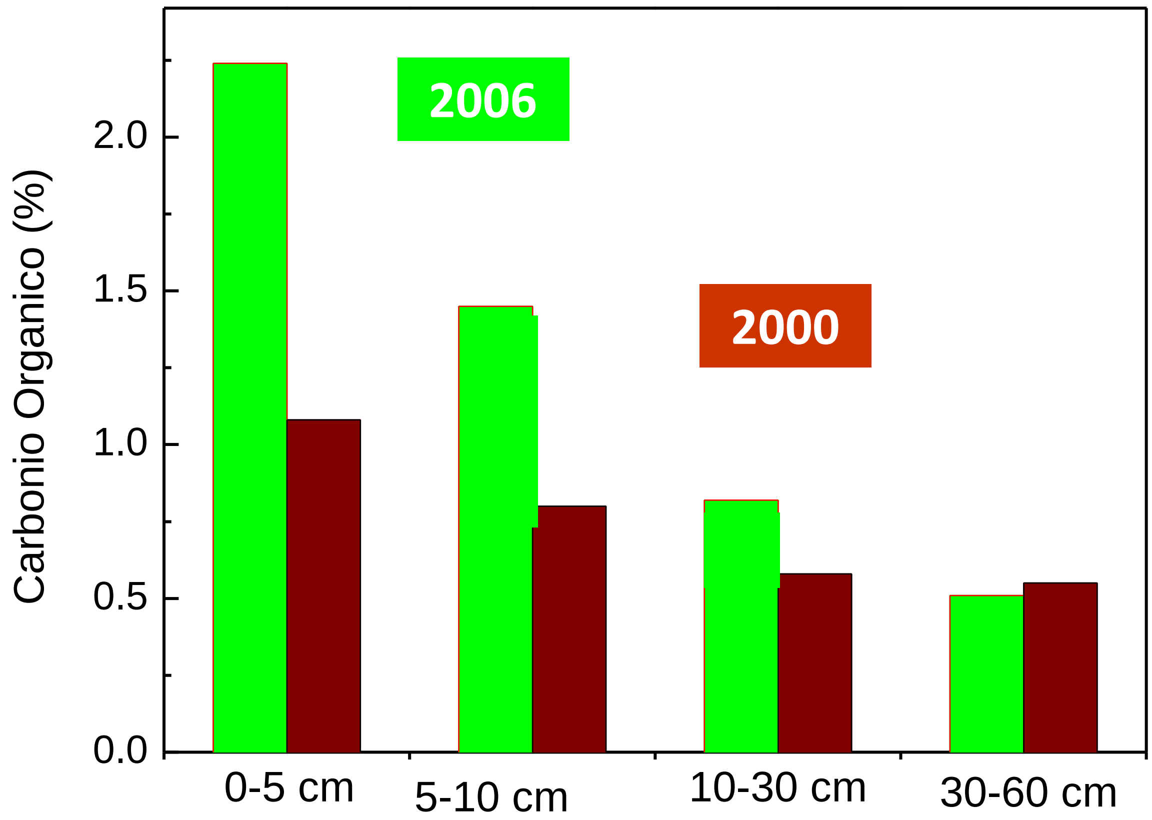
	Sustainable System	Conventional System
	CO_2eq (t ha^{-1} year^{-1})	
Total emissions	+25.42	+27.37
Anthropogenic	+2.42	+1.53
Fertilizers, pesticides		
Farm operations and transport		
Pruning res idues burning	-	+4.84
Soil respiration[1]	+23.00	+21.00
Total NPP	- 38.81	- 16.55
Difference	-13.39	+10.82

[1]elaborated from data reported by Almagro et al. (2009) and Testi et al. (2008)

CARBON FOOTPRINT (Kg CO_2eq/L)
functional unit = 1 L bottled olive oil

	Olive grove	Mill	Package	CF
Sustainable Oil produced 1,552 Kg	-8.93	0.13	1.81	**-6.99**
Conventional Oil produced 672 Kg	17.59	0.13	1.81	**+19.53**

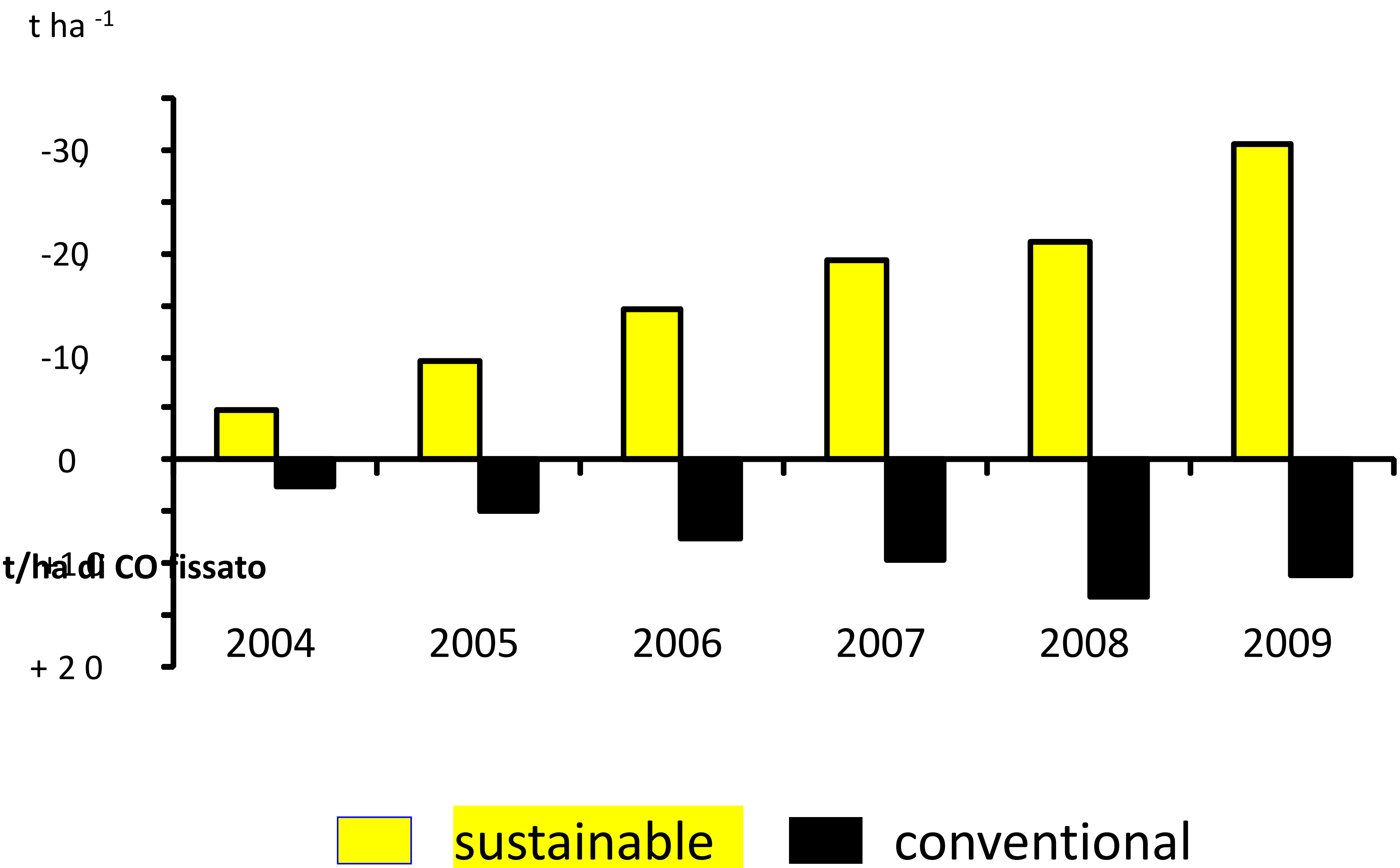
The increase of carbon in the soil of olive trees: 2000-2006 (sustainable management without compost).

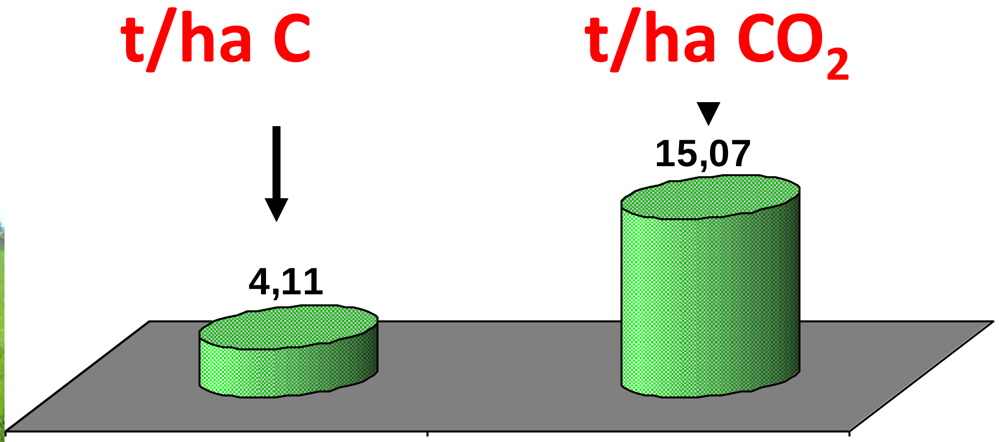


Equivalent of about….

61 t ha^{-1} of CO_2
In the top 30 cm of soil

Carbon Balance in a Mature Peach Orchard





Compost features (%DM)

Moisture	%	24,8
pH		7,98
Total nitrogen	%	1,52
Organic C	%	33,8
Organic Matter	%	58,27
Humus	%	10,4
C/N		22,2
P_2O_5	%	0,68
K_2O	%	1,4

Prices of fertilizing units supplied through compost addition (15 t ha^{-1} FW) and mineral fertilisers

	N	P	K	Mg**	Fe**	Totale	Costo medio
Fertiliser unit*	**228.0**	**33.8**	**130.8**	**10.0**	**1.0**	**403.6**	
COMPOST	€ 104,62	€ 15,60	€60,41	€ 0,50	€ 0,05	€181,20	**€ 0,45**
Mineral fertilisers	€273,60	€28,09	€ 156,96	€ 88,60	€ 12,30	€559,51	**€ 1,38**

* Average price of compost 12,5 €/t (transportation cost not included).

** average amounts uptaken in a regular season.

	Mineral content (kg/t of compost)	CO_2 emissions (kg CO_2 eq)
N_{tot}	18	164.16
P_2O_5	6.8	10.88
K_2O	14	9,29

Some chemical characteristics and mineral composition of pelleted compost released according to D. Lgs n.75/2010

ELEMENTO O SOSTANZA UTILE	VALORE
Umidità (% tq)	≤ 18
pH	7-8,8
Conducibilità (dS/m)	4
Carbonio Organico (% C ss)	28
Sostanza Organica (% ss)	56
Carbonio Umico e Fulvici (% C ss)	10
Acidi Umici e Fulvici (% ss)	20
Azoto Organico (% N ss)	2
Rapporto C/N	13
Azoto Totale (% N ss)	2,2
Fosforo Totale (% P_2O_5 ss)	1,5

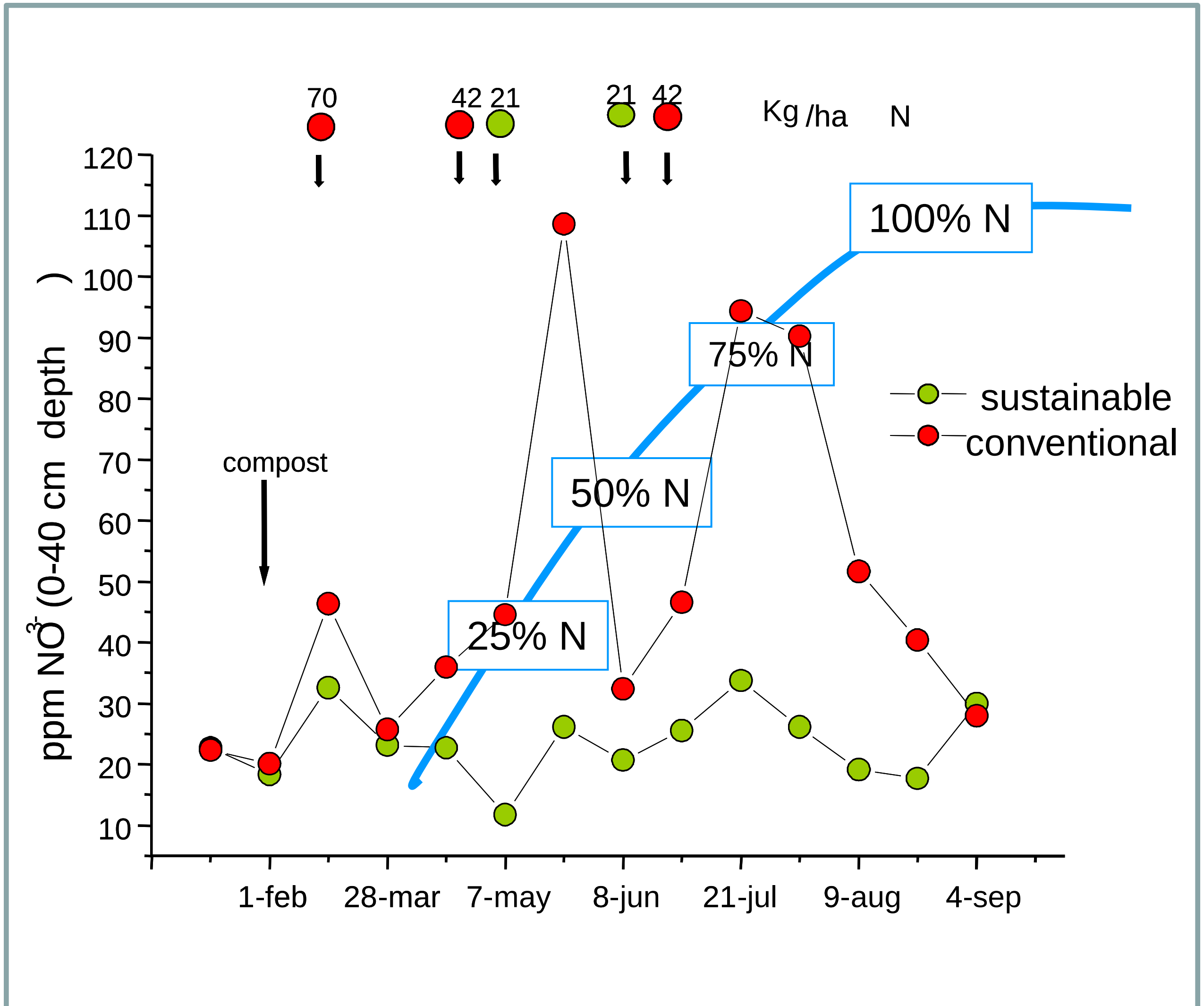
ELEMENTO O SOSTANZA UTILE	VALORE
Potassio Totale (% K_2O ss)	2,1
Calcio (% CaO ss)	16
Magnesio (% MgO ss)	0,8
Zolfo (% SO_3 ss)	0,5
Boro (mg/kg ss)	57
Cobalto (mg/kg ss)	3
Rame (mg/kg ss)	115
Ferro (mg/kg ss)	5335
Manganese (mg/kg ss)	246
Molibdeno (mg/kg ss)	-
Zinco (mg/kg ss)	249

Compost supplied FW (15 t ha^{-1})

	kg ha^{-1}
N	270.60
P	80.53
K	214.36
Ca	1406.72
Mg	59.35
S	17.60
B	0.70
Cb	0.04
Cu	1.41
Fe	65.37
Mn	3.03
	-
Zn	3.06

Substantial increase of annual C input under sustainable practices

the effect on N availability (0-40 cm depth, kiwifruit)



- Sustainable

Fertirriga. 42 kg N ha^{-1}

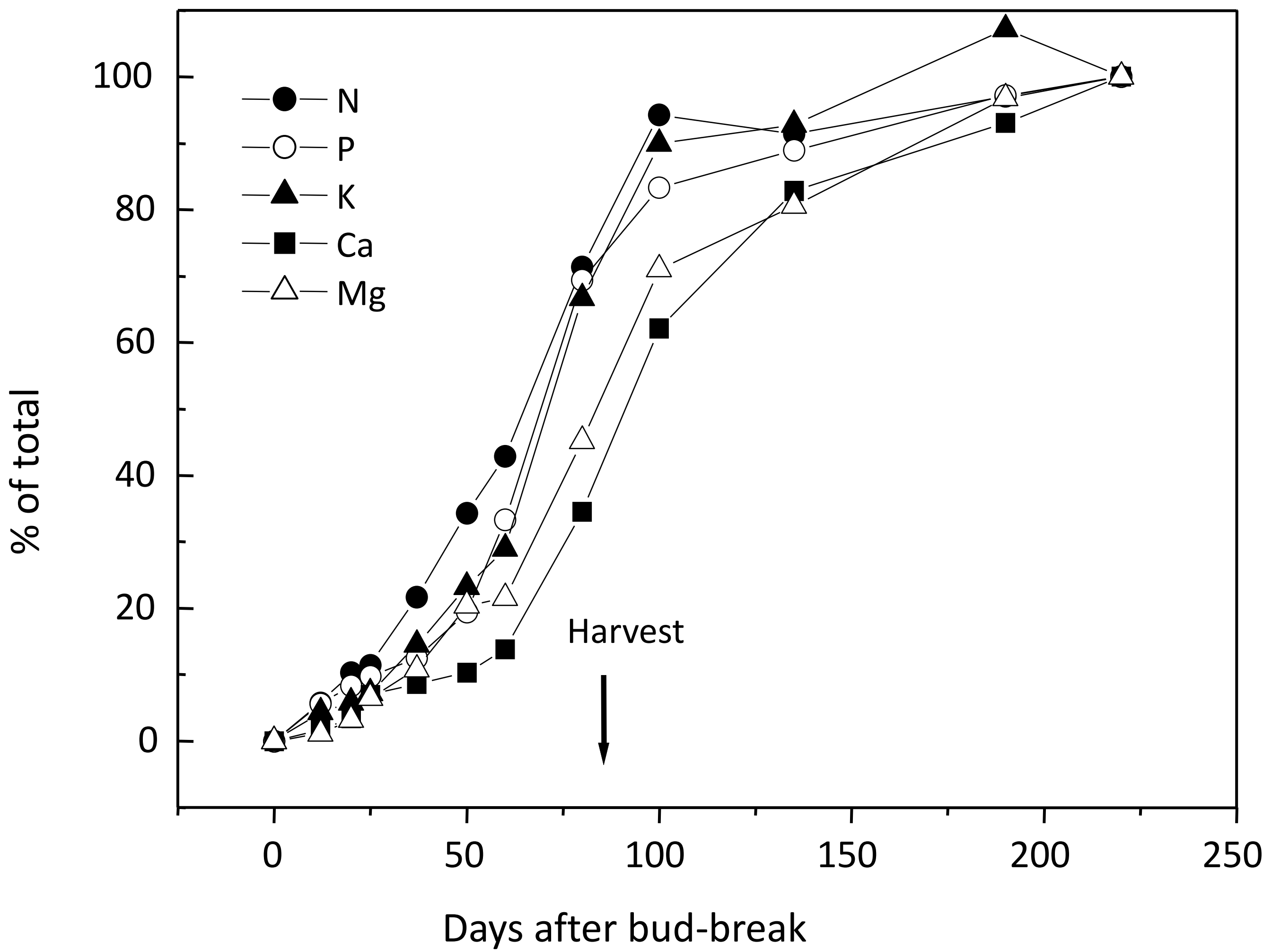
- Conventional

Fertirrig. tot. 84 kg N ha^{-1}

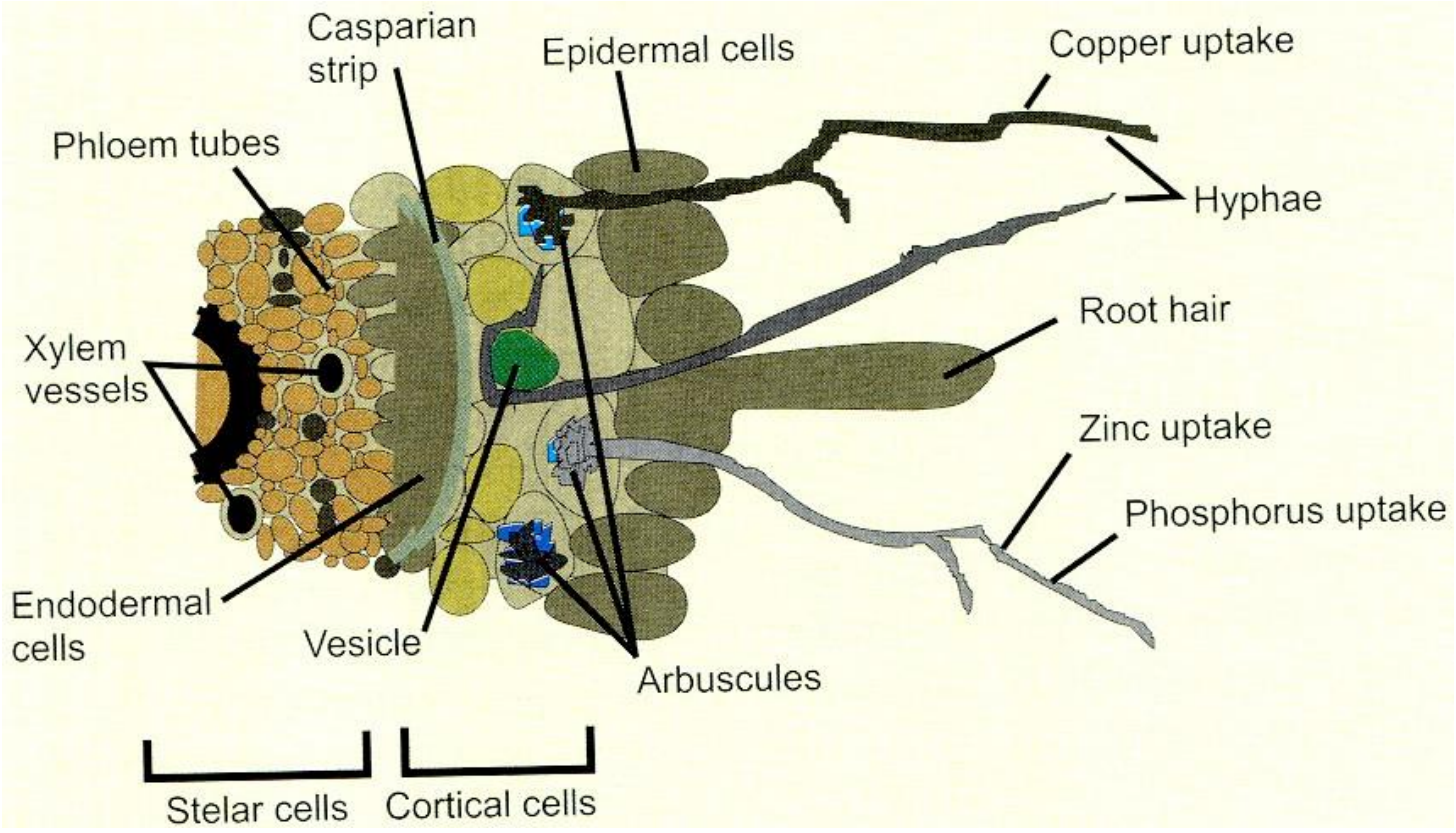
others 70 kg N ha^{-1}

"Nitrachek"

Knowledge of the nutrient uptake pattern throughout the season



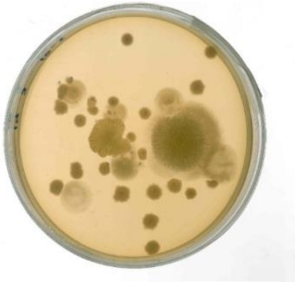
- **50 billions** of microorganisms in fertile soils

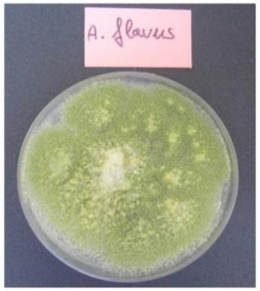


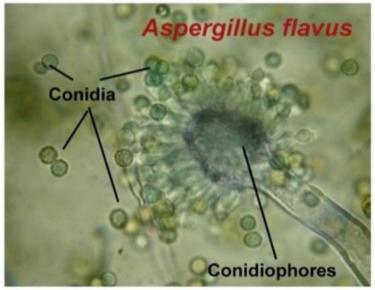
….as intestinal flora in humans

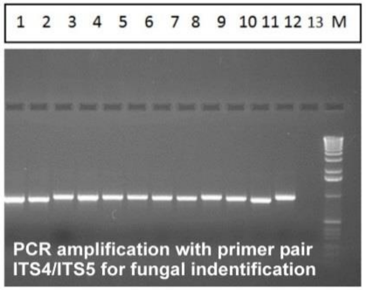
Impact of management practices on some soil biota

	Fungi	Bacteria
	(CFU/g dry soil)	(CFU/g dry soil)
Sustainable	214,000	35,600,000
Conventional	29,000	10,000,000









FILLOSFERA…. Aumento delle difese naturali

La gestione sostenibile incrementa la biodiversità della fillosfera e carposfera:

Table 1. Classification of the bacterial species from olive fruit pulp (mesocarp) identified on the basis of their genomic sequences (NCBI BLAST® hits).

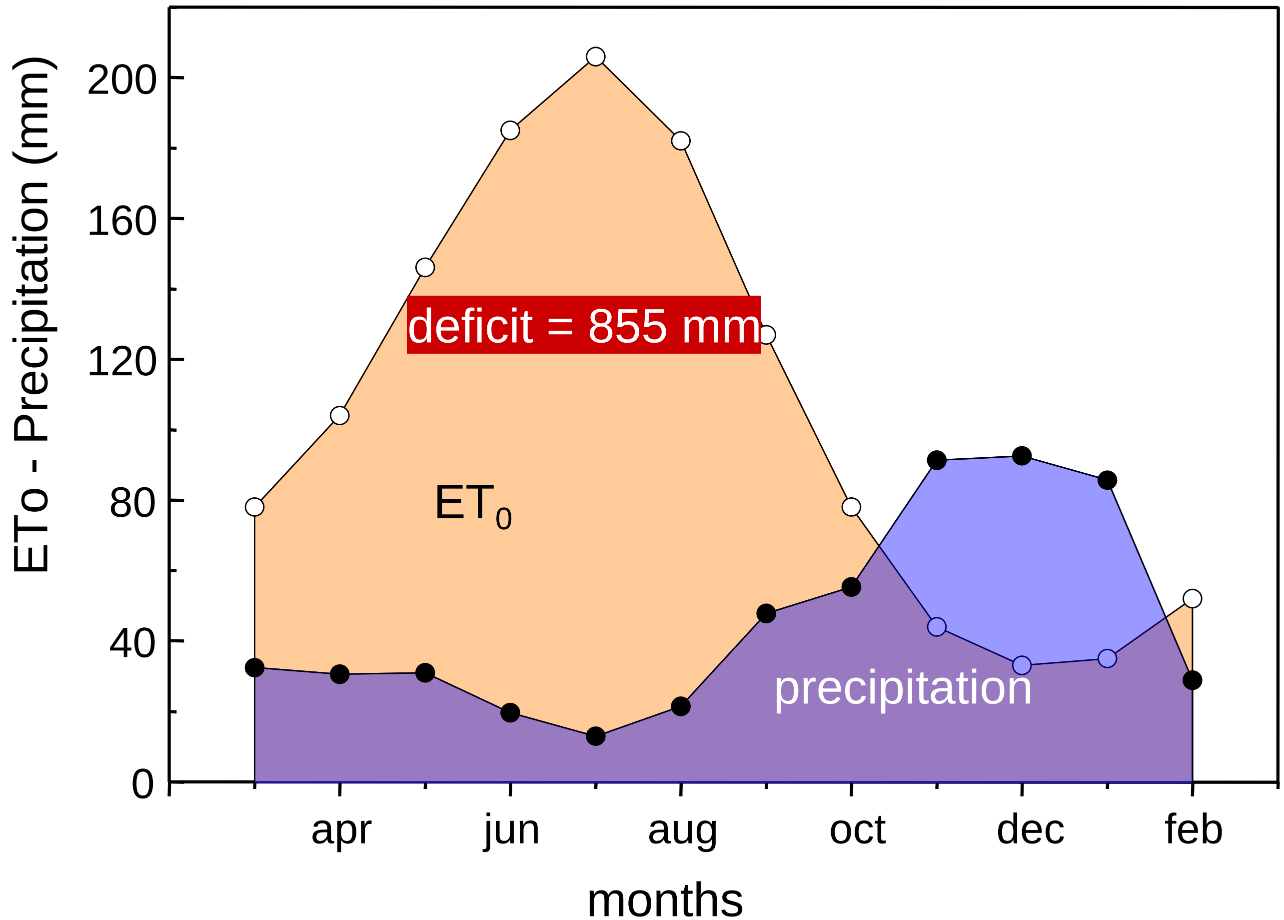
N. species	Phylum	Class	Order	Family	Genus	Species
Sustainable						
8	Proteobacteria	γ-Proteobacteria	Enterobacteriales	Enterobacteriaceae	*Rahnella*	aquatilis
5	Firmicutes	Bacilli	Lactobacillales	Enterococcaceae	*Enterococcus*	unknown
5	Proteobacteria	γ-Proteobacteria	Enterobacteriales	Enterobacteriaceae	*Kluyvera*	*intermedia*
4	Actinobacteria	Actinobacteridae	Actinomycetales	Microbacteriaceae	*Curtobacterium*	unknown
2	Proteobacteria	γ-Proteobacteria	Enterobacteriales	Enterobacteriaceae	*Averyellaa*	*dalhousiens*
1	Actinobacteria	Actinobacteridae	Actinomycetales	Microbacteriaceae	*Frondihabitans*	*suicicola*
1	Proteobacteria	γ-Proteobacteria	Enterobacteriales	Enterobacteriaceae	*Hafnia/Rahnella*	*alvei*
1	Proteobacteria	α-Proteobacteria	Rhizobiales	Methylobacteriaceae	*Methylobacterium*	unknown
1	Proteobacteria	γ-Proteobacteria	Enterobacteriales	Enterobacteriaceae	*Pantoea*	unknown
1	Proteobacteria	γ-Proteobacteria	Enterobacteriales	Enterobacteriaceae	*Serratia/Rahnella*	unknown
1	Proteobacteria	γ-Proteobacteria	Enterobacteriales	Enterobacteriaceae	*Serratia*	unknown
Conventional						
2	Proteobacteria	γ-Proteobacteria	Enterobacteriales	Enterobacteriaceae	*Pantoea*	*agglomerans*

da Pascazio et al., 2015

SUSTAINABLE SOIL MANAGEMENT AND

soil water holding capacity

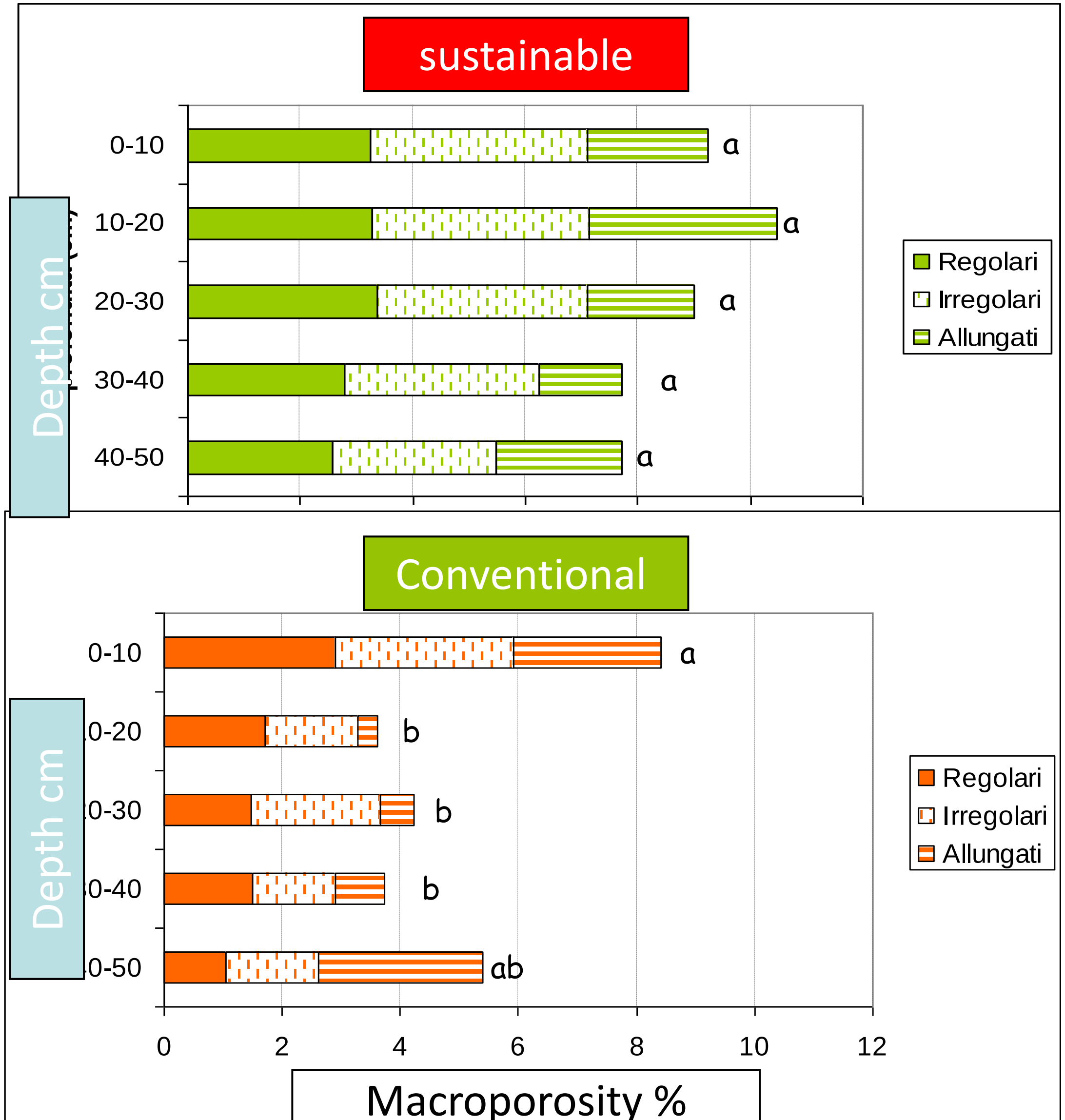
Annual deficit in semi-arid environment

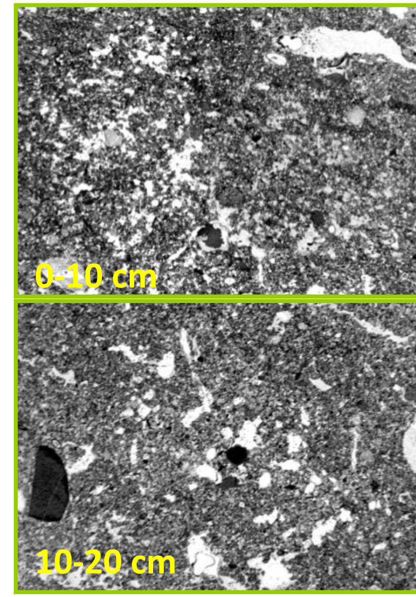


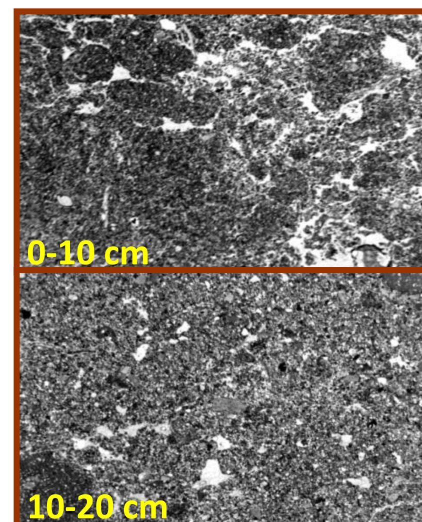
SOUTHERN ITALY

Substantial increase of annual C input under sustainable practices

the effect on SOIL MACROPOROSITY







Impact of soil management on vertical infiltration rate of water (13cm depth – tilling depth-)

	K_{sat} (Guelph) ($mm\ d^{-1}$)	SOIL CONDUCTIVITY CLASS (Rossi Pisa 1997)
COVER CROPS	160	media
TILLED	13	molto bassa

2-year average soil water content (up to 2 m depth) at olive groves managed under different practice

SUSTAINABLE
4,250 m^3/ha

CONVENTIONAL
2,934 m^3/ha

Predicting models of SOC variations

A quite huge number of models exists

CQESTR

EPIC

SOCRATES

ROTH C

STICS

SOMKO

DAISY

CANDY

CENTURY

NCSOIL

VERBENE

SOMM

ITE

STRUC-C

Classifications of models for soil C changes

Process-oriented

Consider C pools subjected to decomposition and stabilization processes. Commonly adopted to simulate changes in C pools resulting from management practices.

Organism-oriented

based on the role of soil biota in C fluxes including mobilization.

C and N fluxes are simulated through functional groups based on their specific death rates and consumption rates, applying energy conversion efficiencies

process-oriented C-models:

- Easier testing in various ecosystems.

- Larger time steps, i.e. months/years versus days/weeks for organism-oriented models.

- Lower computational intensity.

The Rothamsted Carbon Model (RothC)

models the turnover of soil organic carbon (C) in non-waterlogged top soils.

It requires only easily obtainable inputs, and has been widely and successfully used in many regions of the world.

Roth C data requirements

- Monthly climate data: rainfall (mm), open pan evaporation (mm), average monthly air temperature (°C)
- Soil clay content (%)
- Soil cover (vegetated or bare)
- Monthly plant residue additions (t DM ha^{-1})
- Monthly manure/compost additions (t DM ha^{-1})
- Soil depth at which SOC changes will be assessed (30 cm)
- Initial amount of C contained

RothC model separates the SOC into

SOC

 # four active compartments

Plant residues reintroduced to the soil are divided into **decomposable plant materials (DPM)**

resistant plant materials (RPM)

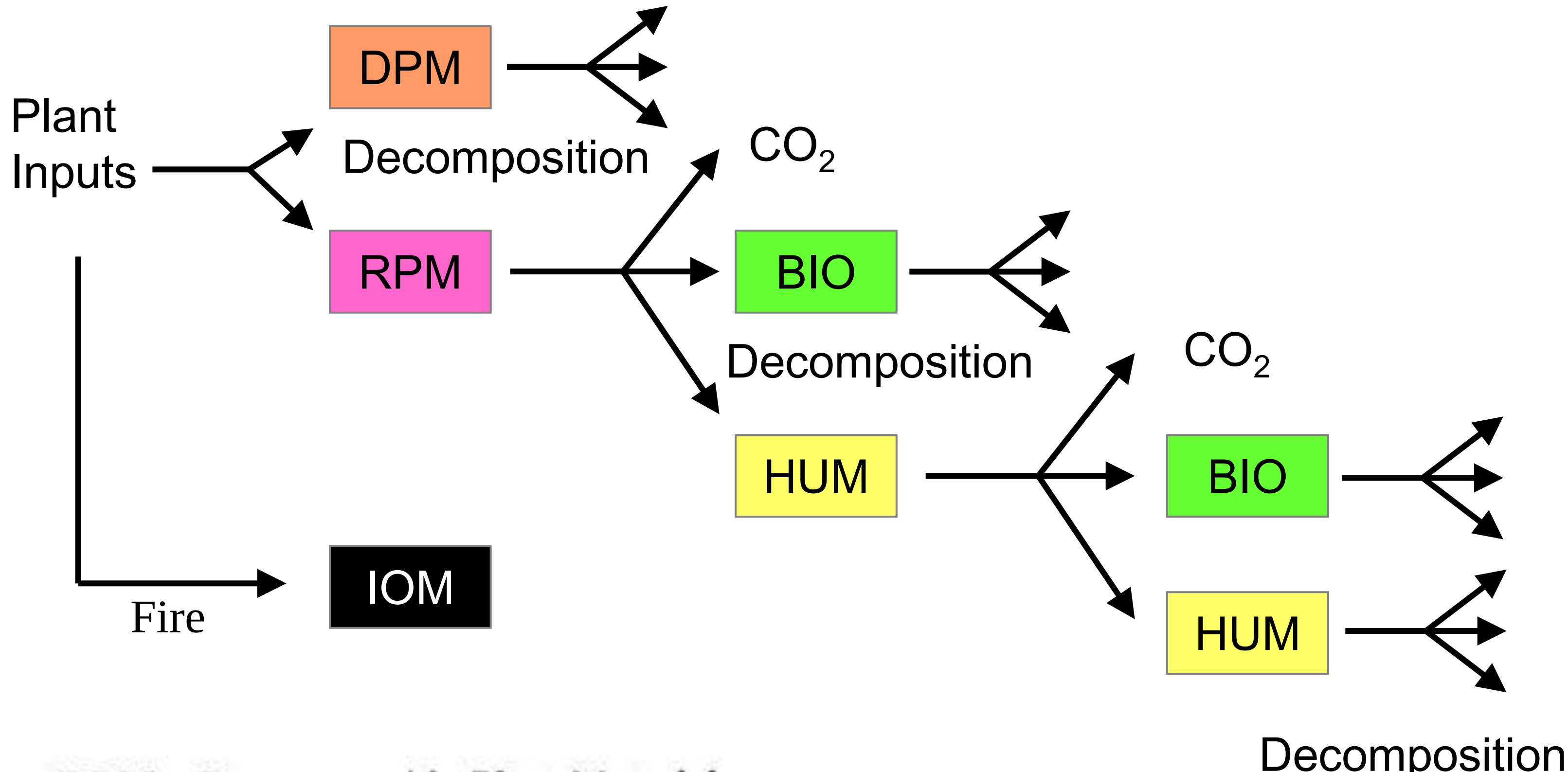
microbial biomass (BIO)

humified organic matter (HUM)

 # one inert organic matter (IOM).

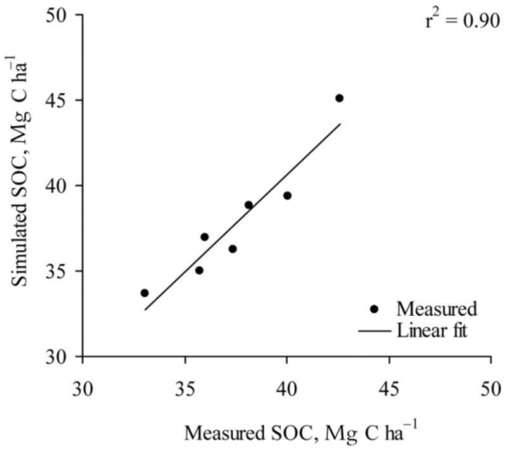
CO_2 emission (lost from the system) is also estimated.

RothC Model

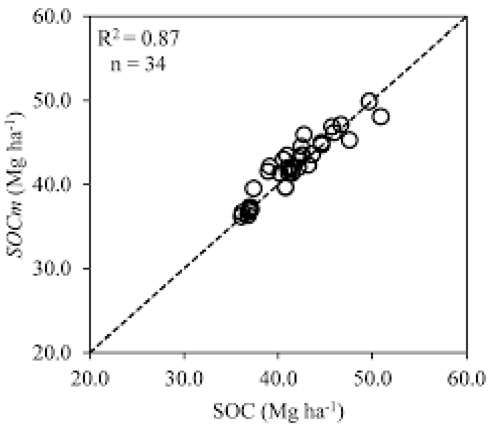


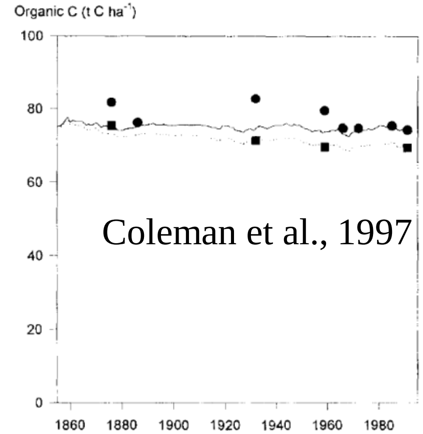
DPM: Decomposable Plant Material
RPM: Resistant Plant Material
HUM: Humified Organic Matter
BIO: Microbial Biomass
IOM: Inert Organic Matter

Abbas and Fares, 2008

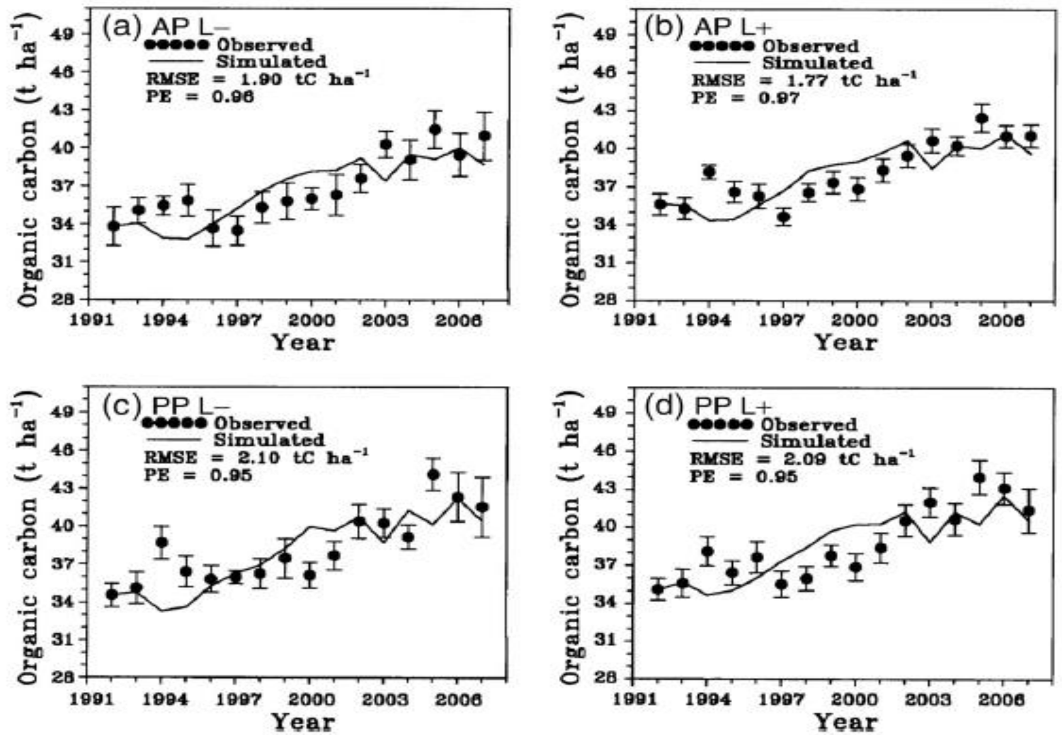


Irizar et al., 2015





D.L. Liu et al. / Geoderma 165 (2011) 69–77



Possible adjustment of RothC for…

Semi-arid environments

(Farina et al., 2013)

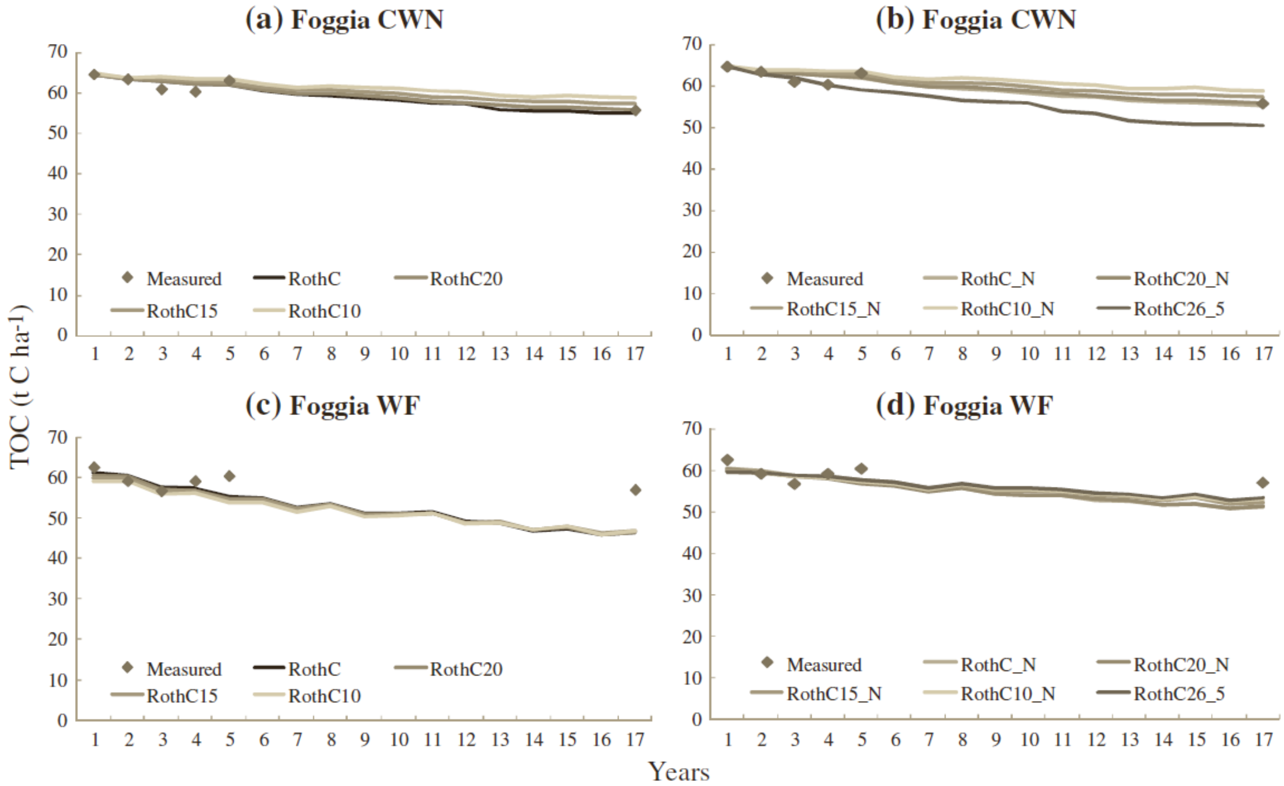


Fig. 2. Measured and simulated values of soil C (t ha^{-1}) at the Foggia site for rotations: (a) CWN, (c) WF, with *dry soil* models; (b) CWN (d) WF, with *dry and bare soil* models and RothC26_5.

Possible adjustment of RothC for…

Localised irrigation and organic fertiliser supply

(Fiore et al., in preparation)

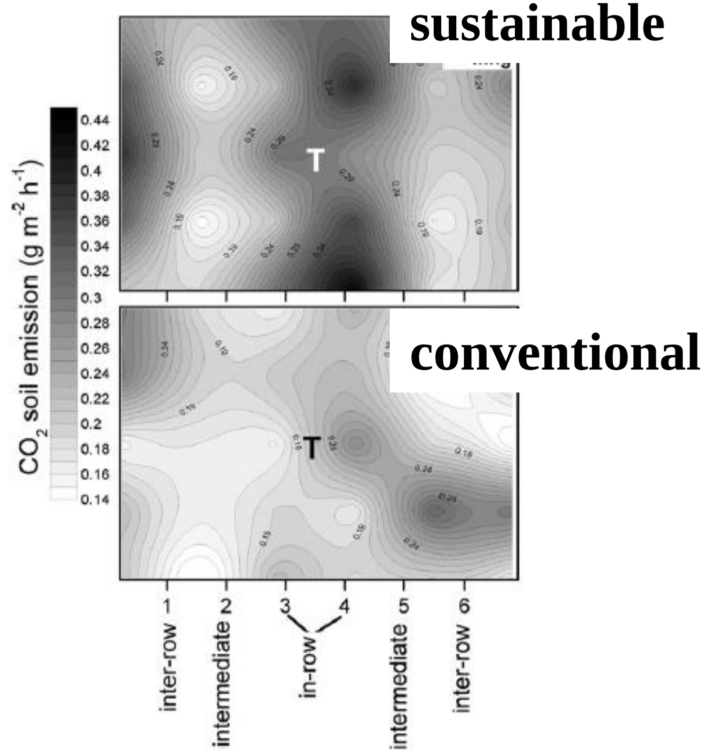
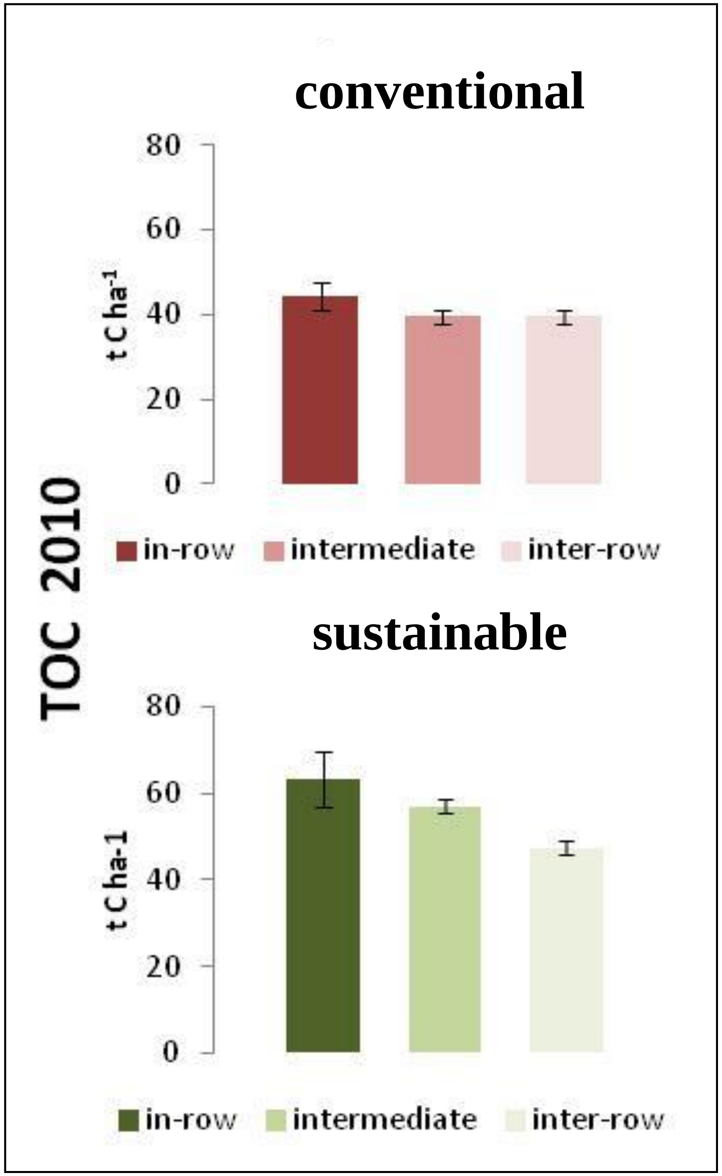


Fig. 7. Isopleth graph of midday soil CO_2 emission rates (g m^{-2} h^{-1}) measured on April 30 across the alternative (A_{mng}) and locally conventional (L_{mng}) plots. The letter *T* indicates the tree position (see Fig. 1 for details of plot dimensions and positions).

Montanaro et al., 2012 AGEE



Spatial variation of SOC

Redrawn from Montanaro et al., 2012 AGEE

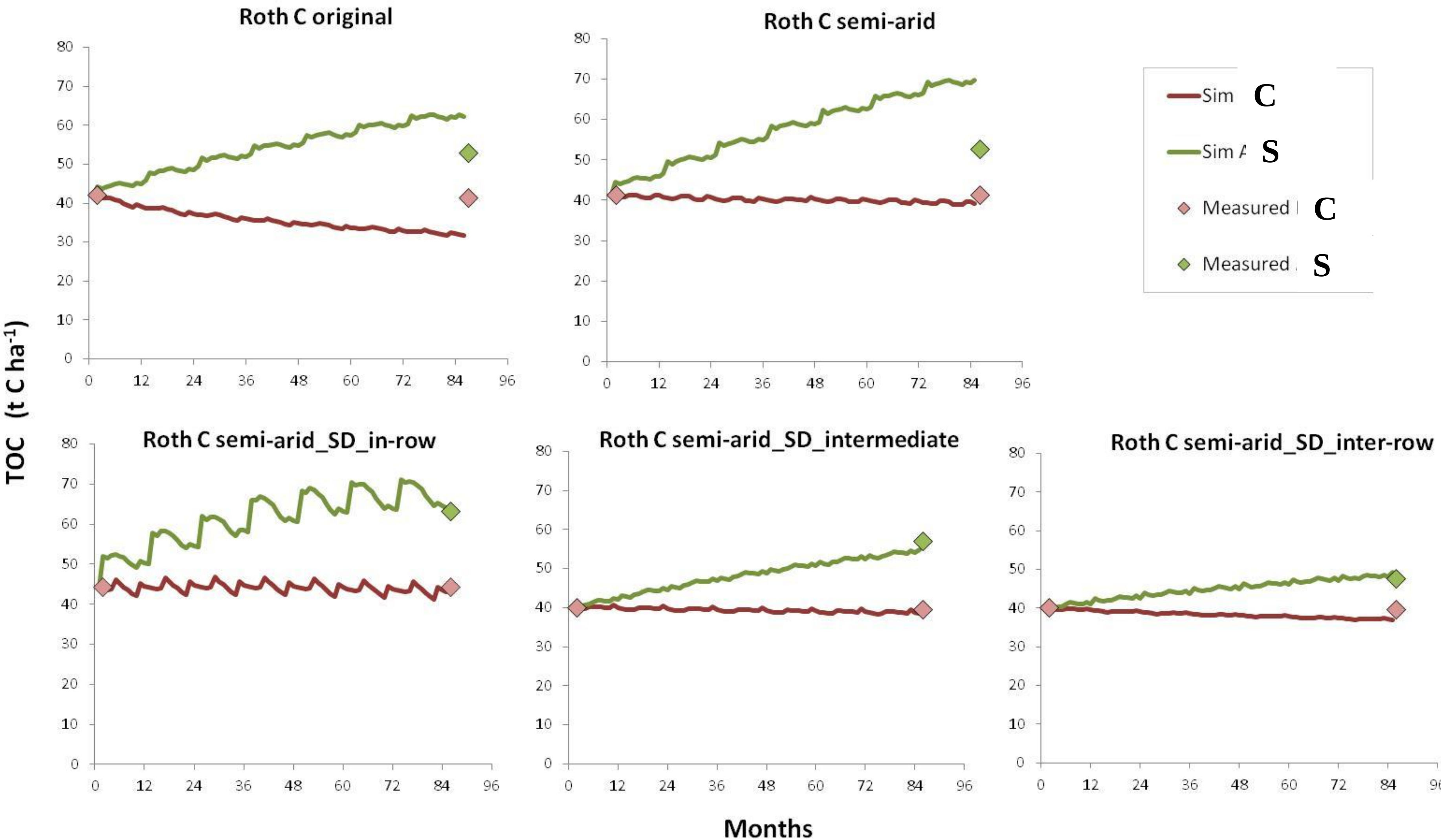
Roth C semi-arid / Spatial Differentiation running mode

Perform one simulation per band (in-row, intermediate and inter-row), differentiating carbon input and soil moisture.

	Lmng	Amng	In-row	Interm.	Inter-row	DPM	RPM
	t C ha^{-1} $year^{-1}$		%			%	
Leaves	0,67	0,67	20	40	40	100	0
Winter pruning	0	1,12	-	40	60	0	100
Summer pruning	0,14	0,14	40	40	20	50	50
Grass cover	0,4	1,84	20	40	40	100	0
Thinned fruits	0,22	0,22	50	50	-	20	80
Roots' turnover	1,09	1,09	80	20	-	50	50
Compost	0	3,40	80	20	-	20	80
	m^3 ha^{-1} $year^{-1}$		%				
Irrigation	6200	4900	100	-	-		

RESULTS

Total Organic Carbon (2004-2010)



Integrating approach to LCA

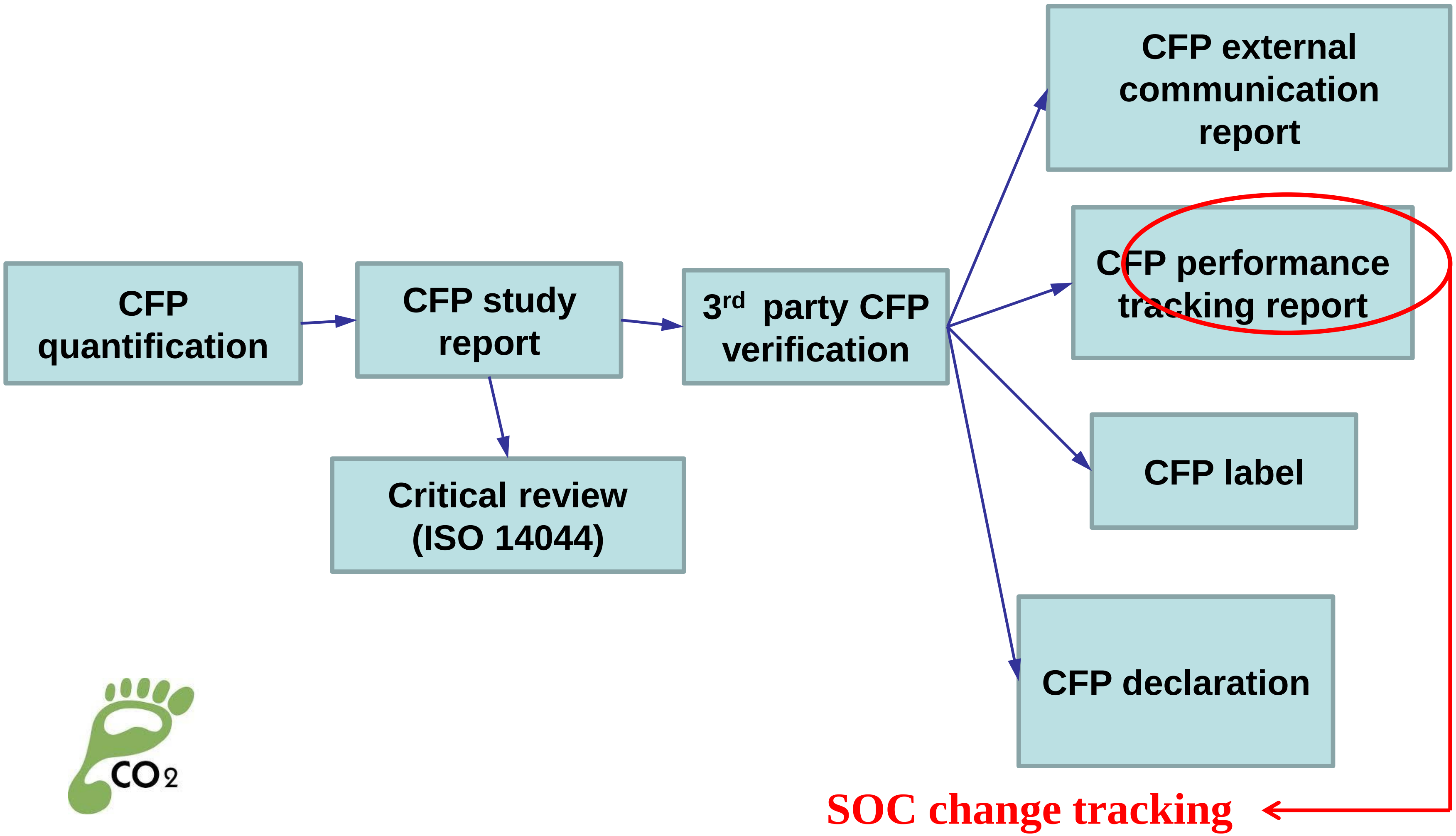
with SOC variations data

ISO 14067: 2013 - International standard for CFP quantification and communication

Elements of CFP to be declared separately in the report	In the olive growing	Current practice
GHG emissions and removals arising from fossil and biogenic carbon sources and sinks	Anthropogenic emissions from agricultural operations	Always accounted using available LCI database (
GHG emissions and removals occurring as a result of dLUC	Variations of carbon stored in AGB/BGB, litter and soil occurring when the land use change.	Accounted using default factors of IPCC guidelines for National GHG Inventory
GHG emissions and removals from soil carbon change, if not already calculated as part of dLUC	Soil carbon change after crop management change	Rarely accounted due to lack of consensus in LCA practicioners community or low expertise with available assessment methods.
Non-CO2 GHG emissions and removals (e.g. N2O and CH4) arising from livestock, manure and soils	CH4 and N2O arising from mineral and organic fertilization	Accounted using default factors of IPCC guidelines for National GHG Inventory

Certification procedures

CFP certification workflow (ISO 14067:2013)



CFP performance tracking report (ISO 14067:2013)

Allows for the comparison of CFP results of the same product over time with respect to its original or previous CFP.

The main contributions to the change in CFP shall be specified, e.g. :

a) improvements made by the reporting organization;

b) selection of other suppliers;

c) improvements made by suppliers;

d) improvements in the use stage and in the end-of-life stage made by improved product design or an improved end-of-life procedure;

e) changes due to process improvements, e.g. introducing no-till or low-till cultivation, external input of C in agricultural processes.

Proposal for monitoring of SOC changes as verification tool

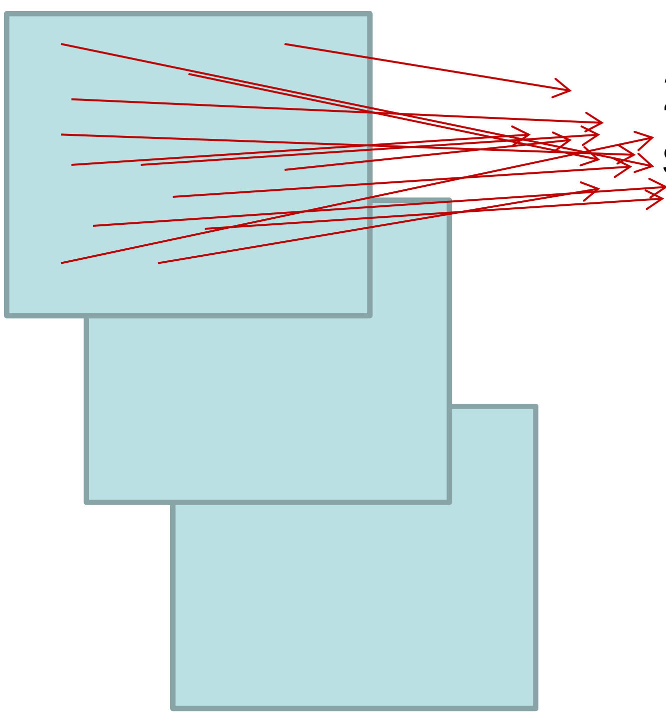
- Every 5 years
- Minimum of 3 analysis on 75/18 soil samples per ha

This will also help to have a dataset on SOC variation useful for RothC implementation

Proposal for monitoring of SOC changes as verification tool

Soil sampling method 1

x3 areas per Ha



25 soil samples → 1 bulk sample

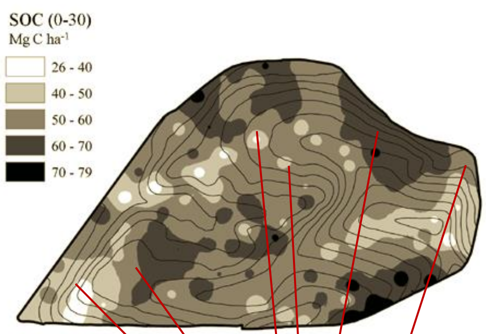
Tot 75 soil Samples → Tot 3 bulk samples for C determinations (30 €)

(1 day-work)

Proposal for monitoring of SOC changes as verification tool

Soil sampling method 2

EMI survey (200 €)



6 areas
(3 samples each)

Tot 18 soil
Samples

(1 day-work)

Tot 3 bulk samples for C determinations (30 €)

….ECONOMIC ADVANTAGE

CO_2 CO_2 CO_2 CO_2 CO_2 CO_2 CO_2

SUSTAINABLE

CO

CO_2 CO_2

CO_2 CO_2 CO_2

CO_2 CO_2 CO_2 CO_2

???? Euro per t CO_2

CONVENTIONAL

oLIVE-CLIMA

Introduction of new olive crop management practices focused on climate change mitigation and adaptation.
LIFE11 ENV/GR/000942

LIFE CLIMATREE-“A novel approach for accounting & monitoring carbon sequestration of tree crops and their potential as carbon sink areas”
LIFE14 CCM/GR/000635

Gruppo di Frutticoltura e viticoltura

C. Xiloyannis
B. Dichio
V. Nuzzo
G. Montanaro
G. Celano
D. Palese
A. Sofo
G. Tataranni
A.Tuzio
E. Lardo
A. Mininni
A. Fiore
E. Xylogiannis

Thank you

Agreenment s.r.l. Spin Off Accademic
University of Basilicata
www.agreenment.it