Use of biowastes for the reclamation of soil and impact on plant productivity and carbon sequestration

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Outlines

- Introductory remarks
- Soil contamination and degradation
- Biowaste for soil remediation
- Biowastes, soil properties and productivity
- Biowastes and soil carbon sequestration
- Conclusions

Organic biowastes

- Organic residues such as sewage sludge, biowastes and composts are increasingly used in soil remediation because they serve dual purpose:
  - disposal of solid waste from municipalities and agricultural operations and
  - a means to improve physical, chemical and biological properties of soils. which in turn promotes crop performance.
- They also provide nutrients and thus reduced the need for inorganic fertilizers.

Organic biowastes

- Thus, their use contribute to integrated nutrient management (INM) by promoting nutrient recycling and minimizing final disposal.

- However, organic residues because of their chemical composition (e.g. presence of harmful metals and organic pollutants) can create a problem to agricultural soils.

Soil organic matter (SOM) in wastes

- SOM Improves

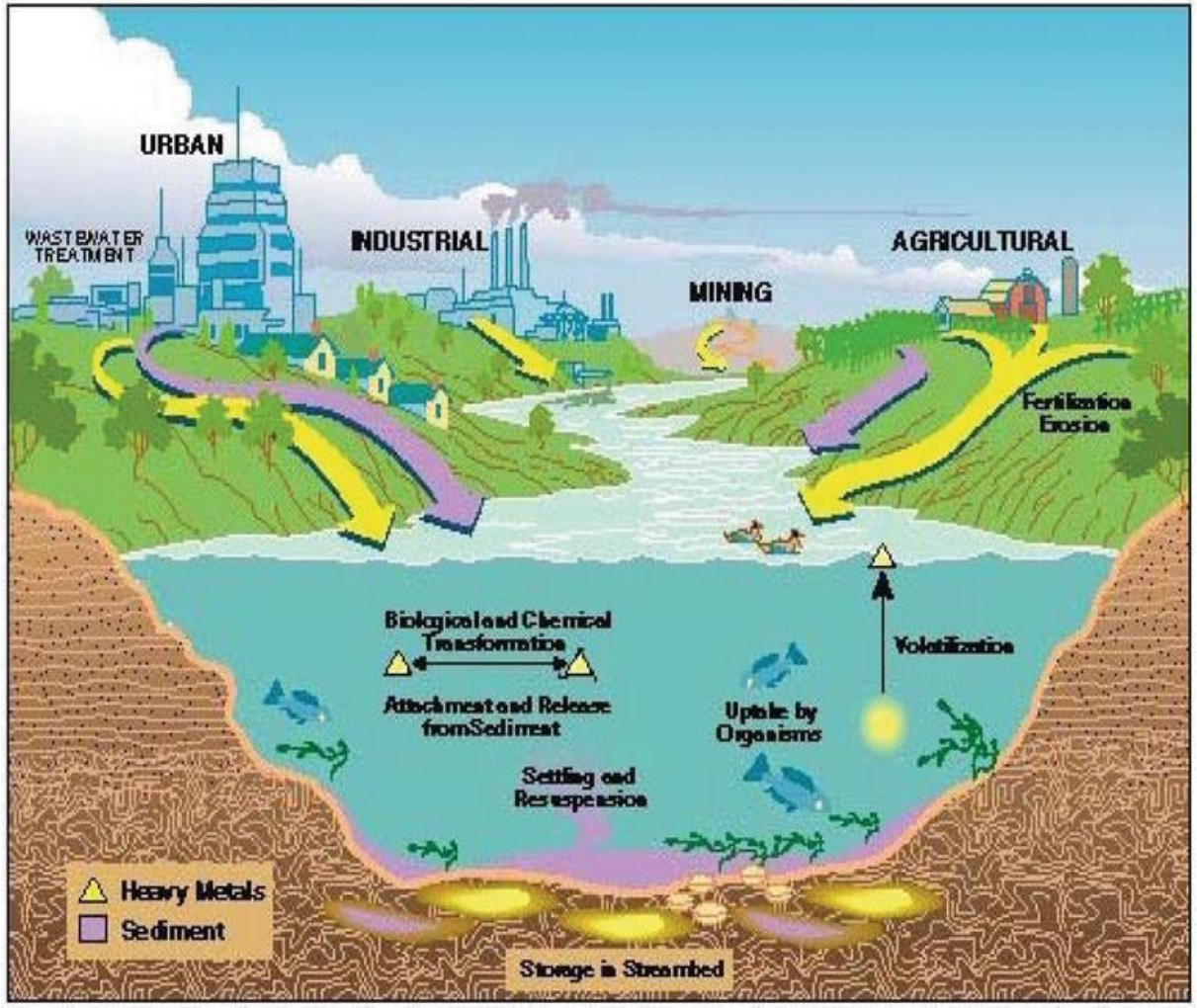
- Physical properties
  - Aggregate stability,
  - infiltration, water retention

- Chemical properties
  - Nutrient release and storage,
  - cation exchange and pH buffering capacities

- Soil Biological Properties
  - Greater abundance, diversity and activity of soil microbes
  - Increased root elongation and abundance

Soil contamination and degradation

Soil contamination and Degradation



Masindi and Muedi (2018)

Soil is contaminated primarily due to:

- ✓ **anthropogenic activities**
- ✓ **but also to a lesser extent by natural processes.**

Natural processes of soil contamination

- Under different and certain environmental conditions, natural emissions of heavy metals occur.

- Such emissions include volcanic eruptions, sea-salt sprays, forest fires, rock weathering, biogenic sources and wind-borne soil particles.

- Natural weathering processes can lead to the release of metals from their endemic spheres to different environment compartments.

Anthropogenic processes of soil contamination

- Industries, agriculture, wastewater, mining and metallurgical processes, and runoffs also lead to the release of pollutants to different environmental compartments.

- Anthropogenic processes of heavy metals have been noted to go beyond the natural fluxes for some metals.

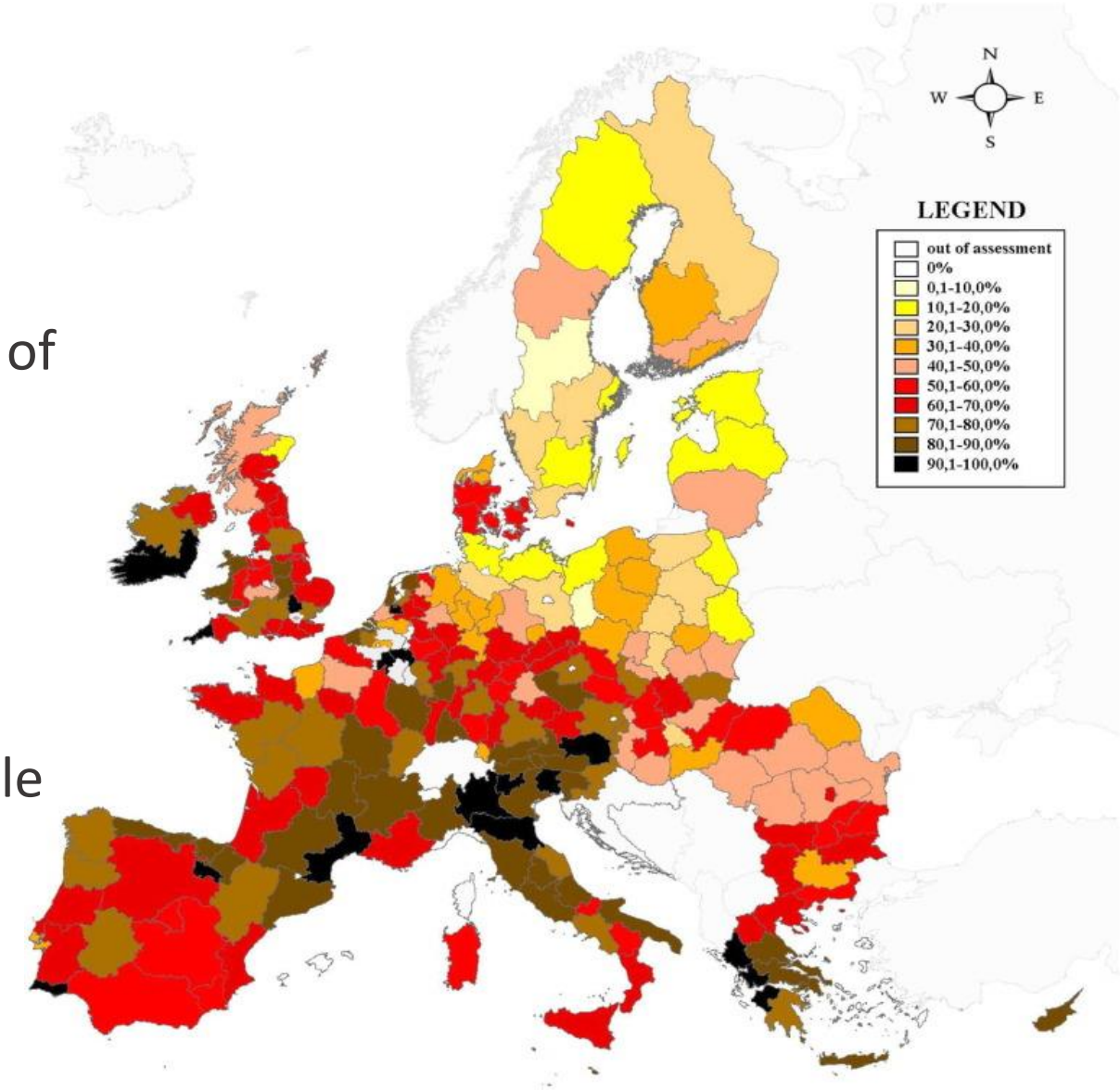
- Metals naturally emitted in wind-blown dusts are mostly from industrial areas.

Metal soil contamination

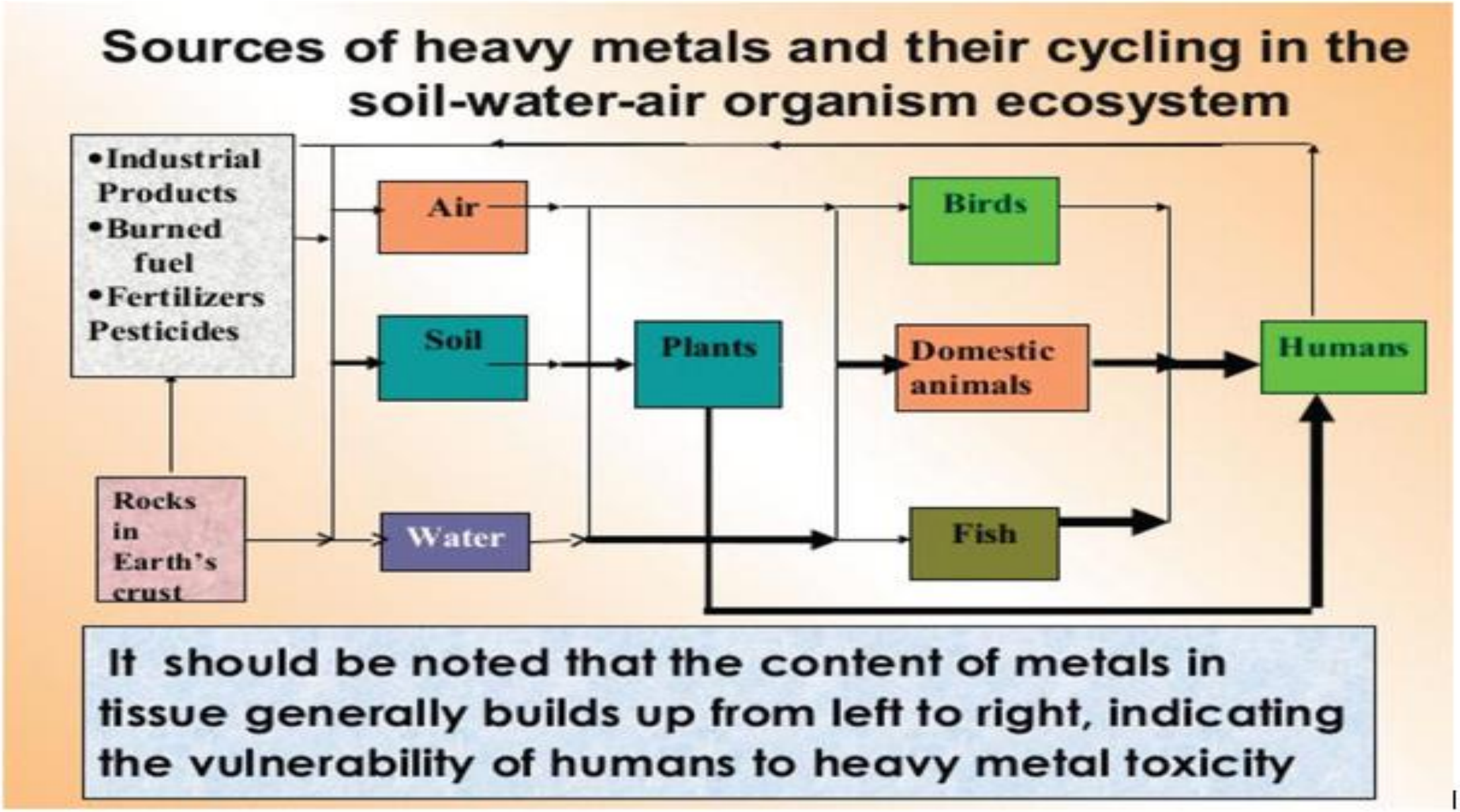
Long-term exposition to a high concentration of pollutants (especially heavy metals) leads to soil contamination but also depletion **of organic fraction in the soil**.

Because metals present in soils, even in relatively low concentrations, have unfavorable impact on soil organisms.

However, biowaste as an organic-rich soil substrate decreases heavy metal stress.



Percentage of samples with concentrations above the threshold value in LUCAS samples from agricultural land. Tóth, et.al. (2016)



(Adopted from Masindi and . Muedi (2018))

- Biowaste for soil remediation

Remediation technologies

- In order to protect the human health, plants, animals, soil and all the compartments of the environment, proper and careful attention should be given to remediation technologies of heavy metals.

- Most physical and chemical heavy metal remediation technologies require handling of large amounts of sludge, destroy surrounding ecosystems and are very expensive.

Remediation technologies

- Therfore, use of biowastes provides alternative remidation tecnnologies, which are more cost effective and also provide other benifits, such as

- soil remediation,
- improved soil quality
- crop productivity
- carbon sequestration

Remediation of degraded soils using biowastes

BIOWASTES

Biowastes such as sewage sludge and compost may be effectively used to immobilize heavy metals in the soil:

- cost-effective substrate with a high potential for soil *remediation in situ*,
- low costs;

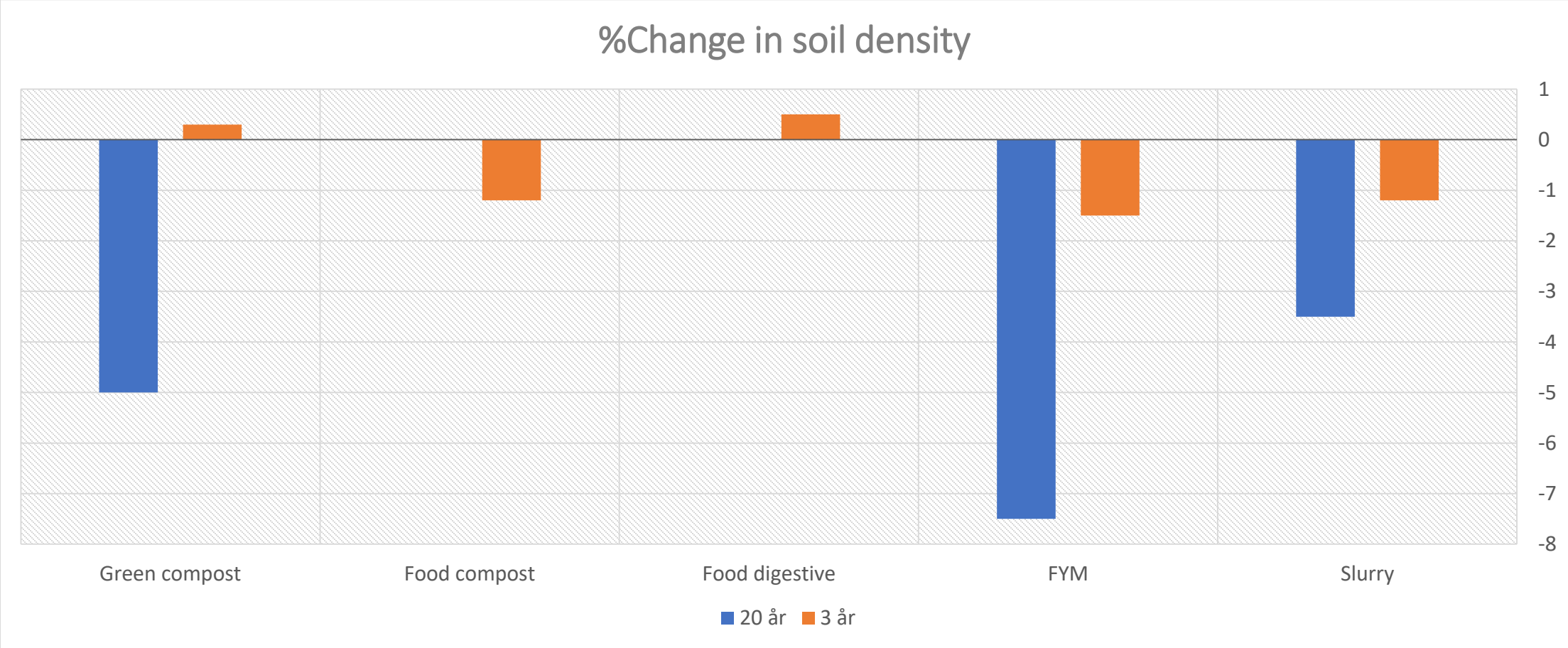
decreases the mobility of heavy metals (Hattab et al., 2015)

by influencing soil properties and especially SOC (Meena et al., 2016)

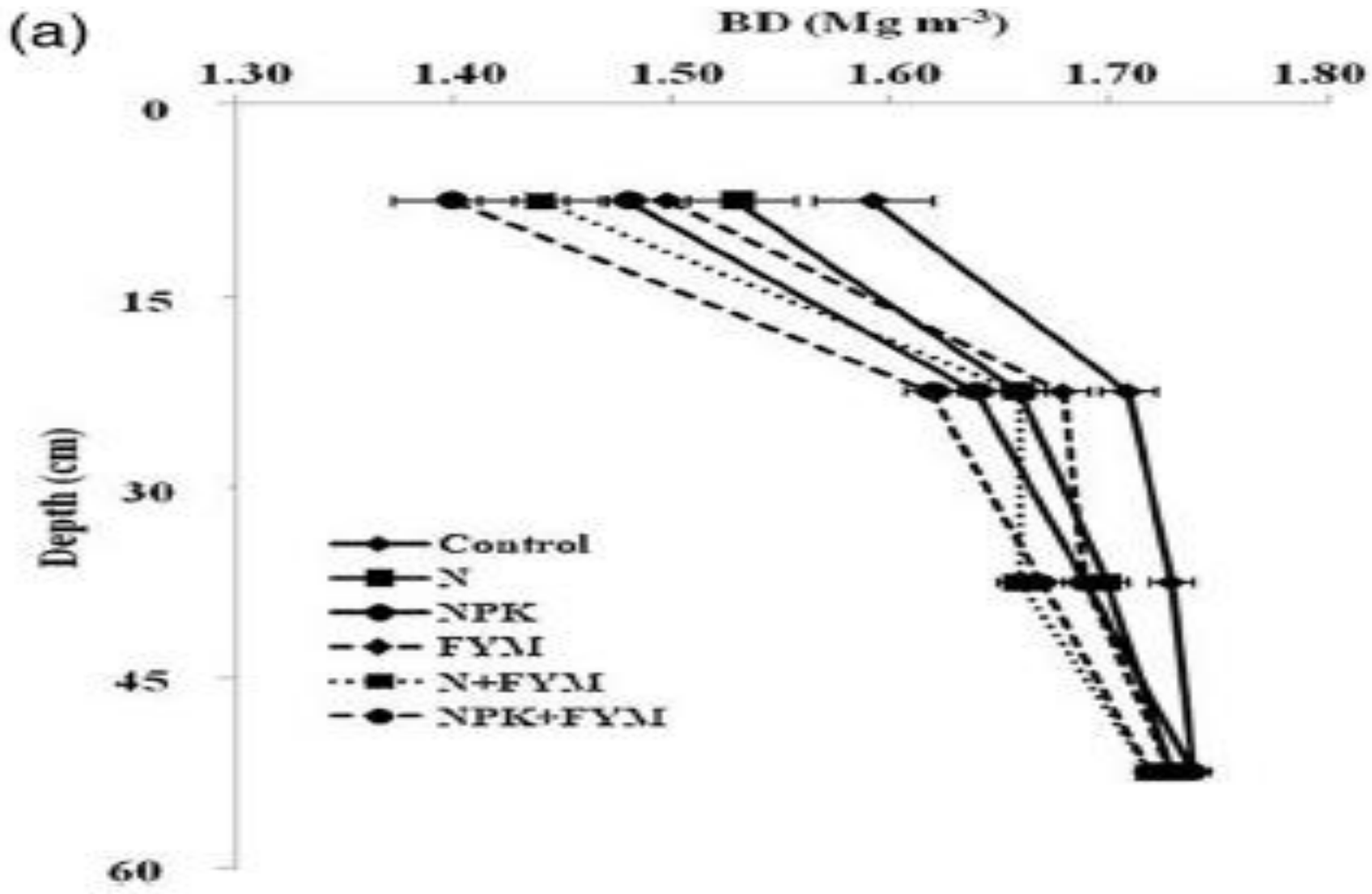
significantly increases the microbial activity and strengthen the remediation process (Placek et al., 2017)

- Biowastes, soil properties and productivity

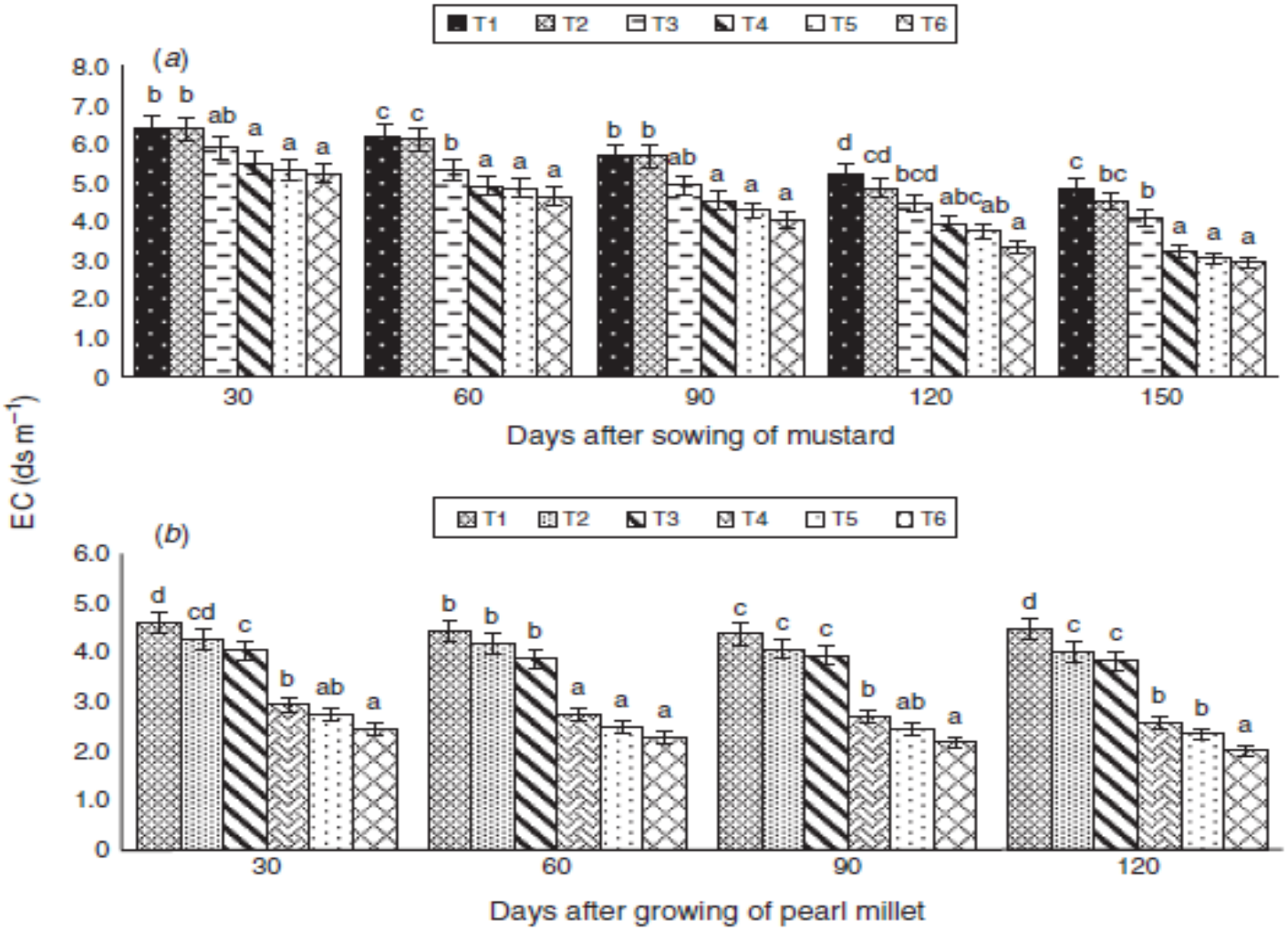
Impact of compost on soil bulk density in grain production



Bhogal et al., Front. Sustain. Food Syst., 2018



Variation of (a) bulk density in different soil layers under a 41 years of chemical and organic fertilization in a sub-humid tropical rice-rice system(Source: Shahid et al., 2017)



T1, Control;
T2, 100% recommended dose of fertilizer (RDF);
T3, rice-straw compost (RSC) at 14 t ha–1;
T4, municipal solid waste compost (MSWC) at 16 t ha–1;
T5, RSC at 7 t ha–1 +50% RDF;
T6, MSWC at 8 t ha–1 + 50% RDF.

Effect of organic amendments and mineral fertilizers on soil electrical conductivity (EC, 1 : 2) during: (*a*) the mustard growing season and (*b*) the pearl millet growing season 2013–14. Capped lines represent standard errors (%). For each date, means with the same letter are not significantly different at $P = 0.05$ according to Duncan's multiple range test for separation of means (adapted from Meena et al. 2016)

Effect of organic manure in improving soil and biomass productivity of reclaimed mine soil

Soil properties	Source and amount of organic manure	Soil depth (cm)	Amended mine soil	Un-amended mine soil	References
BD (Mg m^{-3})	25 Mg poultry manure and 40 Mg sawdust ha^{-1}	0–10	1.4	1.5	Coyne et al. (1998)
	280 Mg ha^{-1} flue gas desulfurization by-products	0–10	1.0	1.4	Shukla et al. (2005)
Water holding capacity (kg kg^{-1})	25 Mg poultry manure and 40 Mg sawdust ha^{-1}	0–10	0.21	0.20	Coyne et al. (1998)
Total carbon (g kg^{-1})	25 Mg poultry manure and 40 Mg sawdust ha^{-1}	0–10	9.6	4	Coyne et al. (1998)
	155 Mg biosolids ha^{-1}	NA[1]	18.5	2	Vinson et al. (1999)
	112 Mg ha^{-1} of limestone incorporated into the graded spoil and was covered with 20 cm of graded borrowed topsoil	0–10	30[a]	11[a]	Shukla et al. (2005)

Tomato production in soil produced from wastes

Plant productivity in biowaste treated soils

Plant	Plant properties	Alternation	Reference
SEWAGE SLUDGE			
Vigna radiata L.	Root length (cm plant^{-1})	Increase	Singh and Agrawal, 2010
	Shoot length (cm plant^{-1})	Increase	
	Leaf area (cm^2 plant^{-1})	Increase	
	Number of leaves (plant^{-1})	Increase	
	Number of nodules (plant^{-1})	Increase	
	Total biomass (g plant^{-1})	Increase	
Scot Pine	Root biomass production (g)	Increase	Placek et al., 2017
Giant Miscanthus	Root biomass production (g)	Increase	
Dactylis glomerate, Festuca arundinacea, F. rubra, Lolium perene	Biomass yield	Increase	Kacprzak et al., 2014
Tomato	Fresh weight (kg)	Increase	Waqas et al., 2015

Root biomass by biowastes in contaminated soils

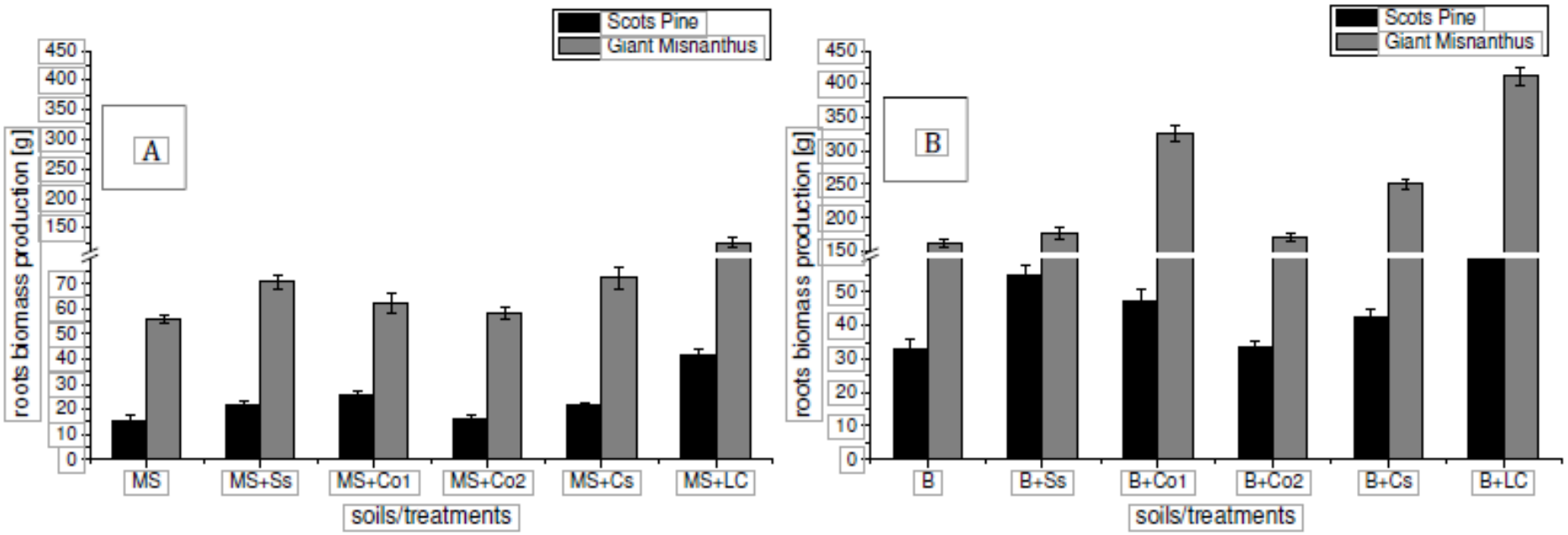
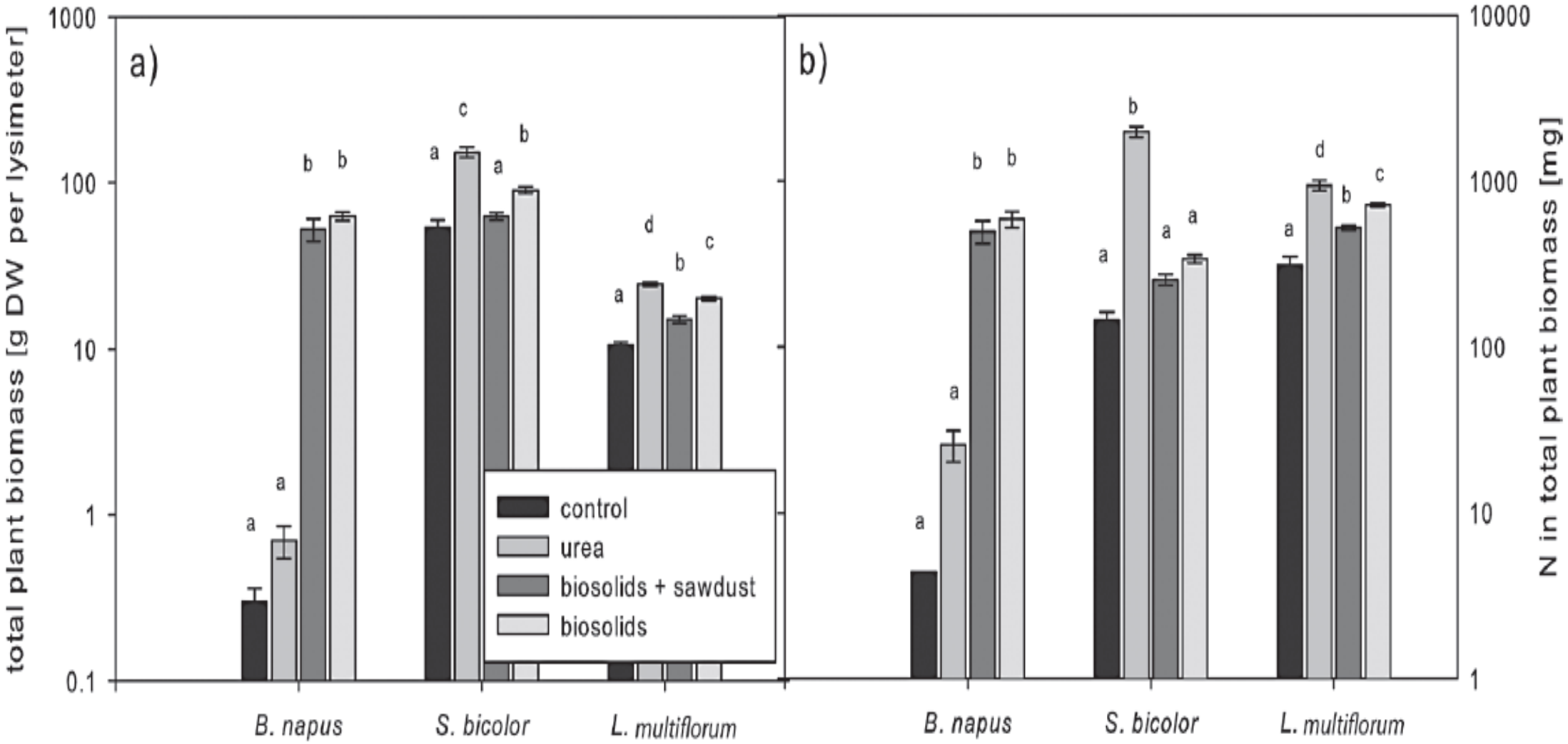


Figure 4. Roots biomass production of Scots Pine and Giant Miscanthus cultivated in smelter-polluted soil (A) and in post-mine soil (B), the letter combinations on x-axis stand for: Zinc smelter soil (MS), Brown coal mine soil (B), Sewage sludge (Ss), Municipal compost (Co1), Compost from sewage sludge (Co2), Coal slurry (Cs), Lake Chalk (LC)

(Placek et al. (2017)



Total plant biomass (including seed and root biomass) at the end of the experiment (a) and total N recovered from plant biomass (b) from sorghum (*S. bicolor*), rapeseed (*B. napus*), and ryegrass (*L. multiflorum*). Different levels of significance *p* £ 0.05 are represented by lowercase letters. (Esperschuetz etal. 2016)

Effect of biosolids

- Biosolids application to low-fertility soil provided sufficient nutrients to ensure adequate growth of all plant species.

- Biosolids application rates equivalent to 1250 kg N ha^{-1} (equv. to 50 t ha^{-1}) did not result in an increased N loss via leaching compared with urea treatments.

- The use of sawdust did not reduce NO3 leaching but instead may have immobilized and reduced available N for plant growth.

Table 4. Plant cover after the application of crushed cotton gin compost (CCGC) and poultry manure (PM) during the experimental period.

Treatment†	2000	2001	2002	2003
	%			
Control soil	4	4	4	5
CGCC1	13	27	32	48
CGCC2	20	33	47	62
CGCC3	31	47	62	79
PM1	16	30	40	55
PM2	28	40	59	70
PM3	34	56	70	88

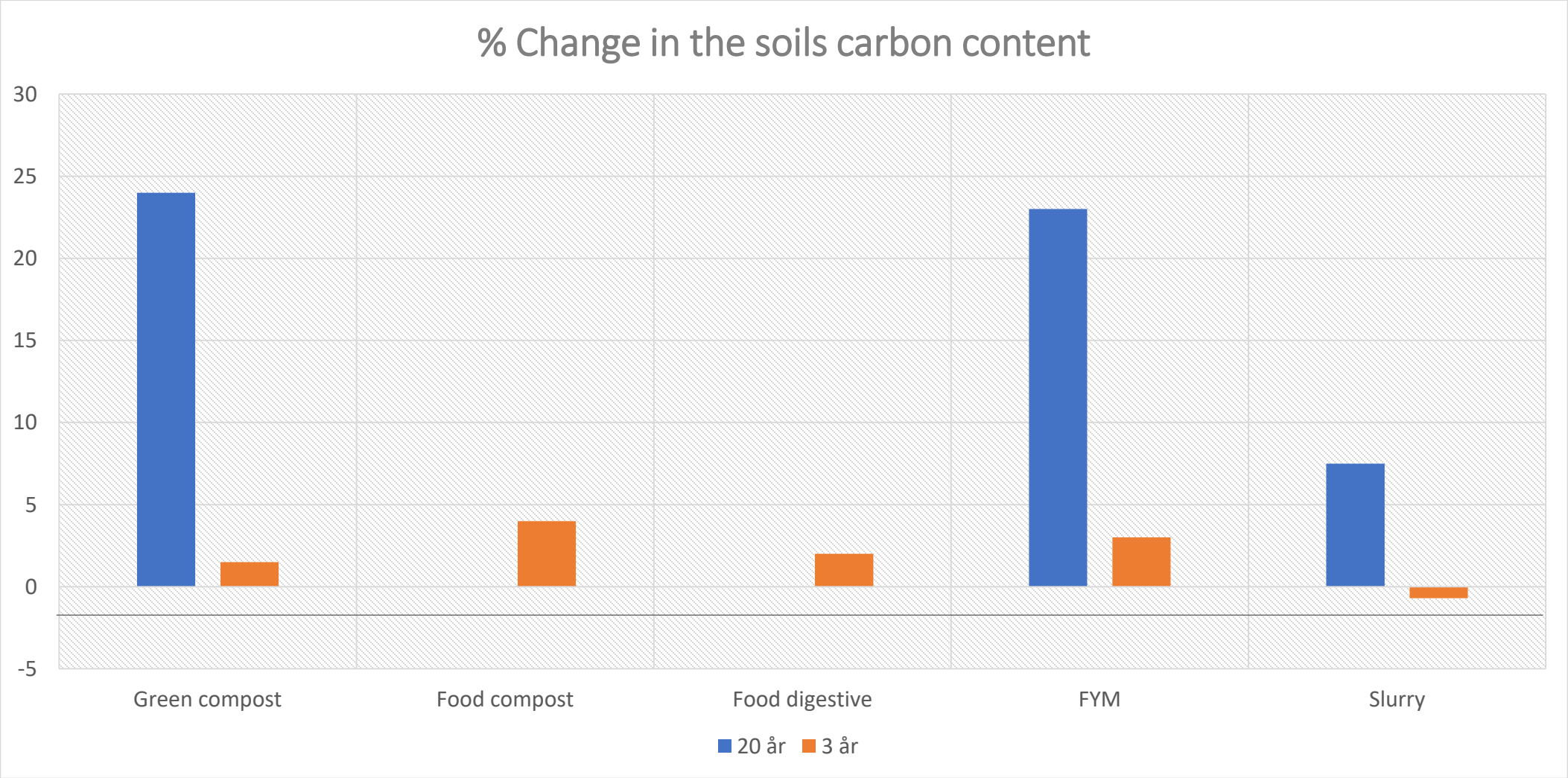
Tejada et al. (2006)

CGCC1, CCGC2 and CGCC3 were fertilized with cursed cotton gin compost (CGCC) at the rate of 14.4 , 27.06 and 28.08 Mg Ha^{-1} (35 % DM) , respectively.

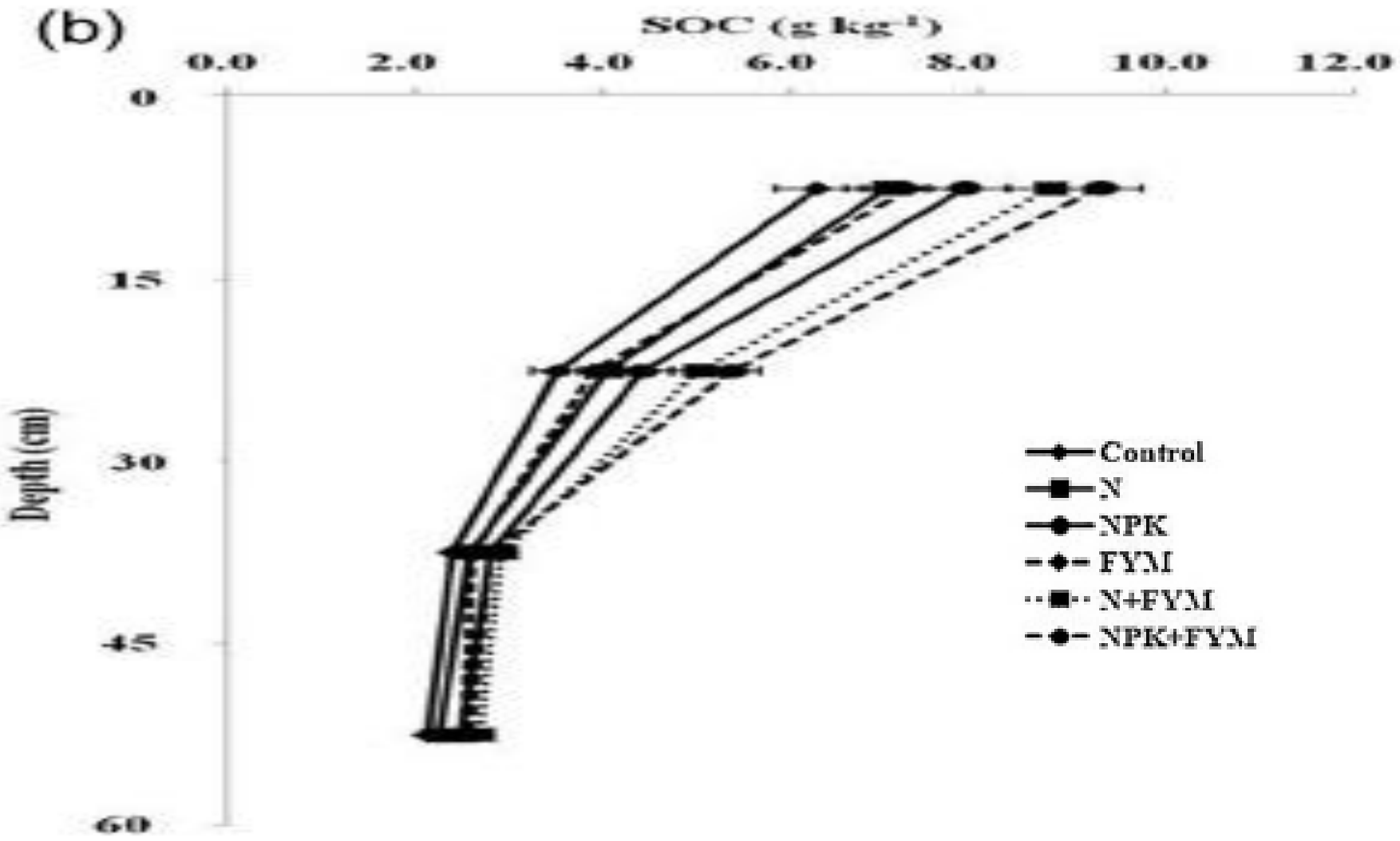
PM1 PM2 and PM3 were fertilized with poultry manure (PM) at the rate of 8.14,12.21, 16.28 Mg Ha^{-1} (60%DM), respectively.

- Biowastes and soil carbon sequestration

Effect of biowastes on carbon sequestration

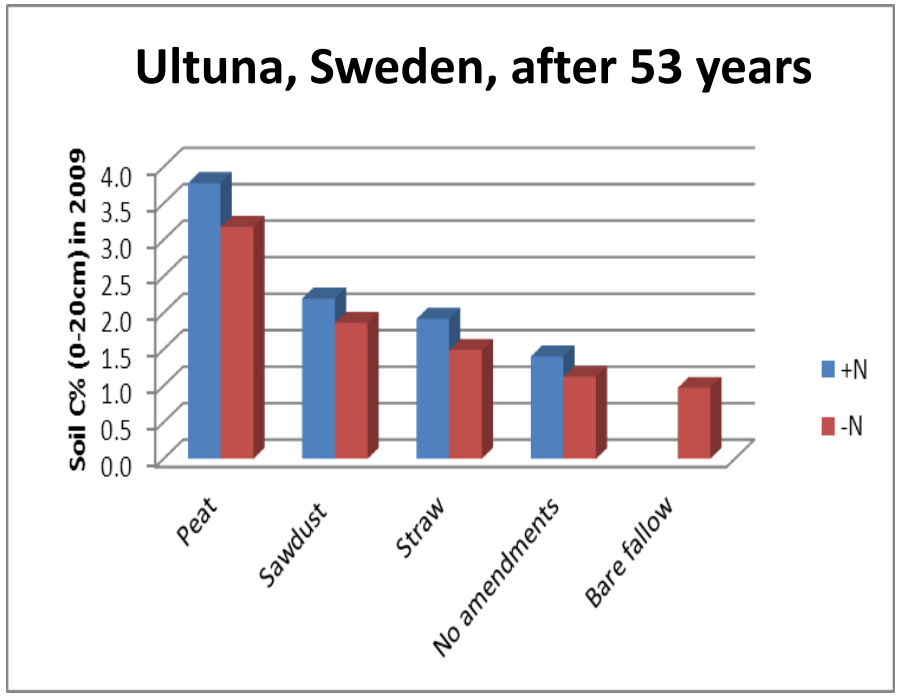


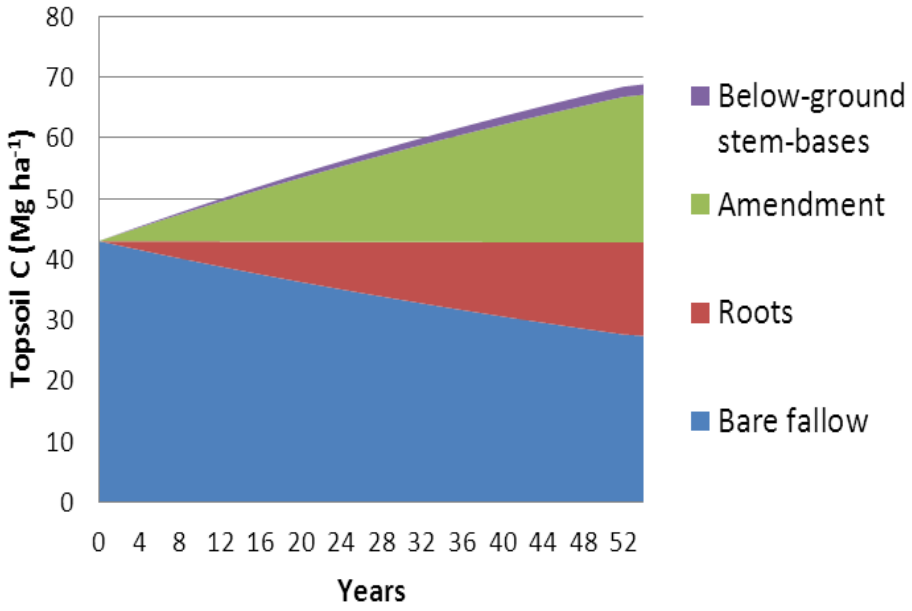
Bhogal et al., Front. Sustain. Food Syst., 2018



Variation of distribution of SOC in different soil layers under a 41 years of chemical and organic fertilization in a sub-humid tropical rice-rice system(Source: Shahid et al., 2017)

Effect of organic amendments and N fertilization on soil C





- **C retention differs considerably between C sources**
- **Retention of root-derived C is 2.3 times higher than for above-ground residues**
- **N fertilization results in higher root production and, consequently, in higher soil C stocks**

Kätterer et al., AGEE 2011, Kätterer et al. ACTA 2012

SLU

Enhancing SOC pools of degraded soils

- The low SOC concentration in reclaimed mine soils can be enhanced by:
  - proper reclamation,
  - adoption of recommended management practices (RMPs),
  - improvement in soil fertility using integrated nutrient management (INM) technologies,
  - nutrient cycling by returning biomass to the soil, and
  - growing leguminous annuals or tree plants with potential of biological N2-fixation (BNF)

Reclamation of contaminated sites

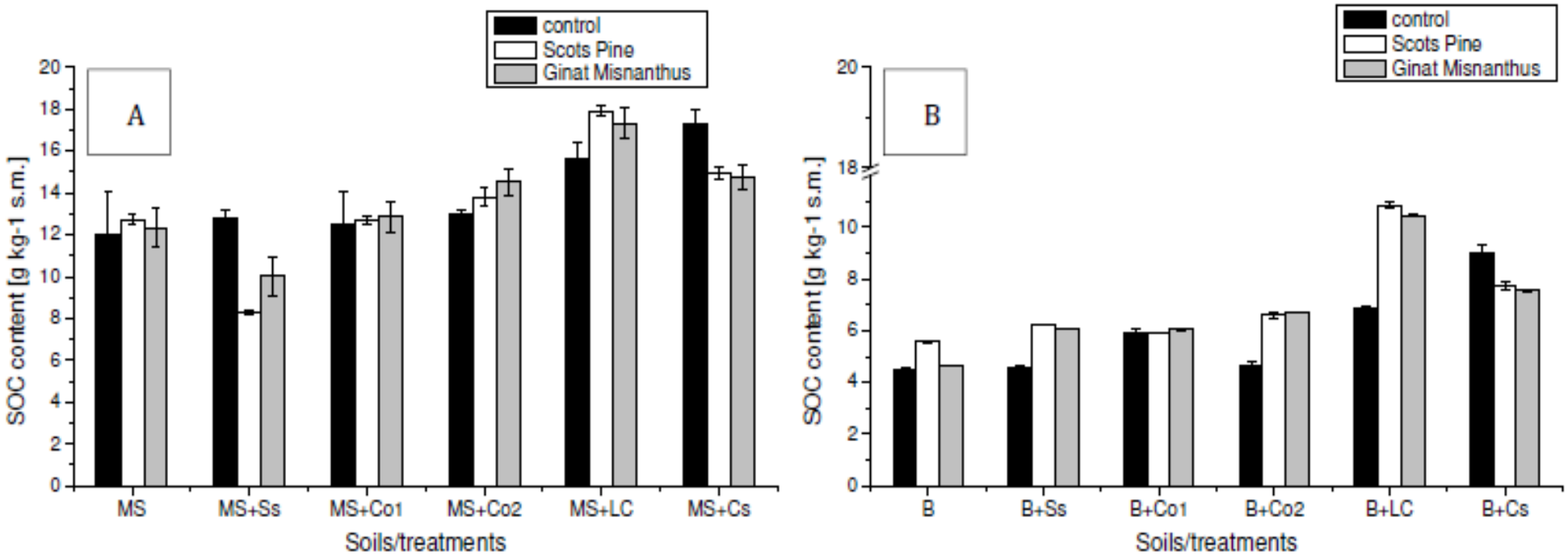


Figure 1. Changes in TOC content in zinc smelter soil (A) and coal mine soil (B), the letter combinations on x-axis stand for: Zinc smelter soil (MS), Brown coal mine soil (B), Sewage sludge (Ss), Municipal compost (Co1), Compost from sewage sludge (Co2), Coal slurry (Cs), Lake Chalk (LC)

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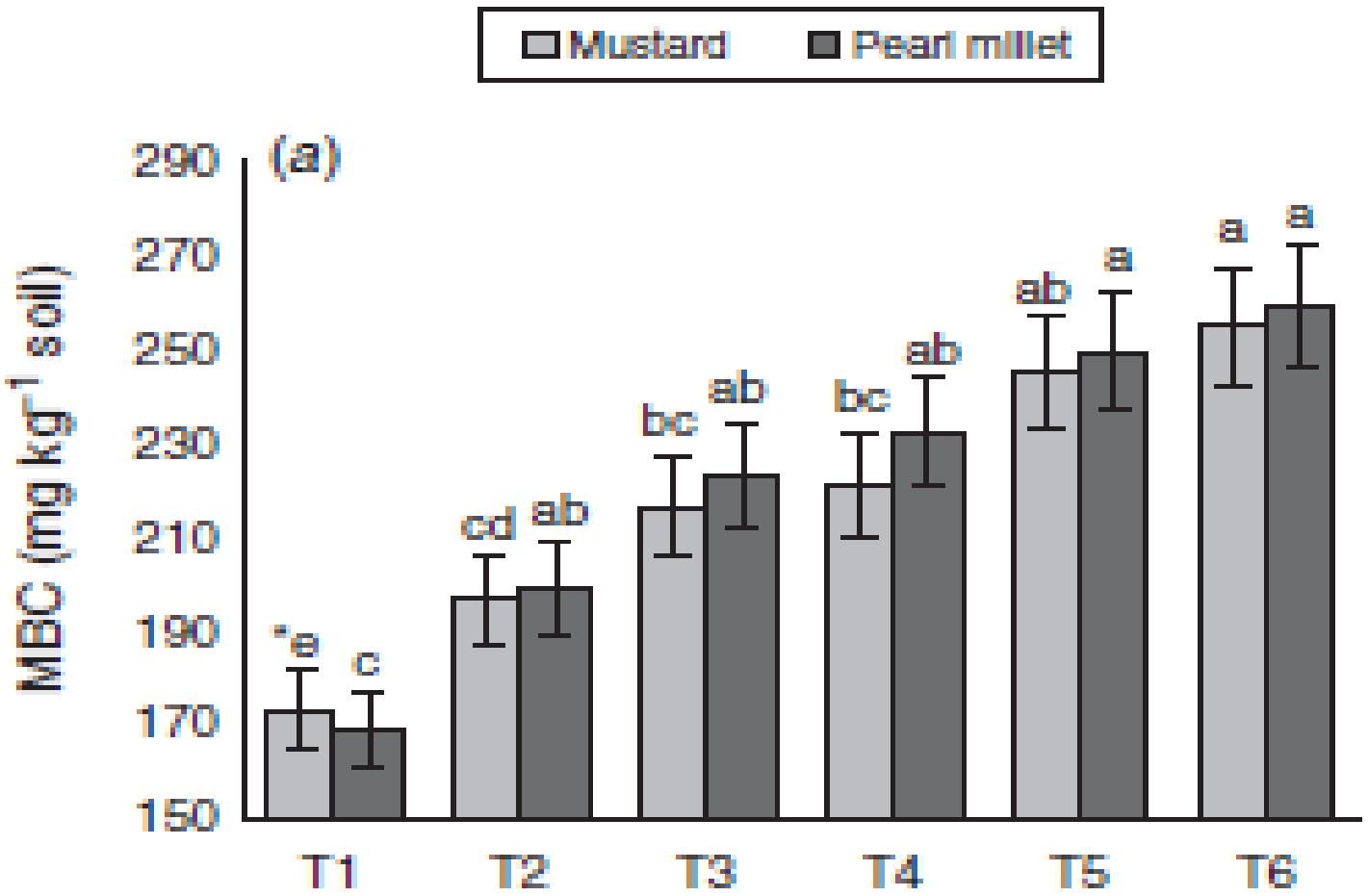

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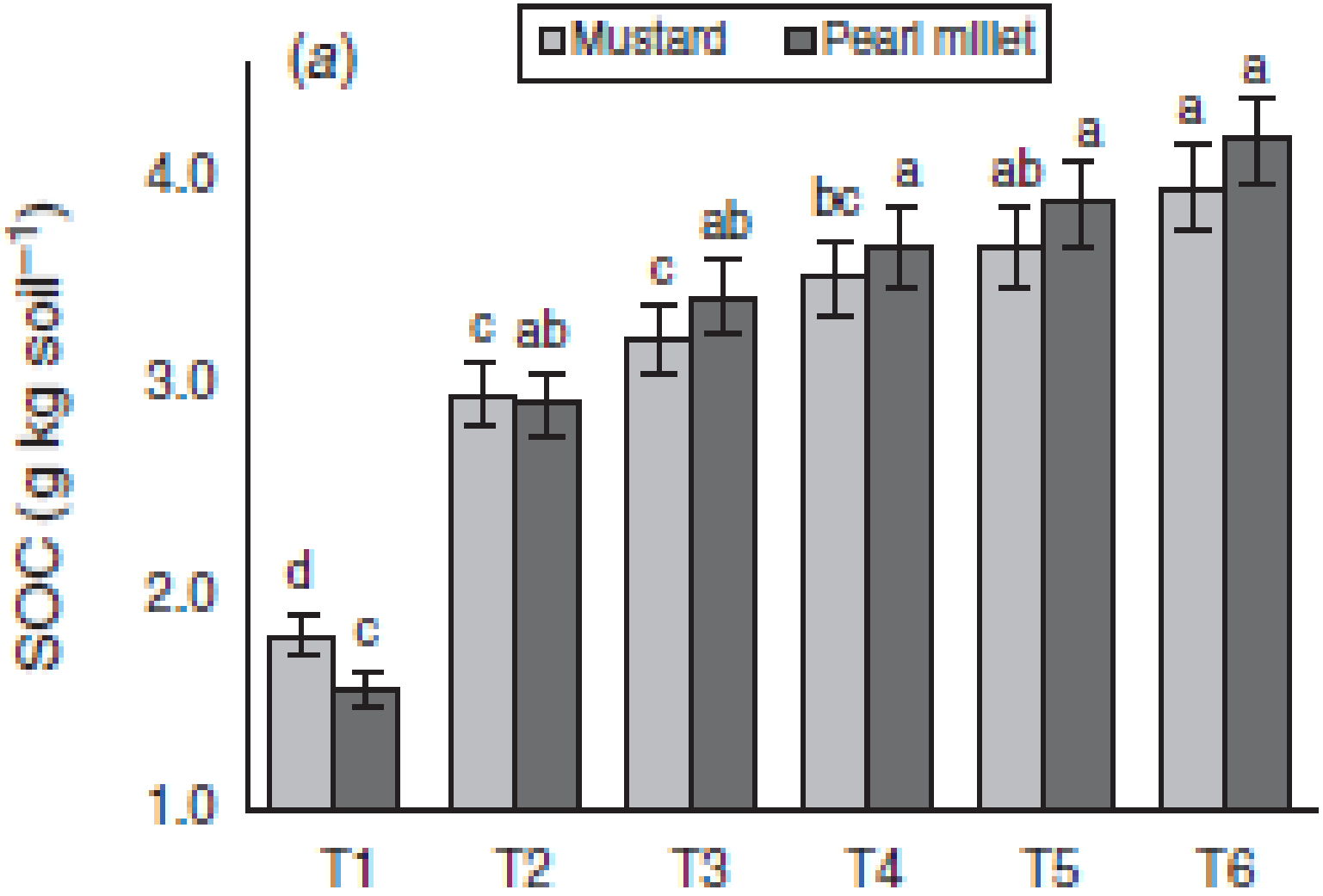
Effect of organic amendments and mineral fertilizers on microbial biomass carbon (MBC) during: (*a*) 2012–13 after mustard pearl millet harvest. *For each parameter, means with the same letter are not significantly different at $P = 0.05$ according to Duncan's multiple range test for separation of means. Capped lines represent standard errors (%). (Meena et al. (2016)



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SOC sequestration

- Application of organic amendments at 7–8 t / ha along with mineral fertilizers under a mustard–pearl millet cropping system in saline soil resulted in higher MBC, enzyme activities, SOC and available N, P and K, which improved crop yields.
-
- MSWC at 8 t ha–1 + 50% RDF resulted in the highest grain and straw yield for both crops throughout the 2-year cropping cycle.

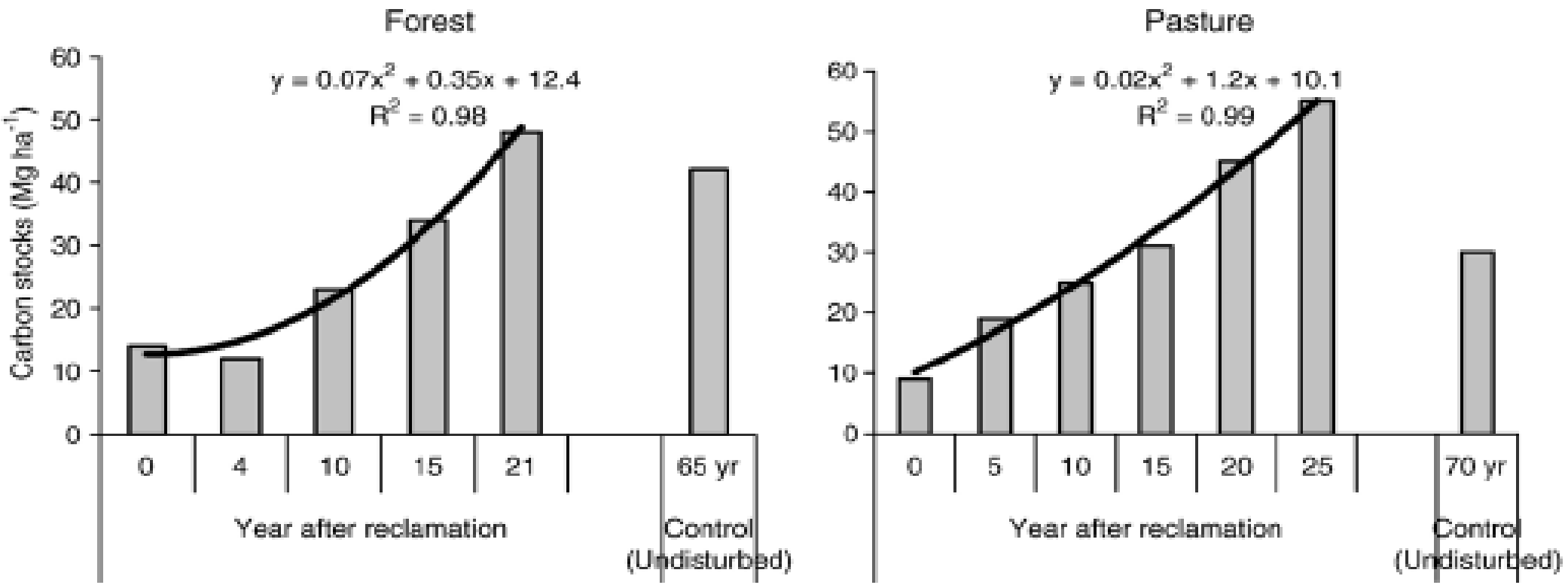
Effect of biowaste on microbial biomass

Treatment	2000	2003
Control	122	127
CGCC1	175	392
CGCC2	229	455
CGCC3	258	537
PM1	198	449
PM2	257	546
PM3	298	641
LSD	105	702

CGCC1, CCGC2 and CGCC3 were fertilized with (cursed cotton gin compost (CGCC) at the rate of 14.4 , 27.06 and 28.08 Mg Ha^{-1} (35 % DM) , respectively.
PM1 PM2 and PM3 were fertilized with poultry manure (PM) at the rate of 8.14,12.21, 16.28 Mg Ha^{-1} (60%DM), respectively.

Tejada et al. (2006)

Carbon sequestration in reclamed soils



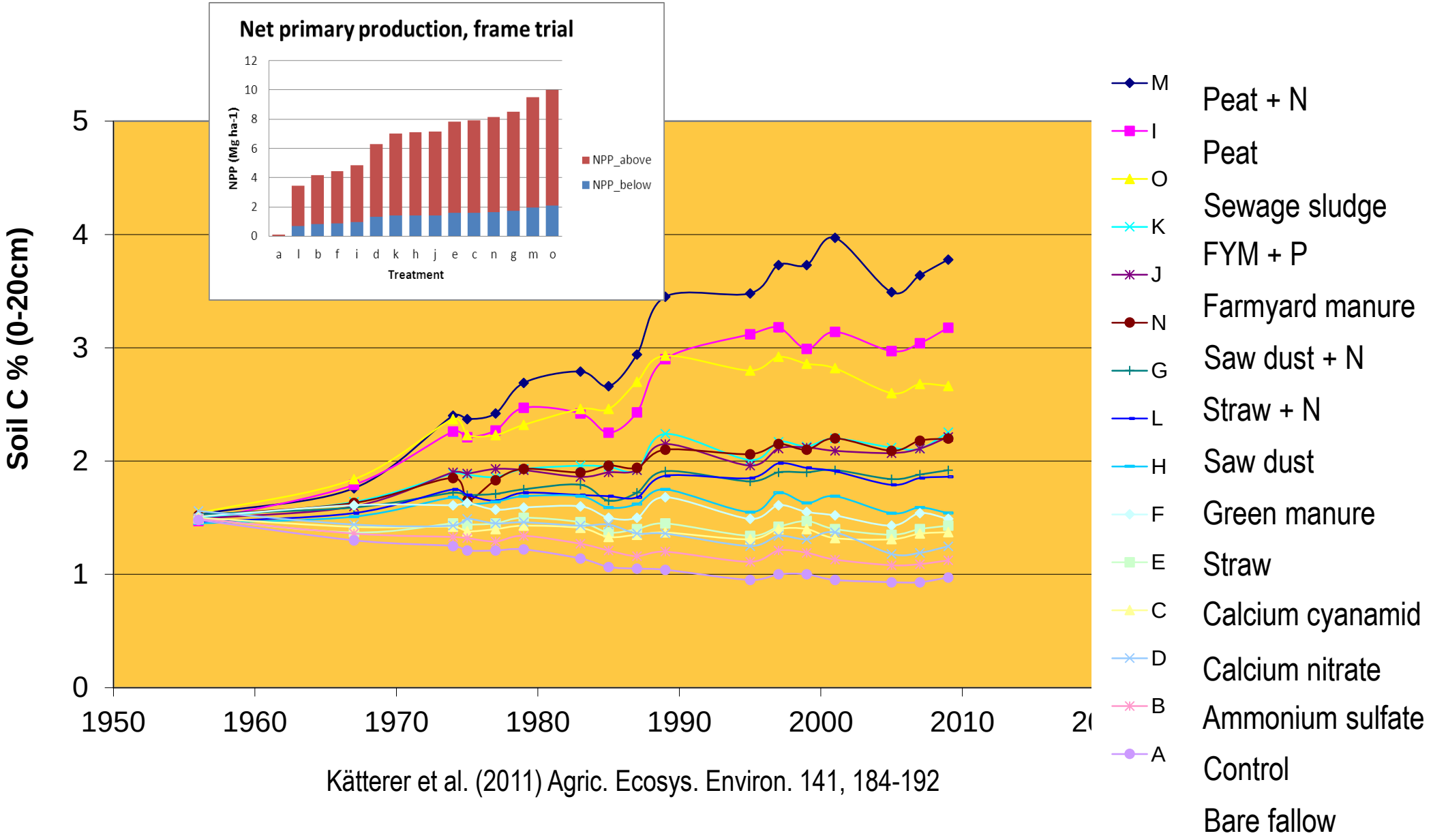
Carbon stocks in 0–15 cm soil depth in reclaimed mine soils and undisturbed soil of Ohio (drawn using data from Akala and Lal, 2001).

Table 5
Carbon sequestration in reclaimed mine soils

Land use	Depth (cm)	Period (Years)	Rate of C sequestration Mg ha^{-1} yr^{-1}	Reference
Grass	0–15	11	3.1	Akala and Lal (2000)
	0–15	25	0.5–3.1	Akala and Lal (2001)
	0–15	47	0.53	Shukla and Lal unpublished
	–	45	0.13	Wali (1999)
Forest	0–15	14	2.6	Akala and Lal (2000)
	0–15	21	0.7 to 2.3	Akala and Lal (2001)
	–	–	4.0	Burger (2004)
	0–10	40	0.58	Sourkova et al. (2005)

Shrestha and Lal (2006) Environmental International 32

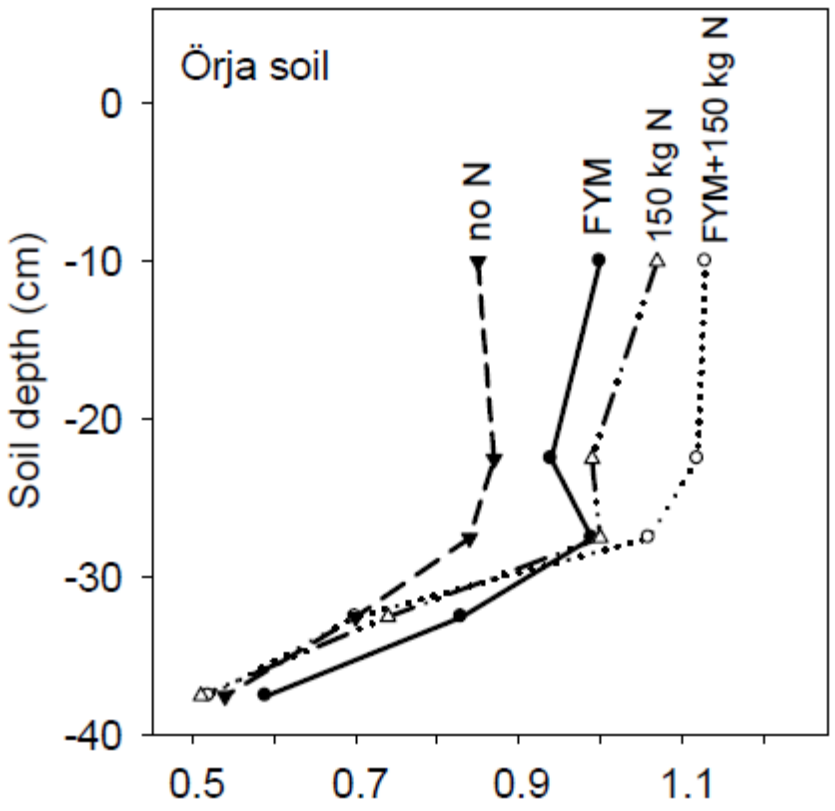
Changes in topsoil C over time in the Ultuna frame trial



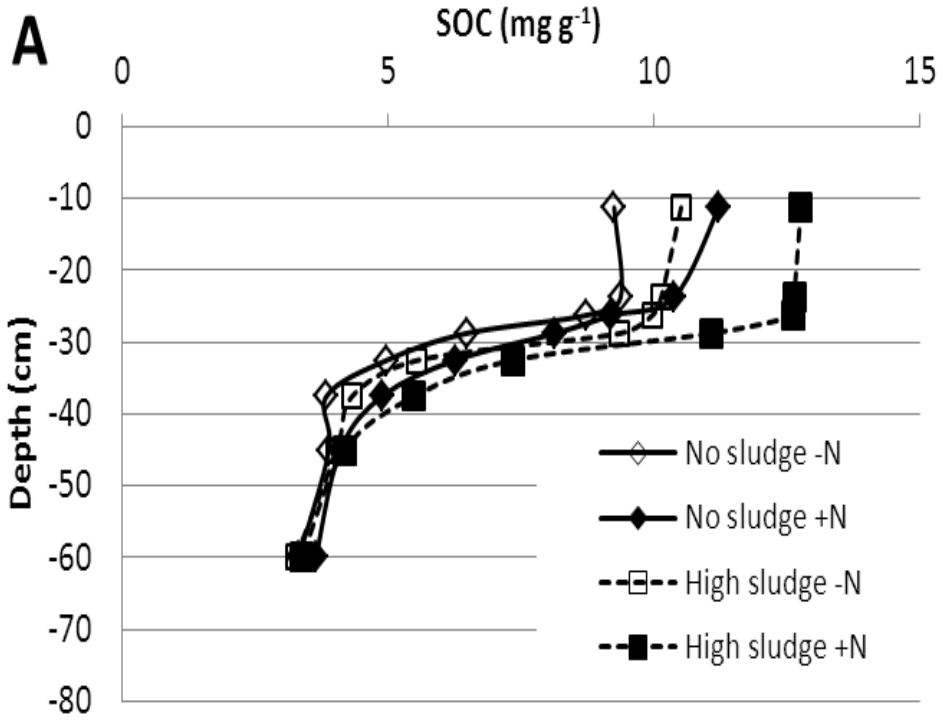
Kätterer et al. (2011) Agric. Ecosys. Environ. 141, 184-192

Significant SOC changes in upper subsoil (to 40 cm) in long-term experiments

50 years



30 years



About 30% of SOC accumulation occurred below maximum ploughing depth (25 cm) Kirchmann et al., 2013; Kätterer et al., 2014;

Conclusions

- Biowastes, due to their high content of organic matter, improve physical and biological properties of soils.
- Thus they have potential for increased soil productivity leading to improved crop yield and plant quality.
- They also lead to increased microbial activity contributing to higher humus production.
- Biowastes can supplement commercial fertilizers and may lead to integrated nutrient management (INM).

Conclusions

- Biowastes are effective immobilization agent for heavy metals in the soil and thus lowering the costs of soil remediation.

- They show potential of soil carbon sequestration and thus contributing to mitigation of climate change.

- However, comosition and properties of biowastes, especially the concentration of **potential toxic elements (PTE) and pathogens** must be **carefully controlled because they** may pose a risk for environmental as well as human health by their entrance in the food chain.