Improving productivity, resilience and sustainability through conservation agriculture based systems in the Ethiopian highlands

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ECHO East Africa highlands symposium Addis Ababa, 01/11/2016

1. Introduction – what is the problem?

➢ Causes of cropland degradation in Ethiopia:

Human factor:

- complete crop residue removal at harvest,
- aftermath overgrazing,
- intensive & repeated tillage,
- burning of crop residue,
- crop straw & animal dung for firewood,
- deforestation,
- monocropping/limited option in lowlands

Climatic factor

- repeatedly occurred drought

soil quality loss, SOM depletion → soil erosion and runoff → ↓ in crop yield & ↑ vulnerability of smallholders to climate change and variability

1. Introduction – what is the problem?

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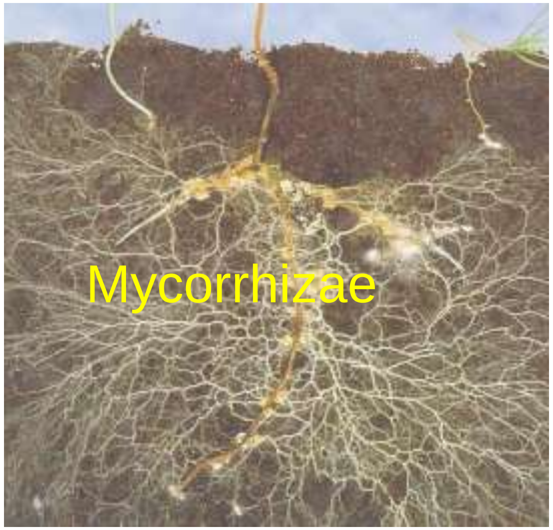
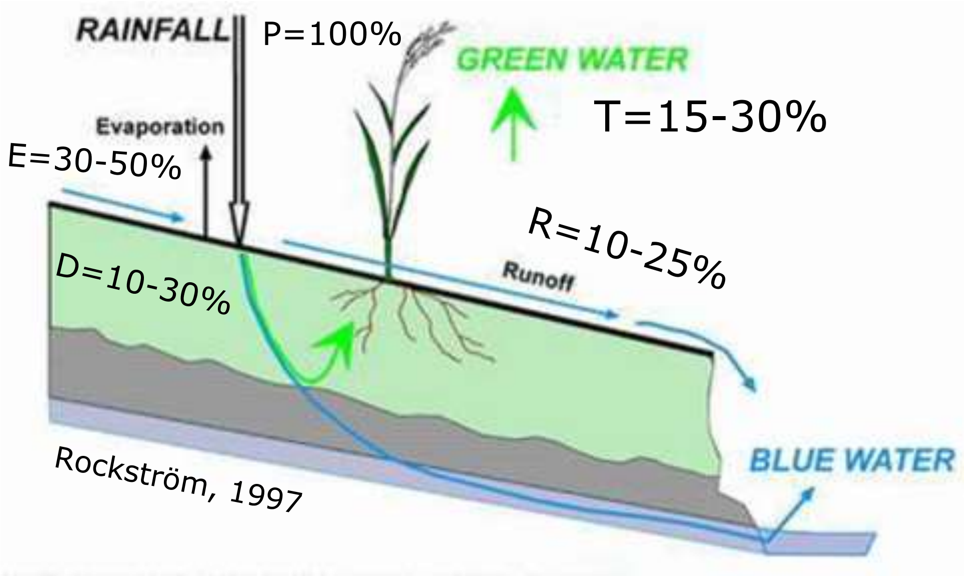


- Other major potential limitations for crop production:
  - periodical (agricultural) drought/dry spell
  - water logging in Vertisols (coverage area=10.5% in Ethiopia)

1. Introduction – what is the problem?

- Rain fed farming agriculture is dominant in Ethiopia
- Rainfall is erratic and insufficient in the drylands of Ethiopia



Green water=water stored in the soil and used by plants

Blue water=runoff and deep drainage, recharging groundwater and feeding streams (Falkenmark, 1995)

imbalanced soil hydrology

↓

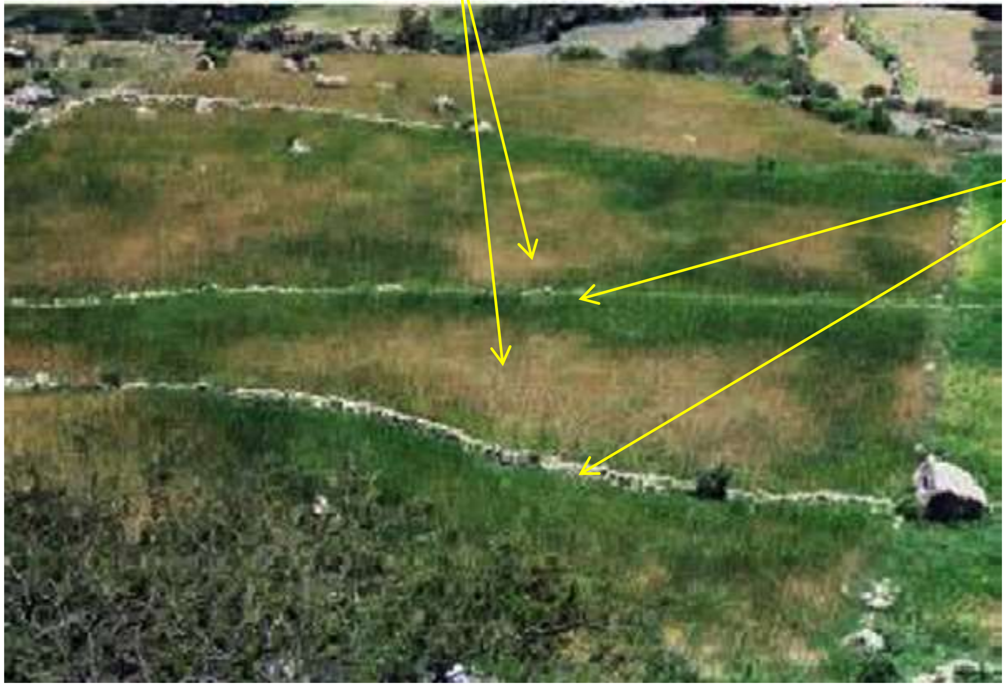
often due to

- deteriorated physical quality of soil
- absence of add. control measures

1. Introduction – what is the problem?

Crop wilting at the onset of the dry season

Soil and water conservation: stone bund



(after Vancampenhout et al., 2006)

- Food shortages remain a major concern in Ethiopia due to:
  - Climate variability: insufficient and erratic nature of rainfall
  - imbalanced soil hydrology – high runoff and evaporation
  - cropland degradation

1. Introduction – what is the problem?

- Conventional tillage systems require high labour:
  - barrier to participation for poor, disabled, elderly farmers and women headed HHs (>30%)
  - Delayed planting

1. Introduction – is there a solution?

1. Complete harvest
2. Aftermath overgrazing
3. Repeated tillage

conservation agriculture (CA) based system is a simultaneous practice of:

1. Keeping the soil covered (>30% residue)
2. Minimal soil disturbance
3. Mix and rotate crops

} CA

4. Local *in-situ* soil and water conservation practices

1. Introduction – is there a solution?

- CA-based systems can:
  - reduce cropland degradation
  - improve the soil hydrology- reduce rainwater loss in the form of runoff and evaporation
  - increase agro-ecosystems resilience to climate change and climate variability
  - bring a sustainable crop yield improvement over time

- However, CA-based systems practice is not common in Ethiopia

1. Background: Does CA practice exist in Ethiopia?

SNNPR/Derashe Traditional CA Practice

They prepare planting holes between trash lines by hand and Residue returned to the soil improves tilth and reduces compaction.

The use of residue also results in better moisture infiltration, and, consequently, less runoff and loss of soil.

1. Background – why research on CA?

- Impact of CA vs. conventional agriculture practices based on experiments in different parts of the world has not been consistent across:
  - socioeconomic setups: small-scale farming systems
  - Topography: 6.5% slope in sub humid and 3% slope semi-arid areas
  - soil types: Vertisols
  - climate: sub humid and semi-arid areas
  - crops: local crop rotations in Ethiopian highlands (incl. teff)
  - ploughing implements: ox-drawn *marhresha* ard plough

1. Background – why research on CA?

- Two local tillage practices, namely, *derdero* and *terwah*, were modified to comply CA principles

indigenous conservation practices

+

tillage tools (*marasha* ard plough)

↕

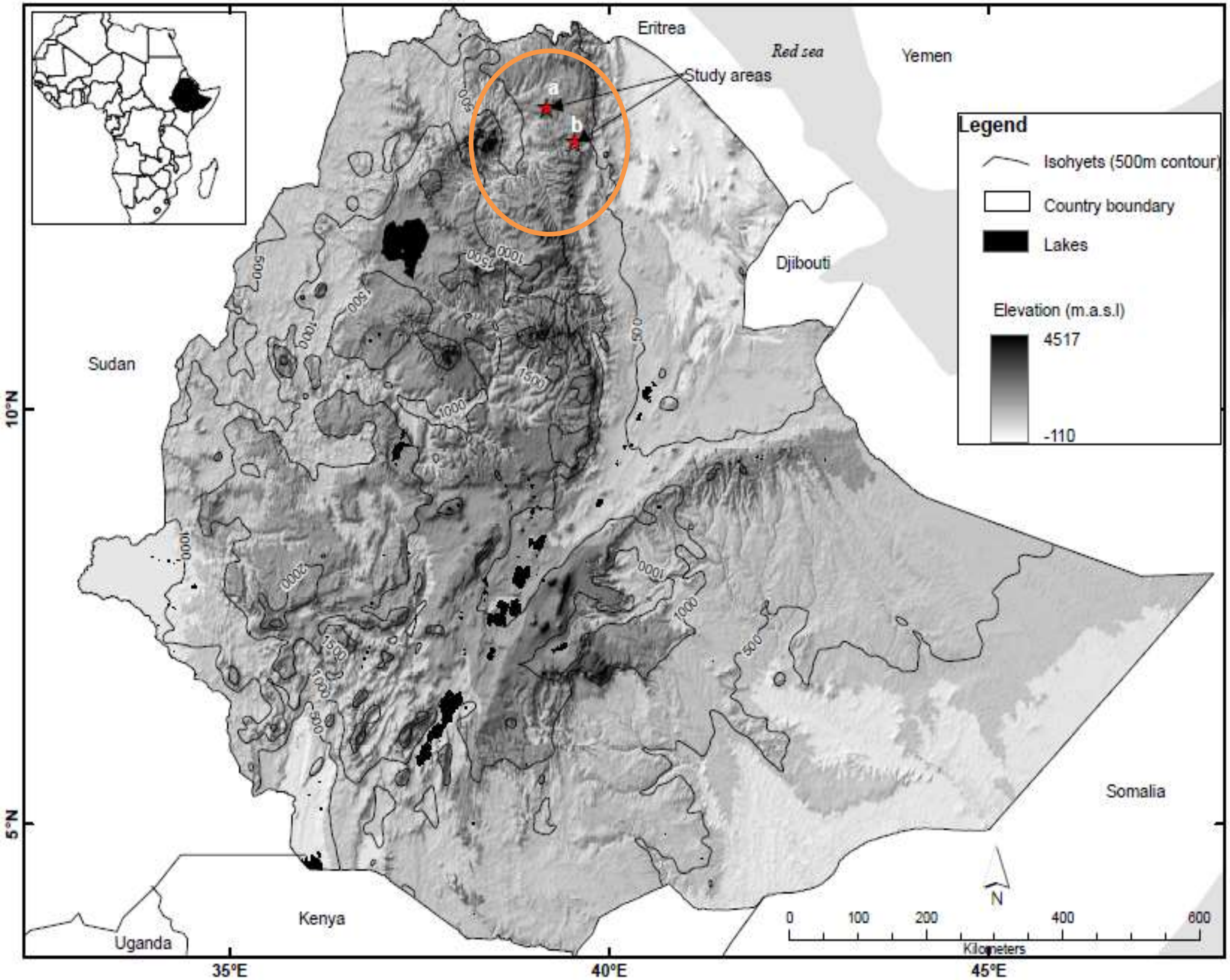
wide international body of knowledge on CA

1. Introduction – objectives

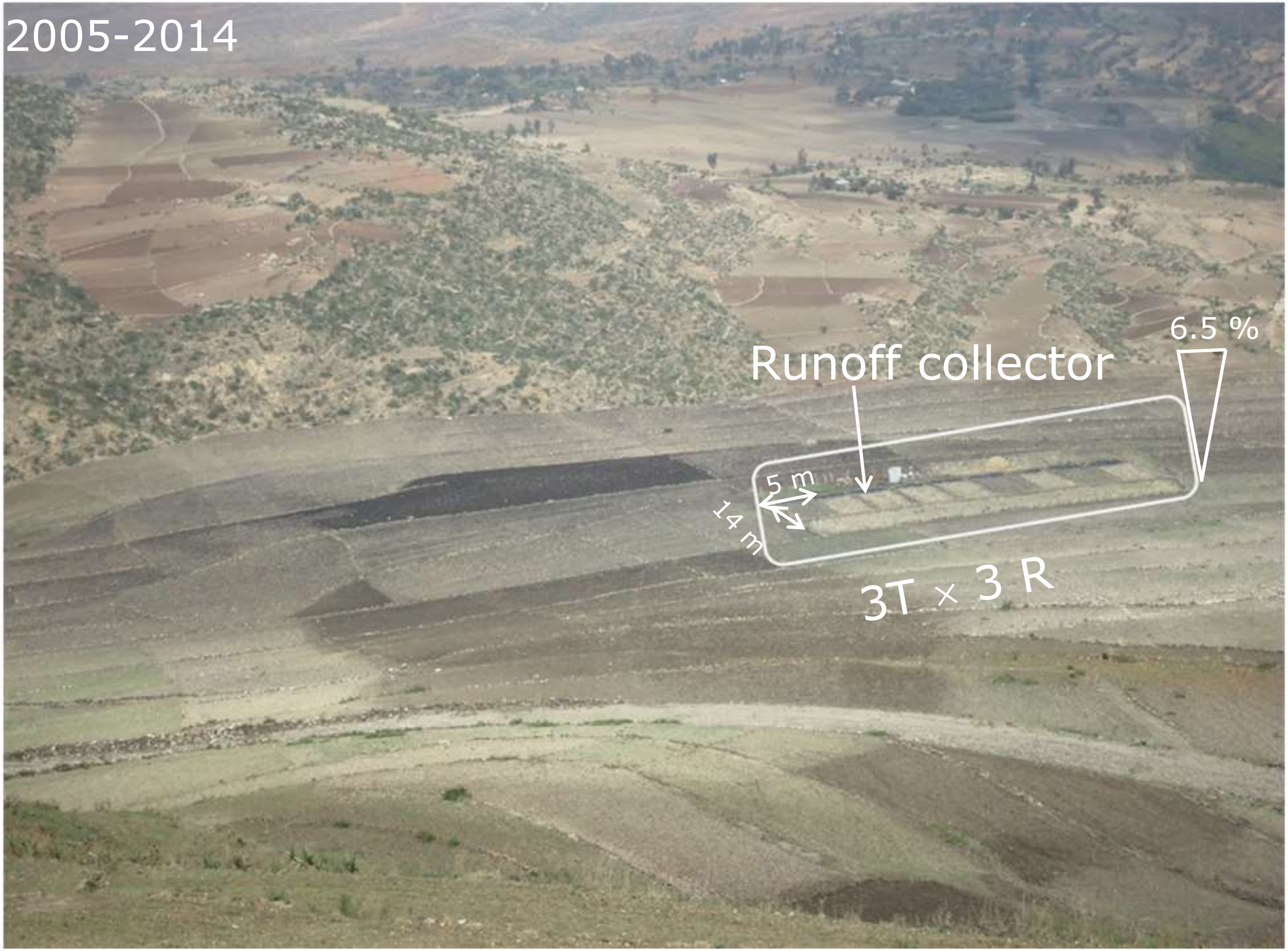
- To assess the long-term (10 years) impacts of CA-based cropping systems on:
  - building resilience against climate change
  - runoff and soil loss
  - Soil quality
  - soil rainwater storage
  - crop productivity and
  - Economic profitability

→ in the Ethiopian highlands

2. Field experiments– where?



2. Field experiments – design in sub humid area



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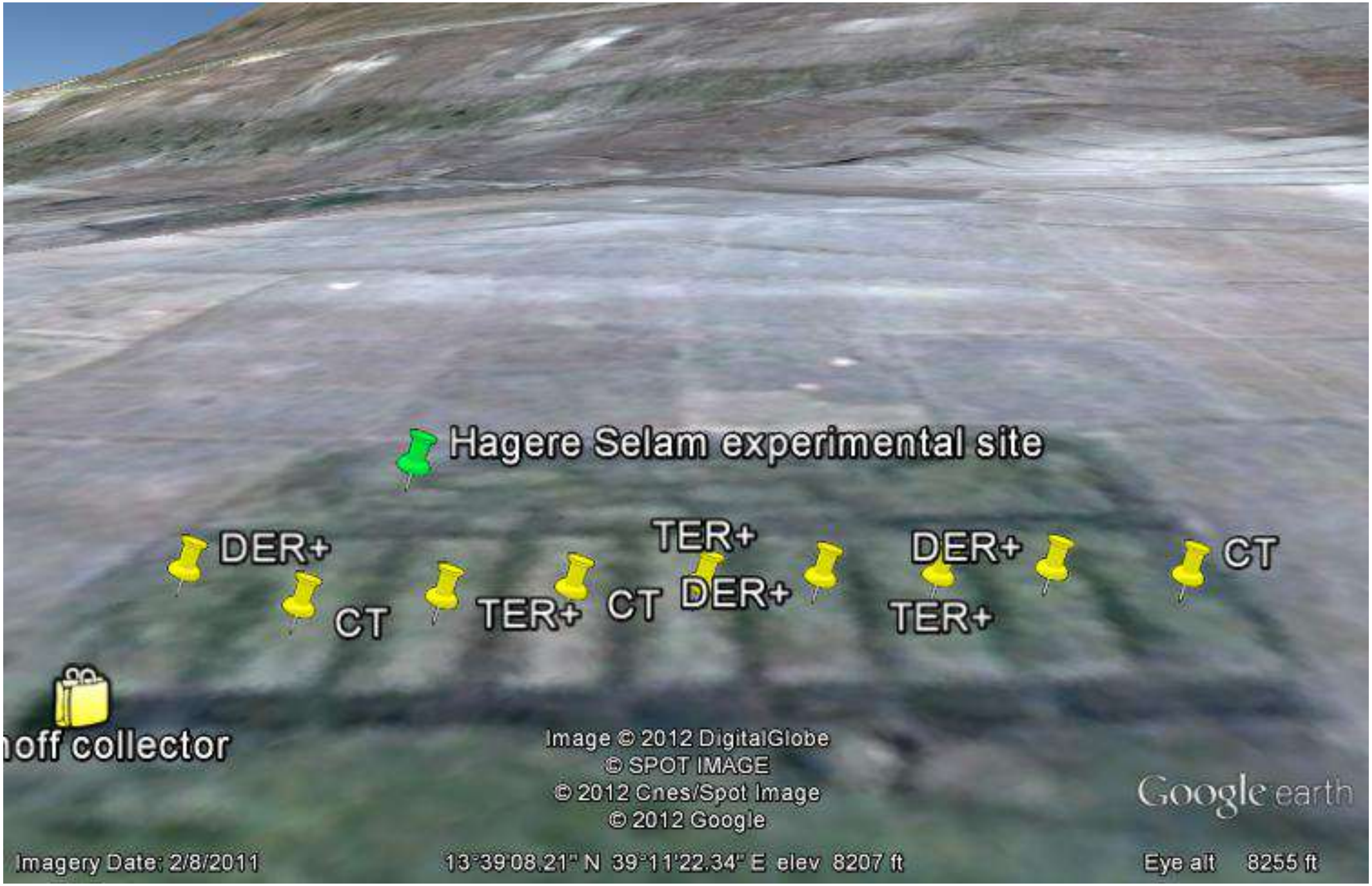
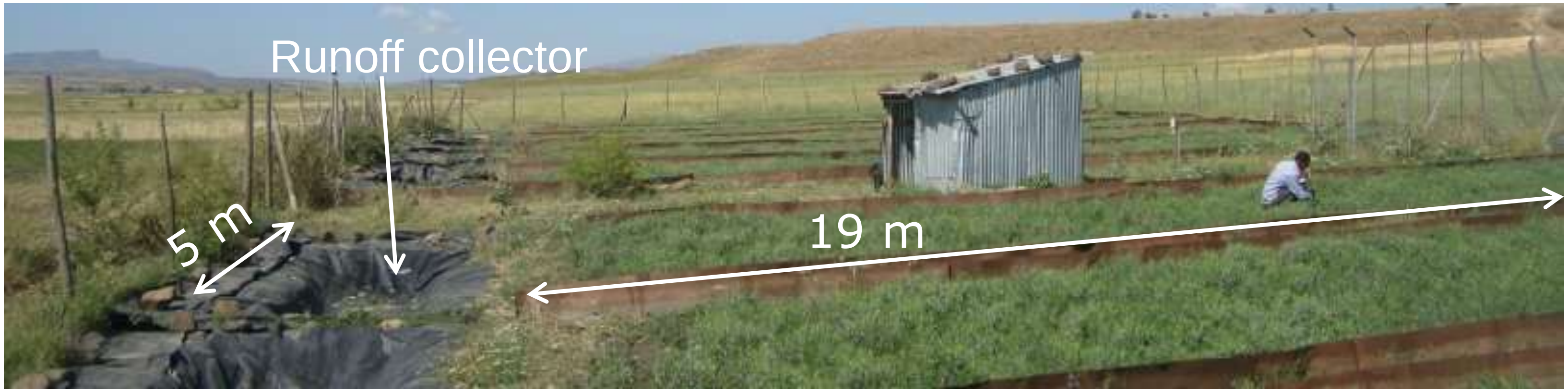


2. Field experiments – design in semiarid area



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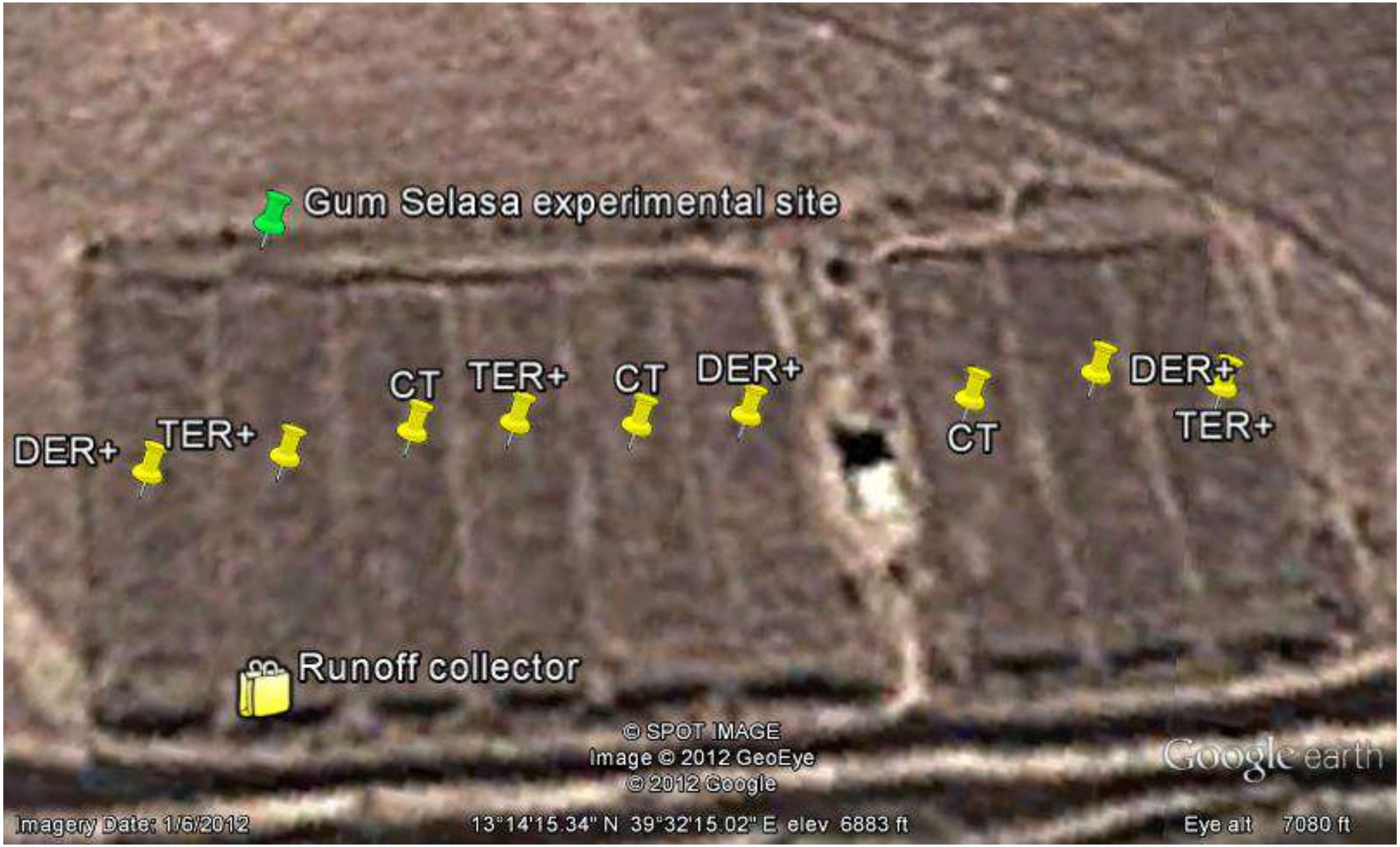


2. Field experiments – design in irrigable fields

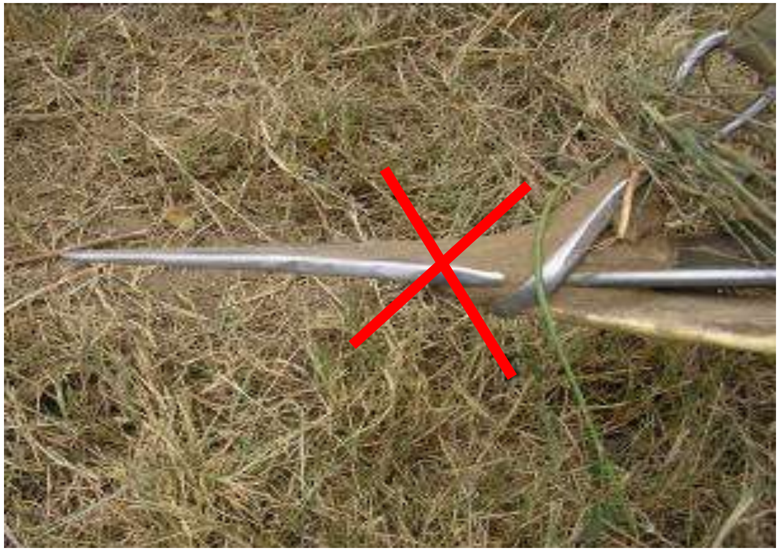
Cereal and vegetable crops in rotation

- Rainfed: wheat, barley, grass pea, teff
- Off season with irrigation: maize, onion, garlic

2. Field experiments – treatments

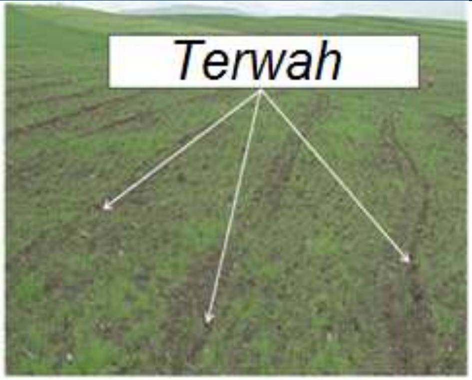
a. <u>conventional tillage</u> (CT)

- ploughing pattern was similar to local practice for the type of crop and year
- ploughed at least three times per year
- crop straw was completely harvested without leaving residue on the surface as farmers do

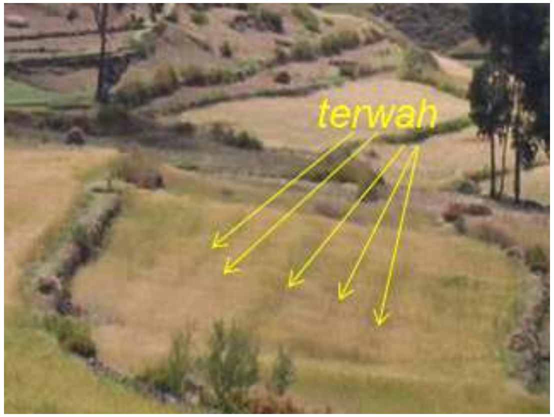


2. Field experiments – treatments

b. *terwah+* (TER+)



- *Terwah* local practice
  - at least 3 tillage per cropping
  - practiced typically for teff
  - furrows made at 2-4 m intervals along the contour



- Modified *terwah+*:
  - furrows made at 1.5 m intervals along the contour
  - practiced for all experimental crops
  - tillage was done only once at sowing
  - 30% the crop residue was left as standing stubble
  - 2 l/ha glyphosate was applied to control pre-emergent weeds starting in 2007

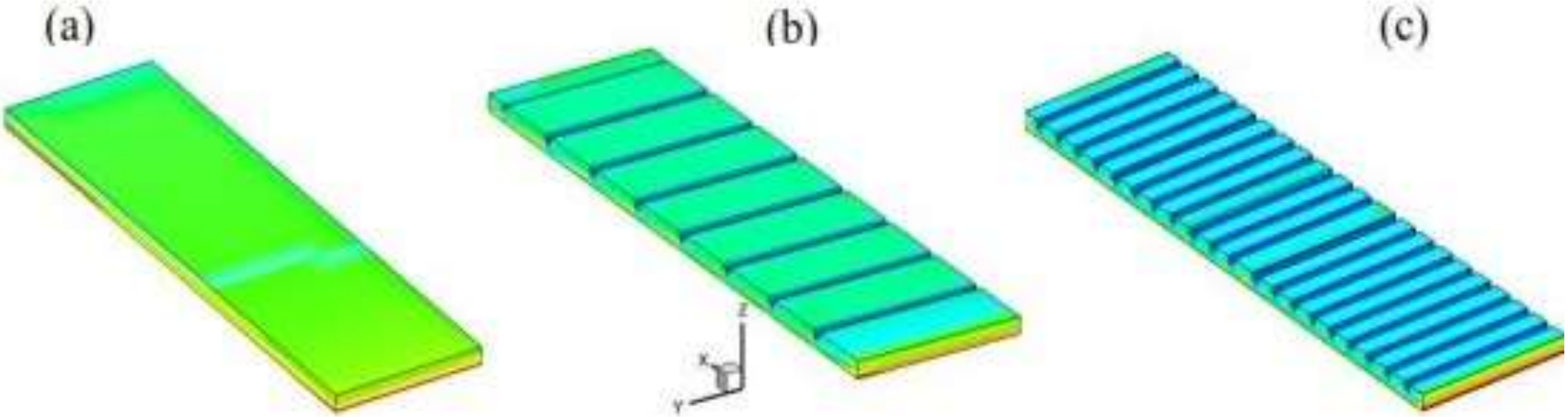
2. Field experiments – tillage practices

c. <u>*derdero+*</u> (DER+)

- *Derdero* local practice:
  - have furrows and raised beds (35 cm)
  - at least 3 tillage per cropping
  - typically on vertisols for fenugreek, lentil, wheat and teff (local crop)

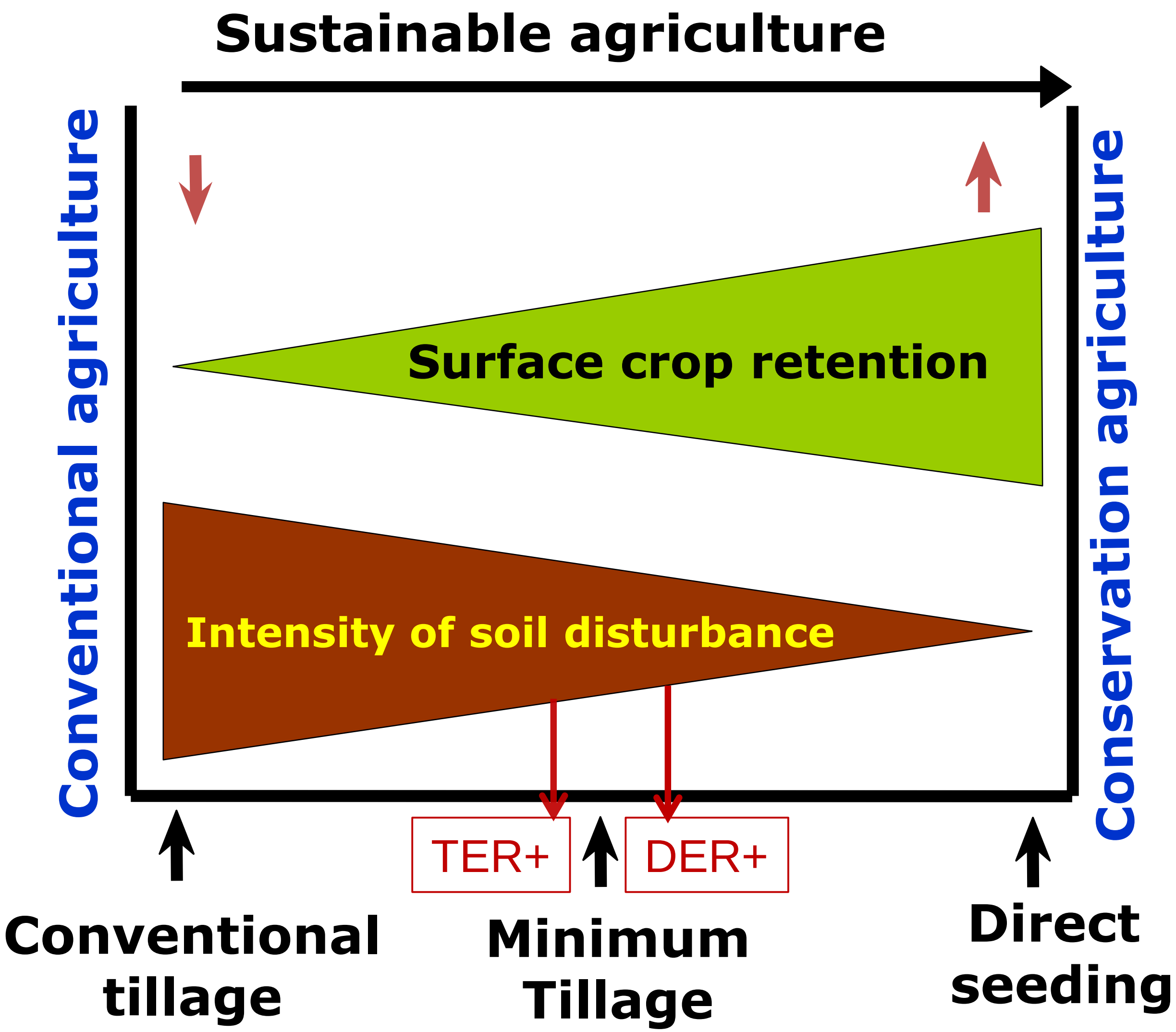
- Modified *derdero+*:
  - have furrows and permanent raised beds (35 cm)
  - no tillage on the top of the raised bed
  - tillage was done once at sowing by refreshing furrows
  - 30% crop residue was left as standing stubble
  - 2 l/ha glyphosate herbicide was applied starting in 2007

2. Field experiments – treatments/tillage practices



2. Field experiments– *derdero*+ in demonstration plots?

2. Field experiments – soil disturbance level?



2. Field experiments – treatments/Crop residue

2. Field experiments – weed control?

2. Field experiments – planting method, seed rate and fertilizer?

2. Methods - measuring runoff and soil loss


Measuring runoff


Sample for soil loss

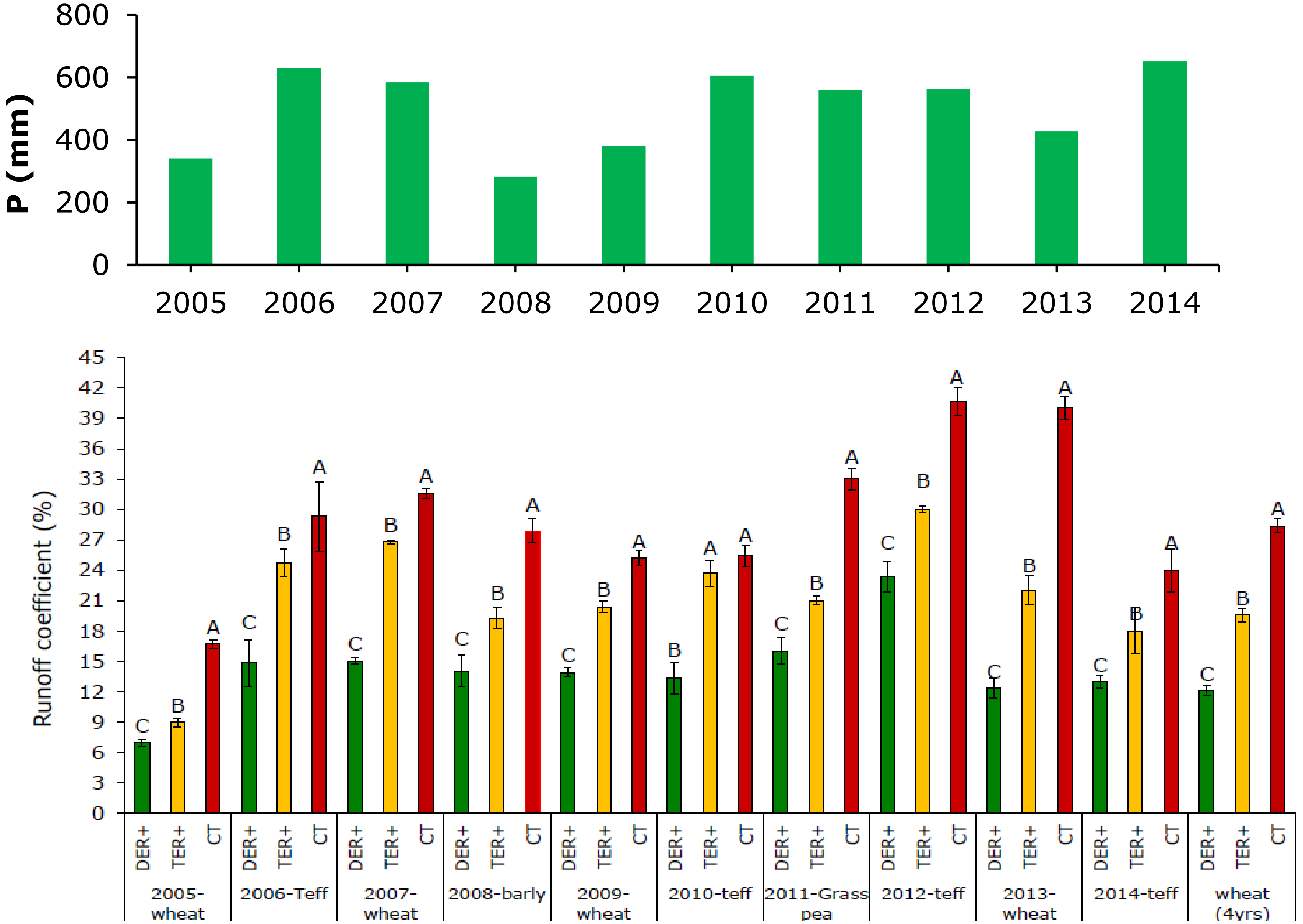

Runoff removing


Calibration

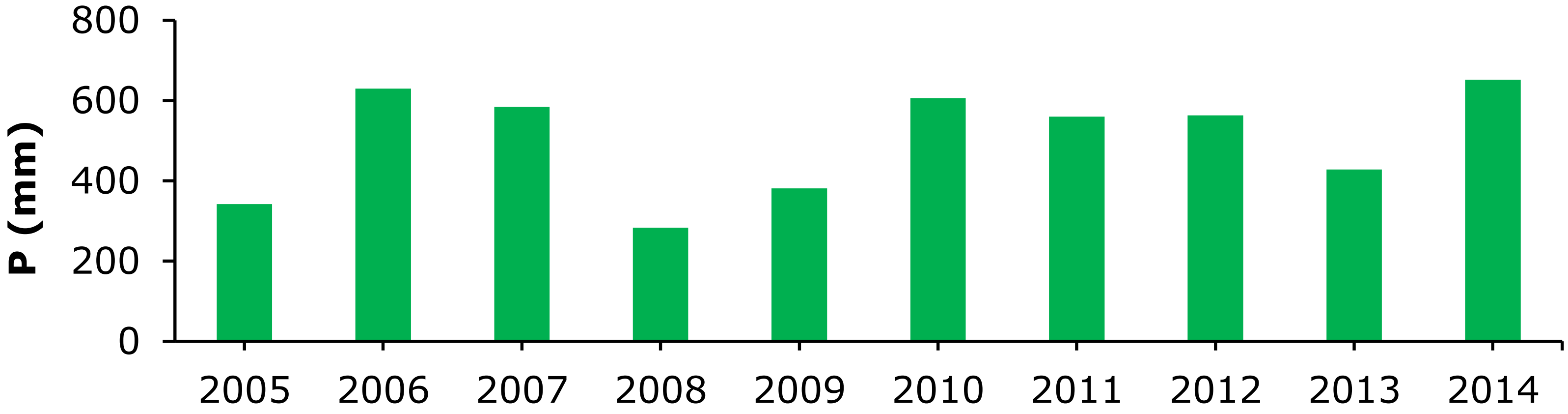

Soil loss


Dry soil

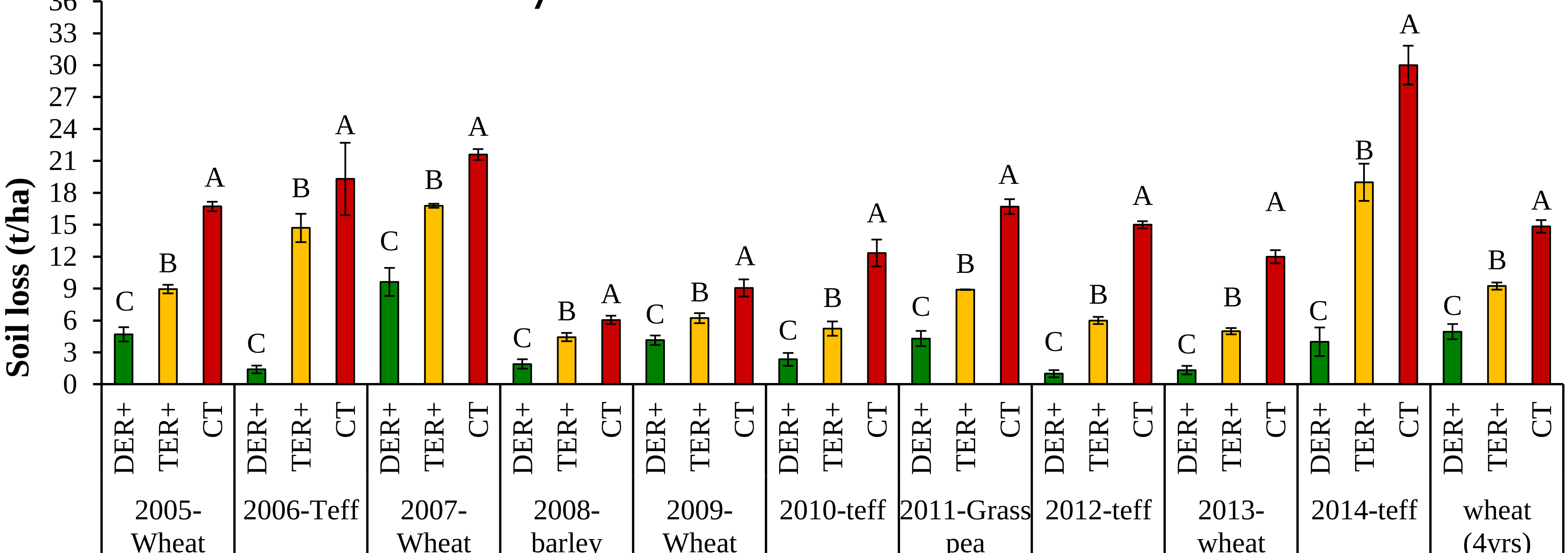
3.1. Results – does RCA affect runoff coefficient?



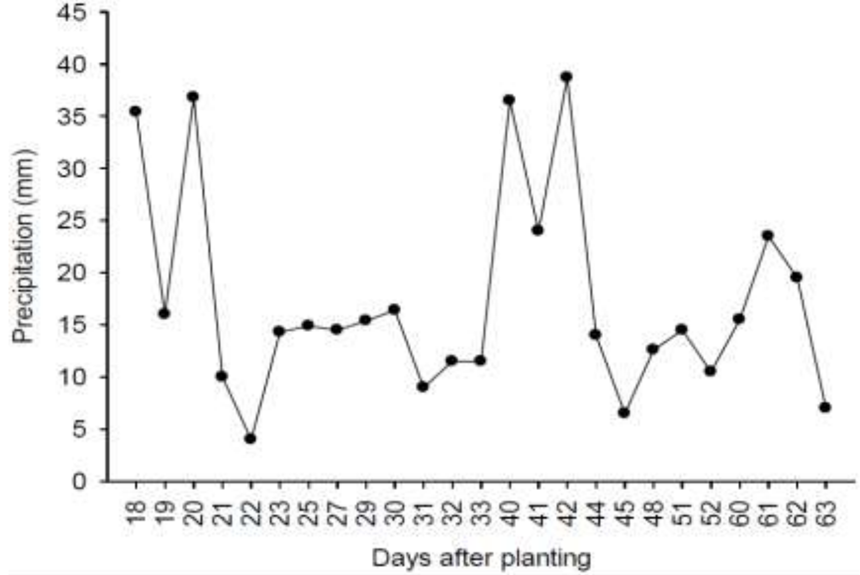
3.1. Results – does CA-based systems affect soil loss?

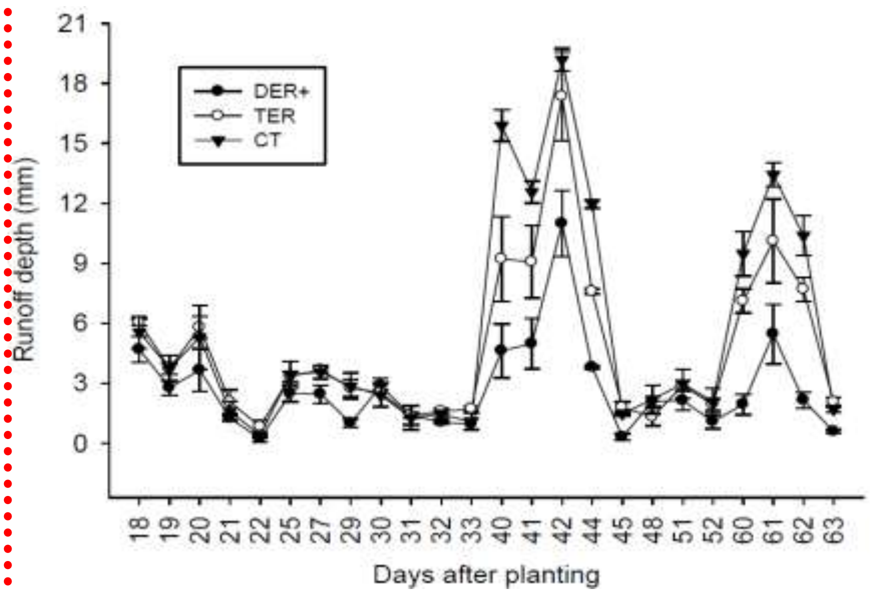


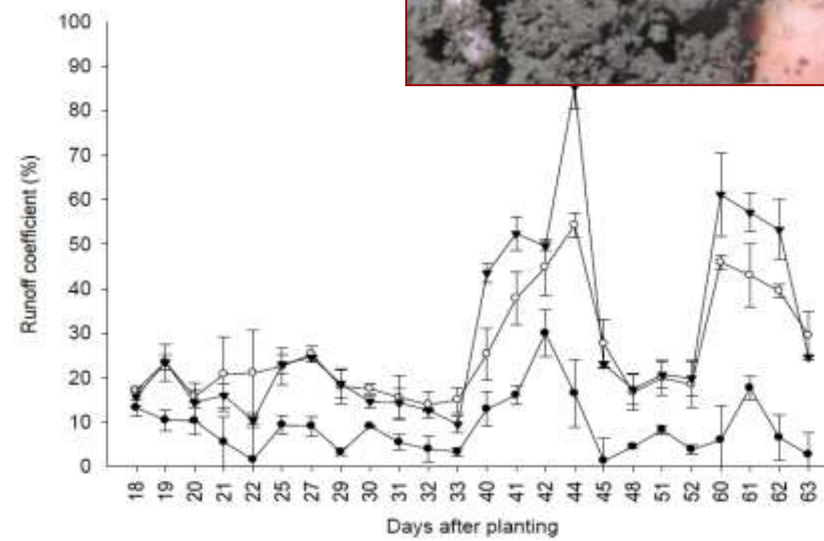
- CA-based systems builds erosion resistant soils



3.1. Results – does CA-based systems affect daily runoff?







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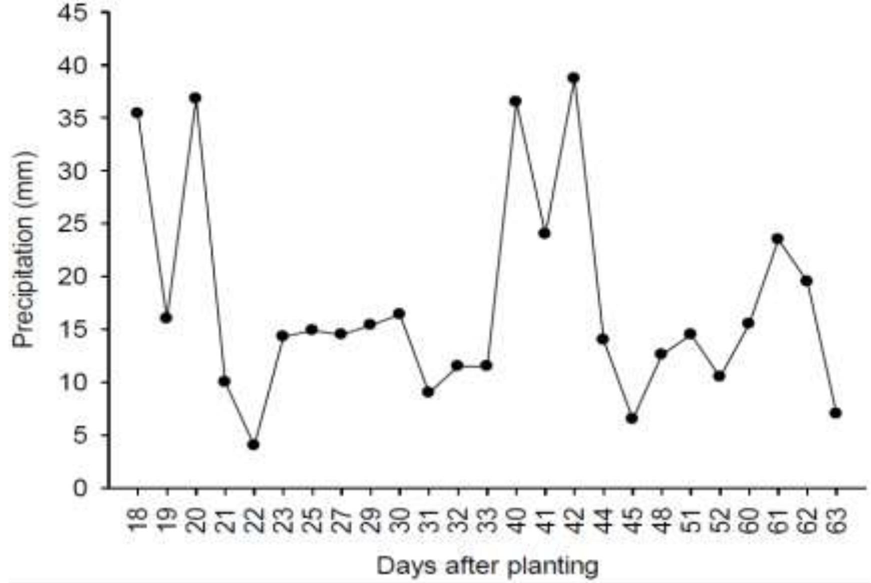
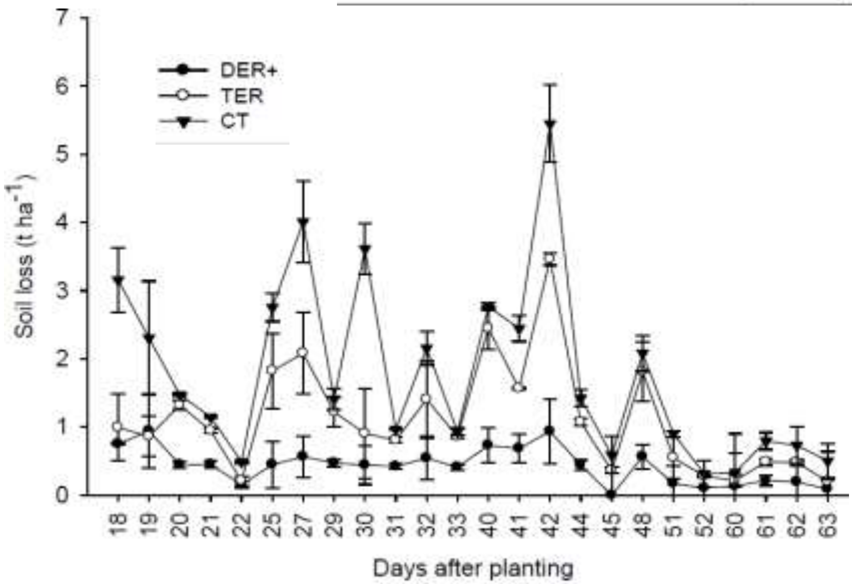
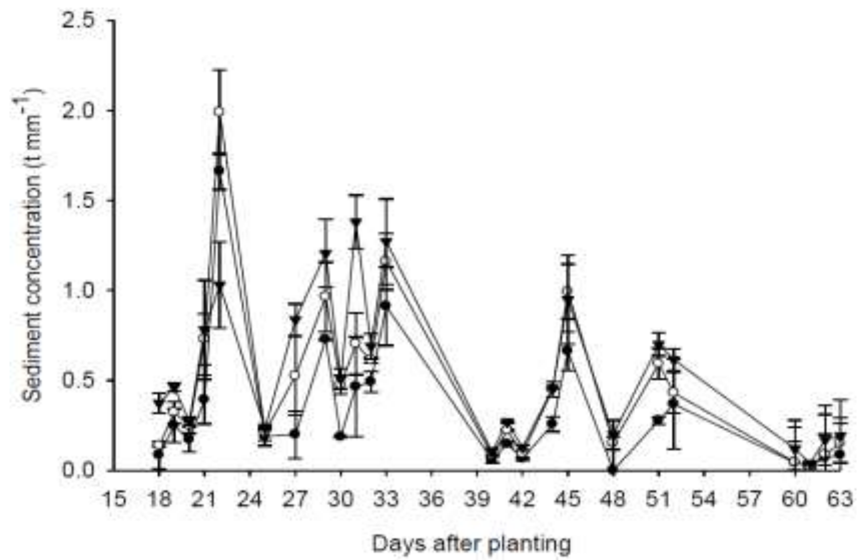






3.1. Results – does CA-based systems affect adaptation to climate change and variability?

- Drought – decrease in rainfall or dry spell
- Water-logging - increase in rainfall

Photographs of CT and DER+ plots taken 15 min after a 38.7 mm rainfall event on August 22, 2007 Araya et al., 2011

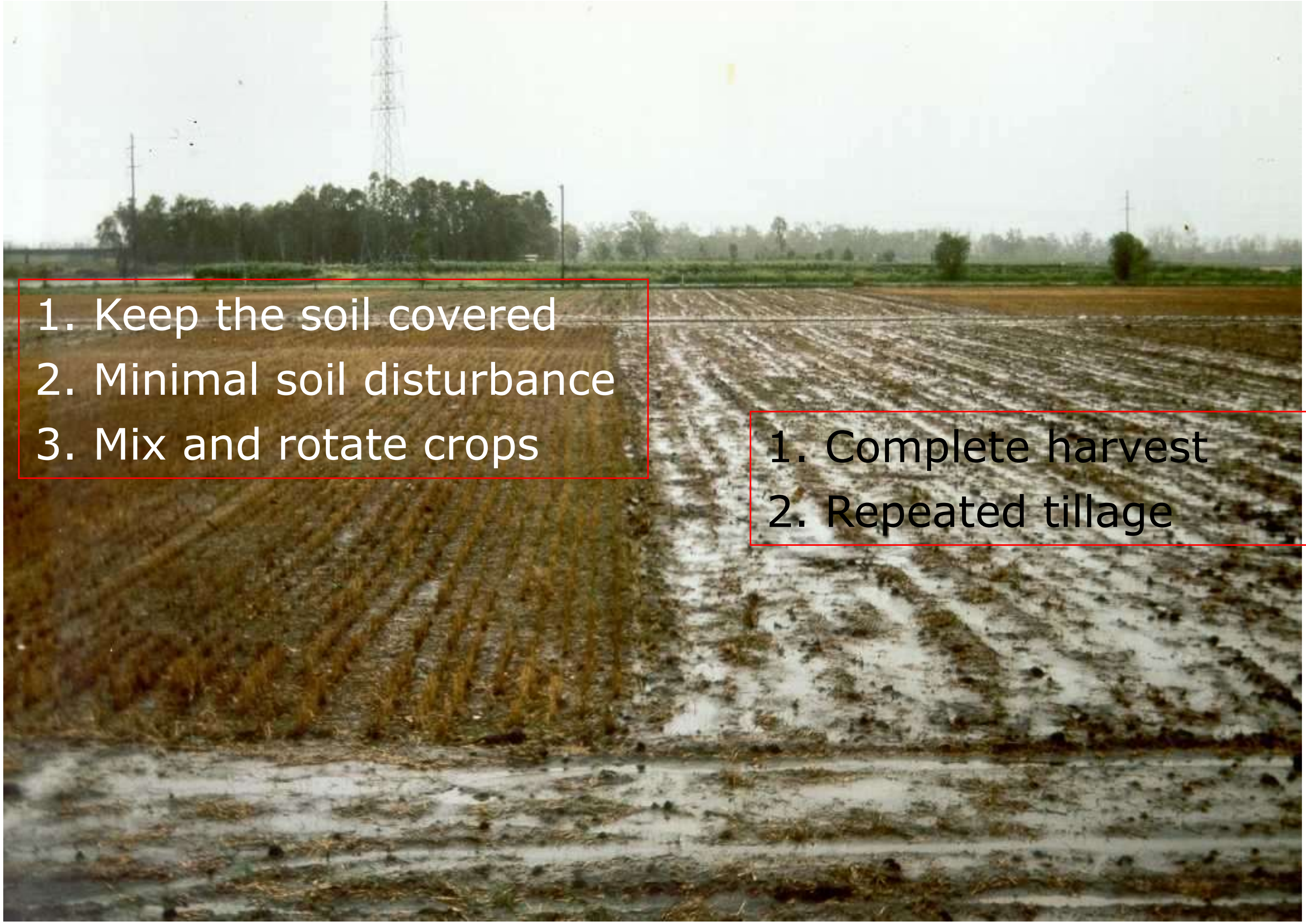
3.2. Can CA affect future climate change?

Using the EdGCM (Educational Global Climate Model) simulation, the rainfall in the sub humid study area was predicted to increase by 14.7% (>100 mm yr^{-1}) in 2040

Catchment level management (187 ha)	Soil loss (t ha^{-1} yr^{-1})	Curve number	Ponding	Organic matter
Conventional tillage	30.2	68.9	↓	↓
CA-based (derdero+)	12.4	67.2	↑	↑

Lanckriet et al. (2012)

3.1. Does CA affect soil loss and runoff



Sayre, 2008

2. Methods - measuring soil chemical properties

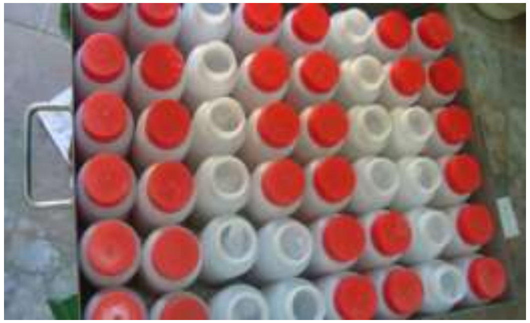
Carbon content

Nitrogen,
CEC,

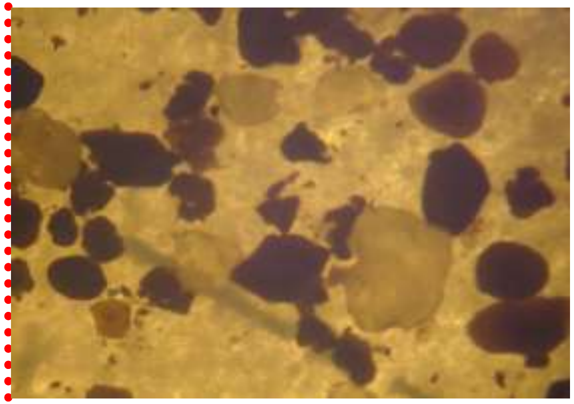
pH

phosphorus

2. Methods - measuring soil biological properties



Soil microbial biomass carbon content



Arbuscular mycorrhizal fungi

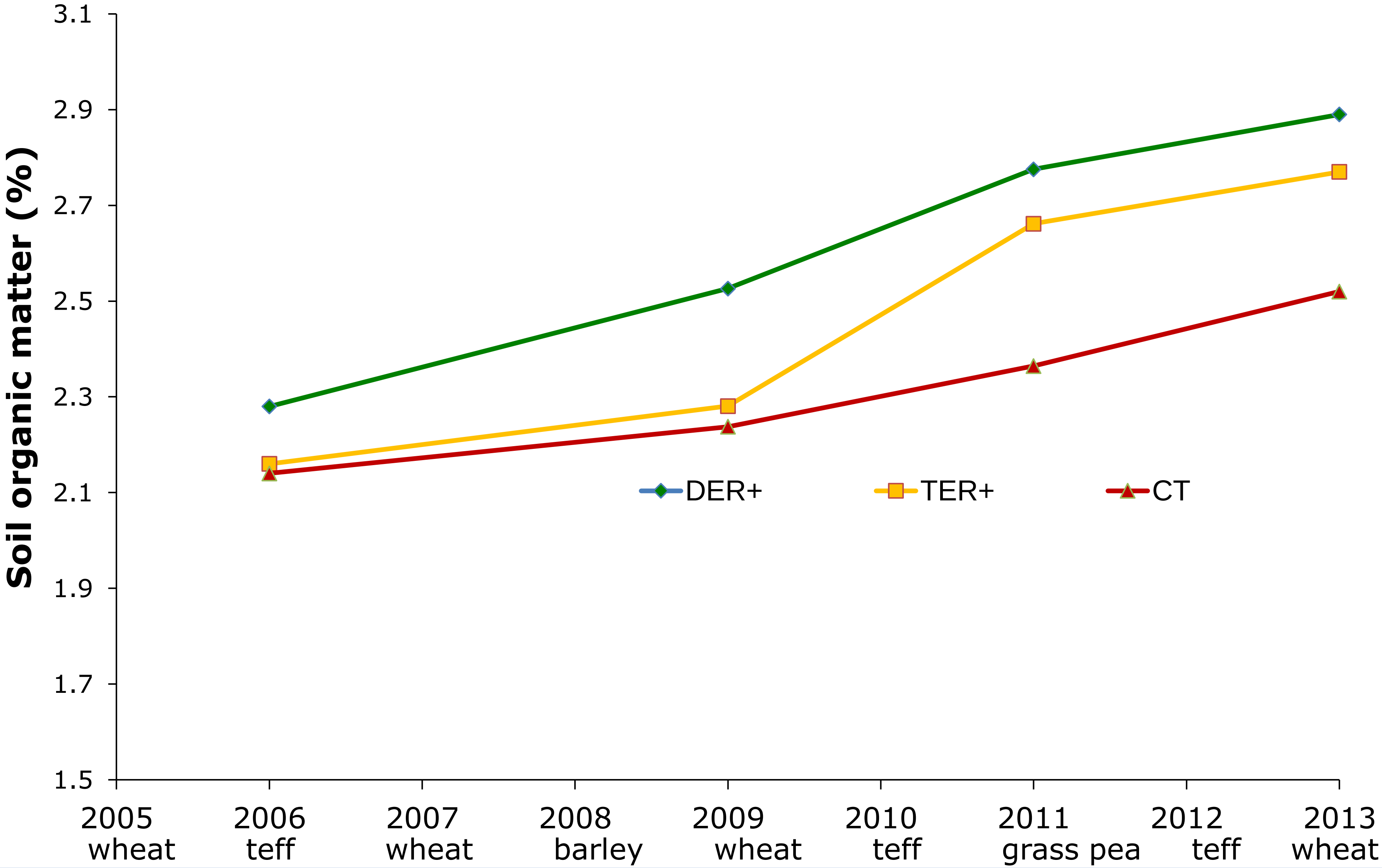
Soil bacteria

3.2. Results – does CA-based systems affect soil quality?

Property	DER+	TER+
C	>	>
N	>	=
P	>	=
soil microbial biomass carbon	>	>
time to ponding	>	>
aggregate stability index	>	>
consistency index	>	>
cone index	>	>
air capacity	>	>
macroporosity	>	>
crack size at harvest	<	<
relative water capacity	<	=
plastic limit	<	=
CEC, pH	=	=
liquid limit, plasticity index	=	=
FC, PWP, PAWC, MatPOR, S	=	=
field saturated hydraulic conductivity	=	=

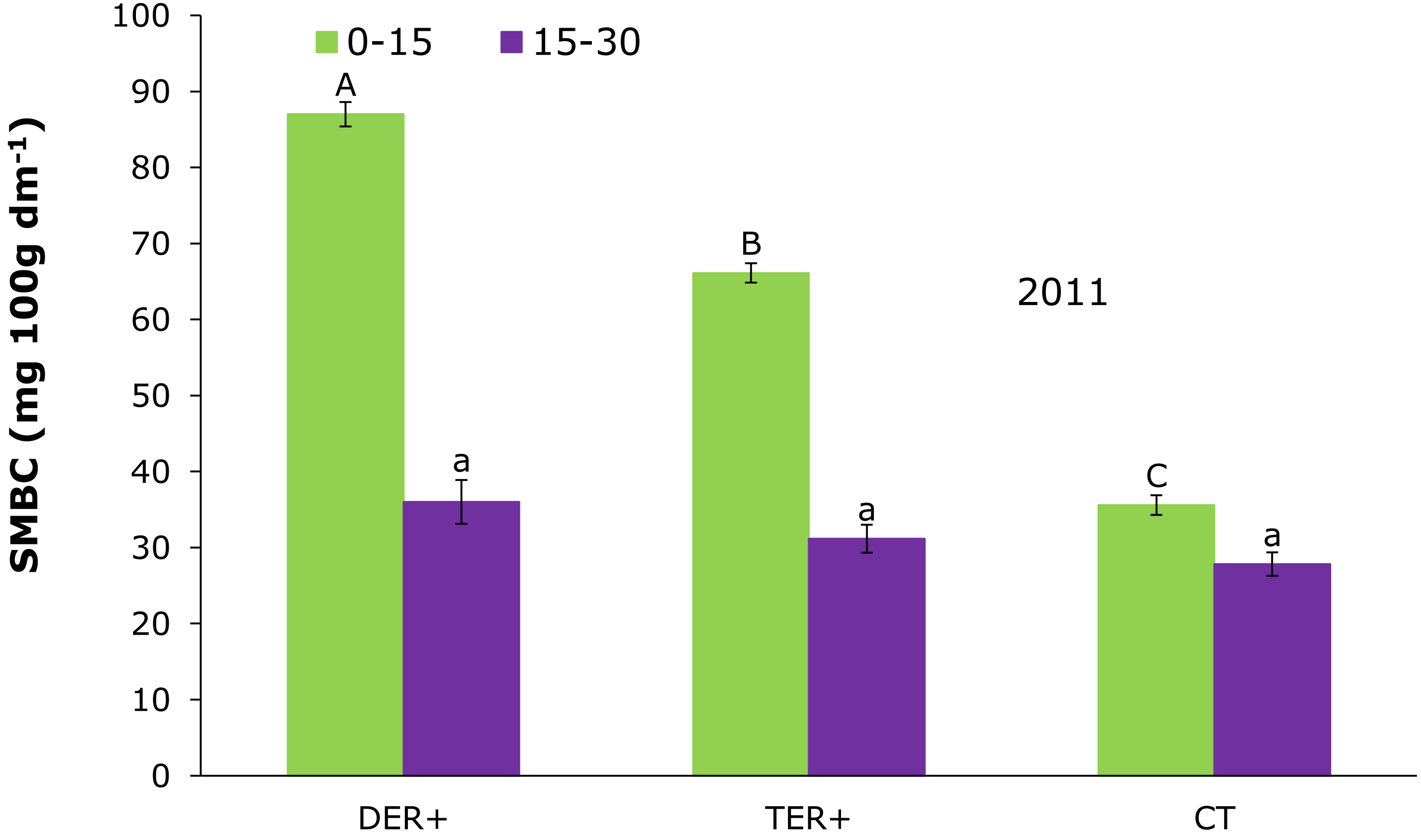
CT

3.2. Results – does CA-based systems play a role in adaptation and mitigation to climate change?



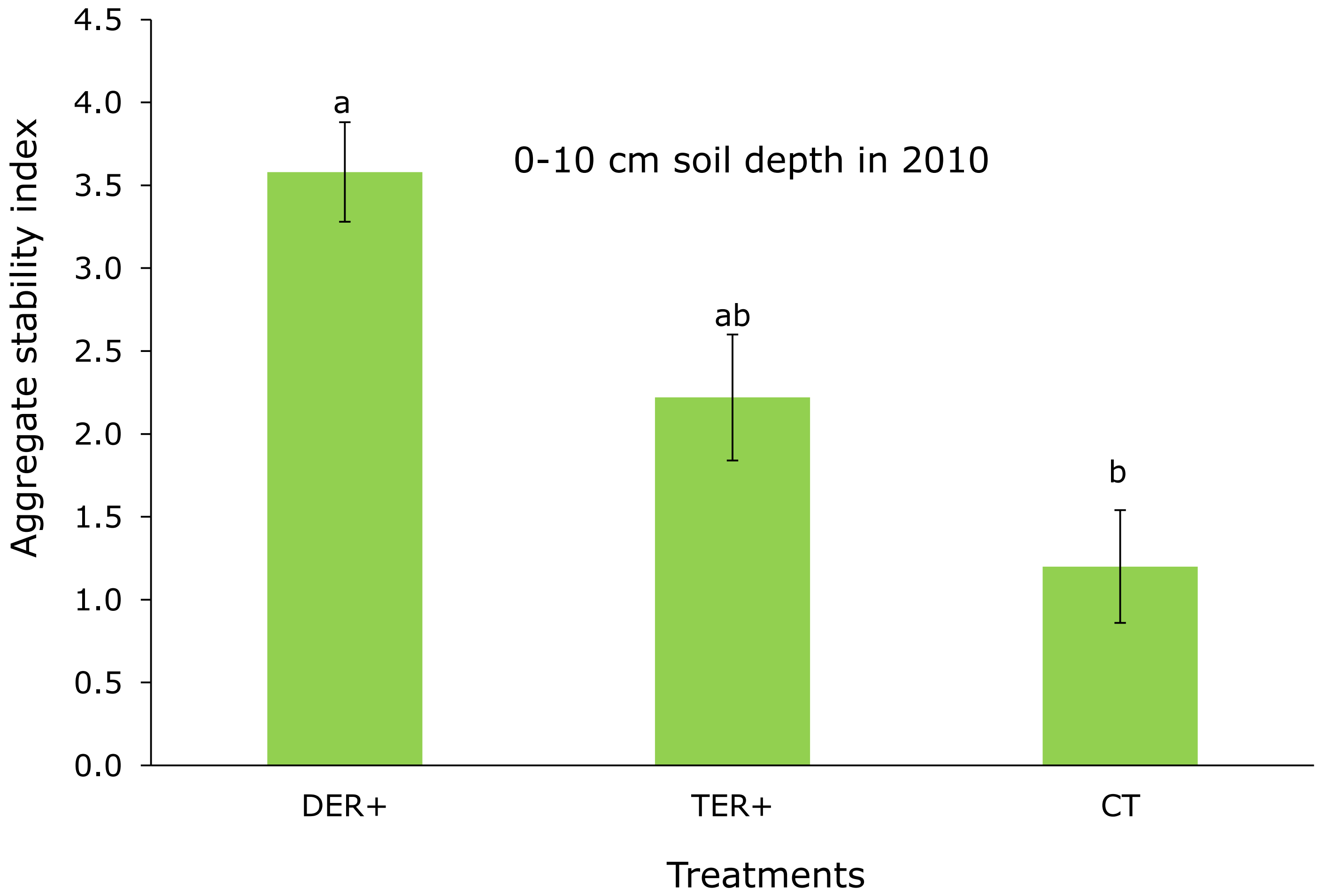
3.2. Results – does CA affect soil quality?

SMB is part of the active pool of SOM playing a vital role in **decomposition of OM**, **nutrient cycling** and **biophysical manipulation of soil structure**.



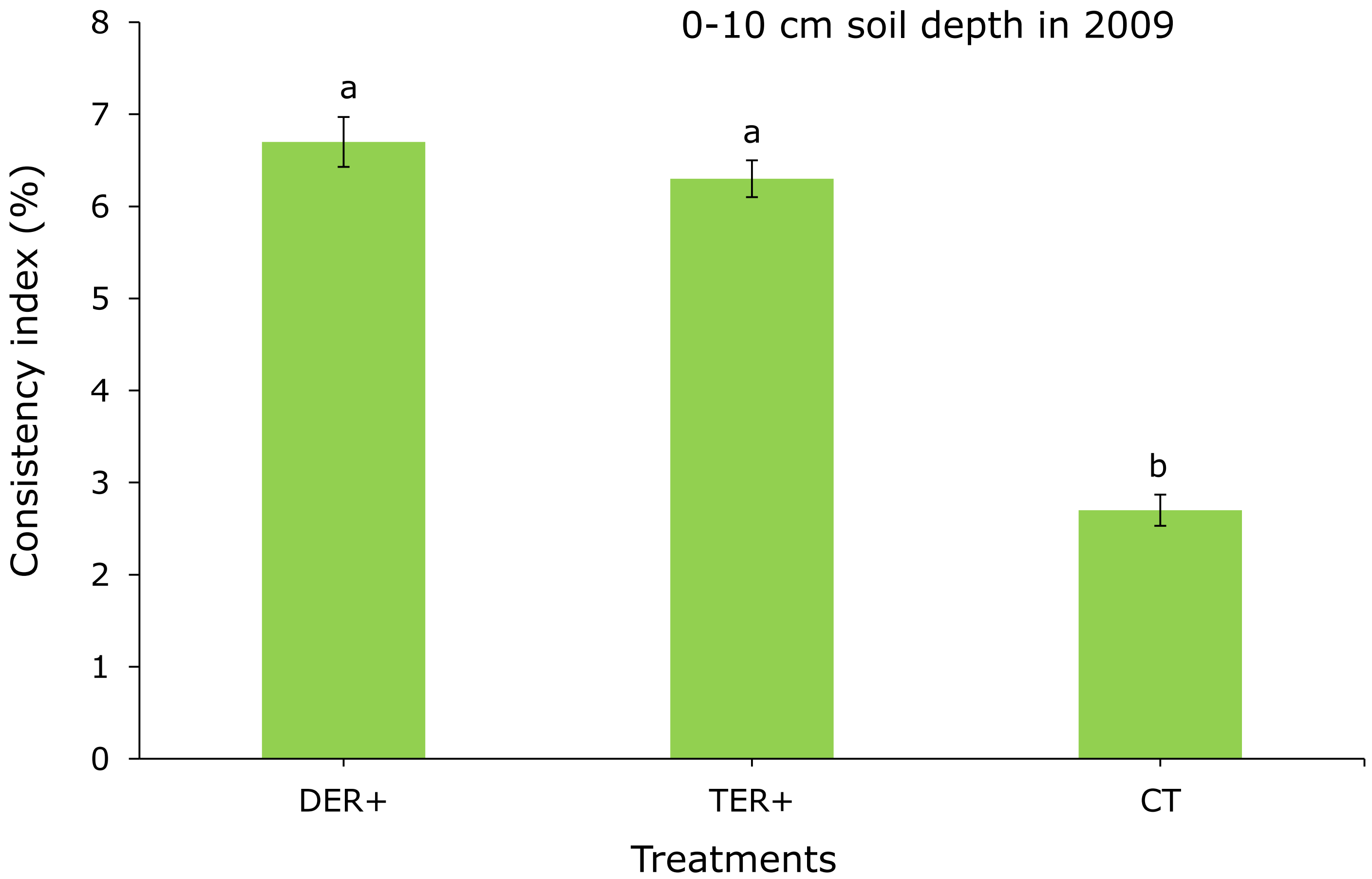
3.2. Results – does CA affect soil quality?

Aggregate stability refers to the ability of aggregates to resist disruption



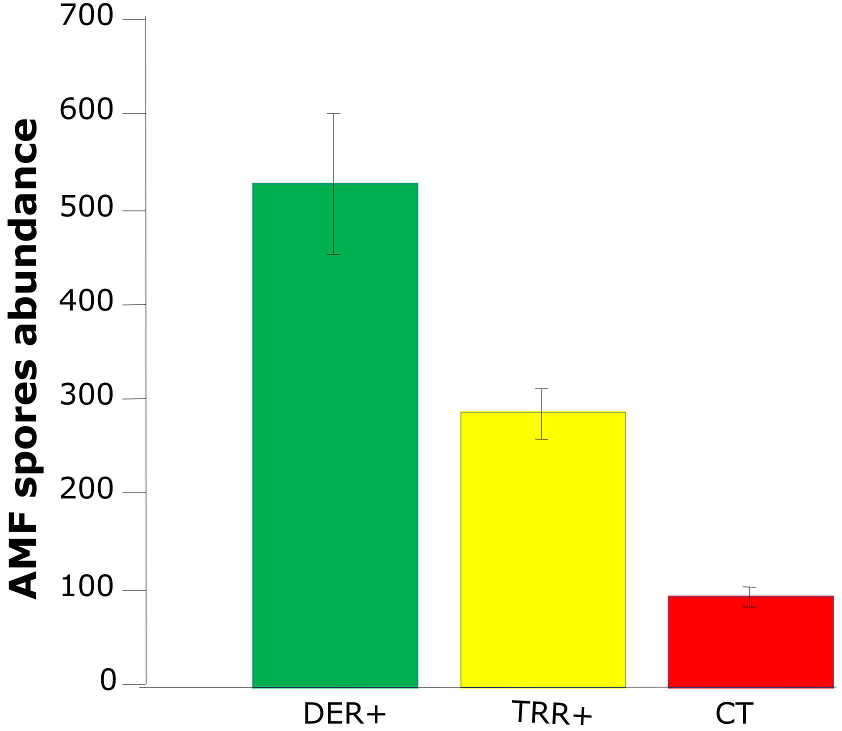
3.2. Results – does CA affect soil quality?

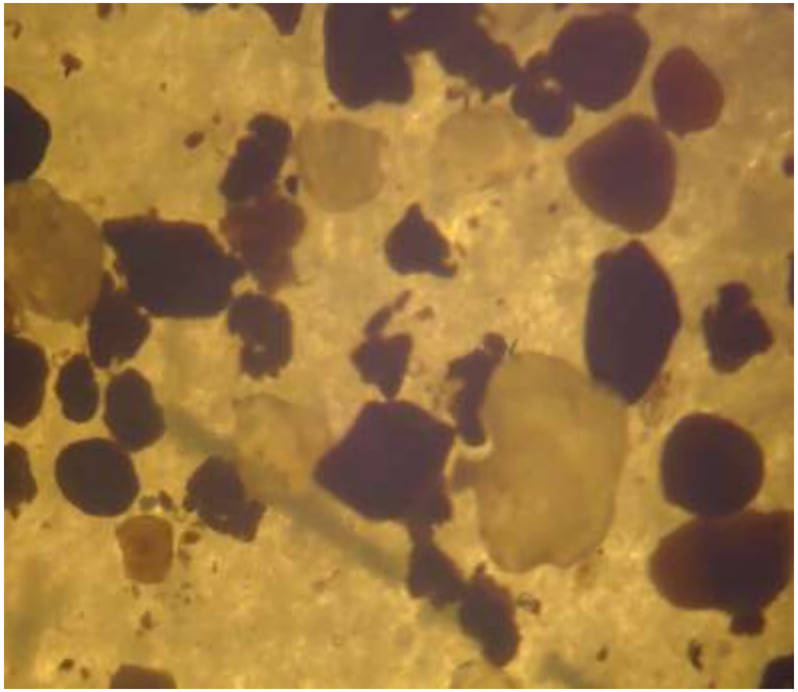
- CI predicts the relative sensitivity of topsoil for crusting.
- DER+ and TER+ was more stable and thus less runoff and soil loss.



3.2. Results – does CA affect soil quality?

Abundance of Arbuscular mycorrhizal fungi (AMF) spores

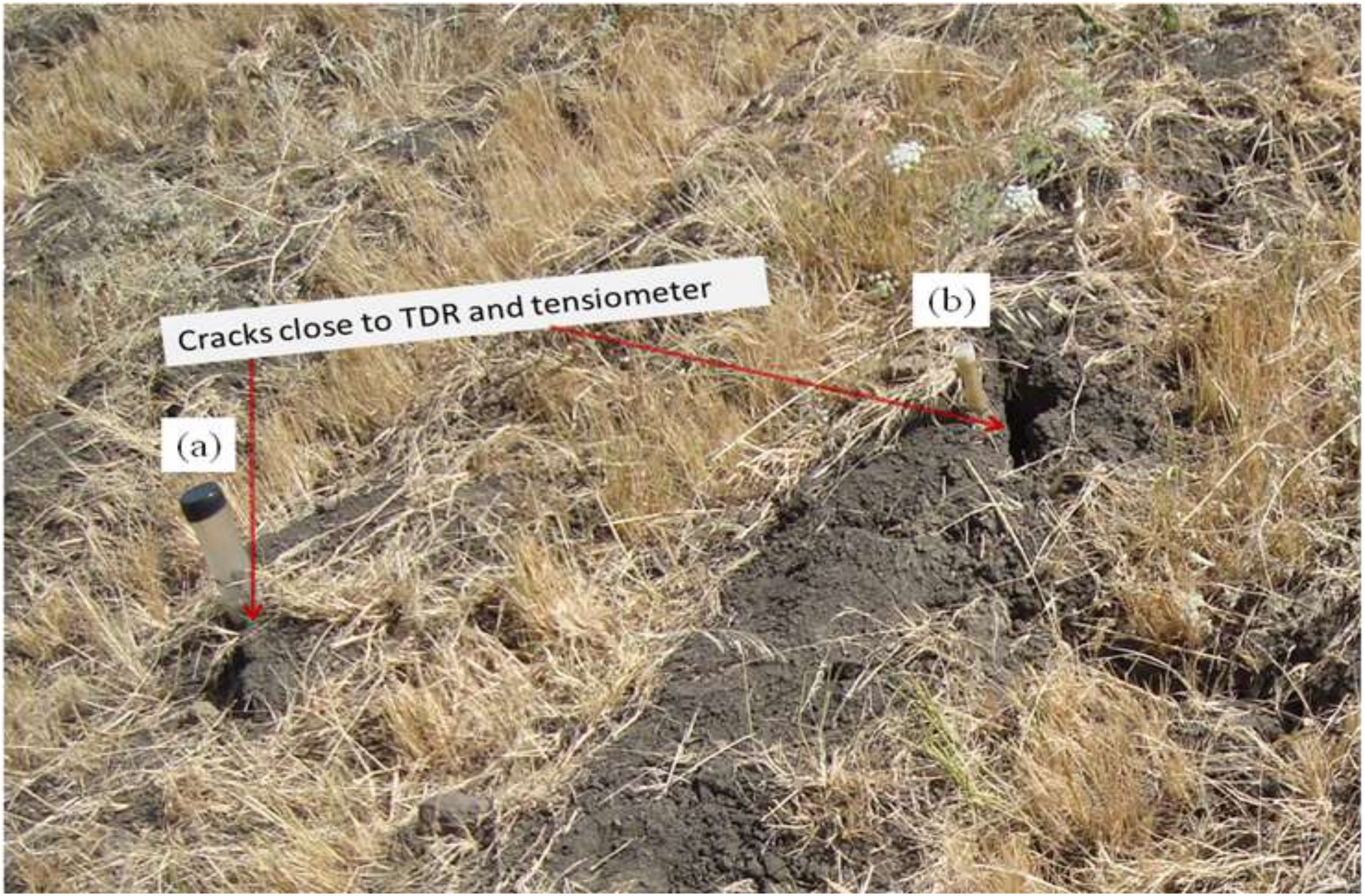




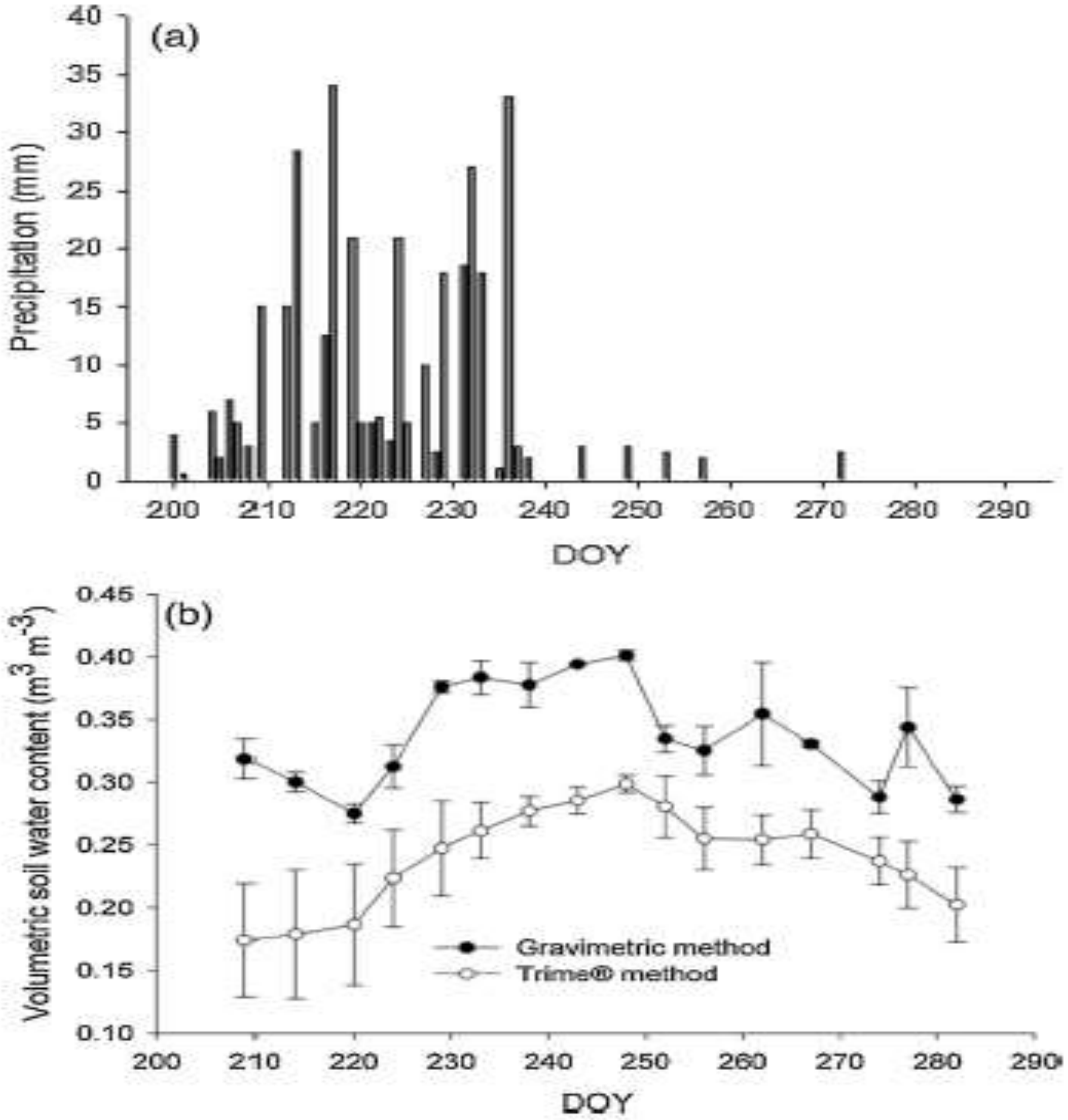
2. Methods - measuring soil rainwater balance

2. Methods - measuring soil rainwater balance

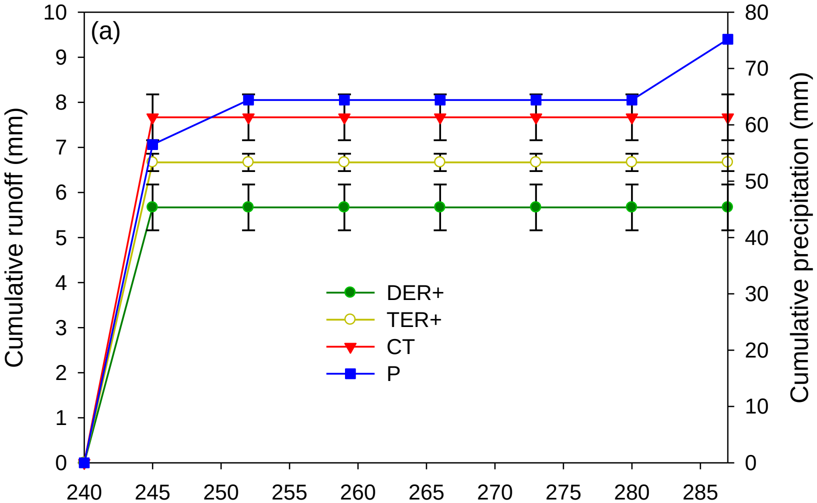
$$\Delta S = P - R - (ET + D) + L_i - L_o$$



2. Methods – is TDR measured soil water content reliable data?



$$\Delta S = P - R - (ET + D) + L_i - L_o$$



Planting: 198 DOY

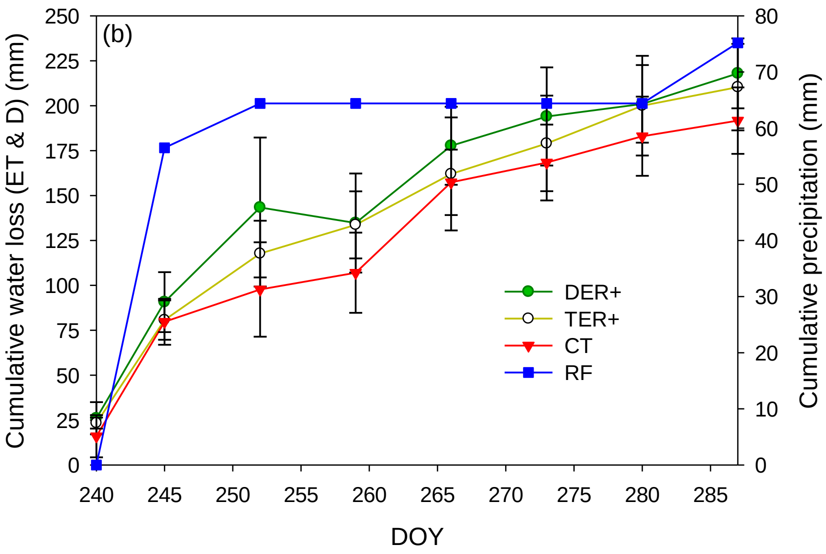
Harvesting: 300 DOY

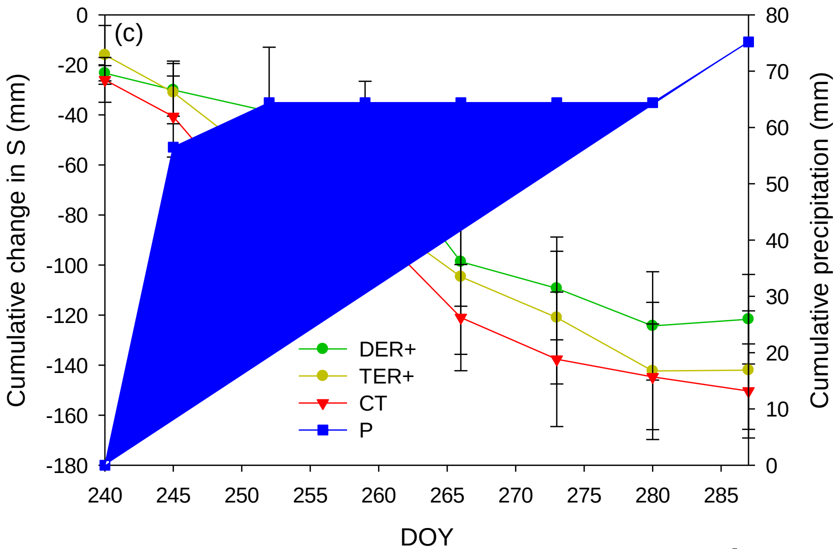
Rootzone soil depth: 80 cm

Runoff: DER+ < TER+ < CT

water loss (ET+D): DER+ > TER+ > CT

Soil water storage: DER+ > TER+ > CT



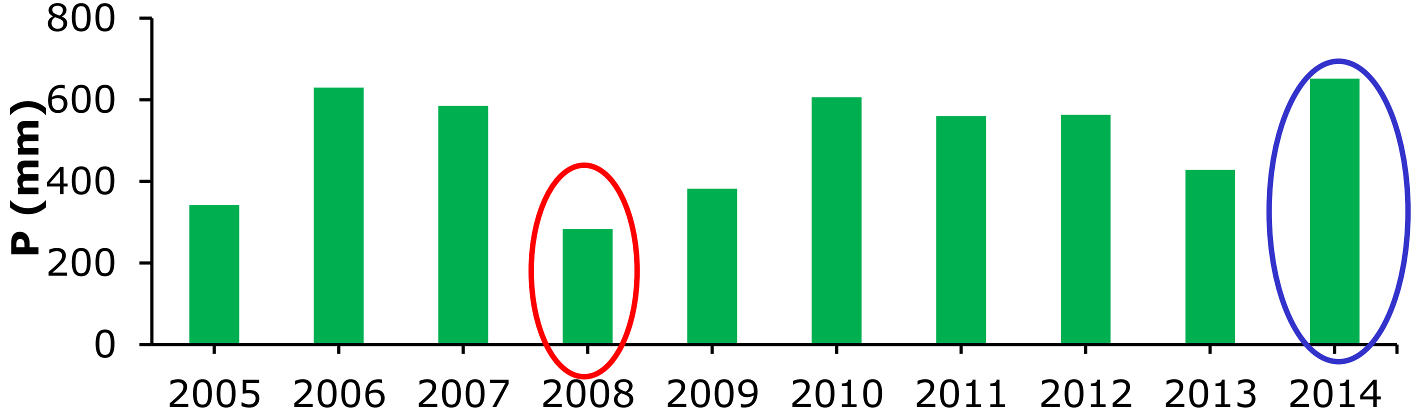


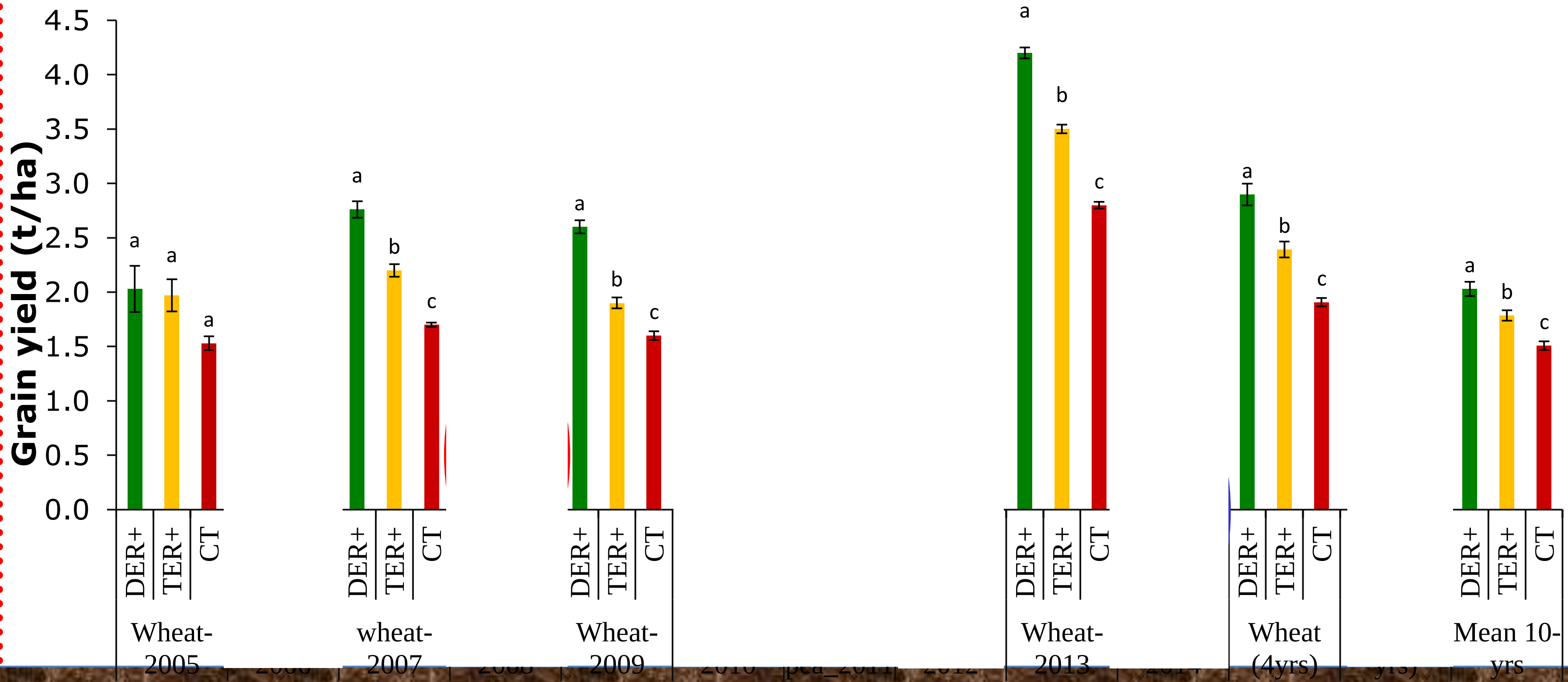
Araya et al. 2015

2. Methods – measuring crop yield

- Grain and straw yield (2005-20134) were determined from 1 m X 1 m area in three replicates per plot
- weed count, oven dry matter weed biomass and fresh weight was measured in similar sampling techniques

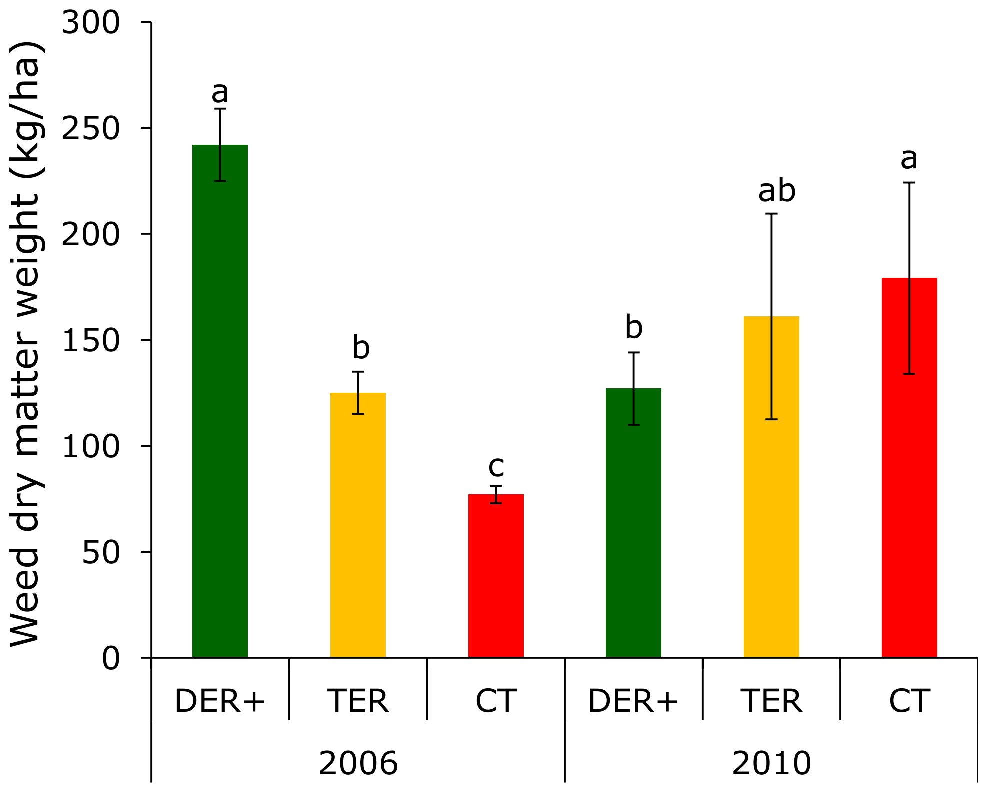
3.4. Results – does grain yield increase under CA-based systems?

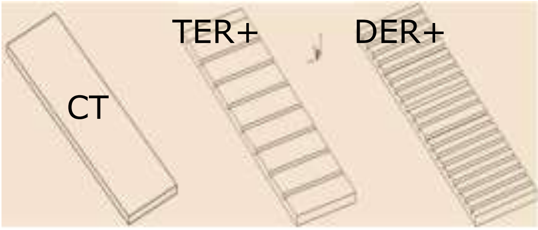




3.4. Results – why lower teff yields in DER+ in 2006?

- water logging in furrows: seeds are washed into furrows → teff grows in furrows
- weed infestation





3.4. Results – does teff yield increase under zero tillage?

- Average annual rainfall: 1110 mm
- Without using herbicide to control weed
- Teff (*Eragrostis tef* Zucca)

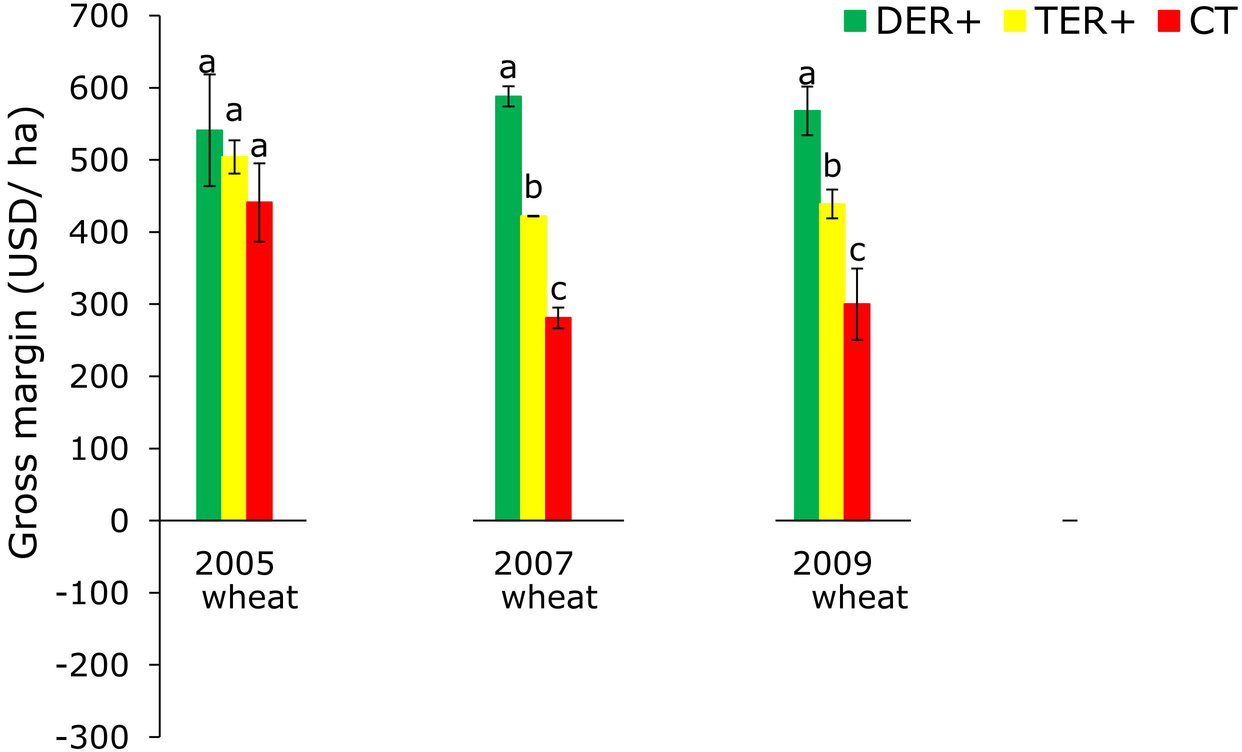
Treatments	Biomass yield (kg/ha)				Grain yield (kg/ha)			
	Nitisol		Vertisol		Nitisol		Vertisol	
	2001	2002	2001	2002	2001	2002	2001	2002
Zero	19^{a}	33^{b}	38^{a}	27^{a}	6^{a}	9^{b}	15^{a}	14^{a}
minimum	20^{a}	32^{b}	44^{a}	30^{a}	5^{a}	12^{a}	17^{a}	15^{a}
conventional	19^{a}	46^{a}	40^{a}	33^{a}	5^{a}	13^{a}	14^{a}	16^{a}

Balesh et al., 2008

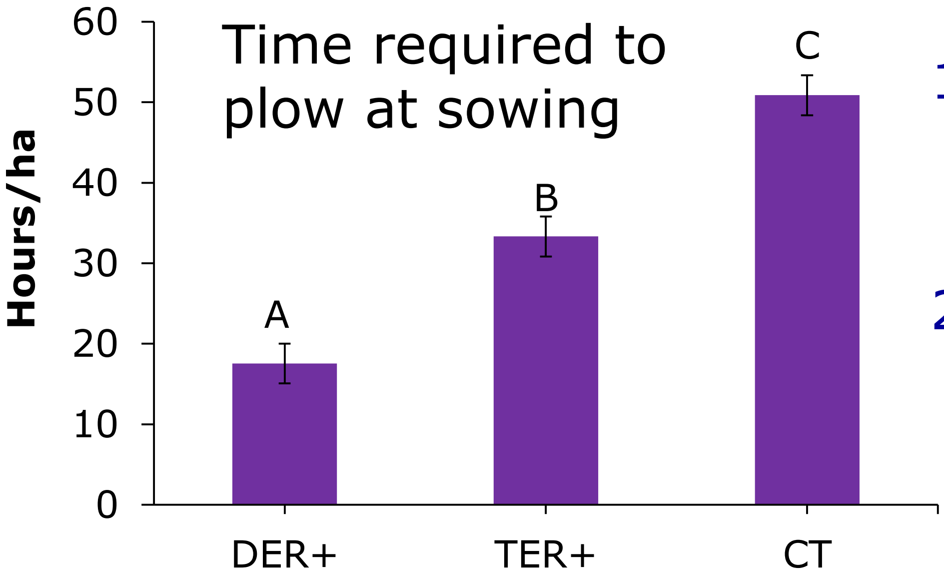
2. Methods – measuring economic returns

- **Gross income**
  - Grain and straw yield
- **Total costs**
  - plowing
  - 30% crop residues
  - glyphosate spray
  - seed
  - fertilizer (DAP and urea)
  - hand weeding
  - harvesting
  - threshing
- **Gross margin**
  - gross income- total costs

3.5. Results – does CA increase economic benefit?

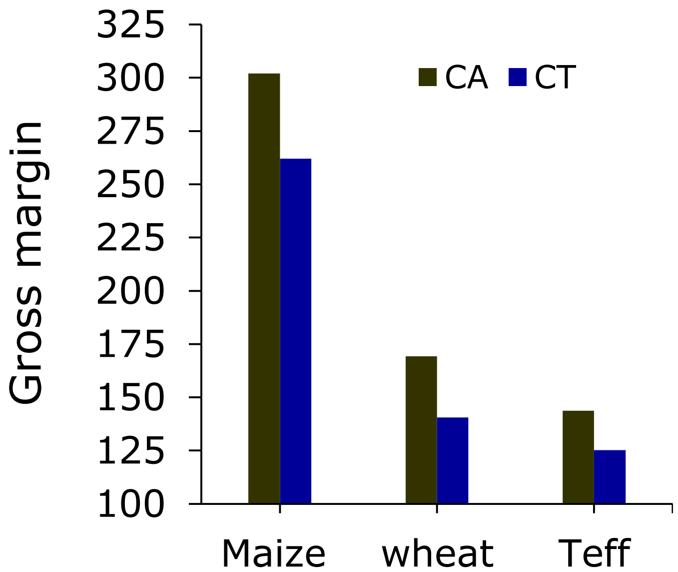


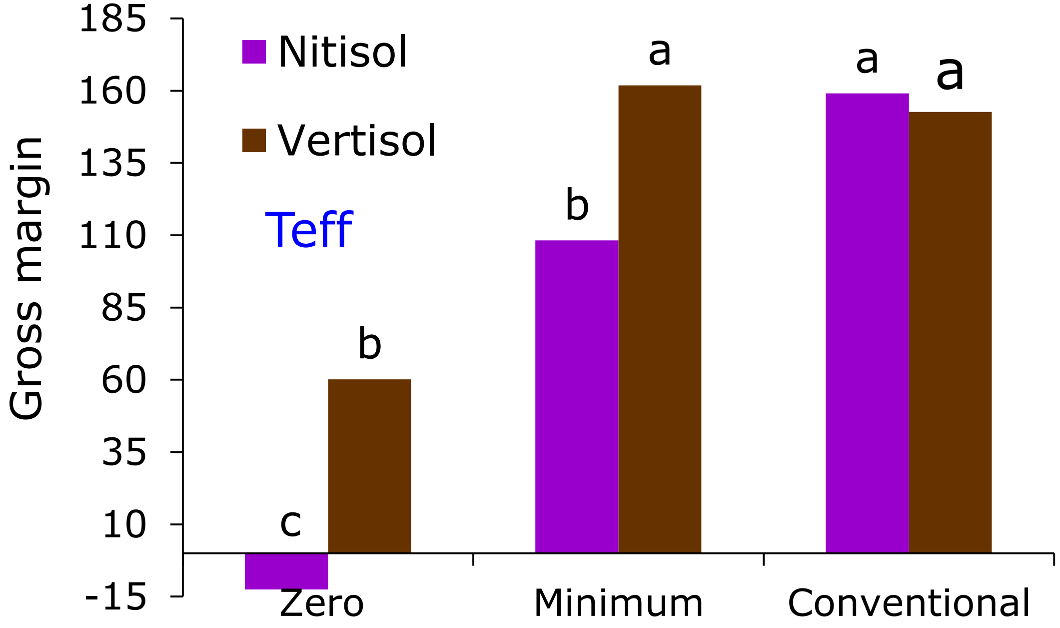
3.5. Results – does CA-based systems save time?



1. How many oxen span days per ha required at sowing for each systems?
2. Does CA reduce labour demand?

3.5. Results – does CA increase economic benefit?





- With application of glyphosate

Ito et al., 2007

- Without herbicide application

Balesh et al., 2008

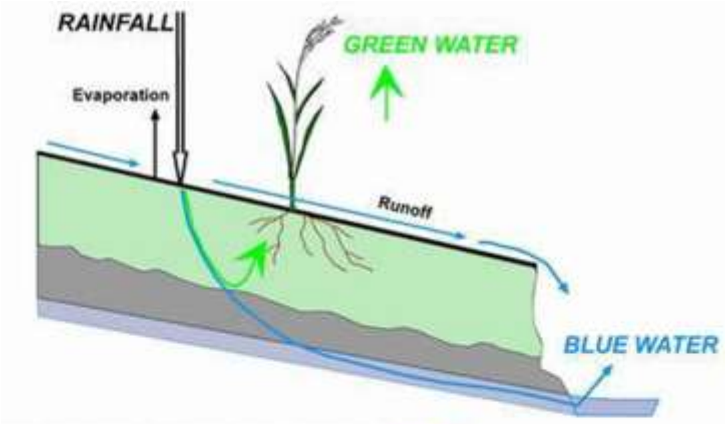
Teklu et al. (2006) also reported that wheat, lentil and teff were found more profitable in minimum tillage than in CT

3.6. Challenges for CA-based systems scaling up & out

- Crop-livestock mixed smallholder farming system is dominant
- CA implementation and adoption requires:
  - abandoning of repeated plowing,
  - abandoning of free grazing system ⇒ there is a policy support towards zero/controlled grazing systems,
  - Willingness to leave crop residue in the field,
- Minimize tradeoff for straw (livestock feed VS leaving crop residue)
- CA extension requires community based practice,
- Improvements in soil fertility and crop yield are long term
- Weed infestation at early stage of CA implementation ⇒ IWM option
- Lack of knowledge and experience on how to do it – requires training
- Availability and affordability of CA inputs (Herbicides, farm tools)

4. Conclusions

- CA-based resource saving practices have positive effects on:
  - Runoff and soil loss
  - Soil water storage
  - Crop yield of wheat, barley and grass pea
  - Organic matter
  - Soil microbial biomass C
  - Aggregate stability
  - Economic return
  - Adaptation and mitigation to climate change



Water, stored in the soil and used by plants, equals green water.
Runoff and deep drainage, recharging groundwater and feeding streams, equals blue water.

CA-based systems > CT

- Water conservation in **CA-based systems** is mainly associated with bed and furrow system (runoff harvesting)

4. Conclusions

- But… crop yield of teff was lower in CA-based systems due to higher weed infestation in the absence of herbicide use and water logging

  CA-based systems < CT

- Beds avoid temporal water logging (except for teff)

- Reduction in draught power requirement $\rightarrow$ reduce in oxen and straw demand

- CA-based planting systems that employ CA principles can be recommended for large scale dissemination and implementation in different soils

4. Conclusions

Minimum tillage + residue retention + crop rotation + *in situ* SWC

↓

More soil organic matter

↓

Improved soil physical, chemical and biological properties

↓

Reduce runoff and soil loss

↓

Reduce land degradation

↓

Increase resilience to climate change

↓

Improve crop productivity & food security

Selected Publications

1. **Araya**, **T**., Nyssen, J., Govaerts, B., Bauer, H., Deckers, J., Cornelis, W. M., 2016. Effects of seven years resource-conserving agriculture on soil quality in Vertisol of Ethiopian drylands. Soil and Tillage Research. 163, 99-109
2. **Araya, T.**, Govaerts, B., Baudron, F., Carpentier, L., Bauer, H., Lanckriet, S., Deckers, J., Nyssen, J., Cornelis, W.M., 2015a. Restoring cropland productivity and profitability in Eastern African drylands after nine years of conservation agriculture-based systems. *Experimental Agriculture*, 52, 165-187. doi:10.1017/S001447971400060X
3. **Araya**, **T**., Nyssen, J., Govaerts, B., Deckers, J. Cornelis, W. M. 2015. Impacts of conservation agriculture-based farming systems on optimizing seasonal rainfall partitioning and productivity on vertisols in the Ethiopian drylands. Soil and Tillage Research. 148, 1–13
4. Opolot, E., **Araya, T.,** Nyssen, J., Al-Barri, B., Verbist, K., Cornelis, W.M., 2014. Evaluating *in situ water and soil conservation practices with a fully-coupled, surface/subsurface process-based hydrological model in Tigray, Ethiopia. Land degradation and development.* DOI: 10.1002/ldr.2335
5. Lanckriet, S., **Araya**, **T**., Derudder, B., Cornelis, W., Bauer, H., Govaerts, B., Deckers, J., Mitiku Haile, Naudts, J., Nyssen, J., 2014. Towards practical implementation of conservation agriculture: a case study in the May Zeg-zeg catchment (Ethiopia). Agroecology and Sustainable Food Systems. 38:9, 13–935.
6. Lanckriet, S., **Araya**, **T**., Cornelis, W. M., Verfaillie, E., Poesen, J., Govaerts, B., Bauer, H., Deckers, J., Haile, M., Nyssen, J., 2012. Impact of conservation agriculture on catchment runoff and soil loss under changing climate conditions in May Zeg-zeg (Ethiopia). J. Hydrol.475, 336–349.
7. **Araya**, **T**., Cornelis, W.M., Nyssen, J., Govaerts, B., Getnet, F., Bauer, H., Raes, D., Amare, K., Haile, M., Deckers, J., 2012. Medium-term effects of conservation agriculture for *in situ* soil and water management and crop productivity in the northern Ethiopian highlands. Field *Crops* Res. 132, 53–62.
8. **Araya**, **T**., Cornelis, W.M., Nyssen, J., Govaerts, B., Tewodros Gebregziabher, Tigist Oicha, Raes, D., Mitiku Haile, Deckers, J., Sayre, K.D., 2011. Effects of conservation agriculture on runoff, soil loss and crop yield under rain fed conditions in Tigray, Northern Ethiopia. *Soil Use Manage.* 27, 404-414.
9. Nyssen, J., Govaerts, B., **Araya**, **T**., Cornelis, W.M., Bauer, H., Mitiku Haile, M., Sayre, K., Deckers, J., 2011. The use of the *mahresha* ard plough for conservation agriculture in northern Ethiopia. Agron. Sustain. Dev. 31, 287-297.

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Thank you for your attention!