INSTITUTE OF LIFE SCIENCES
Scuola Superiore Sant'Anna

Seasonal School
THE SOIL – WATER AND PLANT CONTINUUM FOR URBAN AND RURAL WASTEWATER PHYTOTREATMENT AND CONTAMINATED SITE REMEDIATION (SWAP)

WORKSHOP/WEBINAR

Phytoremediation of contaminated land and phytotreatement of polluted water: successfull case studies

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30th June 2021 —- from 14.00 pm to 18.15 pm
Aula Magna Storica — Scuola Superiore Sant'Anna, Pisa (Italy)

Phytotreatment techniques for dredging sediments: the LIFE AGRISED and LIFE SUBSED experiences

Grazia Masciandaro – CNR-IRET

Dredging sediment management

Every year in Europe 100-200 million m^3 of polluted sediments are dredged and need to be disposed of in specific and expensive ways.

On a national level, port sediments in surplus amount to about 50 million m^3 with an average increase of about 5 million m^3/year.

Italy is the second European country in the Mediterranean for the length of its coasts and it has 653 ports (Apat 2006)

Contaminated sediment = dangerous waste

The quality of the sediment is defined exclusively by the concentration values of the contaminants

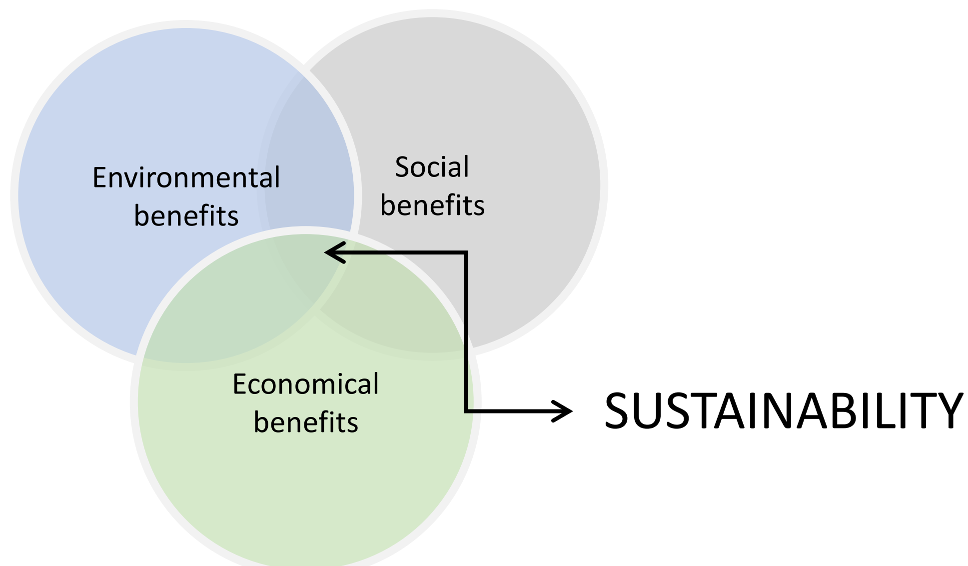
Consolidated technologies

- Landfill disposal
- Inertization

future perspectives

Contaminated sediment ≠ dangerous waste

No more destructive remediation goals



GREEN DEAL 2019

The Green Deal sets ambitious targets of which the circular economy is a key element

Normative upgrade path from waste to resource

D. LGS.152/06 art.183

sediment = waste?

…any substance or object that falls within the categories listed in Annex A Part Four of this decree and of which the holder decides, has decided or is obliged to discard.

D.M. 173/2016

sediment = resource

The new decree starts from the assumption that sediment is a resource to be recovered and used

…Many steps forward but critical issues remain

COMPLEX MATRIX

Bio-geo-morphological characteristics

Biogeochemical aspects

- Sink of contaminants
- **Difficulty of treatment due to compact physical structure and low microbial activity**
- Multiple factors impact on their quality and danger

Ecological aspects

- In direct contact with other matrices: biota-water-air

Normative aspects

EU Regulations

- Lack of specific rules for sediments
- Lack of EU standardized sediment quality guidelines

Different scientific approaches

- Empirical, theoretical and/or integrated

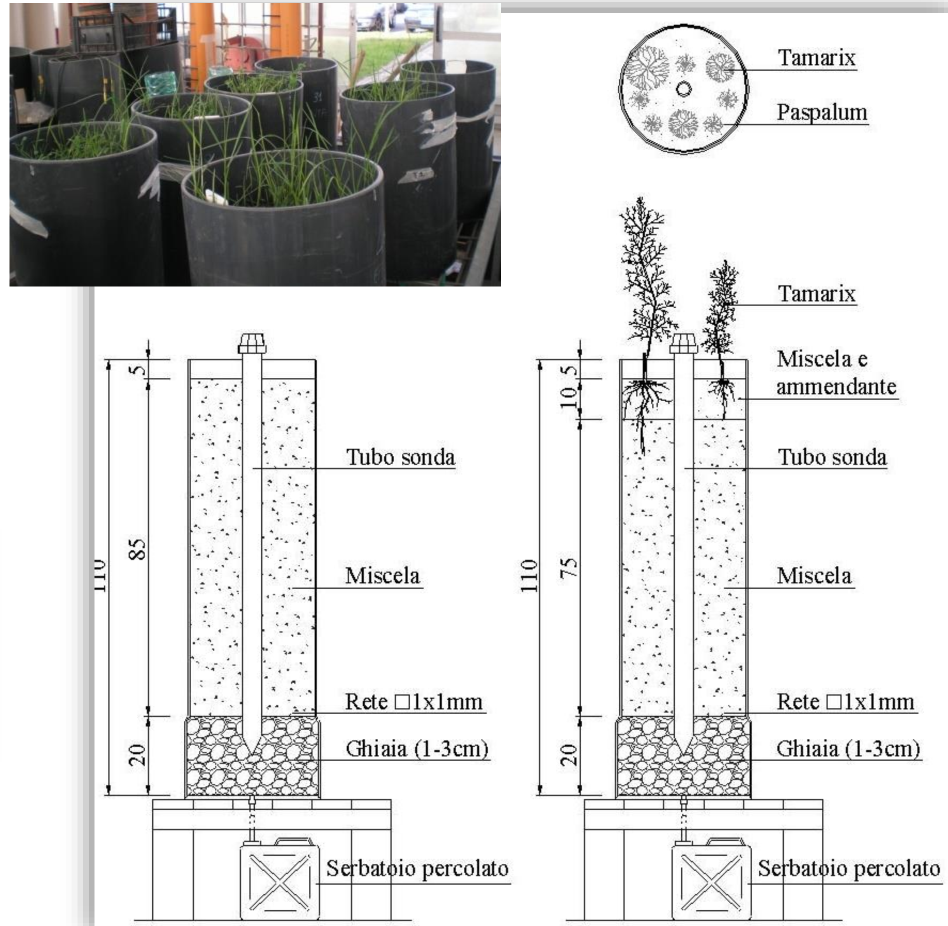
Member States legislation

- Different ways of characterization
- Continuous regulatory updating

Preliminary experiments on mesocosms

association of a grass and a schrub

Addition of earthworms



Physical/chemical pre-conditioning:

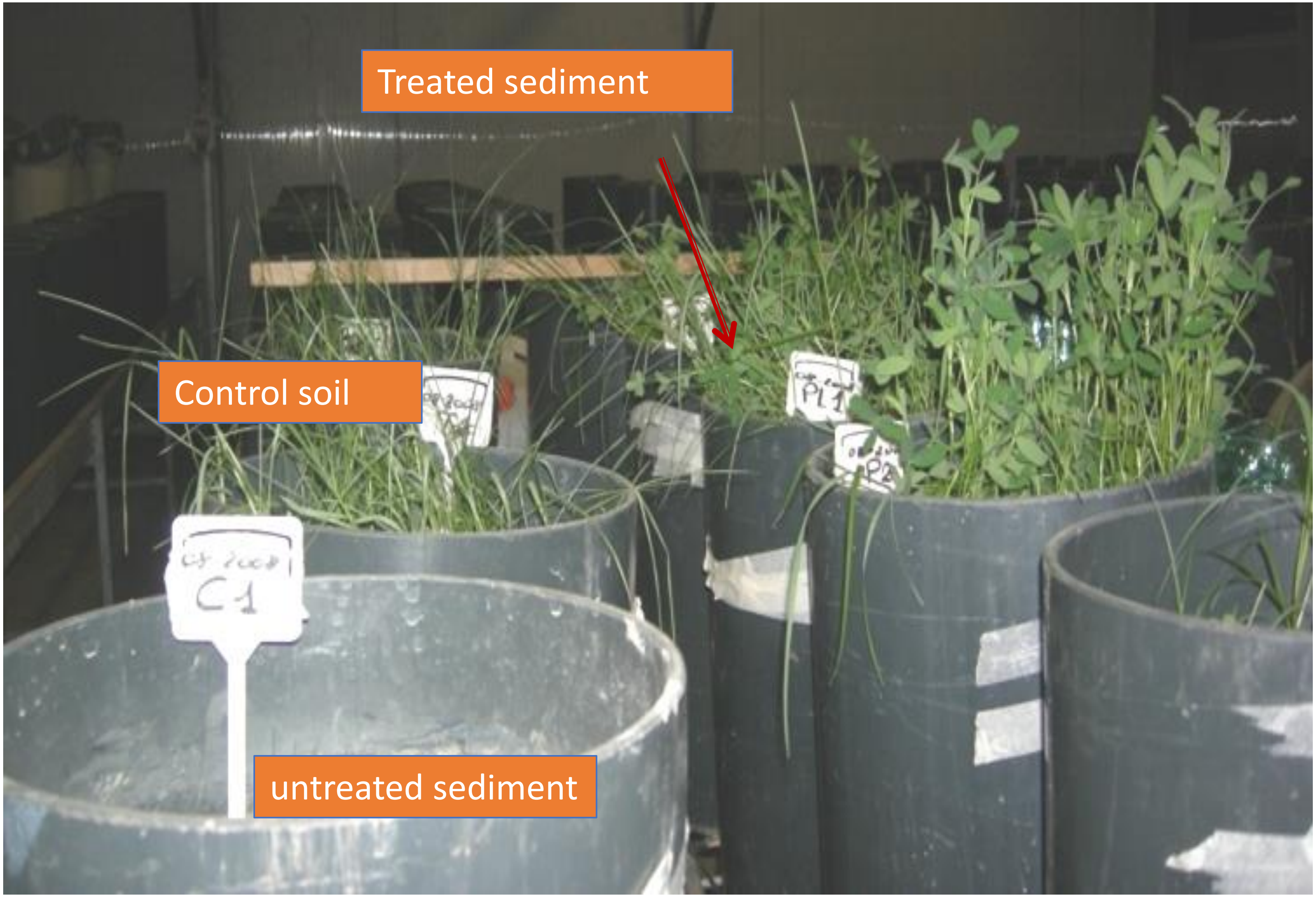
a) Sediment : soil mixing (5:1 v/v)

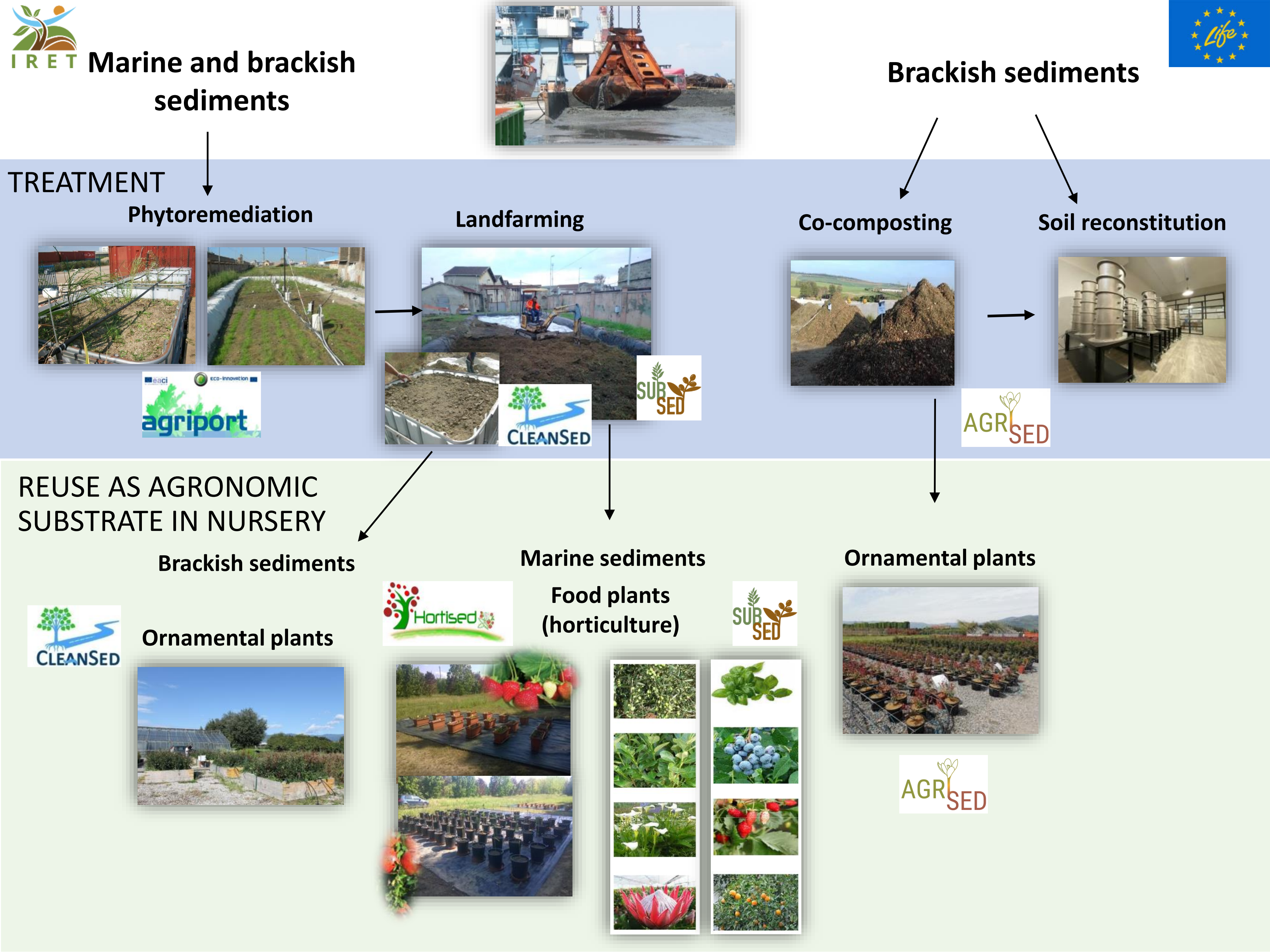
$K_0 = 10^{-6}$ m/s → $K = 10^{-3}$ m/s

b) Planned irrigation aimed at reducing salinity to levels tolelated by the selected plants.

c) Surface application of vegetal compost

Capacitive probe for detection of soil moisture vertical distribution


Treated sediment
Control soil
untreated sediment


IRET
Marine and brackish sediments
Brackish sediments
TREATMENT
Phytoremediation
Landfarming
Co-composting
Soil reconstitution
agriport
CLEANSED
SUBSED
AGRISED
REUSE AS AGRONOMIC SUBSTRATE IN NURSERY
Brackish sediments
Marine sediments
Ornamental plants
CLEANSED
Ornamental plants
Hortised
Food plants (horticulture)
SUBSED
AGRISED

Research objectives

Research aimed at **reclaiming slightly contaminated sites through phytoremediation** as an innovative technology to recover dredging sediments using plants.

Two experimental sites:

1. **Marine sediments from harbor (Livorno, Italy)**

2. **Brackish sediments from navigable canal (Pisa, Italy)**

agriport

Agricultural Reuse of Polluted Dredged Sediments

ECO-innovation
WHEN BUSINESS MEETS THE ENVIRONMENT

executive agency eaci
EUROPEAN COMMISSION
for competitiveness & innovation

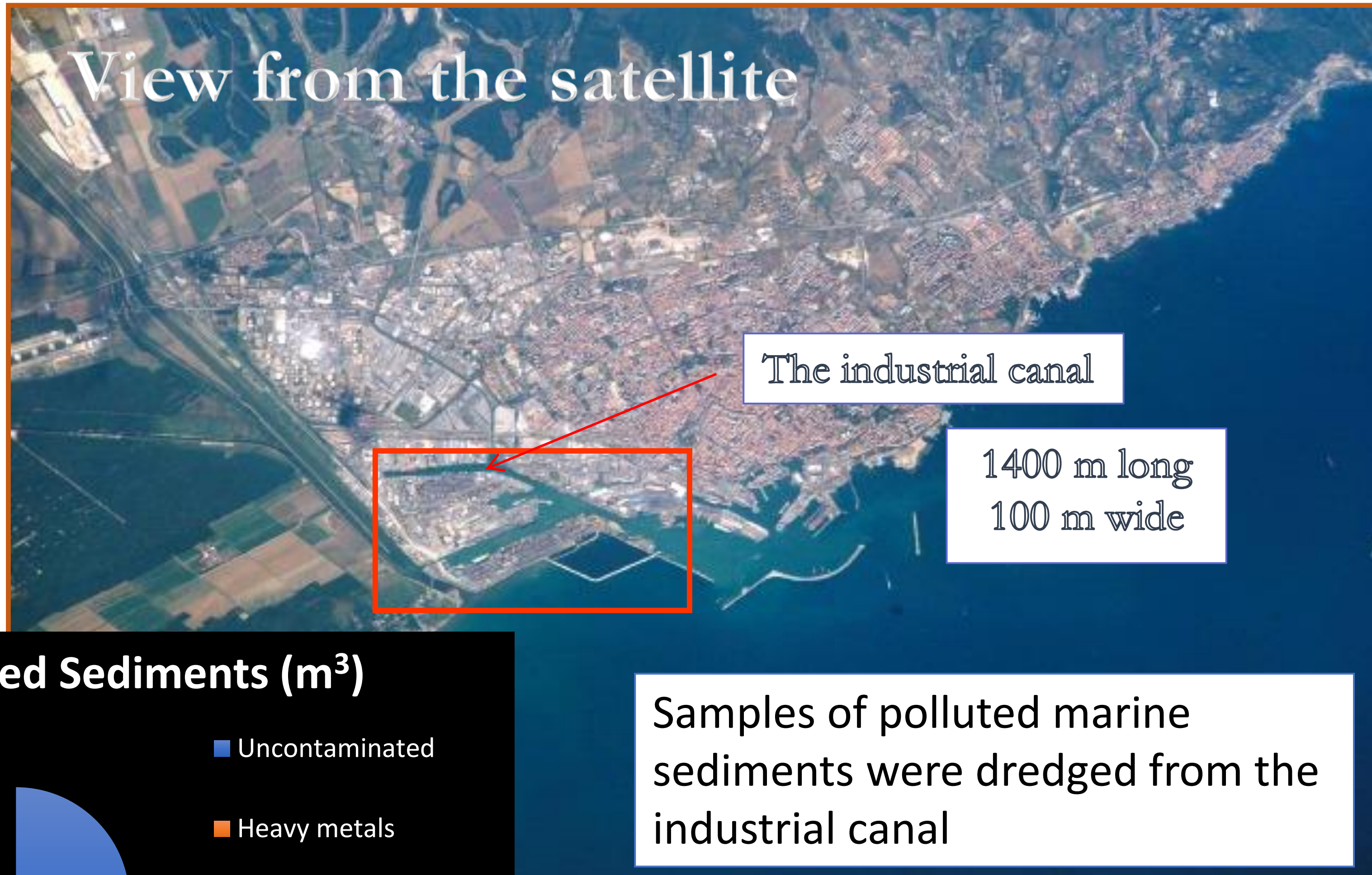
Specific Objectives

An integrated system, at pilot level, based on simultaneous **plant–microorganism** action is proposed for the recovery of dredged marine sediment from the following points of view:

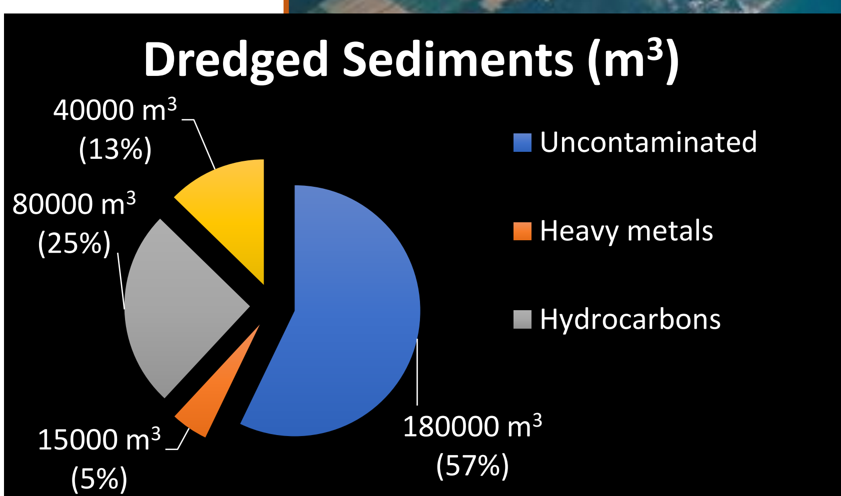
1) Contaminant reduction (**DECONTAMINATION**)

2) Restoration of agronomical and biochemical fertility (**FUNCTIONAL RECOVERY**)

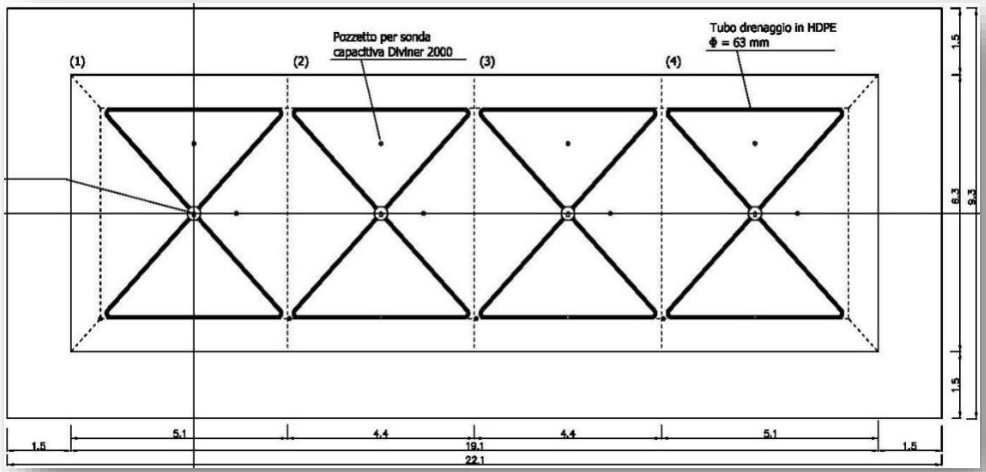
The Livorno harbour
(Central Italy)



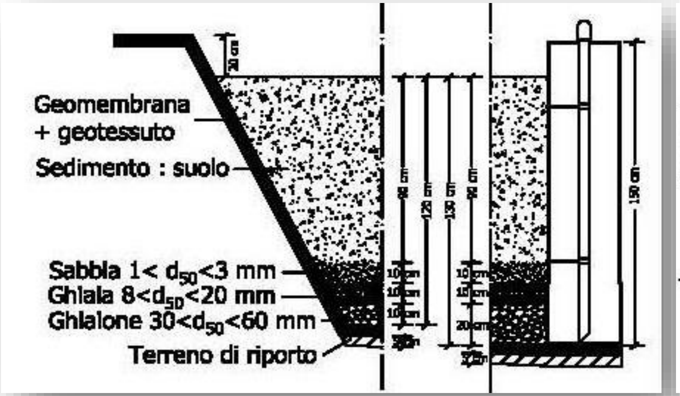
Samples of polluted marine sediments were dredged from the industrial canal

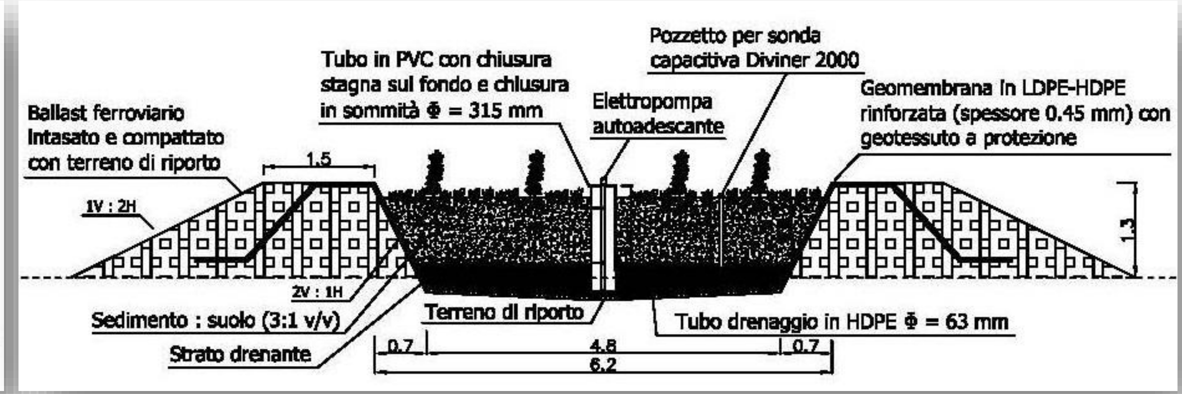


Design of the basin



- Length 15 m
- Width 6 m
- Depth 1.3 m
- Treated sediments 80 m^3

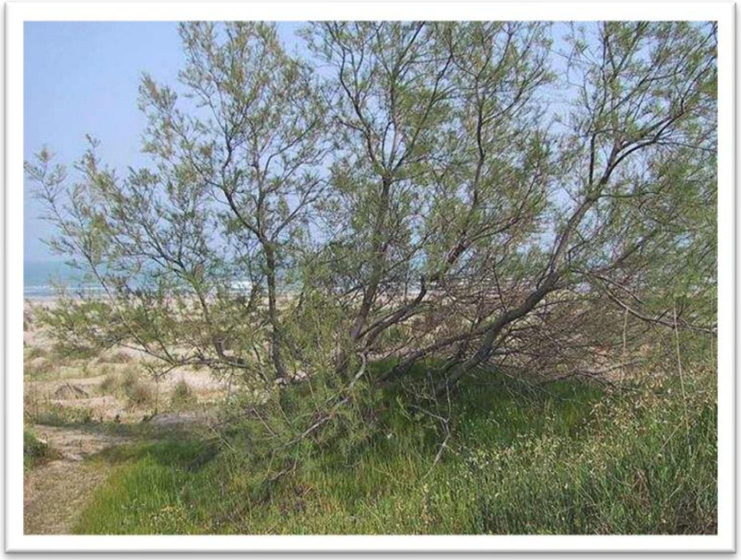




Plants selection

1. High adaptability to water stress;
2. Resistance to high salt concentrations;
3. Survival in the presence of pollutants.

Paspalum vaginatum

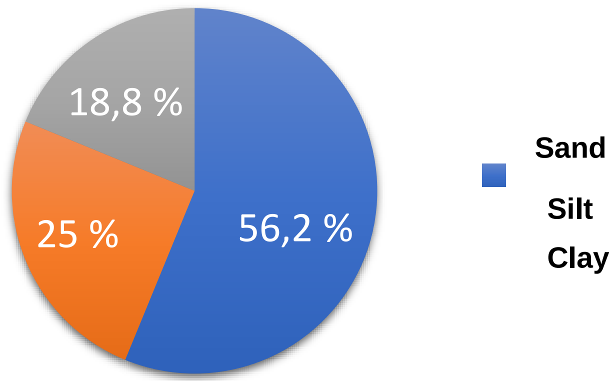


Tamarix Gallica

Spartium Junceum

Characteristics of sediments

	Sediment	Soil	Compost	Mix Soil -sediment	Italian legislation 152/06 Column A
Clay (%)	38.0	4.6	-	18.8	
Silt (%)	46.5	26.2	-	25.0	
Sand (%)	15.4	69.2	-	56.2	
pH	7.78	7,99	6.92	7.1	
E.C. (dS m^{-1})	3,0	0.20	3.69	1.9	
TOC (%)	1.20	0,075	45.1	0.860	
TN (%)	0.119	0	1.49	0.078	
TP (mgP kg^{-1})	640	197	2015	536	
Cd (mgCd kg^{-1})	1.55	-	1.44	1.43	2
Cu (mgCu kg^{-1})	65	-	80.7	52.0	120
Zn (mgZn kg^{-1})	278	-	258	256	150
Ni (mgNi kg^{-1})	84	-	21.7	63.0	120
Pb (mgPb kg^{-1})	83	-	35.5	64.0	100
Cr (mgCr kg^{-1})	60	-	30.0	37.0	150
TPH (mgTPH kg^{-1})	1566	-	-	1430	10 + 50 (C<12+ C>12)



Pre-condictioning

✓ **Sediment : soil (5:1 v/v)**

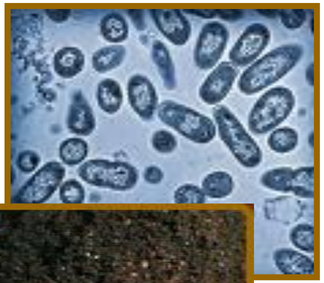
✓ **A top layer (about 10 cm) mixed with green compost (40 t/ha) to give nutritional support at the early stage of plant development**

Experimental setup

Organic matter (compost) addition

Planting - *Paspalum vaginatum*, *Tamarix gallica*, *Spartium junceum*

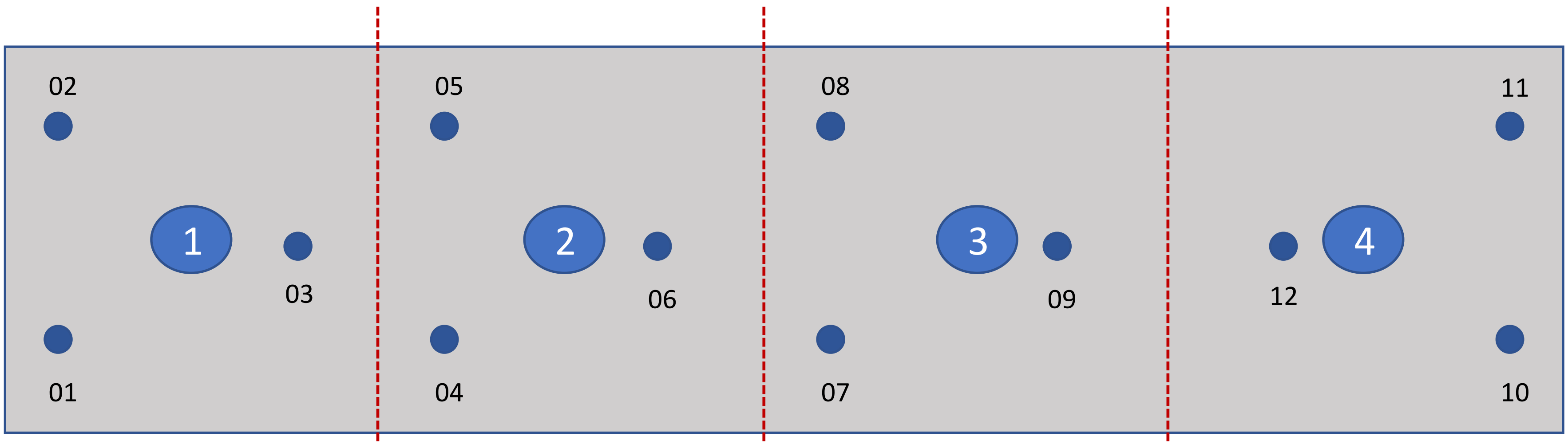
Organic matter role



- **Physical:**
  - Improves sediment structure
  - Increases porosity and water-holding capacity
- **Chemical:**
  - Modifies and stabilizes pH
  - Increases cation exchange capacity
  - Supplies nutrients
- **Biological:**
  - Increases microbial biodiversity and activity
  - Suppresses plant diseases
- **Other:**
  - Binds/degrades contaminants
  - Binds nutrients

All these characteristics enhance the sediment health and provide a medium satisfactory for plant growth.

Experimental setup

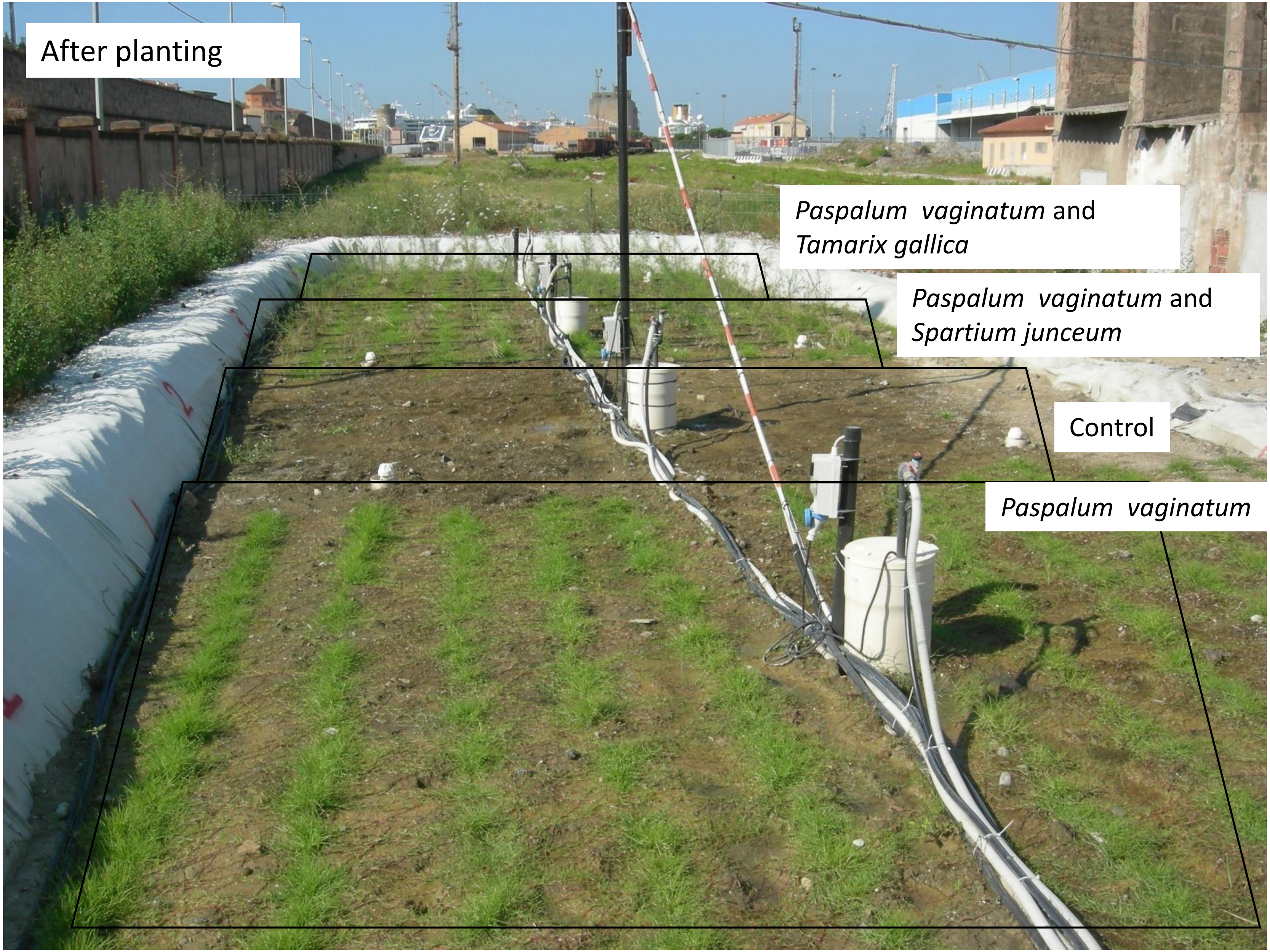


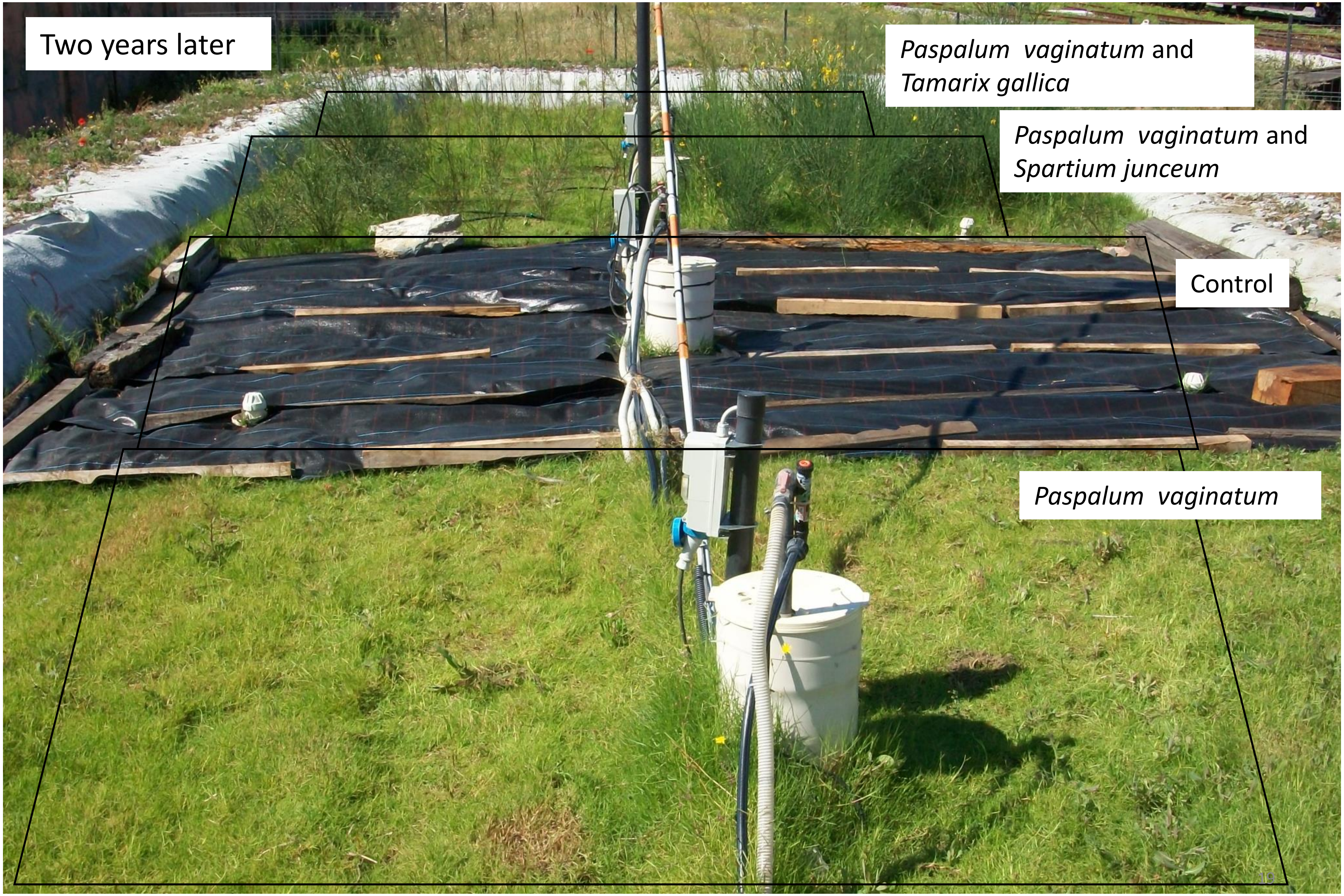
Paspalum (~1440 PLANTS)

CONTROL (NO PLANTS)

Spartium (~120 PLANTS) + Paspalum

Tamarix (~120 PLANTS) + Paspalum


After planting
Paspalum vaginatum and *Tamarix gallica*
Paspalum vaginatum and *Spartium junceum*
Control
Paspalum vaginatum


Two years later
Paspalum vaginatum and *Tamarix gallica*
Paspalum vaginatum and *Spartium junceum*
Control
Paspalum vaginatum

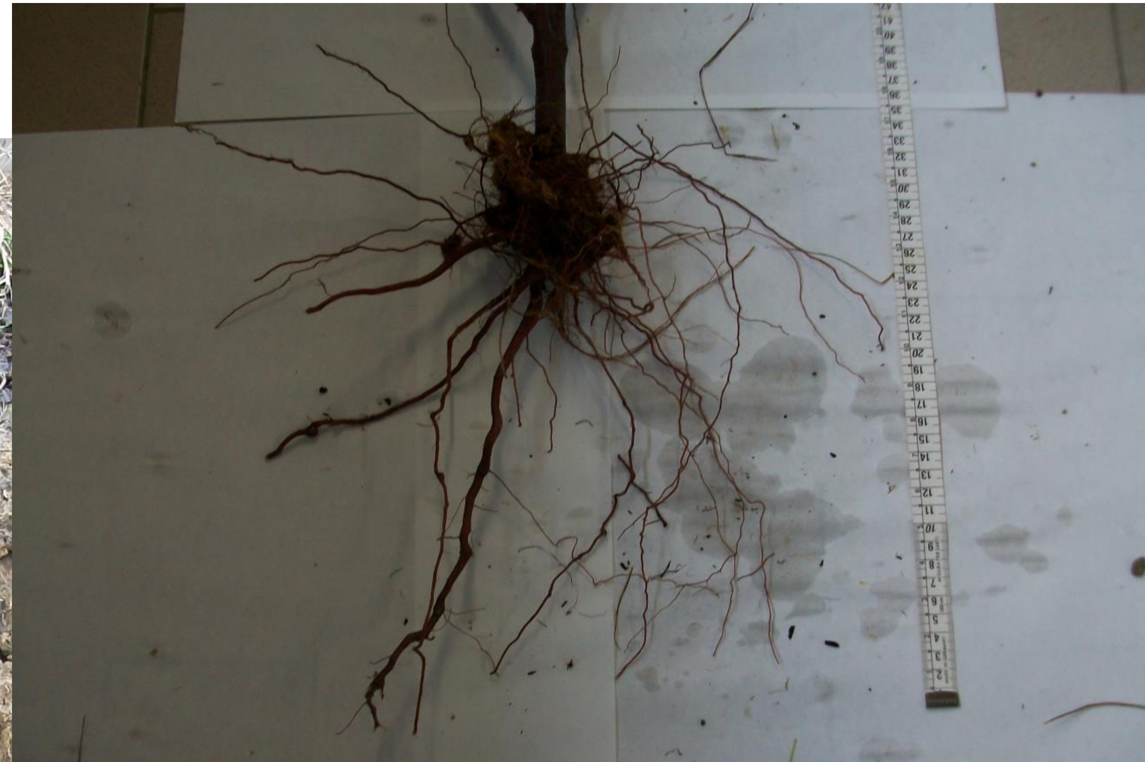
Paspalum vaginatum

IRET

Spartium Junceum

Spartium junceum (L.) has a root system predominantly taproot,
consisting of few roots with a diameter between 10 and 20 mm and a depth between 50 and 80 cm.

Tamarix Gallica



Root depth: 40 cm

Tamarix gallica usually has a root system consisting of roots with a depth between <u>60 and 100 cm</u>.

Plant growth

	P+S treatment	P+T treatment	P treatment
	Spartium junceum	***Tamarix gallica***	***Paspalum vaginatum***
	Height cm		Coverage %
June 2010 (T0) after planting	**20**	**25**	**20**
December 2011 (T3) 1.5 year	**143±33**	**130±24**	**100**
Growth from T0 to T3	**715%**	**520%**	**500%**

P+S, *Paspalum+Spartium*; P+T, *Paspalum+Tamarix;* P, *Paspalum*

Monitoring

The monitoring of the pilot system consisted of samplings carried out twice a year. The results **after planting (T0)** and **after two years (T3)** from the experiment set up are reported.

- **Agronomical parameters:**
  - Total Organic Carbon
  - Total Nitrogen (TN)
  - Total Phosphorus (TP) Nitrate

1) Functional recovery:

- **Biochemical parameters:**
  - Microbial population quantity
  - Microbial biodiversity
  - Microbial activity:

    1) *general parameters* (ATP, CO_2, Dehydrogenase activity)

    2) *specific parameters* (hydrolitic enzymes)

Enzyme role:

- Provide information about the nutrient cycles
- Expression of the level of microbial activity in soil
- Ecological and functional response of sediment to recovery practices

2) Decontamination:

- **Inorganic and organic contaminants:**
  - Heavy metals : Zn, Pb, Ni, Cu, Cr, Cd
  - Total Petroleum Hydrocarbon (TPH)

Enzymes in soil and sediment

1) Intracellular enzymes: within microbial cells
2) Extracellular enzymes: a) free and b) stabilised with organo-minral compounds (humus-enzyme complexes)

Intracellular enzymes being inside the microbial cells are very sensitive to any environmental change and are strictly **dependent** from microbial biomass number and activity

Extracellular enzymes reprensent the biochemical activity **not dependent** from microorganisms

Extracellular enzymes adsorbed to, ***complexed*** with, or ***entrapped*** within clays and humus (***humo-enzyme complexes***), are relatively stable and can persist for extended periods.

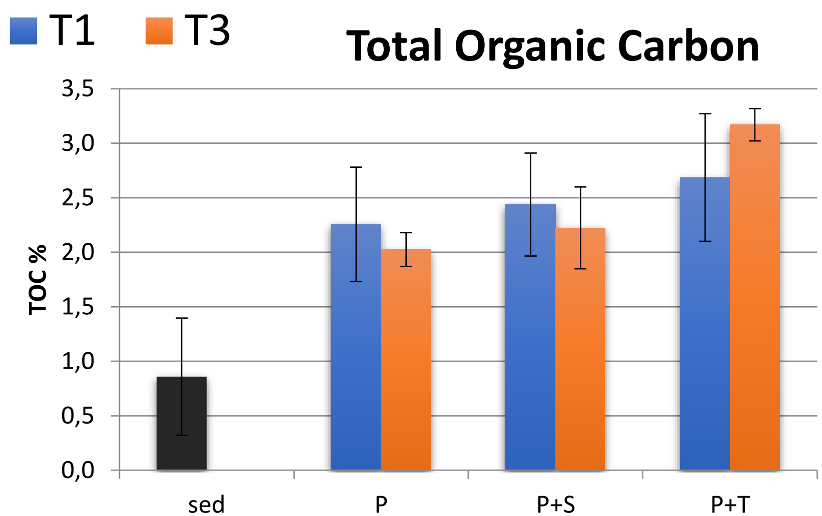
The activity of stabilised enzymes can be important under conditions unfavourable for the microbial activity

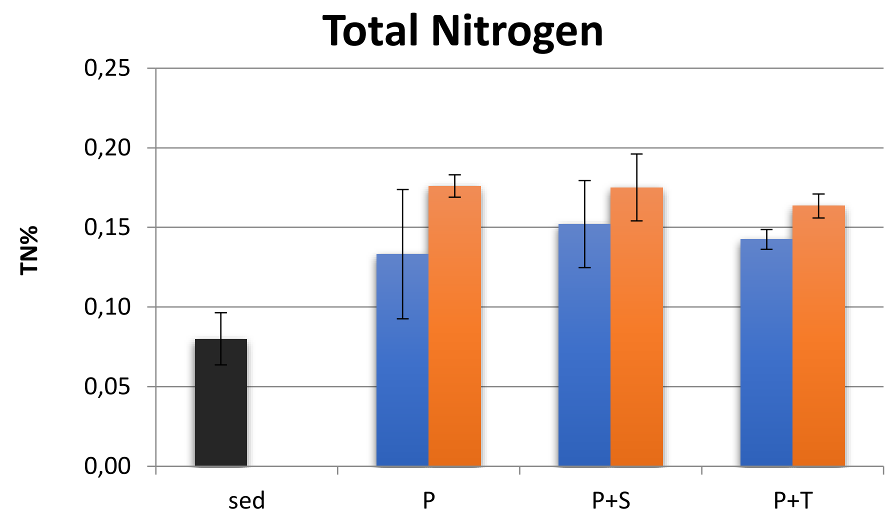
It is possible that an intial build up on an extracellular component is vital during the **early stages of microbial proliferation**, because such enzymes may catalize the commencement of degradation of the macromolecular substrates

Results

1) FUNCTIONAL RECOVERY: agronomical parameters

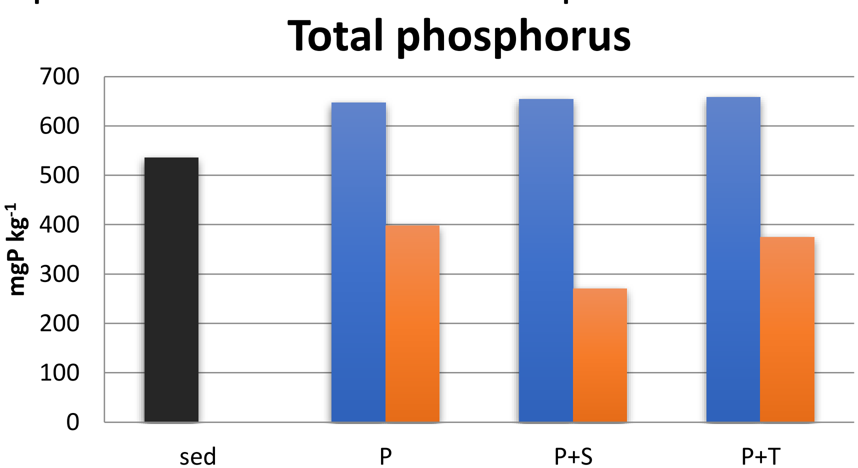
P, *Paspalum*;
P+S, *Paspalum+Spartium*;
P+T, *Paspalum+Tamarix*

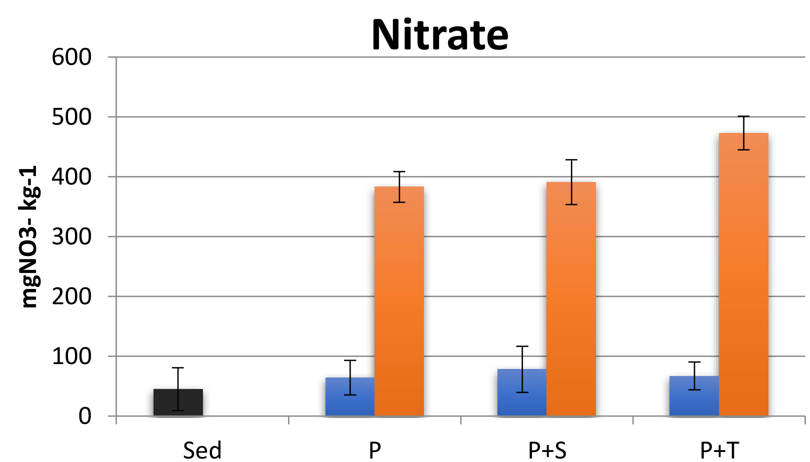




The maintenance of a vegetation cover exerts a positive influence on the input of C in sediment

Improvement of the chemico-physical conditions for microorganisms and plants



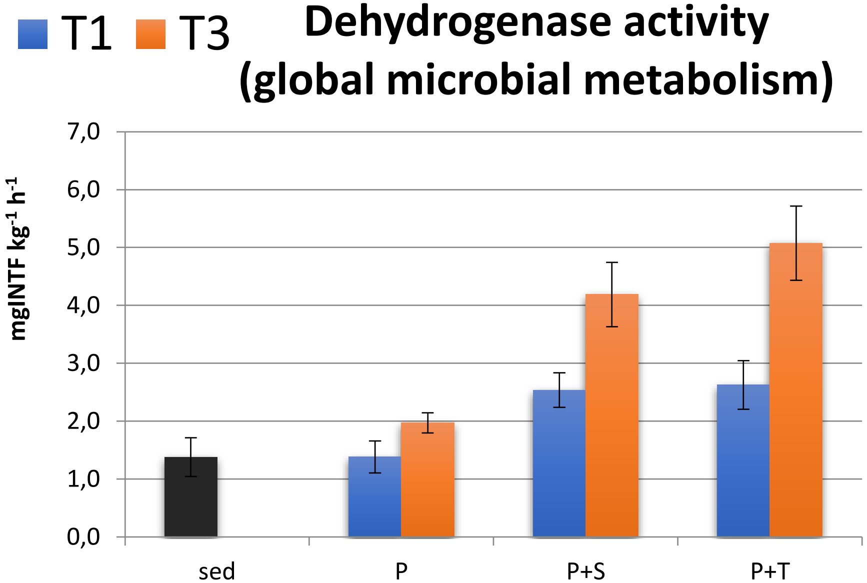


Results

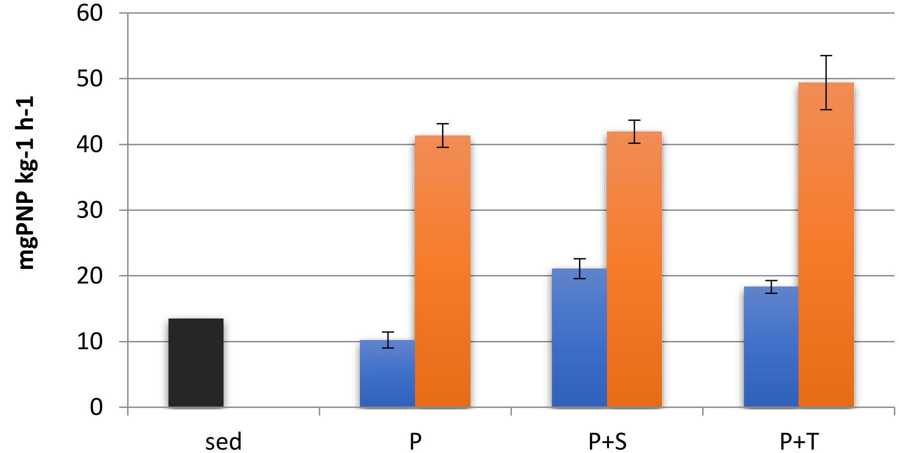
1) FUNCTIONAL RECOVERY: biochemical parameters

P, *Paspalum*;
P+S, *Paspalum+Spartium*;
P+T, *Paspalum+Tamarix*

Dehydrogenase activity (global microbial metabolism)

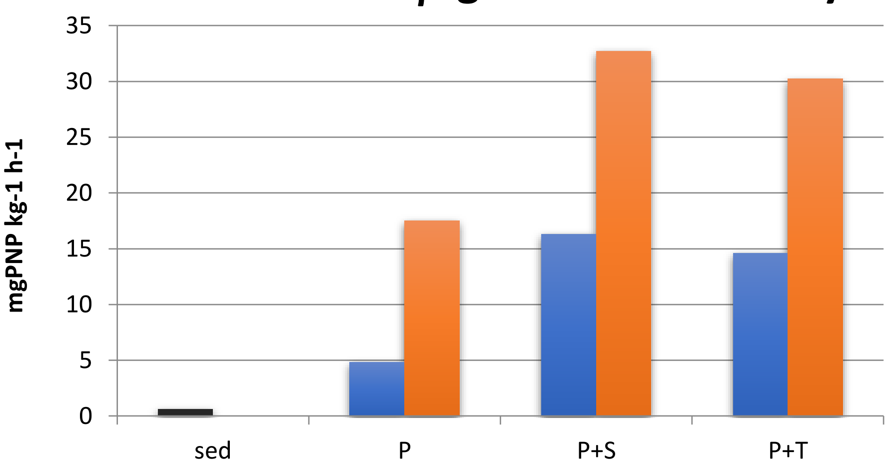


Total β-glucosidase activity (Carbon cycle)

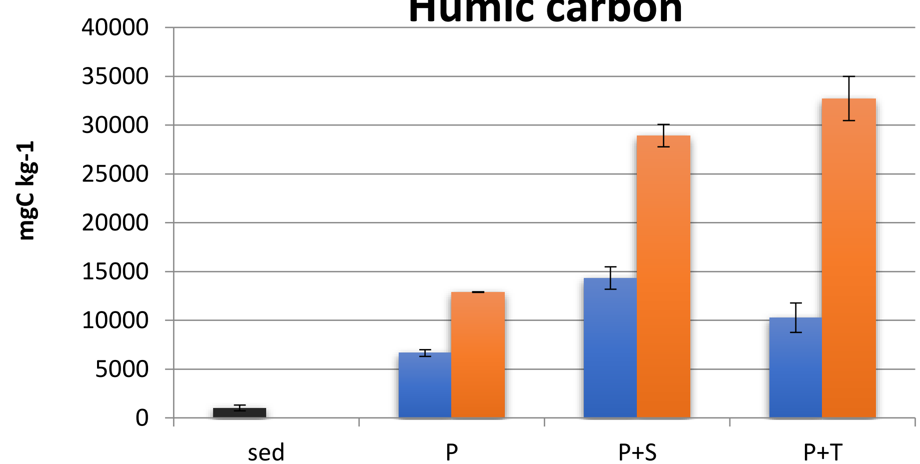


Formation of stable organic matter (<u>humus</u>) rich in biochemical energy (<u>enzyme activity</u>)

Extracellular β-glucosidase activity



Humic carbon

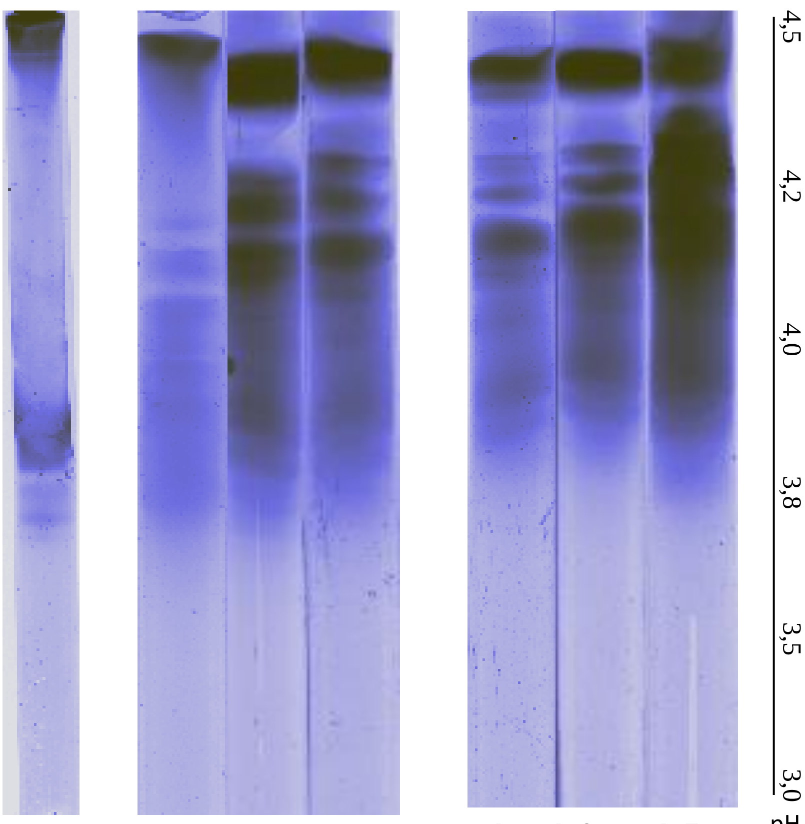


Results

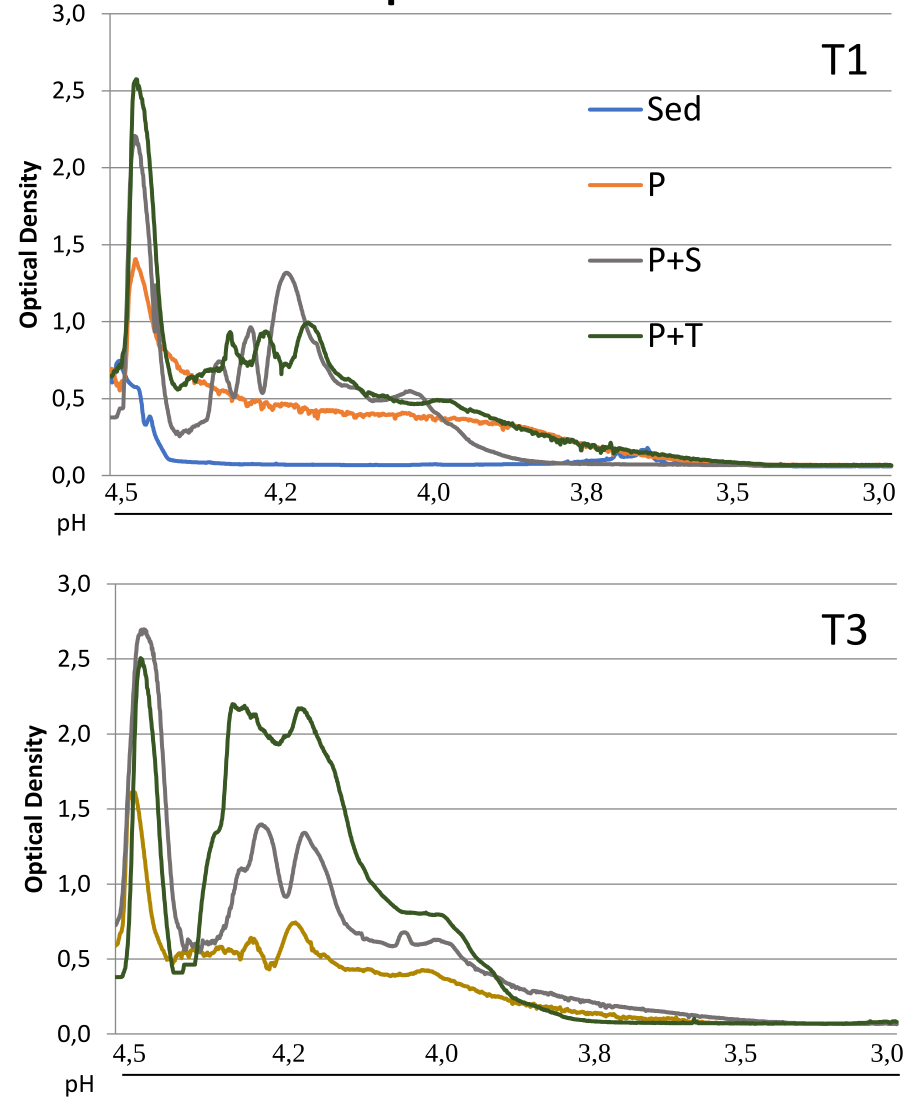
1) FUNCTIONAL RECOVERY: biochemical parameters

Isoelectric focusing

Enzyme purification



IEF profile



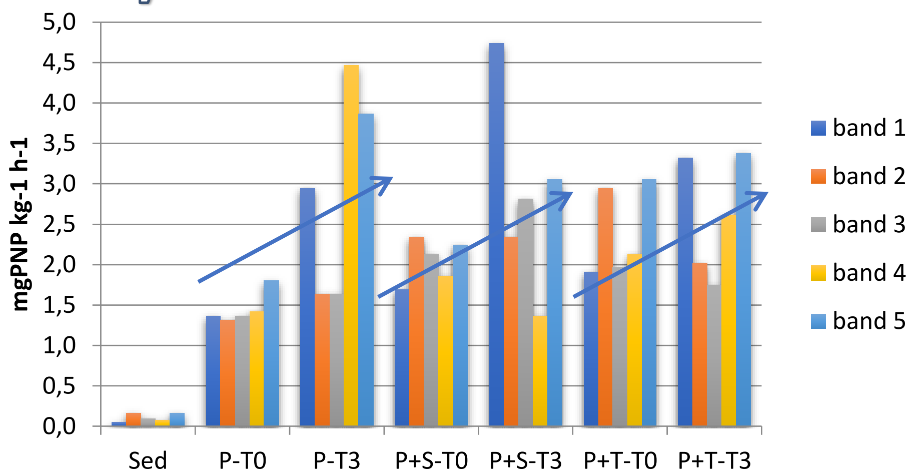
P, *Paspalum*; P+S, *Paspalum+Spartium*; P+T, *Paspalum+Tamarix*

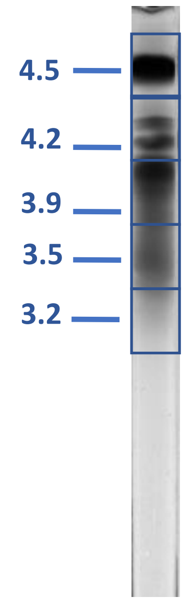
Results

1) FUNCTIONAL RECOVERY: biochemical parameters

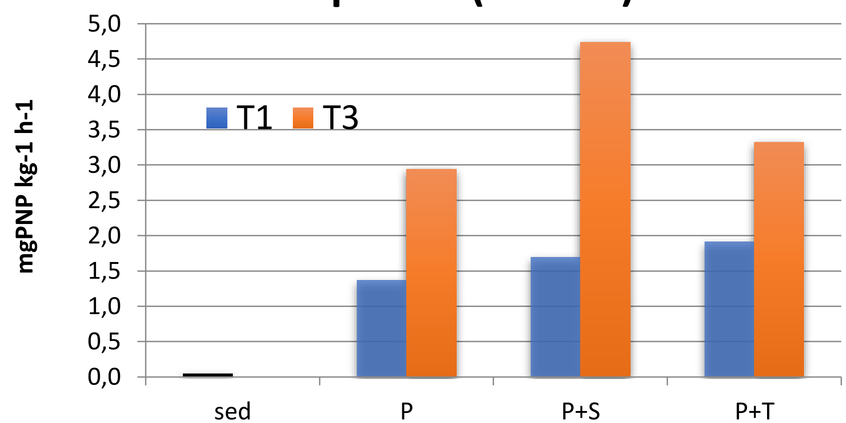
Enzyme purification

Enzyme activities in the IEF bands





Humic-β-glucosidase activity pH 4.5 (band 1)



Corroboration of the strict linkage between extracellular enzyme and humic substance (stable humo-enzyme nucleus)

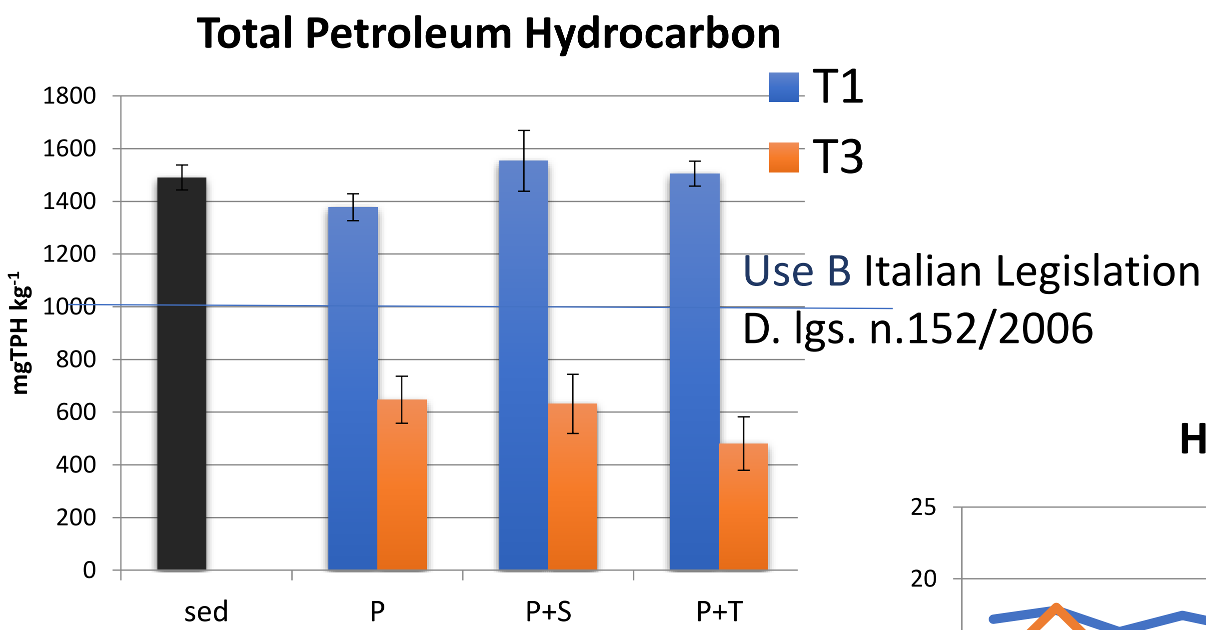
P, *Paspalum*; P+S, *Paspalum+Spartium*; P+T, *Paspalum+Tamarix*

Results

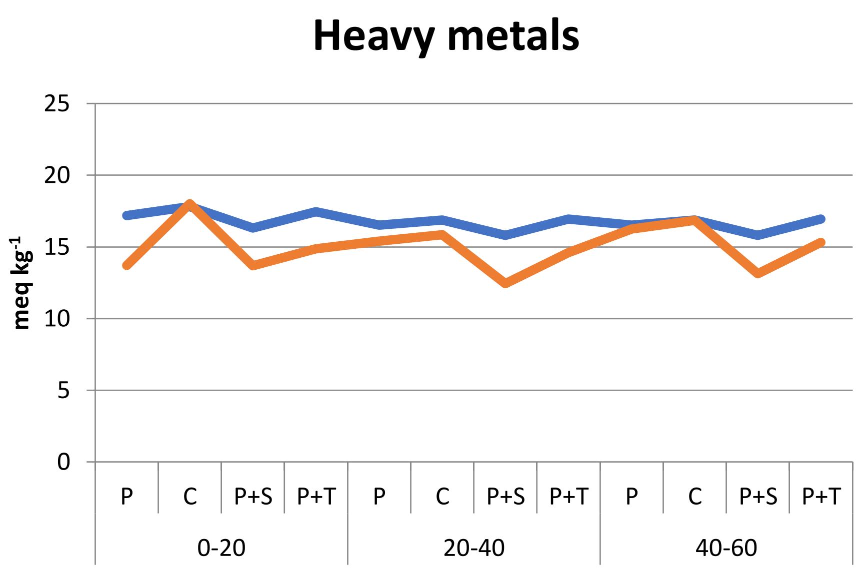
2) DECONTAMINATION:

- **Heavy metals :Cd, Cu, Ni, Zn, Pb, Cr**
- **Total Petroleum Hydrocarbon (TPH)**

P, *Paspalum*;
P+S, *Paspalum+Spartium*;
P+T, *Paspalum+Tamarix*



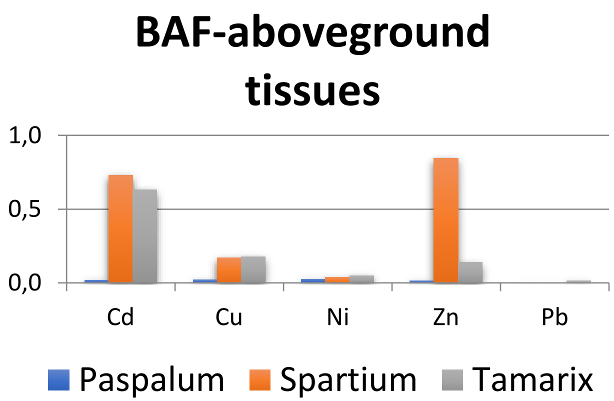
The decrease during the time of TPH indicated the effectiveness of the phytoremediation system (about 60%).

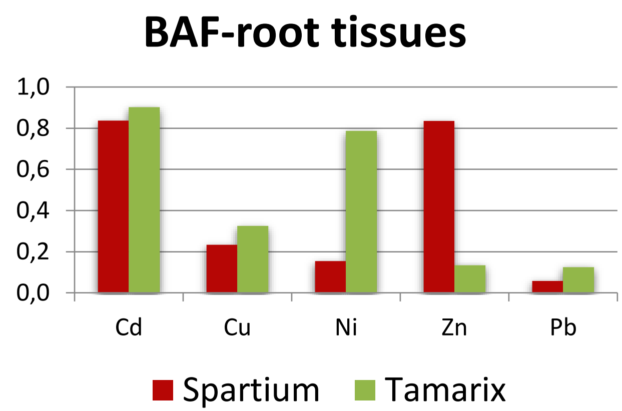


Metals in plant tissues

BAF=Cplant tissue/Csediment, where Cplant tissue and Csediment are metals concentration in the plant tissue (aboveground or root) ($mg\ kg^{-1}$) and sediment ($mg\ kg^{-1}$)

Bioaccumulation factor (BAF)

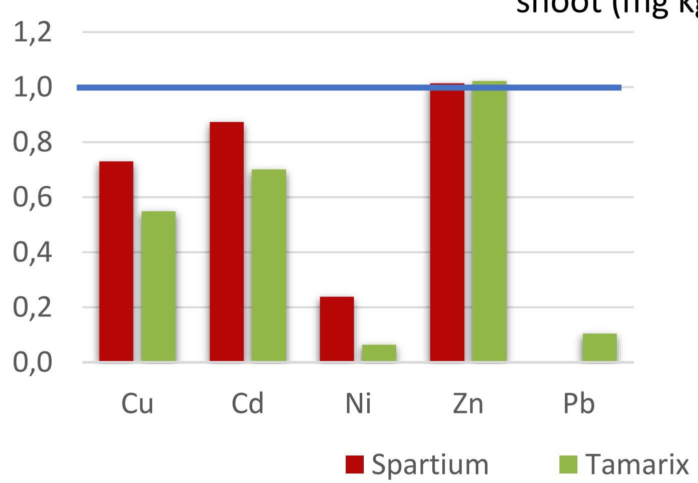




BAF was generally higher in roots with respect to aboveground tissues in both *S. junceum* and *T. gallica*, the BAF of Cd was the higher in the two shrub plants, thus confirming its higher plant availability.

Translocation factor (TF)

$TF=C_{shoot}/C_{root}$, where C_{shoot} and C_{root} are metals in the shoot ($mg\ kg^{-1}$) and root of plant ($mg\ kg^{-1}$)

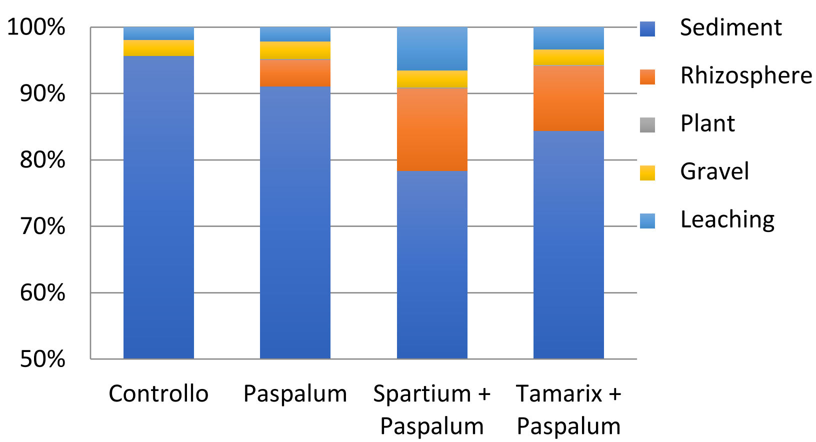


In agreement with BAF, metals accumulated by the selected plant species were largely retained in roots, TF values <1

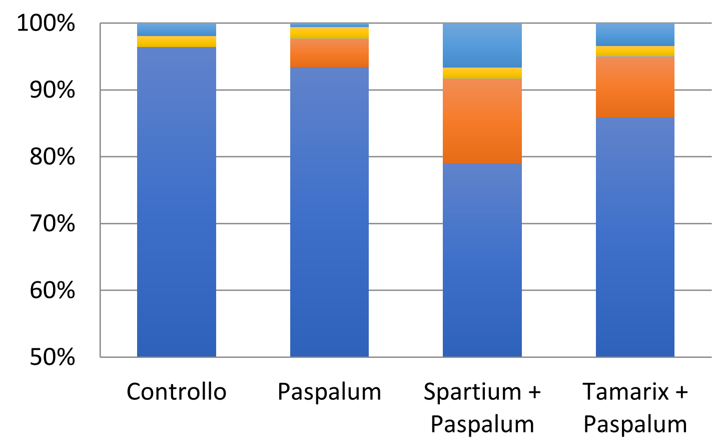
Zn Cu, Cd were more translocated

Heavy metal mass balance

Heavy metals



Zn



Concentrations of heavy metals in the leachate

	E.C. dS/m	pH	Cd mg/l	Cu mg/l	Ni mg/l	Zn mg/l	Pb mg/l	Cr mg/l
After planting (T0)								
P	10.5	7.96	0.014	0.027	0.032	0.070	<0,0060	0.033
C	10.6	7.78	0.013	0.013	0.035	0.060	<0,0060	0.015
P+S	9.67	7.96	0.013	0.017	0.039	0.063	<0,0060	0.013
P+T	9.41	7.79	0.017	0.047	0.036	0.180	<0,0060	0.006
Two years later (T3)								
P	0.90	7.05	0.0062	0.005	0.0086	0.05	0	0
C	2.96	6.92	0.0051	0.0051	0.0117	0.0333	0	0
P+S	0.72	7.22	0.0079	0.0045	0.0112	0.0618	0	0
P+T	1.42	7.42	0.0077	0.0056	0.0056	0.037	0	0
Limiti allo scarico D.Lgsl 152/2006								
Scarico in acque superficiali			0.02	0.1	2.0	0.5	0.2	2.0
Scarico sul suolo			-	0.1	0.2	0.5	0.1	1.0

Comments

FUNCTIONAL RECOVERY:

➢The improvement of the chemico-nutritional properties of all treated sediments indicated the activation of nutrient cycles sustaining the agronomical fertility.

➢The increase of the biochemical parameters in particular in the grass+shrub treatments, has a key role in the establishment and maintaining of soil quality.

Finally, extracellular enzymes linked to humic matter (humus-enzyme complexes) represent an ecological advantage since they could represent the starter engine to activate the processes contributing to a natural soil formation

DECONTAMINATION:

➢The decrease during the time of heavy metals (about 20%) and TPH (about 60%) indicated the effectiveness of the phytoremediation system.

Coordinator:

SGI Studio Galli Ingegneria (Padova, Italia)

Associated beneficiaries:

- Autorità Portuale di Livorno (Livorno, Italia)
- Università di Pisa - Dip. di ingegneria civile (Pisa, Italia)
- **CNR - Istituto per lo studio degli ecosistemi (Pisa, Italia)**
- Agricultural Research Org. - Volcani Center (Israel)
- D'Appolonia s.p.a. (Genova, Italia)
- DFS Engineering d.o.o. Montenegro (Montenegro)

National patent: Iannelli R, Masciandaro G, Ceccanti B, Bianchi V, Doni S (2012). Metodo per il trattamento di residui di dragaggio mediante fitorimediazione e impianto che realizza tale metodo. PI2012A000013. Il Brevetto italiano è stato rilasciato il 05/09/2014 con No. 0001410263

Brackish sediments

100-200 million m^3 of sediments are dredged yearly in Europe, about 65% contaminated and need to be disposed of in specific and expensive ways.

Brackish sediments

Navicelli Canal (Pisa-Italy) a navigable canal which connects Pisa to Livorno and flows into the sea

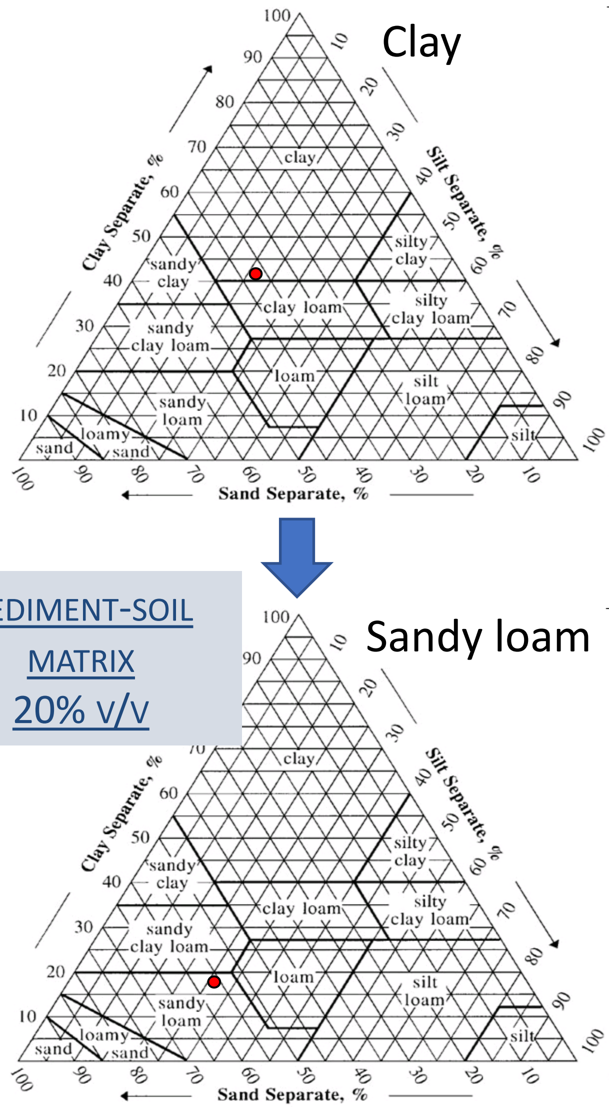
20 000 m^3 dredged yearly

View of the Navicelli canal

Length: 16 km
Width: 32 m
Depth: 3 m

Sediment characteristics in the storage basin of Navicelli

		Italian legislation 152/06	Italian legislation 152/06 Column B
Sand (%)			
Silt (%)			
Clay (%)			
Texture (USDA clas			
pH			
Electrical Conductiv			
Total Organic			
Total N (%			
C/N			
NH_4^+ (mg kg			
Total P (mg k			
Ni (mg kg			500
Pb (mg kg			1000
Cu (mg kg			600
Cr (mg kg			800
Cd (mg kg			**15**
Zn (mg kg			1500
Total Petroleum Hy (mg kg^{-1})		(C<12+ C>12)	**250+ 750 (C<12+ C>12)**



SEDIMENT-SOIL MATRIX
20% v/v

- High fraction of fine particles
- Unbalanced nutrient content
- Low biological activity
- Slight contamination of heavy metals and a more significant contamination of pollutant organic compounds.

Experimental setup

CONTAINERS OF ABOUT 1 m^3 FILLED WITH THE CONTAMINATED SEDIMENTS DREDGED FROM NAVICELLI CANAL

a) GRAVEL-SAND DRAINAGE,
b) PLASTIC NETWORK,
c) MIXTURE SEDIMENT-SOIL

CONTAINERS ARE EQUIPPED FOR GRAVITATIONAL LEACHATE COLLECTION

a)

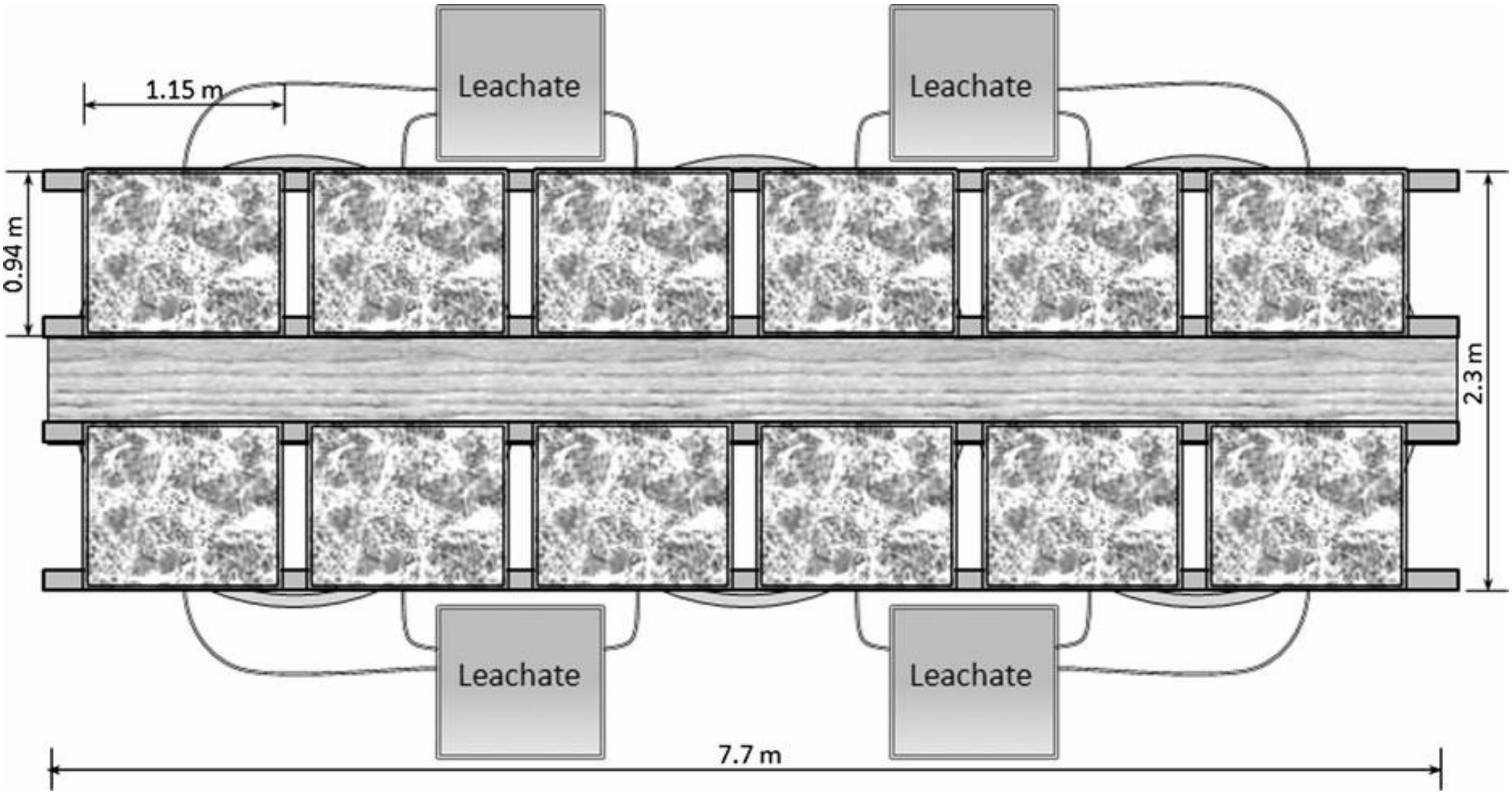
b)

c)

A HIGH QUALITY COMPOST WAS MIXED WITH THE SEDIMENT-SOIL MATRIX AT SURFACE LEVEL (40T/ha)

PLANTATION

Experimental scheme



Plant selection

TREATMENTS:

1. *Nerium oleander l. + Paspalum v.*
2. *Tamarix gallica + Paspalum v.*
3. *Spartium junceum + Paspalum v.*
4. *Phragmites australis*
5. *Paspalum v.*
6. Control

High adaptability to water stress and survival in presence of pollutants

Phragmites australis

Paspalum vaginatum

Nerium oleander

Spartium junceum

Tamarix gallica

Monitoring

The monitoring of the pilot system consisted of samplings carried out every six moths. The results **after planting** (Ti) and **two years later** (Tf) from the experiment set up are reported.

Sediment analysis

AGRONOMICAL RECOVERY

- pH and Electrical Conductivity (E.C.)
- Total Organic Carbon (TOC)
- Total Nitrogen (TN)
- Total Phosphorus (TP)
- Nitrate

DECONTAMINATION

- Heavy metals : Zn, Pb, Ni, Cu, Cr, Cd
- Total Petroleum Hydrocarbon (TPH)

ECOLOGICAL-FUNCTIONAL RECOVERY

- Total cultivable microbial population
- Dehydrogenase activity

Samples of the leachate were collected and analyzed in order to evaluate the need for further treatment before discharging

After two years

Nerium oleander (O)

Phragmites australis (Ph)

Spartium Junceum (S)

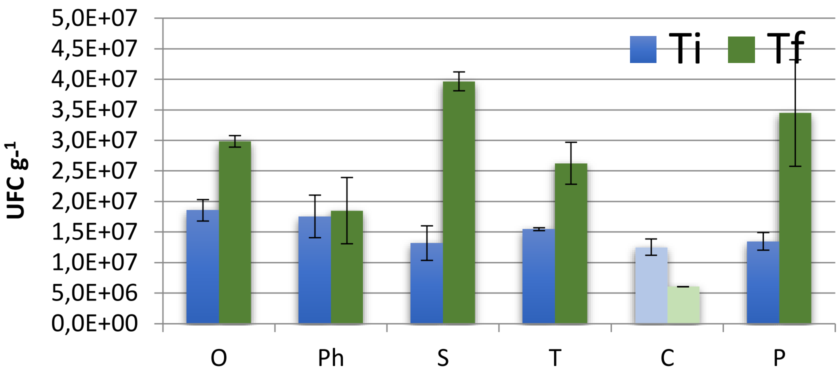
Tamarix gallica (T)

Plant growth	O	Ph	S	T
	Height (cm)			
October 2010	**25**	**20**	**20**	**25**
May 2012	**104±2.1**	**110±9**	**134±30**	**145±10**
Growth (%)	**410**	**551**	**670**	**581**

FUNCTIONAL RECOVERY

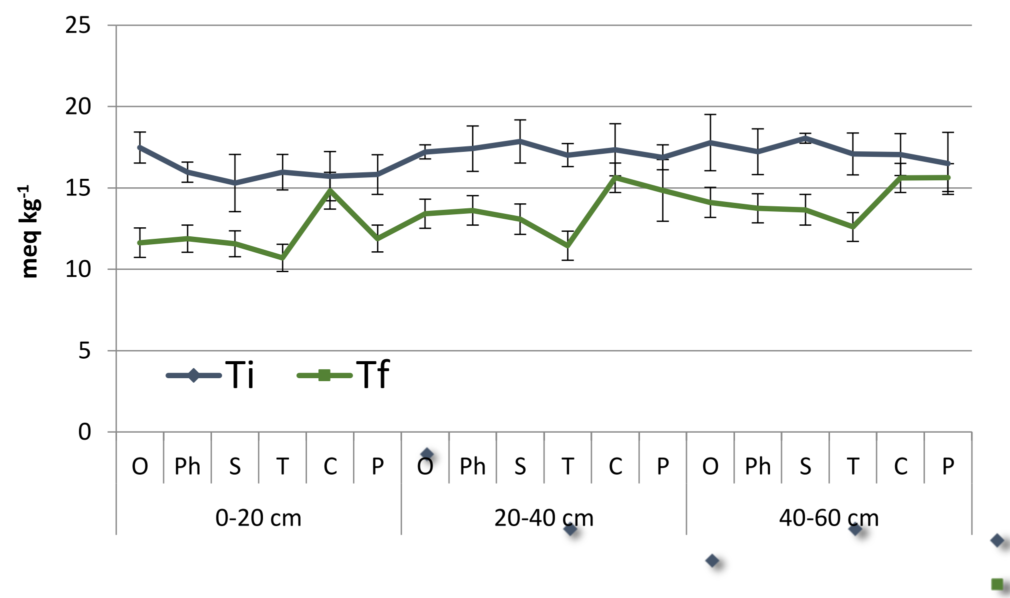
O= *Oleander +Paspalum*; Ph= *Phragmites*; S= *Spartium+Paspalum*; T= *Tamarix+Paspalum*; C=Control; P= *Paspalum*

Total cultivable microbial population



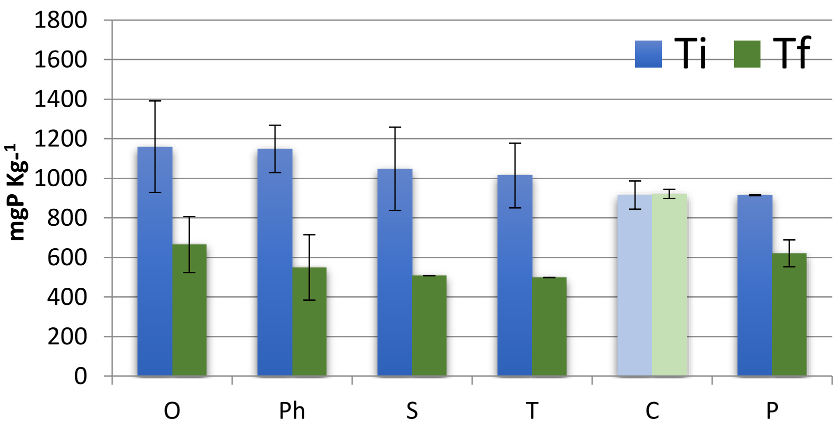
Significant increase during the time (>50%) in total cultivable microbial population

Heavy metals



DECONTAMINATION

Total Petroleum Hydrocarbons



Average decrease higher than 50%

Average reduction in heavy metals of 20%

Comments

- After two years from the experiment set up all the plant species were well adapted and in a healthy condition (plant growth 400-700%)
- An increase in the dehydrogenase activity, which is an enzyme related to the soil microbial functionality, was obtained at 20-40 and 40-60 cm in the shrub-grass treatments. This suggested an improvement of the chemical-physical conditions for microorganisms and plants
- The microbial metabolism stimulation in the plant treatments determined the higher efficiency of Ph, S and T plant species in TPH (>50%) removal with respect to the other treatments
- A general decrease in heavy metal (20%) content were obtained in the planted sediments with respect to the control sediments
- Very low concentrations of contaminants were measured in the leachate, if comparing the data with the Italian Legal limits (D.lgs. 152/2006)

Phragmites reached 60% of plant cover

Paspalum reached 100% of plant cover in all the treatments

Landfarming of phytoremediated brackish sediments to:

- **Homogenize the substrate**
- **Increase the biological activities**
- **Further reduce the organic contamination**

<u>Matrix suitable for nursery activity</u>

-Removal of plants
-Periodically turning over of the sediments inside each containers (12)

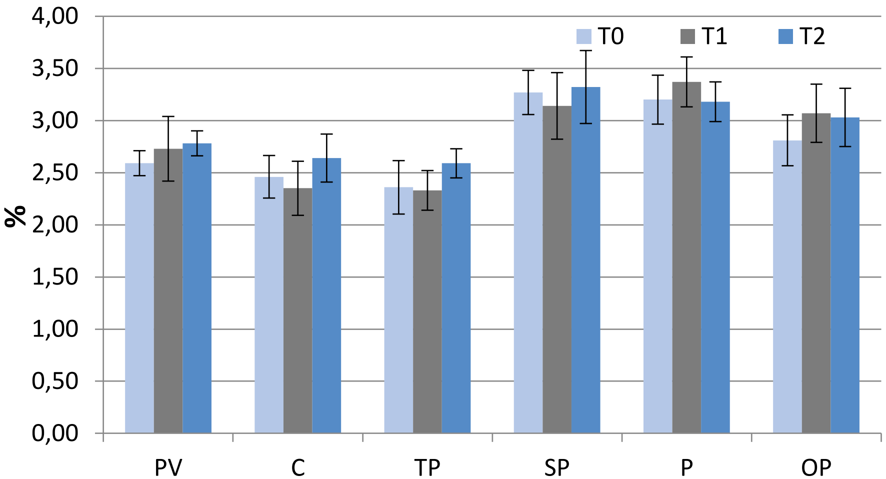
-3 months of landfarming
-Collection of the sediment: 1.5 months (T1) and 3 months (T2)

Results

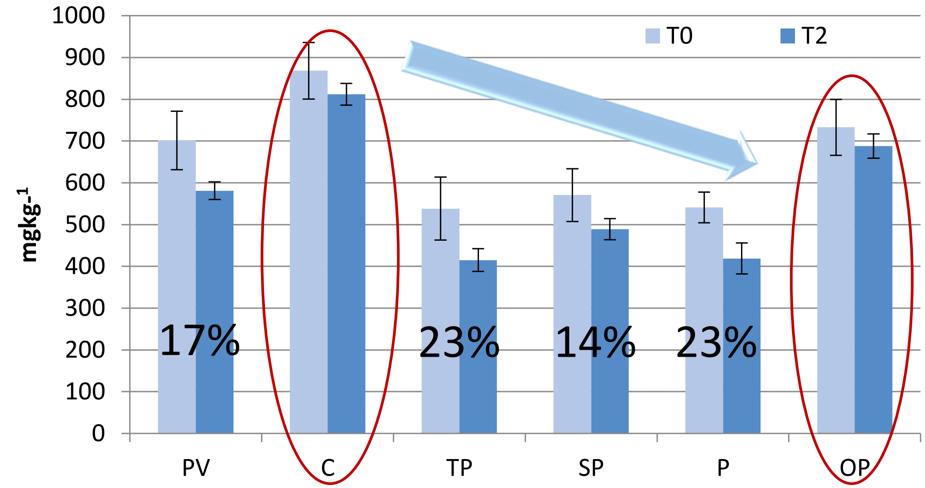
PV= *Paspalum*
C=*Control*
TP= *Tamarix+Paspalum*
SP= *Spartium+Paspalum*
P= *Phragmites*
OP= *Oleander +Paspalum*

T0= landfarming Start
T1= 1.5 months landfarming
T2= 3 months landfarming

Organic C

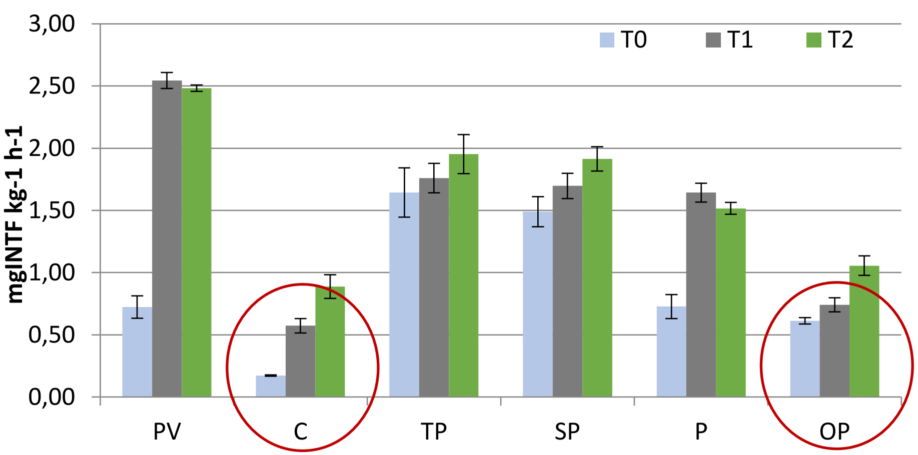


TPH



Further significant decrease in the organic contaminants

Dehydrogenase



Indicator of whole microbial activity in the substrate Increases over time

Lower enzyme activities in the control and in the Oleander treatment

Lower contaminant reduction

Treated sediment reuse
Purposes

Agronomical

- Reforestation
- Agronomic substrate in nursery companies
- Improvement of fertility of abandoned soils
- Functional recovery of degraded soils

Environmental

- Filling (quarries)
- Beach nourishment
- Land improvement and road fund filling
- Restoration of marginal areas

Agronomic substrate in nursery companies

Soil/sediment mixtures

Treated brackish sediment (Phytoremediation and Landfarming)

	CTL	T33	T50
% phytoremediated sediment	0%	33%	50%

Selected ornamental plants

Photinia x fraseri var. Red Robin - FOTINIA	*Viburnum tinus L.* – VIBURNO TINO	*Eleagnus macrophylla* OLIVAGNO
		

Plant growth

No difference in the three substrates for Photinia and Eleagnus growth

planting

8 months later

CTL

T33

T50

Greater growth in T33 and T50 for Viburnium

Agronomic substrate in nursery companies

Treated marine sediment (phytoremediation and landfarming)

Landfarming (3 months)

periodical (once per week) aeration by mechanically moving the sediments and turning them over

- homogenization of the substrate
- increase in biological activities (double)
- further reduction in organic contamination (C>12 25%)
- reduction in toxicity (BioTox 50% lower)

Parameters	Sediment at the end of landfarming	D. lgs. 75/2010
Bulk density (g/cm³)	1,08 ±0,07	0,95
pH	8,10 ±0,01	4,5-8,5
Electrical conductivity(dS/m)	0,33 ±0,04	<1
TOC %	1,57 ±0,02	>4
TN %	0,13±0,01	<2,5
TP (g/Kg)	0,58±0,03	
P_2O_5 %	0,11±0,02	<1,5
Cd (mg/kg)	0.96 ±0,06	1,5
Cu (mg/kg)	34,3 ± 4,3	230
Hg (mg/kg)	0,075± 0,001	1,5
Ni(mg/kg)	34,6 ± 5,33	100
Pb(mg/kg)	35,2 ± 3,7	140
Zn (mg/kg)	248 ± 11	500

To obtain a matrix suitable for reuse in horticulture (food plants) in compliance with Italian regulation for agronomic substrate (D.lgs: 75/2010), mixing of sediment with a source of organic matter rich in Carbon and light, such as peat, is necessary

Peat/sediment mixtures

	TS0	TS50	TS100
% phytoremediated sediment	0%	50%	100%

Selected food plants

STRAWBERRY PLANTS

Camarosa,Montere, Sant'Andrea

POMEGRANATE TREES

Purple Queen, Mollar

LETTUCE HEADS

Ballerina

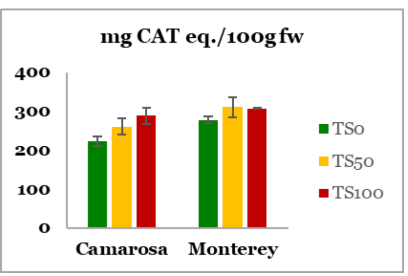
Plant analysis

- Plant Biomass
- Plant Production
- Nutraceutical qualities
- Food safety: Organic and inorganic contaminants

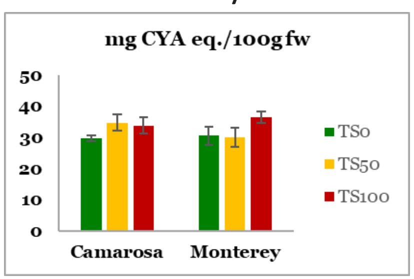
Agronomic and functional properties of all substrates, also TS100, were suitable for plant growth

Strawberry nutraceutical properties

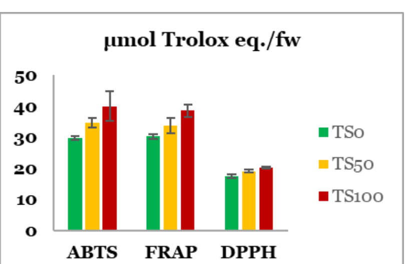
Total polyphenols



Total anthocyanins

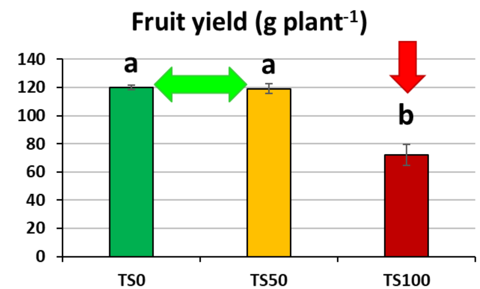


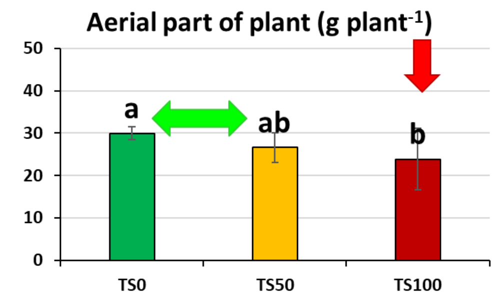
Antioxidant capacity



In TS 50 and TS100 nutraceutical properties comparable or greater than the control (TS0)

Strawberry growth





Yield, number of fruits and average weight of fruits in TS50 and TS0 similar, while the worst production in TS100

Agronomic substrate in nursery companies

2018-2022 Sustainable substrates for agriculture from dredged remediated marine sediments: from ports to pots (**LIFE SUBSED LIFE17 ENV/IT/000347**)

Phytoremediated marine sediment

Landfarming (3 months)

periodical (once per week) aeration by mechanically moving the sediments and turning them over

- Increase in microbial acivities
- Complete reduction of C>12
- Increase in germination index (GI% 140)

The objective of the LIFE SUBSED project was to demonstrate that it is possible to convert a waste (dredging marine sediment) into a resouce (commercial substrate) through the application of environmentally and economically sustainable techniques. In order to achieve the purpose, sediment-based substrates were applied to nursery production.

Selected plants

- **Fruit trees** (olive and citrus)
- **Ornamental plants** (protea, calla, laurel)
- **Food plants** (basil, blueberry, wild strawberry and citrus).

Agronomic substrate monitoring

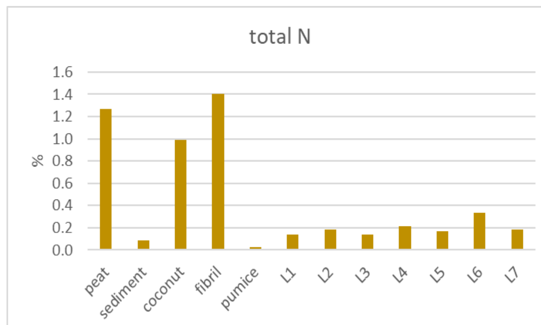
Parameter	Sediments at the end of landfarming in the Subsed Project	D. lgs. 75/2010
Bulk density (g/cm³)	1,19 ±0,05	<0,95
pH	7,4±0,2	4,5-8,5
Electrical conductivity (dS/m)	0,13 ±0,01	<1
TOC %	1,38 ±0,08	>4
TN %	0,12 ±0,01	<2,5
P_2O_5 %	0,17 ±0,01	<1,5
Cd (mg/kg)	< LOD	1,5
Cu (mg/kg)	48,6 ±1,7	230
Hg (mg/kg)	0,070 ±0,001	1,5
Ni(mg/kg)	37,7 ±0,7	100
Pb(mg/kg)	37,2 ±6,4	100
Zn (mg/kg)	145 ±4	500

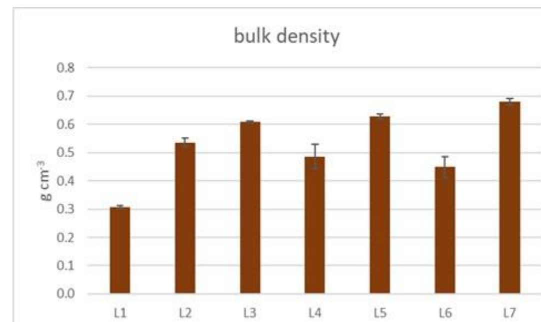
To obtain a matrix suitable for reusing in horticulture in compliance with Italian regulation for agronomic substrate (D.lgs: 75/2010), mixing of sediment with a source of organic matter rich in Carbon and light, such as peat, is necessary

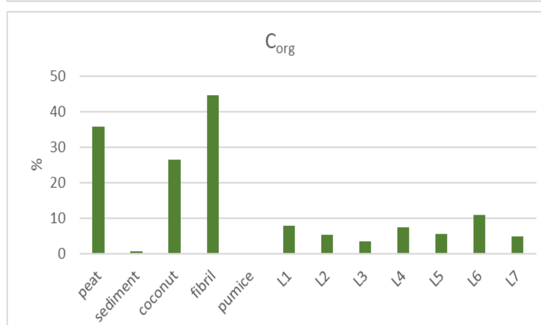
Traditional subtrates/sediment mixtures

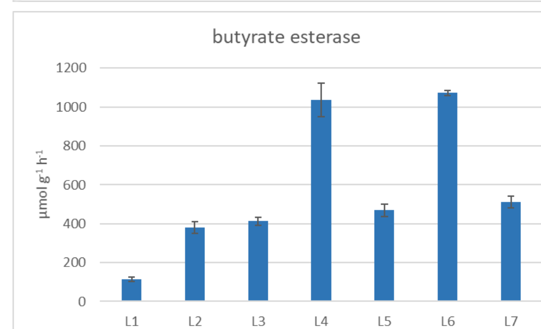
LAUREL/OLIVE/STRAWBERRY/BLUEBERRY

L1		60% peat	40% pumice
L2	25%sediment	45% peat	30% pumice
L3	50%sediment	30% peat	20% pumice
L4	25%sediment	45% coconut	30% pumice
L5	50%sediment	30% coconut	20% pumice
L6	25%sediment	45% wood	30% pumice
L7	50%sediment	30% wood	20% pumice





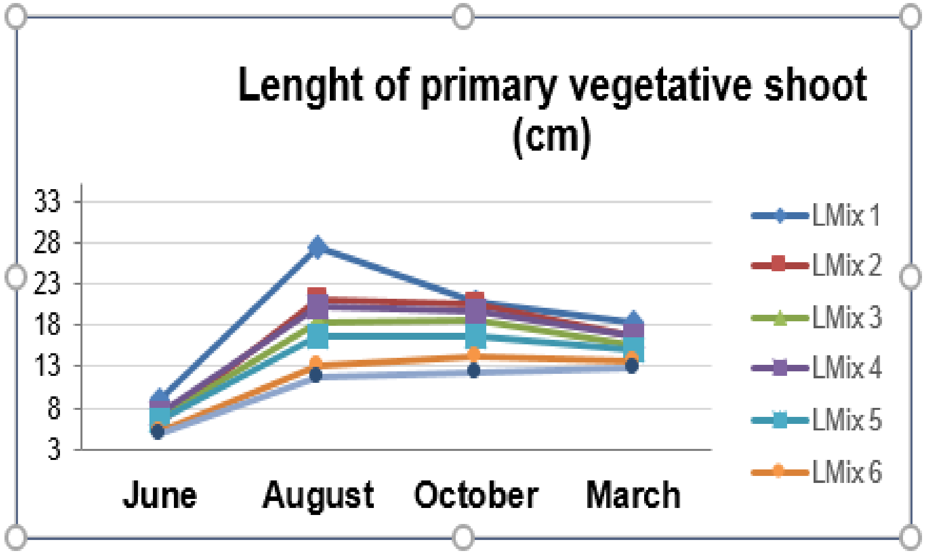




The substrates will be analyzed at the end of the vegetative cycle of each plant

Plant monitoring

Prunus laurocerasus (rooted cuttings)
Lauro



Plant monitoring

- BSD = Stem base diameter;
- MPH = Maximum height of the plant;
- NVS = Number of vegetative shoots;
- LVS = Length of the vegetative shoots;
- NEL = Number of fully expanded leaves on vegetative shoots

25%sediment 45% wood 30% pumice

✓ **Higher chroma index in the substrate containing wood fiber (L6-L7)**

After one year:

✓ **no significant differences between 25% and 50% sediment-based substrate (L2-L3) and traditional substrate (L1)**

✓ **Lower plant healt in the substrate containing wood fiber (L6-L7) with respect to the other substrates**

2018-2022 Use of dredged sediments for creating innovative growing media and technosols for plant nursery and rehabilitation - European project **LIFE AGRISED LIFE17 ENV/IT/269**

Sediment co-composting

Brackish sediments

Navicelli channel (Pisa, ITALY)

Agricultural canal (Kunice, CZECH REPUBLIC)

-high sand content (greater porosity, air and drainage)
-low content of heavy metals
-low salinity

Green waste

Grass, corn cob, wood chips, wood, leaves

provide carbon and nutrients that stimulate microbial activity and improve the physical structure

Objective 1: to demonstrate the suitability of dredging co-composted sediments with green wastes as **agronomic substrate in nursery**

Reconstituted soil

Objective 2: to demonstrate the suitability of dredged sediments used as such to produce innovative technosols (reconstituted soils) for reclamation of degraded land and brownfields

Viburnum tinus

Photinia x fraseri

Co-composting process monitoring

- temperature,
- humidity,
- bulk density
- organic matter
- humic substances
- pollutant contents
- microbial communities
- enzyme activities

Compost maturity

Decrease in organic matter content, electrical conductivity, microbial activity, organic contaminants and increase in humification rate and germination index

	Agrised Compost/substrate Czech Republic			Agrised Compost/substrate Italy			Italian legislation on fertilizers D. Lgs. 75/2010		Czech Republic legislation Sediment reuse in agriculture Decree No. 257/2009	European Legislation on fertilizers 1009/2019
	75% sed	**50% sed**	**25% sed**	**75% sed**	**50% sed**	**25% sed**	Green Compost	Mixed substrate		Growth substrate
Bulk density(g/cm³)	1,00	0,81	0,75	0,88	0,69	0,58		<0,95		
pH	8,12	8,12	8,18	7,4	7,5	7,3	6-8,5	4,5-8,5		
E.C.(dS/m)	0,86	0,78	0,75	2,7	2,4	1,2		<1		
TOC %	3,02	3,04	5,04	1,66	3,54	9,39	>20	>4		
Volatile solids(%)	6,5	7,8	13,3	4,1	8,2	18,4				
TN %	0,26	0,31	0,48	0,15	0,31	0,58		<2,5		
C/N	11,6	9,8	10,5	11,1	11,4	16,2	<50			
P_2O_5 %	0,002	0,003	0,005	0,001	0,001	0,005		<1,5		
Humic substances	2,09	2,62	3,3	1,37	2,24	6,28	> 2,5			
Salmonella	no	no	no		To be determined		no		no	no
E.Coli (CFU/g)	<100	<100	<100		To be determined		<1000			<1000
Germination Index(%)	124	117	108	85	86	80	>60		>30	
E.Coli (CFU/g)	<100	<100	<100		To be determined		<1000			<1000
Cd (mg/kg)	0,2	0,02	0,2	0,38	0,30	0,23	<1,5	<1,5	<1	<1,5
Cu (mg/kg)	34	27	32	33	29	21	<230	<230	<100	<200
Hg (mg/kg)	<0,1	<0,1	<0,1	0,05	0,04	0,05	<1,5	<1,5	<0,8	<1,5
Ni (mg/kg)	16	12	13	32	30	28	<100	<100	<80	<50
Pb (mg/kg)	12	9,4	11	23	22	20	<140	<140	<100	<120
Zn (mg/kg)	70	60	60	96	105	99	<500	<500	<300	<500
Cr (mg/kg)	19	15	15	30	36	29		<100	<200	
As(mg/kg)	2,9	2,9	3,9						<30	
Be (mg/kg)	0,5	0,4	0,6						<5	
Co (mg/kg)	4,3	4,1	5,4						<30	
V (mg/kg)	20	19	24						<180	
IPA(mg/kg)	0,45	0,41	0,40						<6	
PCB (mg/kg)	<0,01	<0,01	<0,01						<0,2	
C10-C40 (mg/kg)	85,5	64,8	62,9						<300	

All metal limits are respected

Compared with their own reference legislation:
-CZ: compost in compliance with the legislation for all parameters
-IT: Again lower TOC and higher Electrical Conductivity in composts which contain 75% and 50% of sediment

Agronomic substrate in nursery companies

Substrates	Composition
1	50% peat, 50% pumice+ 4kg/m³ Basacote
2	Compost (75% Green Waste, **25% Sediment)** + 4kg/m³ Basacote
3	Compost (50% Green Waste, **50% Sediment)** + 4kg/m³ Basacote
4	Compost (25% Green Waste, **75% Sedimen**t) + 4kg/m³ Basacote
5	40% Compost (75% Green Waste, 25% Sediment), 40% peat, 20% pumice + 4kg/m³ Basacote
6	40% Compost (50% Green Waste, 50% Sediment), 40% peat, 20% pumice + 4kg/m³ Basacote
7	40% Compost (25% Green Waste, 75% Sediment), 40% peat, 20% pumice + 4kg/m³ Basacote

Photinia x fraseri

Viburnum tinus

Agronomic substrate in nursery companies

Photinia x fraseri

After 5 months from plantation

Substrate	H		FW	DW			S/R	DW/FW
	T0	T5		shoots	roots	Total		
50% peat, 50% pumice (control)	59	61	396	79.6	35.4	115.0	2.2	0.29
100% Compost (**25% Sediment)**	57	57	280	63.8	26.8	90.6	2.4	0.32
100% Compost (**50% Sediment)**	57	70	364	85.2	36.0	121.2	2.4	0.33
100% Compost (**75% Sedimen**t)	58	62	381	83.5	47.7	131.2	1.8	0.34
40% Compost (25% Sediment), 40% peat, 20% pumice	59	61	339	76.2	29.5	105.7	2.6	0.31
40% Compost (50% Sediment), 40% peat, 20% pumice	60	60	318	74.4	26.4	100.8	2.8	0.32
40% Compost (75% Sediment), 40% peat, 20% pumice	57	62	367	82.7	33.4	116.1	2.5	0.32

H: height; FW: fresh weight; DW: dry weight; S/R: shoots/roots

- Limited plant growth due to the rather cold winter season;
- The plant growth parameters did not show significant differences between the different substrates

The substrates will be analyzed after one year from plantation, that is at the end of 2021

Soil Reconstitution to improve the pedological properties of degraded soils

1. mixing of soils with wastes from different sources: biological sludge, **dredging sediments**, paper mill sludge;
2. crumbling and fragmentation of the aggregates, together with the possible addition of humic compounds, and further mixing;
3. mechanical decomposition and destructuring combined with the defibration and dispersion of the organic components within the entire mass;
4. mechanical pressure made by a rotating system allows the incorporation of organic substances to the mineral fraction, generating the neo aggregates of the **reconstituted soil**

DEGRADED SOIL
DREDGED SEDIMENT
DEGRADES SOIL / DREDGED SEDIMENT / MATRICES
CO-COMPOST 1:1
CO-COMPOST 1:1 / DEGRADED SOIL
CO-COMPOST 1:1 / DEGRADED SOIL / MATRICES
CO-COMPOST 1:3
CO-COMPOST 1:3 / DEGRADED SOIL
CO-COMPOST 1:3 / DEGRADED SOIL / MATRICES
CO-COMPOST 3:1
CO-COMPOST 3:1 / DEGRADED SOIL
LINEA CO-COMPOST 3:1 / DEGRADED SOIL / MATRICES

Final Considerations

Life CLEANSED, HORTISED, SUBSED and AGRISED projects implemented the concept of circular economy through actions that guarantee the recycling of dredging sediments in environmental and agricultural production sectors, contributing significantly to the sustainable management of wastes

-In particular, the LIFE CLEANSED project has demonstrated, for the first time, the possibility of recycling dredging sediments, appropriately treated (phytoremediation and landfarming), in **nursery sector (ornamental plants)** as an alternative to traditional growth substrates

-The LIFE HORTISED project has demonstrated, for the first time, the possibility of recycling dredging sediments, appropriately treated (phytoremediation and landfarming), in **horticulture (food plants)**, as an alternative to peat

-The LIFE SUBSED project has demonstrated the possibility of recycling dredging sediments, appropriately treated, in both **horticulture and nursery sectors**

-The LIFE AGRISED project has demonstrated the possibility of co-composting sediments with green waste for the production of a growth substrate for **nursery sector** and for **soil reconstitution**. Experimental tests are currently ongoing and will confirm the suitability of the substrates in these two environmental sectors.

Publications

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