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Contents

Conservation Agriculture and Soil Quality

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Introduction

Soil is a key resource that sustains several ecosystems and stands as the basis of food Production while also playing an important role in climate regulation. Overpopulation and food pressure during the last decades have caused severe damages on soil quality as a consequence of intensive agriculture i.e. erosion, desertification and salinization, also compromising soil fertility and yields for the next decades. New and better agricultural practices are needed to ensure a sustainable use of this resource and to fully take the advantages of its associated ecosystem services. Also, new and better soil quality indicators are crucial for soil diagnosis and to help farmers decide on the best management practices to adopt on specific pedo-climatic scenarios situations. Conservation agriculture and its fundamental principles: minimum (or no) soil disturbance, permanent soil organic cover and crop rotation /intercropping certainly figure among the possibilities that contribute for a sustainable soil management.

The iSQAPER project – *Interactive Soil Quality Assessment in Europe and China for Agricultural Productivity and Environmental Resilience* – is tackling this problem with the development of a Soil Quality app (SQAPP) that links soil and agricultural management practices to soil quality indicators and is of easy use by farmers and other suitable actors. The University of Évora is the leader of the WP6 - *Evaluating and demonstrating measures to improve Soil quality*. During the duration of this WP, several promising agricultural measurements will be tested in selected sites and evaluated under a new set of soil quality indicators and finally results will be disseminated in demonstration events. Conservation agricultural practices will then be evaluated and the soil quality improvement (measured through a selected set of indicators) for specific pedo-climatic zones will be assessed.

The first task of WP6 is the *selection of sites for testing, evaluating and demonstrating of selected 'soil improving' measures*. This task includes the identification of different farmers and land managers located along the main pedo-climatic zones in Europe and China, currently undergoing innovative agricultural management practices (AMP).

1. Materials and Methods

WP6 Framework

The iSQAPER project – *Interactive Soil Quality Assessment in Europe and China for Agricultural Productivity and Environmental Resilience* has started in May 2015 and has a duration of 5 years. It is divided into 9 working packages (WP) and includes 25 partners from Europe and China, including 14 Case Study Sites (CSS) – Fig.1.

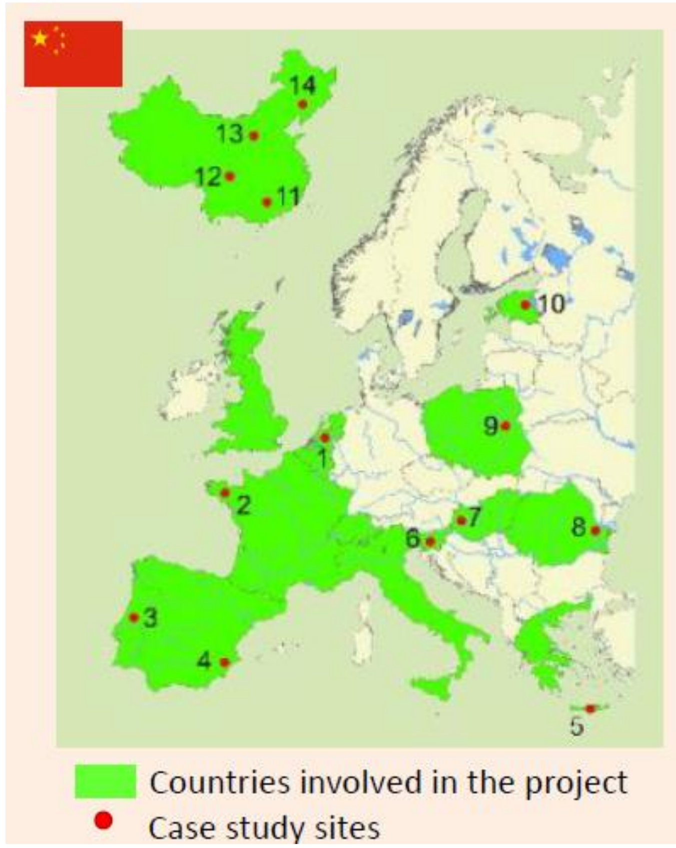

Figure 1. Countries involved in the iSQAPER project and location of Case Study Sites (CSS)

Pedo-climatic zonation and Identification of Stakeholders

The establishment of different climatic zones and soil types within each zone was performed in WP2 of iSQAPER – *Spatial analysis of crop and livestock farming systems across pedo-climatic zones in Europe and China*. Climatic zonation based on initial 35 climatic areas served as spatial units for the assessments on the continental scale in Europe. Regrouping of the Climatic Areas was performed to create climatic zones for pedoclimatic zonation, as developed by Tóth et al. (2013) for the productivity evaluation of European soils. From this work resulted several maps with the pedo-climatic diversity in Europe. Also, during the first task of WP5 of iSQAPER – *Multi-stakeholder case study inventories of soil quality and selection of innovative practices*, a questionnaire was prepared and sent to the CSS to identify different stakeholders. For the farmers and land managers, the questionnaire included questions about the type of farming system (arable, permanent crops, intensive grazing, extensive grazing and open field vegetables) and the innovative AMP's (cover crops, diversified crop rotation, leguminous crops, min-till, no-till, permanent soil cover and residue maintenance).

Identification of the testing sites

In order to select the testing sites, we have isolated the stakeholders identified by the questionnaire and only farmers and land managers reporting farming systems and innovative AMP's in their answers were further considered. Consequently, using their coordinates we were able to trace them in the respective climatic zone and identify if they were located in a dominant soil type for the region or not. We considered any soil with a representation higher than 10% for a certain climatic zone as a dominant soil type. Finally, for land managers fulfilling all the criteria, we analysed the AMP's reported.

2. Results

Pedo-climatic zonation and stakeholders

Based on the definition applied by WP2 eight different climatic zones were identified in Europe: Boreal to sub-boreal, Sub-oceanic, Atlantic, Northern sub-continental, South sub-continental, Mediterranean semi-arid, Mediterranean temperate and sub-oceanic and Temperate Mountainous (Fig.2).

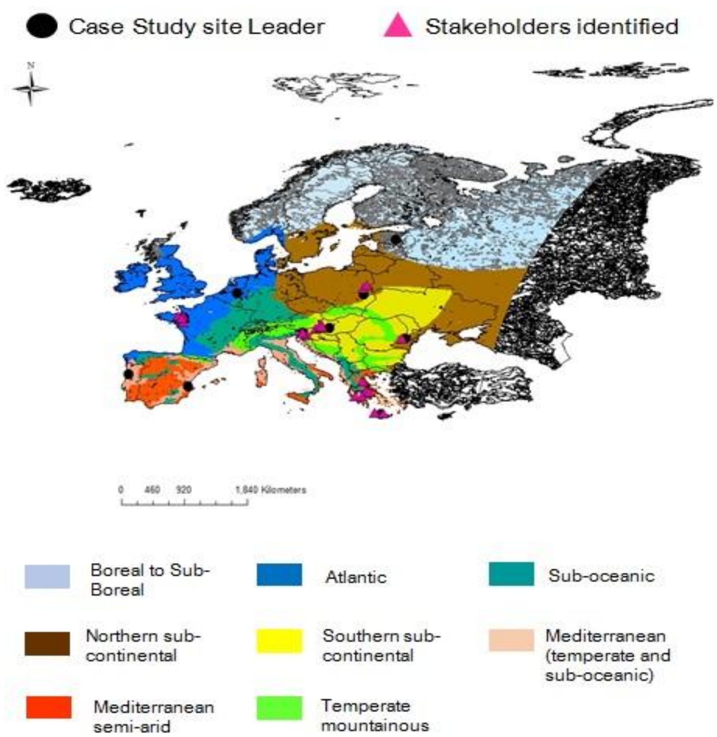

Figure 2. Climatic zones in Europe, location of different CSS and also stakeholders identified in the project

Stakeholders were mostly identified near the region where the CSS is located and cover 5 of the 8 climatic regions. So far, only Boreal, Sub-oceanic and temperate mountainous regions were not covered (Fig.2,3).

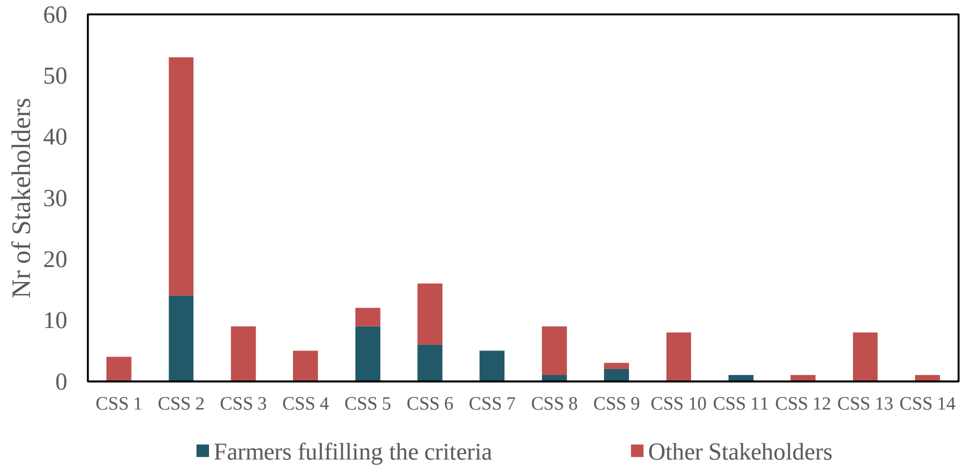

Figure 3. Number of stakeholders and farmers fulfilling the requests – reporting farming systems and AMP's (see Materials&Methods)

In order to select representative sites and to test the innovative AMP's, we identified the most dominant soil types of every climatic zone identified in Europe. According to the threshold established (> 10%) three to five dominant soil types were identified for the different climatic regions. Cambisols dominate in Atlantic, sub-oceanic, Mediterranean and Temperate mountainous regions. Podzols are found mainly in the boreal region, Chernozems are only found in Northern and Southern sub-continental and Regosols are only present in the Mediterranean (Fig.4).

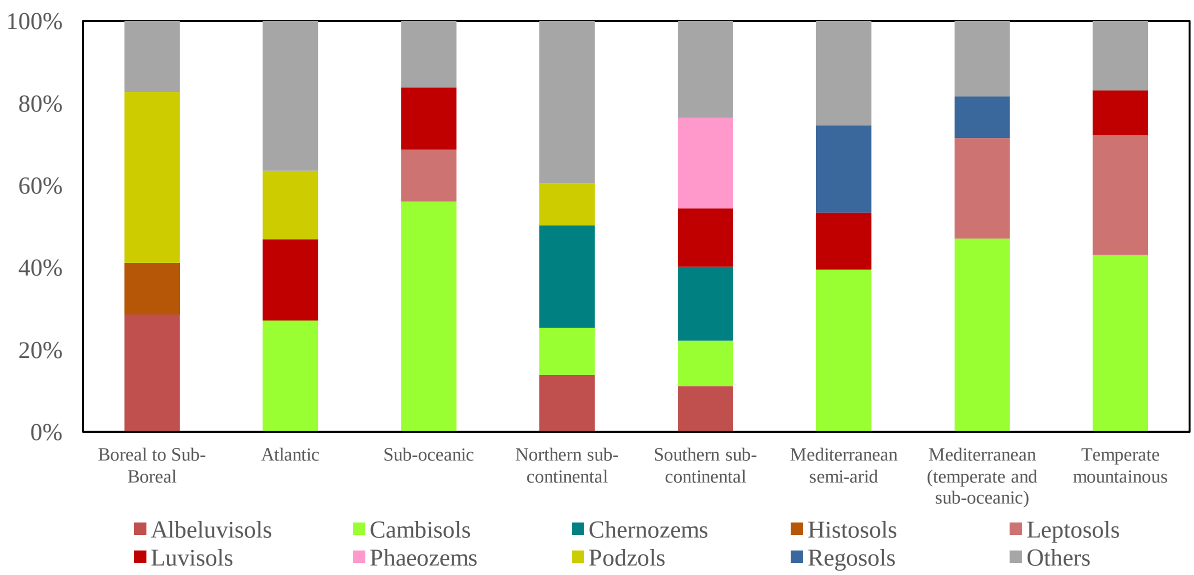

Figure 4. Distribution of the dominant soil types (>10%) within each climatic zone

Farming systems identification per climatic region

The preliminary results show that only in the Atlantic region it was possible to identify a reasonable number of farmers (fulfilling the criteria) with different farming systems. The most common were arable and intensive grazing. Northern and Southern sub-continental climatic regions also account for a high diversity of farming systems identified, although in lower number. Finally, in the Mediterranean regions, only arable and permanent crops were identified (Fig.5).

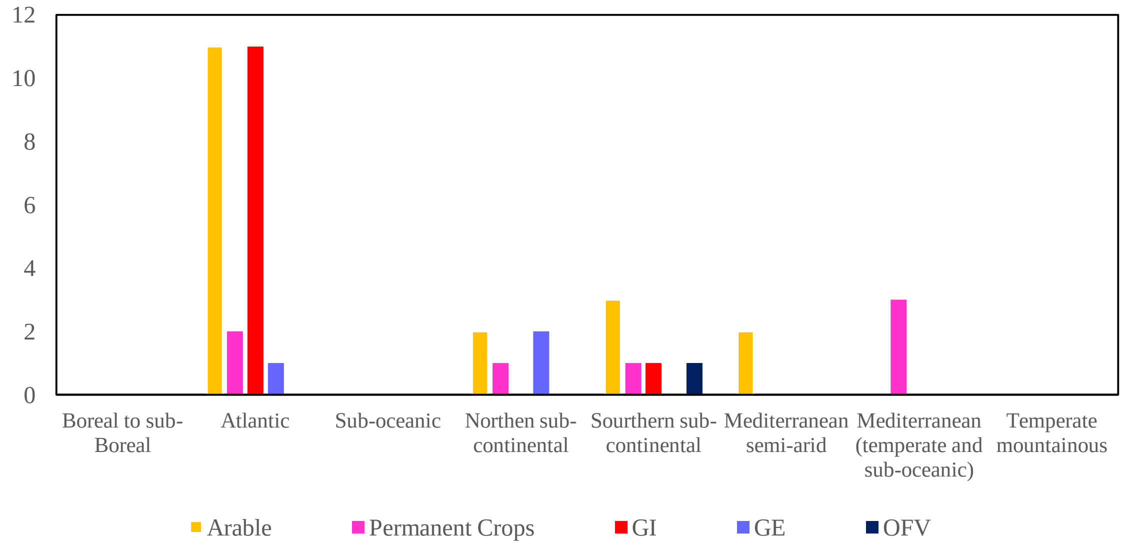

Figure 5. Distribution of the different farming systems reported within each climatic zone
AMP's identification per climatic region

The preliminary results also show that diversified crop rotation, min-till, leguminous crops and cover crops were the most reported by farmers and identified in all 5 climatic regions were stakeholders are represented (Fig.6). No-till was not reported in Mediterranean semi-arid and Northern sub-continental, permanent soil cover was absent from both Mediterranean regions and residue maintenance is not reported by the Mediterranean temperate zone.

3. Discussion

Results from this initial exercise show that many more stakeholders need to be identified in the dominant soils for every climatic zone. Although it is already possible to recognize the most 'popular' AMP's, the overall sample is not diversified enough. To overcome this problem, the CSS were asked to identify specifically farmers and land managers in the most dominant farming systems and soil types in their region in the next months.

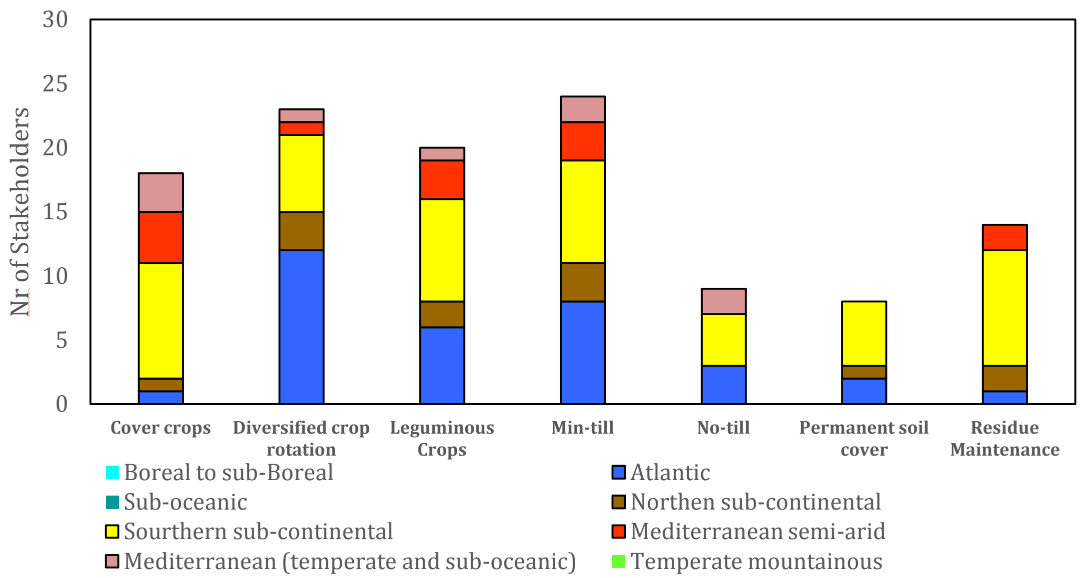

Figure 6. Distribution of the different AMP's reported within each climatic zone

Conclusion

In the first task of WP6 of iSQAPER project we aim to identify testing sites for the most innovative AMP's. Our initial identification of farmers and land managers is still incomplete, but the preliminary results show a variable co-existence of different farming systems in the climatic regions of Atlantic, Northern and Southern sub-continental, while Mediterranean regions account only with arable and permanent crops. The most popular AMP's identified were diversified crop rotation, leguminous crops, cover crops and min-till, especially important in Atlantic, Southern sub-continental and Mediterranean semi-arid climatic regions. More stakeholder identification is necessary to cover conveniently the most dominant soil types and farming systems in every region. Also, a detailed assessment of the dominant soil types in China is required, especially for the regions covered by the Chinese CSS.

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Determination the soil erosion of lake watersheds according to RUSSLE method using RS-GIS

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Introduction

To understand the formation of Erosion, It is necessary to determine the degree of impacts which are rainfall, soil characteristics, topography, plant cover and land management. Remote Sensing and Geographic Information Systems are helping to determine these factors and prediction of erosion. The aim of this study is determine erosion potential of Karacaören and Beyşehir Lakes Watersheds around Isparta in Turkey according to RUSSLE method using RS-GIS.

1. Materials and Methods

Karacaören Lake Basin has 240 thousand ha; Beyşehir Lake Basin has 500 thousand hectares (Fig 1). In the study, cartographic material was prepared for the watershed area. The various research results and reports, meteorological data, statistical information, August 2009 and April 2011 Landsat - 5 TM satellite image, the data obtained via field surveys, ArcGIS 9.3 and ERDAS Imagine 8.4 software were used. The RUSLE methodology was used as an erosion model. According to the method annual soil loss was calculated by the following equation as tons/ha/year.

$$A = R \times K \times LS \times C \times P$$

Where;
A = estimated average soil loss in tons per acre per year,
R = rainfall-runoff erosivity factor,
K = soil erodibility factor,
L = slope length factor,
S = slope steepness factor,
C = cover-management factor,
P = support practice factor.

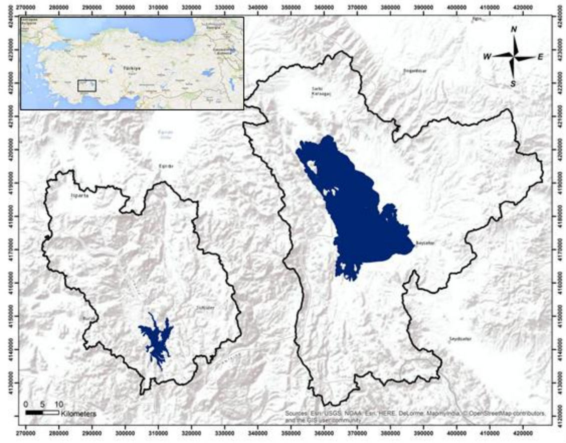

Figure 1. The location of the study area

2. Results

R factor was calculated using monthly average rainfall and annual average rainfall. For this purpose, Kriging interpolation process with linear semi variogram model was carried out in ArcGIS software (Fig 2).

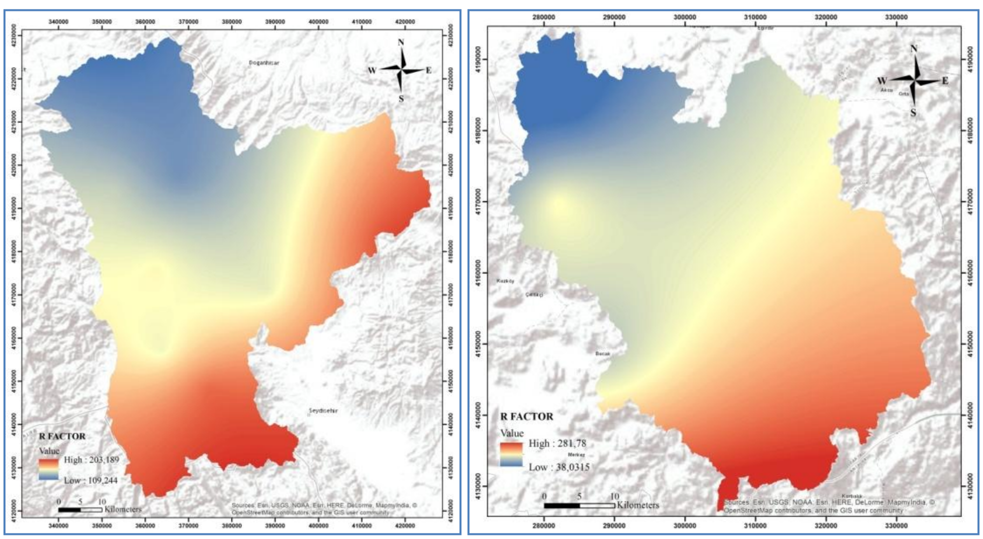

Figure 2. Map of R factor

K factor was calculated by the following equation and mapped (Fig 3).

$$100 \text{ x } K = (2.1 \text{ x } 10\text{-}4) \text{ x } (12\text{-}OM) \text{ x } M1.14 + 3.25 \text{ x } (S\text{-}2) + 2.5 \text{ x } (P\text{-}3) *0.1317$$

K = Soil erodibility factor,
OM = % Organic matter,
S = Soil structure class (1-6),
P =Soil water permeability,
M =Particle size.

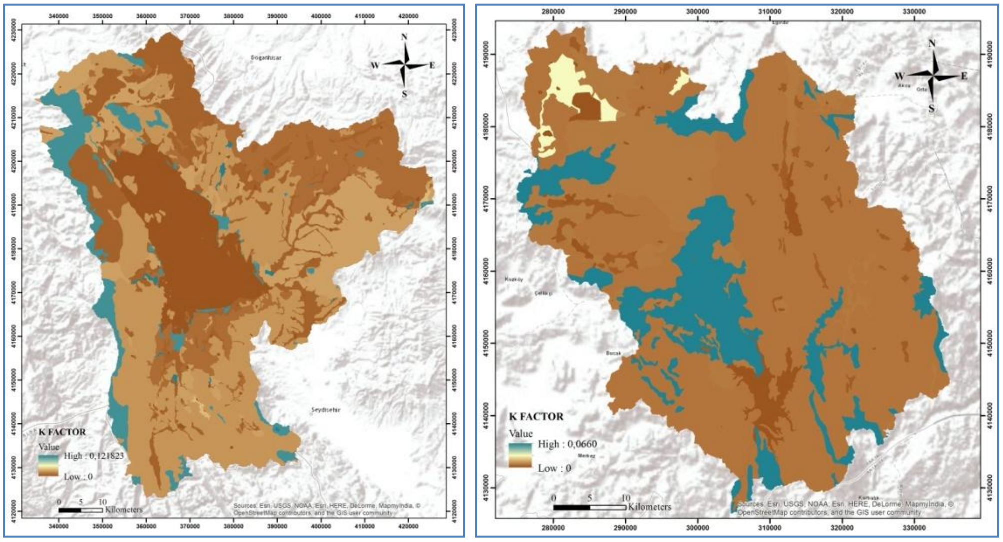

Figure 3. Map of K factor

Calculation of the ***LS factor,*** 30 x 30 m resolution Digital Elevation Model (DEM) was used. The Hydrology tool of ArcGIS software was run in order to determine of the LS value (Fig 4). The following sequence of operations was applied in the calculation of the LS factor with ArcGIS software.

$$LS = [Flow\ accumulation\ x\ (cell\ size/22.13)]^{0.4}\ x\ (Sin\ slope/0.0896)^{1.3}$$

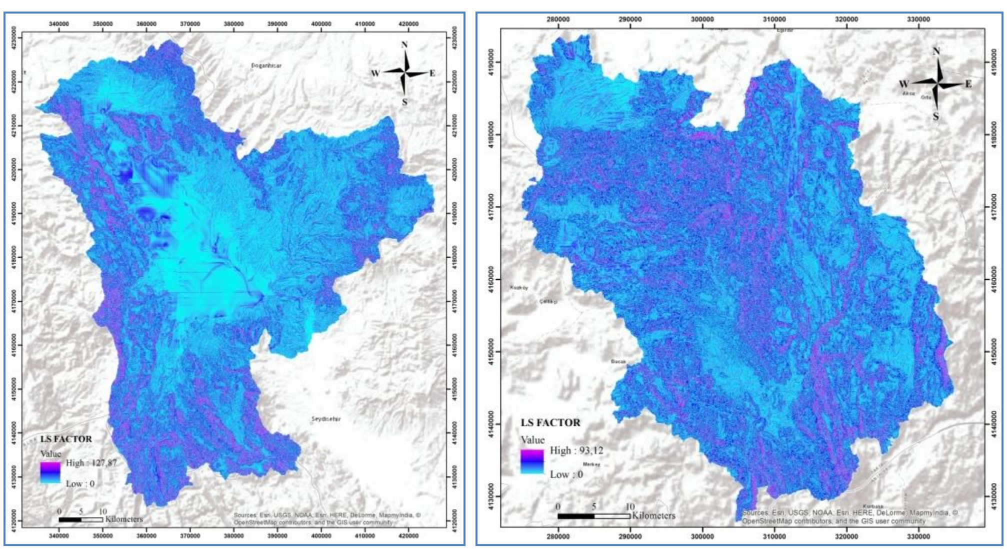

Figure 4. Map of LS factor

Calculation of the ***C factor,*** August 2009 and April 2011 Landsat - 5 TM satellite image was used to determinate of plant density. For this purpose, in the ERDAS Imagine was performed NDVI (Fig 5).

NDVI=(Bant 4)-(Bant 3) / (Bant 4)+(Bant 3)

P factor was taken as 1.0 due to the lack of an application for soil protection.

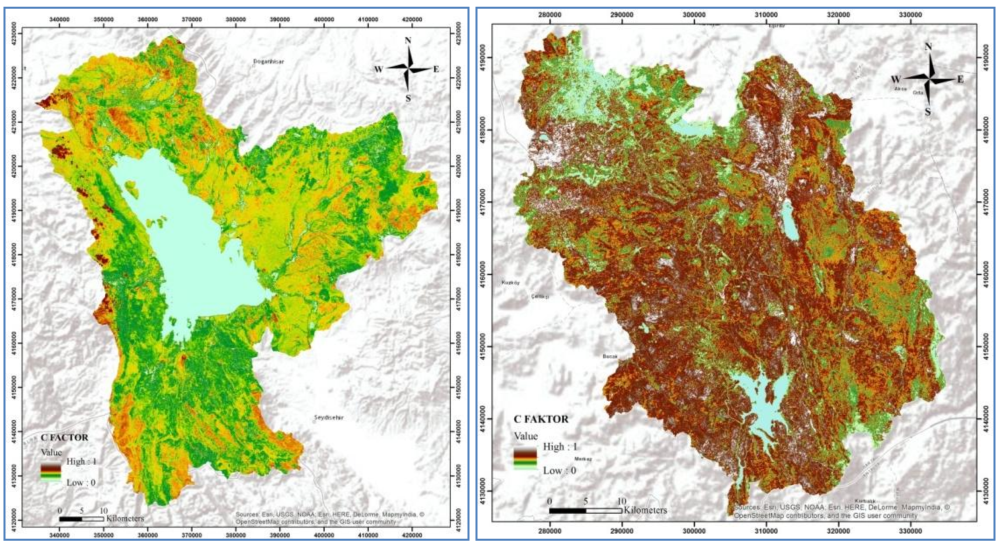

Figure 5. Map of C factor

3. Conclusions

The erosion risks of watersheds were predicted with RUSSLE model by using RS-GIS. Erosion clas was found as severe in 21% of Karacaören Basin and 85% of Beysehir Basin. In Karacaören lake basin, the total annual soil loss was calculated as 11.429.374 tons / year. Average soil loss was estimated at 47.51 tons/ha. The total annual soil loss was calculated as 36,049,081 tons/year, and average soil loss was estimated at 83.97 tons/ha in Beyşehir lake basin (Fig 6).

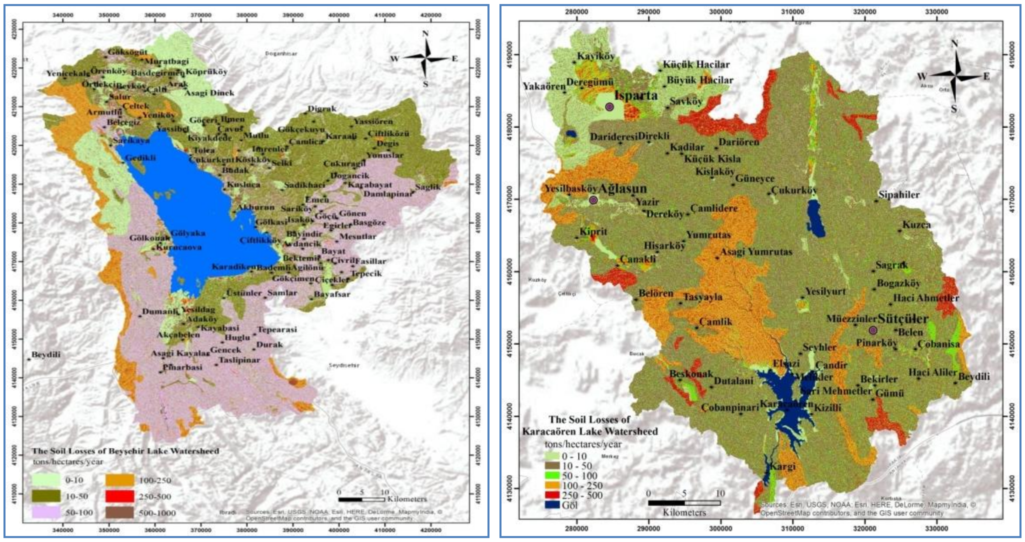

Figure 6. Map of average soil loss

Discussions

Remote sensing (RS) and geographic information systems (GIS) were found effective methods for predicting soil loss according to RUSLE model. Using of together with these techniques was allowed to producing an erosion map for lake watersheds. The results clearly demonstrated that the simulated annual soil losses have general relative validity. Consequently, the erosion severity map can be used to target areas where erosion control should have priority, particularly areas of high erosion which contribute sediment directly to the lake.

Acknowledgement

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Soil carbon sequestration and biological activity in Conservation Agriculture systems in North Italy

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Introduction

A Life project called HelpSoil has been started to compare Conservation Agriculture systems with conventional "arable" agriculture in North Italy (http://www.lifehelpsoil.eu). To this purpose 20 experimental sites have been selected all over the Po plain, where agronomic and environmental indicators are monitored. Each site is arranged with two test plots, respectively cultivated under conservation and conventional practices. Different soil types and mean annual precipitation characterize the sites; crop rotations include winter (wheat and barley) and summer cereals (maize and sorghum), soybean and seeding of cover crops in the conservation managed test plots. Conservation practices mainly consist of no-till soil management. The main part of farms where study sites occur are irrigated; some of them are dairy farms and soils are fertilized with manure applications. A first soil sampling was carried out in the 2014 after the harvest of summer crop, providing three replications per plot. Results of this trial showed that SOC (Soil Organic Carbon) stock is considerably higher in Conservation Agriculture farming systems. Earthworms abundance, QBS-ar index based on presence/absence of microartropodes and IBF index (Soil Biological Fertility Index) based on microbial activity were also detected to study the soil biological activity and biodiversity. All indicators pointed out a positive and often considerable effect of Conservation Agriculture methods and a strong correlation with differences in SOC content. However a second soil survey is planned by the project in the autumn 2016 to verify data and trends over the time.

1. Material and methods

Farms where the experimental sites occur are characterized by different soil types (Figure 1), classified as Luvisols, Vertisols, Cambisols and Fluvisols (IUSS-WRB, 2007). Soils have a clay content in the topsoil ranging from 7 to 49 %, and a pH from 5,6 to >8.

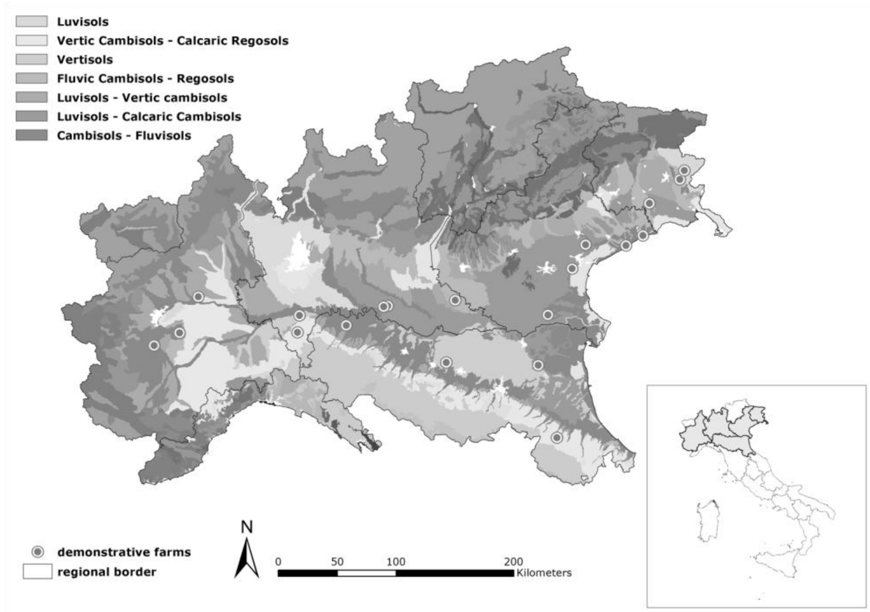


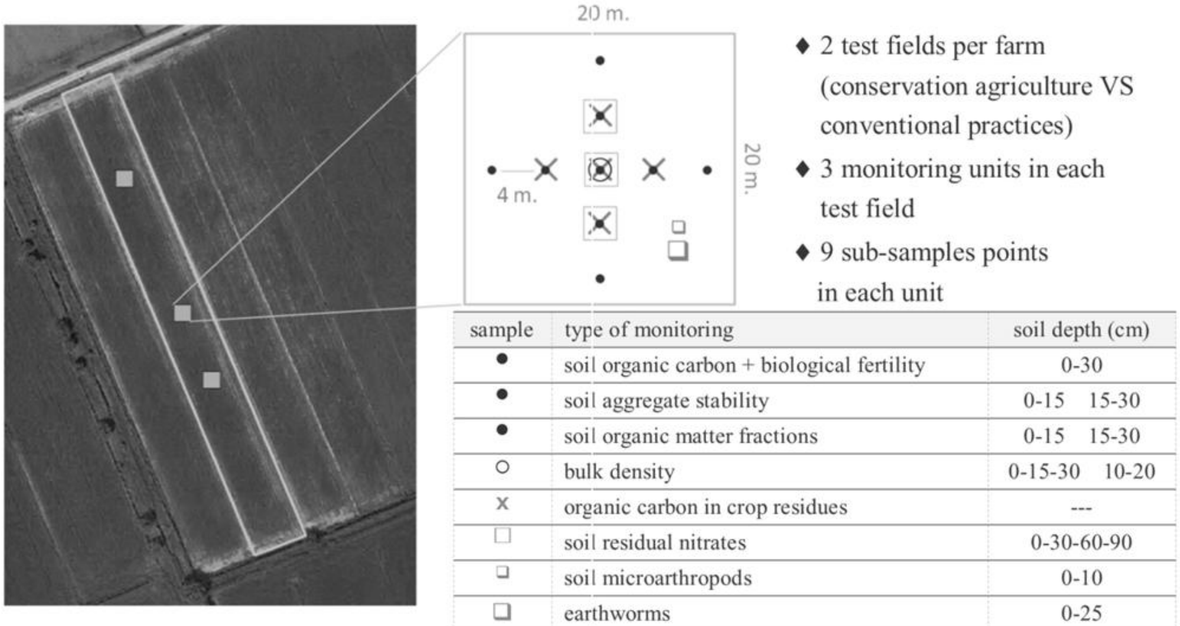
Figure 1. Soil Map of Italy (1:1.000.000) and location of HelpSoil demonstrative farms

The cropping systems included winter cereals, such as wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.), alfalfa (*Medicago sativa* L.) and summer crops, such as maize (*Zea mays* L.) mainly produced for sileage, soybean [*Glycine max* (L.)Merr.] and sorghum (*Sorghum vulgare* Pers.). Rice (*Oryza sativa* L.)is cultivated in one of the demonstrative farms. Winter cover crops, formed by cereals (Italian Raygrass, Triticale) or a mix of different species (Vetch, Rye, Italian Raygrass, Radish) were sowed in the study sites managed under conservation practices. The mean annual precipitation in the area is ranging from about ~650 mm/year to more than 1000 mm/year.

Conservation practices consist of no tillage in the most farms (73%) and of strip-tillage or minimum tillage in the others (23%) and include improved crop rotations, permanent land cover with crop residues and cover crops. Mould board plough followed by secondary tillage to prepare the seed beds instead identifies conventional practices.

Each experimental site is arranged with two test plots, respectively managed under conservation and conventional practices. In some sites more replications occur.

Three monitoring units per test plot corresponding to an area of 20 x 20 m were used in this study (Figure 2). Within each monitoring unit, a cross-sampling scheme was used, resulting in nine sub-sampling points. Soil subsamples were collected to a 30 cm depth in autumn 2014 after the end of the cropping season using a soil auger. Subsamples were bulked together in a single composite sample per monitoring unit (Stolbovoy *et al*, 2007). This resulted in thre soil composite samples per plot leading to an overall total of 130 samples.
Soil samples were air dried, sieved at 2 mm and analysed for SOC concentration using the Dumas method.



sample	type of monitoring	soil depth (cm)
●	soil organic carbon + biological fertility	0-30
●	soil aggregate stability	0-15 15-30
●	soil organic matter fractions	0-15 15-30
○	bulk density	0-15-30 10-20
×	organic carbon in crop residues	---
□	soil residual nitrates	0-30-60-90
▫	soil microarthropods	0-10
❑	earthworms	0-25

Figure 2. soil sampling design

Undisturbed samples, using a cylinder with a minimum volume of 100 cm^3, were extracted from the centre of each monitoring unit to quantify BD (bulk density). Samples were collected at a depth of 0-15 and 15-30 cm in the conservation plots and from the middle (at a depth of 10-20 cm) of the ploughed horizon in conventional plots. SOC stock was quantified according to Batjes (1996)

$$SOC\ stock = OC \cdot BD \cdot t \cdot (1 - RM) \cdot \frac{1}{10}$$

Where SOC stock is given in t/ha, OC is the SOC concentration (g/kg) BD is the bulk density (g/cm^3), t is the layer thickness (cm), RM is the mass proportion of rock fragment content (dimensionless).

Soil samples were also analysed for TOC (Total Organic Carbon, using Springler-Klee method), carbon of the microbial biomass, basal and cumulative respiration, metabolic quotient and mineralization quotient, that are the parameters considered for the computation of IBF – Index of Soil Biological Fertility (Benedetti *et al.*, 2006). According to the IBF methodology, a score is assigned to each parameter and then the algebraic sum of the scores leads to rank the soils in 5 classes of biological fertility (Table 1).

Parameter	Score				
	1	2	3	4	5
organic matter (%)	<1	1-1,5	1,5-2	2-3	>3
microbial biomass carbon (ppm)	<100	100-200	200-300	300-400	>400
basal respiration (ppm)	<5	5-10	10-15	15-20	>20
cumulative respiration (ppm)	<100	100-250	250-400	400-600	>600
metabolic quotient (/h)	>0,4	0,3-0,4	0,2-0,3	0,1-0,2	<0,1
mineralization quotient (%)	<1	1-2	2-3	3-4	>4
The sum of the scores of each parameter gives the class of biological fertility according to the following scheme					
total score	1-6	7-12	13-18	19-24	25-30
Biological fertility class	I alarm stress	II pre-alarm stress	III medium	IV good	V high

Table 1. IBF – Index of Soil Biological Fertility methodology

To assess the the soil biological activity and biodiversity two indexes based on the presence of earthworms and arthropods in the soil populations were selected To this purpose, the same sampling design implemented for SOC was used, collecting in this case 1 sample per monitoring unit. Samples were drawn from the soil surface separately for the determination of earthworms and arthropods, each having a volume of 25 cm^3 and 10 cm^3 respectively.

Clods were manually broken up to extract earthworms and assess their density.

The index used to assess soil quality with respect to arthropods is the Biological Index of Soil Quality (QBS/ar), which is obtained by summing the eco-morphological indexes (EMI) of the taxa found (Parisi *et al.*, 2001). The extraction of the arthropods was carried out using Berlese-Tullgren selectors; after the extraction, a stereo microscope was used for classifying and counting. The data collected were processed according to the QBS method.

2. Results and discussion

SOC stock data are here shown comparing the results achieved from two groups of farms. The first group (A) is given by the experimental sites where the test plots were under their respective conservation and conventional soil management practices for at least 8-10 years; instead the second group (B) is formed by the sites where conservation practices was introduced since 3-5 years before the time of soil sampling.

The result of the trial (Figure 3) for group A on average showed an higher SOC stock in the conservation plots (77.9 t/ha) compared to that of the respective conventional plots (67.7 t/ha), with an overall difference of 15%.

For the group B the average difference was of about 5% with conservation plots showing an average SOC stock of 61.4 t/ha and conventional managed plots of 58.5 t/ha.

Moreover clay soils (Vertisols and Vertic Cambisols) have been found to seem more responsive to SOC accumulation compared to other soil types.

However results provided a strong variability depending on the site under study. This may be because soil, and more generally pedoclimatic conditions, as well as the crop management may have a determinant influence on the variation of SOC stocks (Sleutel *et al.*, 2006). In spite of that the first soil sampling provided with the Helpsoil project encourages to support the assumption that cropland can actually be managed using conservation practices to sequester carbon and increase SOC stocks (Basch *et al.*, 2012).

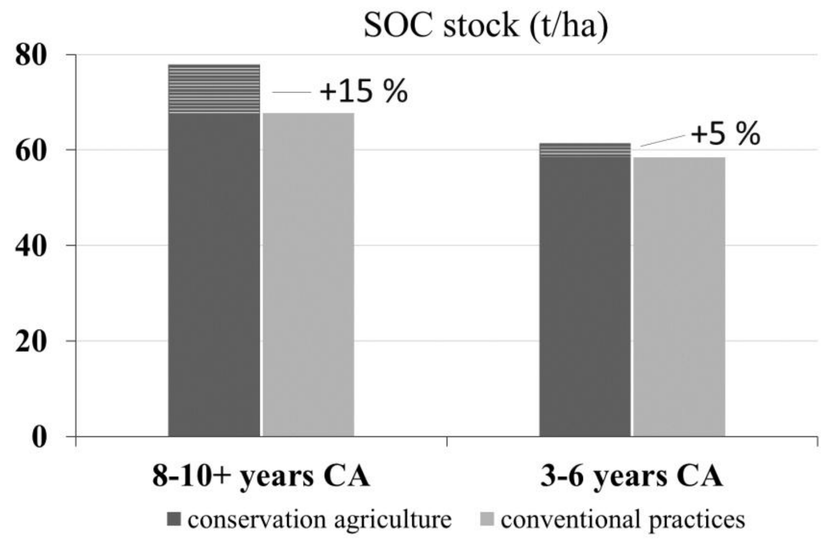


Figure 3. SOC stock in the conservation plots compared to that of the conventional plots

With respect to the IBF index, both conservation and conventionally ploughed plots were classified into the class IV (good) or III (medium), on average showing a very similar total score (respectively 17.3 and 17.2). Nevertheless, further investigations are needed to verify the sensitivity of the Index as a whole rather than its single parameters to the variation of soil tillage practices.

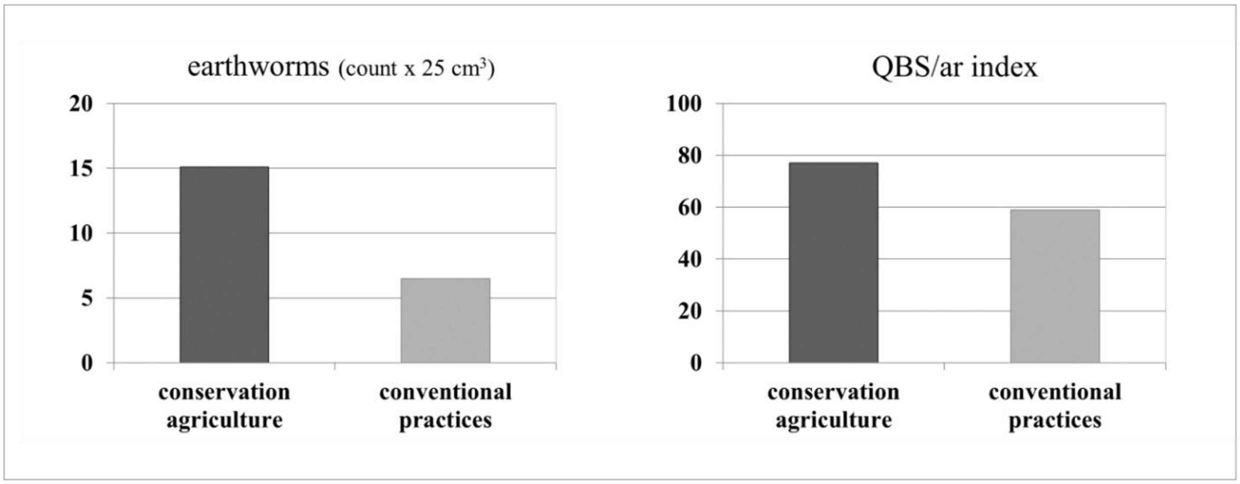


Figure 4. earthworms density and QBS/ar index pointed out in the test plots

On the contrary all the experimental sites showed an abundance of earthworms significantly higher in the conservation plots than in the ploughed fields (on average, respectively 15.1 and 6.5 earthworms per 25 cm^3). This evidence, as well as the higher presence of arthropods (on average the QBS/ar accounted for 77.1 points for the conservation plots and for 58.9 points for the conventionally managed plots), points out the importance of soil fauna indicators to get valuable information on the health status of the soil and, indirectly, of the agroecosystem of which it is a part (Figure 4).

Conclusions

This study is carried out in the frame of a Life+ project named "HelpSoil" (LIFE12 ENV/IT/000578). The project is aimed at monitoring indicators of soil ecosystem functions and assessing the capacity of Conservation Agriculture to restore agro-ecosystems to a more sustainable and productive state.

To this purpose the dissemination of such practices to foster an agriculture durable and capable to produce larger ecosystem services in the North Italy is provided. Farmers and "stakeholders" are actively involved in this process, in order to identify viable solutions and optimize environmental benefits in each specific local situation.

However, in despite of the character of the project that is mainly addressed to demonstrative actions, scientific methodologies are used in the monitoring activities.

Moreover, the results here presented are preliminary. Data indeed were collected from the first soil sampling planned in the project, whereas a second soil survey will occur in the autumn 2016 to verify results and trends over the time.

Anyhow the results achieved to date already support the improvement of knowledge concerning the potential of conservation management practices to sequester organic carbon into cropland soils in the Po plain of Italy. Data collected seem in particular to confirm (Brenna *et al*., 2010) that, together with no-tillage, a wide use of intercropping and cover crops as well as diversified crop rotations using a variety of crop species is determinant for the accumulation of SOC and the enhancement of soil biodiversity and vitality.

The activities illustrated in this study are in any case addressed to identify reliable indicator to assess the impact of soil management practices and their effect on climate change mitigation and adaptation as a part of a broader strategy providing a contribution to control global warming and to enhance beneficial soil natural biological processes.

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EU Life+ HELPSOIL project: helping enhanced soil functions and adaptation to climate change by sustainable agricultural techniques

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To support the dissemination of conservation practices in the North Italy, a Life+ project named "HelpSoil" (LIFE12 ENV/IT/000578) has started in 2013.

The project is aimed at monitoring indicators of soil ecosystem functions and assessing the capacity of Conservation Agriculture to restore agro-ecosystems to a more sustainable and productive state. To this purpose, technical guidelines based on the results of the project and adapted to the different local agro ecological conditions and cropping systems occurring in the North Italy will be carried out, comparing the environmental and agronomic performance of improved and conventional management practices applied in 20 demonstrative farms and actively involving farmers and "stakeholders "in this process.
Life HelpSoil promote innovations in agricultural management practices, based on the principles of conservation agriculture, in order to:

- improve soil functions, organic carbon sequestration, soil fertility and biodiversity, protection against erosion;
- increase irrigation and fertilisers efficiency and limit the use of pesticides;
- develop soil ecosystem indicators and new techniques to assess the environmental benefits of the practices;
- make agricultural systems more resilient against climate change.

On the Po Plain (northern Italy) the soils intensively managed declined their organic matter content over the past decades. Nevertheless, cropland soils could have a potential capacity to re-gain a large amount of carbon. That assessment would be another goal of the project.

The project has the following phases:

1. Implementation in demonstrative farms (Figure 1) of conservation agriculture practices to improve both soil ecological functions (organic carbon sequestration, increase of fertility and edaphic biodiversity, protection against erosion) and sustainability and competitiveness of farming systems;
2. Integration of conservation practices with techniques for increasing the water use and the organic fertilization efficiency, and limiting the use of plant protection products;
3. Monitoring of indicators of soil ecosystem functions to assess the environmental benefits provided by the implemented practices;
4. Sharing experiences between farmers and technicians and promoting demonstration actions to support a dissemination of improved practices as wide as possible;

5. Deliver of guidelines for the application and dissemination of Conservation Agriculture practices in the pedoclimatic conditions of northern Italy.

Communication and dissemination actions, including a mid-term conference during the Expo 2015 event and a field trip in the demonstrative farms, have been finally designed to reach, through an appropriate mix of initiatives (website, field days, newsletters, seminars and conferences), a number and type of relevant stakeholders (farmers, technicians, researchers, citizens, institutions) as larger as possible.
The Lombardy Region is leading the project, that involves 5 other Regions and 3 Technical Agencies.

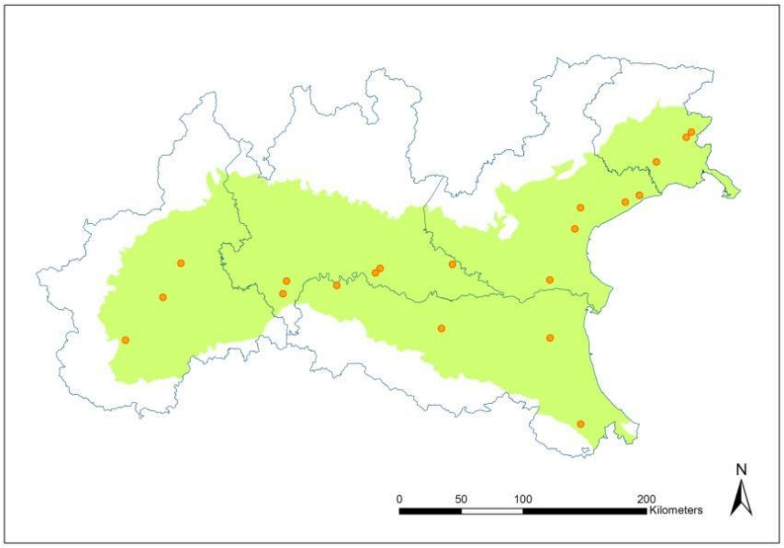

Figure 1. Life HelpSoil project area and location of demonstratives farms

Conservative and innovative practices are applied in 20 demonstrative farms. The widest applied cropping system in Po Plain area are represented in Helpsoil demonstrative farms (*Table 1*).

Table 1. Life HelpSoil crop rotation systems and conservation practices

HelpSoil crop rotation system			**farms (%)**
MAIZE	WHEAT	SOYBEAN	45
MAIZE	SOYBEAN	BARLEY	10
MAIZE	WHEAT	MAIZE	10
MAIZE	MAIZE	SOYBEAN	5
MAIZE			5
SORGHUM	SOYBEAN	BARLEY	5
WHEAT	SOYBEAN	WHEAT	5
ALFA ALFA	WHEAT	SORGHUM	5
ALFA ALFA	BARLEY		5
RICE			5

HelpSoil conservation practices	**farms (%)**
NO TILLAGE	73
MINUM TILLAGE	17
STRIP-TILLAGE	10

The Helpsoil project helped regional administration to develop knowledge on Conservation Agriculture techniques facilitating the choice of specific measures in their rural development programs.

Table 2. Rural development measures connected with Conservation Agriculture practices in Life HelpSoil project area regions

Italian Regions	rural development measures	
	#	title
Piemonte	10.1.3	conservation agriculture techniques
Lombardia	10.1.4	conservation agriculture
Emilia Romagna	10.1.4	conservation agriculture and organic matter maintenance
Veneto	10.1.1	low environmental impact techniques
Friuli Venezia Giulia	10.1.1	conservation crop management

Figure 2. Project events with farmers

The demonstration approach of the project will increase the awareness of the environmental issues related to agriculture and will spread the knowledge among farmers in Conservation Agriculture.

The results already achieved are:

- the good feedback among stakeholders, monitored through the indicators on the web, but also with organized events.
- a first version of the guidelines to support conservation agriculture application published on the project website.

By the end of the project it is planned to publish the final version.

Conclusions

We deem that efforts on field demonstration, training and technical support, involving farmers experience in all these actions, are basis to enable Conservation Agriculture principles to be widely adopted.

Is also expected to contribute to the dissemination of Conservation Agriculture practices and convince farmers they are applicable, suitable, able to sustain profitability and also able to create new perspective, such as the generation of carbon credits.

Adaptation of Agricultural Irrigation to Climate Change

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Introduction

The climate of planet is changing. Huge demonstrations of temperature and precipitation alterations have been documented over the last years. About the variability of these parameters the Intergovernmental Panel on Climate Change (IPCC) concluded that between 1906 and 2005 the mean air temperature in planet had increased 0.74 °C. Some climatic predictions assume variations in precipitation ranging 44.2 to 84.2 mm $year^{-1}$ likewise of an increase to air temperature around 1 ºC; such conditions could occur in 2011-2030 period (IPCC, 2007; Buytaert et al., 2009). Studies in China and Vietnam shown changes in their climate. During Twentieth Century, China experimented the temperature increase above 0.5 ºC especially in the last half of it; besides, this country reflects those irregularities in precipitation; while the Southeast portion increases up to 130 mm, the Northeast portion decreases up to 50 mm both regarding to normal values (Wang et al., 2013). On the issue of Vietnam the impacts that suffered the water are very worrying because this is the most important resource for its development (Thinh et al., 2013); in a recent World Bank study, the Earth has been categorized in five regions: Latin America and The Caribbean (with 25 countries), North and Middle East of Africa (13), Sub – Saharan Africa (29), East (13) and South (4) of Asia. It indicates that the region East of Asia, where is Vietnam, ranks first in the most affected regions by sea levels, in a range of 1 to 5 meters, affecting the GDP with 2.09% to 10.2% and the urbanization (Dasgupta et al., 2007).

Another study has been made, in England they have done predictions that by 2030 their population will increase between 6.5 and 9.6 million based on the population of 2012, which will cause problems with the water demand; also, the Environment Agency predicted a change in water demand with a rank of -28% to 49% for the year 2050 in England and Gales (Arnell et al., 2015); other analysis involve the expected impact of climate change on water demands of crops (Bar et al., 2015; Valverde et al., 2015; Won- Ho et al., 2015), countries like Mexico, Peru and Uruguay have made great progress in planning due to climate change. In 2007 Mexico threw a National Climate Change Strategy (with Spanish acronym ENACC). Identifying the opportunities for the reduction of these impacts and providing measures of adaptation and mitigation for a lot of sectors. As well an Especial Program of Climatic Change (PECC) in 2009, adding the Program of the Mexican Sector Agricola 2007-2012 and the National Hydric Program 2007-2012 where it has information about the strategic measures to discuss this new change (Lee et al., 2014).

Likewise, some predictions have used a statistical method to obtain an assembly with Global Climate Models (GCMs) (Amador and Alfaro, 2009; Ojeda et al., 2011; Montero et al., 2013; Zavala et al., 2013). GCMs are mathematical algorithms that represent the climate system of the Earth (Semenov and Barrow, 1997; Semenov et al., 1998; IPCC, 2007; Acevedo, 2009), they are positioned at the top end of the hierarchy of climate models, these models can predict changes in the variables in a longer time and can be coupled (atmosphere-ocean-floor) (IPCC, 2007; Acevedo, 2009). Each of the main components were created separately, such as, the atmosphere, land surface, oceans and sea ice, to later gradually integrate, as the final goal is to include the major components as possible in the climate system of the Earth (Acevedo, 2009).

The spatial resolution of the calculating mesh and the output results of the GCMs are between 100 km and 500 km per cell, with these spatial dimensions, the process only fits in global way, namely it cannot be used directly at a specific site as a result of the huge resolution (Semenov and Barrow, 1997; Semenov et al., 1998), which in order to obtain approximate solutions of the system equations of GCMs, computers with large capacity of processing are used, and also with the application of various methods of numerical calculation (Semenov and Barrow, 1997; Acevedo, 2009). Therefore, Regional Circulation Models (RCMs) also known as Limited Area Models (LAM) are developed, for analyzing a local area study like irrigation units, districts, watersheds, etc., requiring site-specific with daily temporal resolution, full set of climate variables required by the model, changes in means and climate variability and have an appropriate number of years information (Semenov and Barrow, 1997).

One of the researches on GCMs in Mexico was conducted by Tejeda et al. (2008), which predicted extreme temperatures and humidity in January and July for the years 2020 and 2050, applying only three GCMs, two scenarios and the data base of 50 weather stations for the period 1961-1990. In general terms, the extreme maximum temperature in July 2020 and 2050 will have an increase between them around 2 to 7 °C, and 2 to 6 °C in extreme minimum. Furthermore, Ojeda et al. (2011) modeled the precipitation and temperature for the 075 northern district of Sinaloa, Mexico, using climate data base of station from the period 1961-1990, 23 GCMs and A1B scenario, resulting weather predictions for three periods 2011-2040, 2041-2070 and 2071-2098. The predictions indicate an annual increase on average temperature of 0.03 °C and a decrease on precipitation around 62 to 110 mm per year for all the periods.

From the beginning of the 80's, models of weather generator became available, facilitating the generation of projections as in the case of LARS-WG (Long Ashton Research Station – Weather Generator) program, the most popular model devoted to the study of regional climate change in european community (Racsko and Semenov, 1991; Semenov and Barrow, 1997). In 1998, Semenov et al., makes a comparison between two weather generators named WGEN and LARS-WG, in 18 sites of USA, Europe and Asia, concluding that LARS-WG is better due the complex distributions for weather variables and how matches the observed data much better than WGEN. In addition, Zavala et al., (2013) analyzes the impact in irrigation requirement, as a result of climate change in district 034 in Zacatecas, Mexico. They employed 15 GCMs and three scenarios contained in LARS-WG5, concluding that in maximum and minimum temperatures will have a continuous increase over the time, regardless of the climate change scenario and a decrease in precipitation since 2046 compared to the average historical values.

In the late nineties and early XXI century, in the municipally of Apozol, located in Zacatecas, México, farmers have observed that rainfall patterns changed and it's insufficient the rainwater to the agriculture, in natural and empirical terms. Given that, in 2008 they started the management for the construction of a dam with the aim of getting the crops in this region, inaugurated in 2010 called “El Tecongo”. Today this dam supplies the demand of water necessary for crops. Considering the impacts generated by the climate change, in different parts of the world, this area could be affected, causing changes in temperature and precipitation, which can affect the water supply, this because of the evaporation of water in the case of a temperature increase of the area, and / or insufficient precipitation. For this reason it is important to know the changes of these variables in the irrigation district to take preventive measures against climate change. The focus of this work is to know the climate impact over an agriculture zone with a reservoir as water source, in Zacatecas, Mexico. This is realized by calculating predictions of minimum and maximum temperatures and precipitation with a stochastic weather generator simulation (LARS-WG5) applying three scenarios A2, A1B and B1 related to CO_2 concentrations.

1. Materials and Methods

Study Area Location

The municipality of Apozol it’s located in the south of Zacatecas state, with coordinates 103° 05’ west longitude and 21° 28’ latitude north, at an altitude of 1300 meters above sea level, bounded on the north with the municipality of Jalpa; south with Juchipila; east Nochistlan and west Tepechitlan and Teul Gonzalez Ortega.

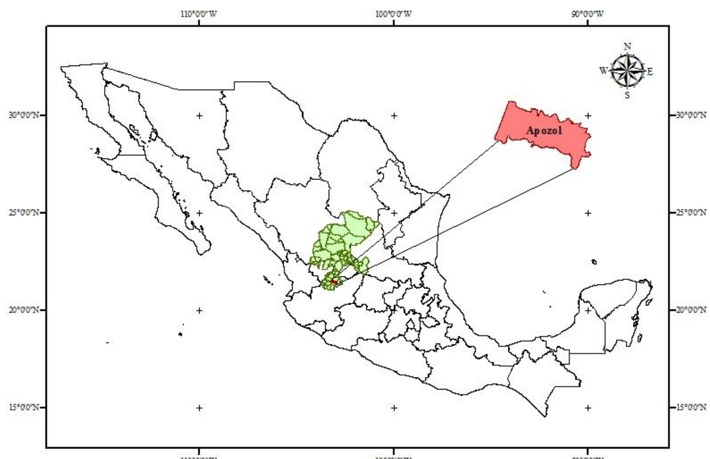

Figure 1. Location of the study area in Mexico

In this town the dam project “El Tecongo” opened on December 28, 2010. The project is between the geographical coordinate’s 21° 30’ 55.72’’ latitude and 103° 07’ 32.01’’ length, on the Rincon Verde stream, which belongs to the hydrologic region No. 12 River Basin Juchipila, having capacity of approximately 1.5 million m^3.

Because of the weather conditions the region has been characterizes by having a variety of crops, which are corn, guava, lemons, limes, tomatoes, squash, tomato leaf, american cucumber, watermelon, crocuses, granada, chili and strawberry, sometimes alfalfa, oats and wheat. The irrigation area has 165 hectares, having three types of irrigation systems, drip, sprinkler and micro sprinkler.

Climatic Data

For the analysis of climate change its necessary to have the knowledge of climatological variables such as, precipitation and maximum and minimum temperatures daily. For this study the data base period was 1978-2014 provided by the National Water Commission (CONAGUA, acronym in Spanish) choosing only three weather stations, Jalpa, Juchipila and La Villita, which are located between the geographical coordinate's 21° 39' 08'' latitude and 102° 58' 47'' length, 21° 23' 14'' and 103° 06' 53'', 21° 36' 08'' and 103° 20' 13'', respectively. In this area the average temperature is 20.7° C and the average precipitation is 691 mm in annually terms.

There are lack of information in the data base of the three weather stations provided by CONAGUA, so it's necessary to realize a homogeneity analysis to fill the missing data. This analysis was made monthly due the magnitude of information, i.e. January since 1978 to 2014. At each base station (Jalpa, Juchipila and La Villita) this calculation was performed by applying:

$$y = ax + b \quad (1)$$

Were x is the missing data of the support station in this case La Villita; y are the calculate values for the base station (Jalpa and Juchipila); a and b are fitting parameters were obtained from a linear regression analysis of the data set measured at stations. Once the data it's filled is necessary to determinate a correlation coefficient, measuring the variation between variables related linearly.

Climate Projection

The first version of LARS-WG was developed in Budapest in 1990, part of the Assessment of Agricultural Risk in Hungary (Racsko and Semenov, 1991). A stochastic weather generator is a numerical model that produces synthetic daily times series of climate variables, such as, precipitation, maximum and minimum temperatures and solar radiation (Racsko and Semenov, 1991; Semenov and Barrow, 1997; Semenov et al., 1998; Zavala et al., 2013). This generator uses daily weather data of a specific site to compute a set of parameters for probability distributions of weather variables as well as correlations between them. The parameters are used to generate synthetic weather time series, by randomly selecting values from the appropriate distributions of an arbitrary length (Semenov et al., 1998). The new version of the LARS-WG incorporates predictions from 15 of 23 GCMs used in the fourth evaluation report (AR4) on 2007 of the IPCC (Semenov and Stratonovitch, 2010).

Under scenarios of climate change, the simulation of predictions for the irrigation unit "El Tecongo" was analyzed with the stochastic weather generator LARS-WG5. This model analyze the weather sequences and the estimation of distribution parameters at any geographical area. Also calculates the Fourier coefficients and creates the file for that location. Table 1 epitomize important properties and their acronyms used in AR4 of GCMs. For most of these GCMs, climate predictions are available for the Special Report on Emissions Scenarios (SRES) emissions scenarios A2, A1B and B1. A2 called the separated world contains a very heterogeneous world, with high population growth and less focus on economy and material wealth. The probable concentrations of CO_2 for the three analyze periods proposed from the IPCC will be 414 ppm (2011-2030), 545 ppm (2046-2065) and 754 ppm (2081-2100), this is the worst scenario development; A1B the rich world, pictures a very rapid economic growth, a low population growth and a fast introduction on new and efficient technologies. The concentrations will be 418 ppm (2011-2030), 541 ppm (2046-2065) and 674 ppm (2080-2099), intermediate scenario of development; and B1 the sustainable world, describes a rapid growth in the economy, reaching the maximum population world by the mid-century, having a global concern regarding environmental and social sustainability, introducing clean technologies. The probable concentrations of CO_2 will be 410 ppm (2011-2030), 492 ppm (2046-2065) and 538 ppm (2081-2100), optimistic scenario development.

Table 1. Global Climate Models (GCMs) include in the stochastic program LARS-WG5

Research Centre of the Global Climate Models GCM	**Country**	**Name of the Global Climate Model**	**Model Acronym**	**Grid Resolution** 1° ≅ 111.1 km	**Emissions Scenarios**
Commonwealth Scientific and Industrial Research Organization (CSIRO)	Australia	CSIRO-MK3.0	CSMK3	1.9°-1.9°	A1B, B1
Canadian Centre for Climate Modelling and Analysis (CCCMA)	Canada	CGCM33.1 (T47)	CGMR	2.8°-2.8°	A1B
Institute of Atmospheric Physics (IAP)	China	FGOALS-g1.0	FGOALS	2.8°-2.8°	A1B, B1
Centre National de Recherches Meteorologiques (CNRM)	France	CNRM-CM3	CNCM3	1.9°-1.9°	A2, A1B
Institute Pierre Simon Laplace (IPSL)	France	IPSL-CM4	IPCM4	2.5°-3.7°	A2, A1B, B1
Imax-Planck Institute for Meteorology (IMM-P)	Germany	ECHAM5-OM	MPEH5	1.9°-1.9°	A2, A1B, B1
National Institute for Environmental Studies (NIES)	Japan	MRI-CGCM2.3.2	MIHR	2.8°-2.8°	A1B, B1
Bjerknes Centre for Climate Research (BCCR)	Norway	BCM2.0	BCM2	1.9°-1.9°	A1B, B1
Institute for National Mathematics (INM)	Russia	INM-CM3.0	INCM3	4.0°-5.0°	A2, A1B, B1
UK Meteorological Office (UKMO)	UK	HadCM3	HADCM3	2.5°-3.7°	A2, A1B, B1
		HadGEM1	HADGEM	1.3°-1.9°	A2, A1B
Geophysical Fluid Dynamics Lab (GFDL)	USA	GFDL-CM2.1	GFCM21	2.0°-2.5°	A2, A1B, B1
Goddard Institute for Space Studies (GISS)	USA	GISS-AOM	GIAOM	3.0°-4.0°	A1B, B1
National Centre for Atmospheric Research (NCAR)	USA	CM	NCPCM	2.8°-2.8°	A1B, B1
		CCSM3	NCCCS	1.4°-1.4°	A2, A1B, B1

Source: Semenov and Stratonovitch, 2010

Applying emissions scenarios A2, A1B and B1, the three periods of concentration and the 15 models included in LARS-WG5 there were obtained maximum and minimum temperature and precipitation daily for the three weather stations. Once generated the series for each station, generate average on GCM was necessary in order to obtain a representative series for every period.

2. Results

The analysis of homogeneity throws the fallowing historical graphs for Jalpa (Figure2), Juchipila (Figure 3) and La Villita (Figure 4), reflecting the average annual precipitation and temperature since 1978 to 2014 as well as the historical average of each one.

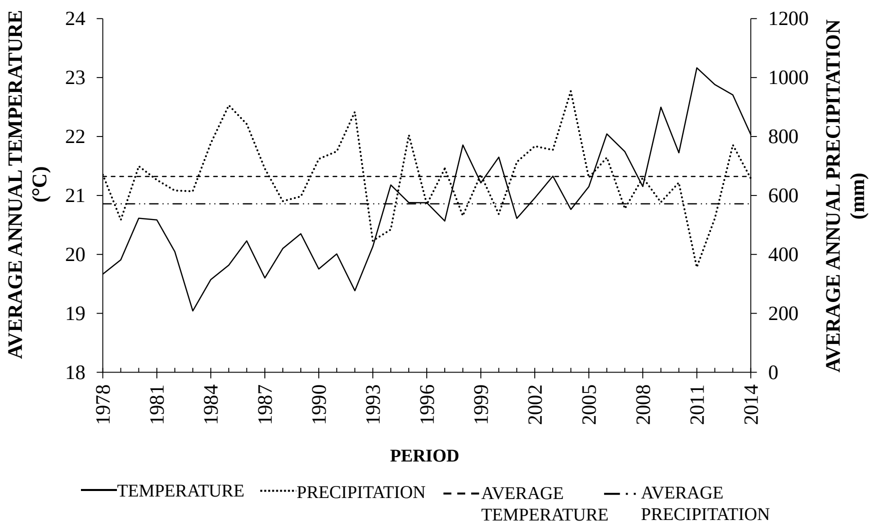

Figure 2. Historical analysis of precipitation and temperature, Jalpa weather station.

According to data temperature of the station JALPA, on the period 1978 to 2014 maximum temperature in this period it is 33.5 °C and 9.5 °C minimum. In 36 years there was an increase of 2.37 °C which means a rate of 0.066 °C per year obtaining an average temperature of 20.86 °C. However such condition shows an increased since 1998. Prior to that period the temperature variation maintains an average of 21.73 °C; on the other hand since 1996 the value was 20.12 °C increasing 2 °C.

When it's analyzed the precipitation, alternative wet and dry periods are observed so it is not possible to establish a trend in this variable. However, we find that since 1993 there are considerable increases; that is, wet years with rainfall higher that the average with a value of 664.46 mm or very dry years with rainfall well below it.

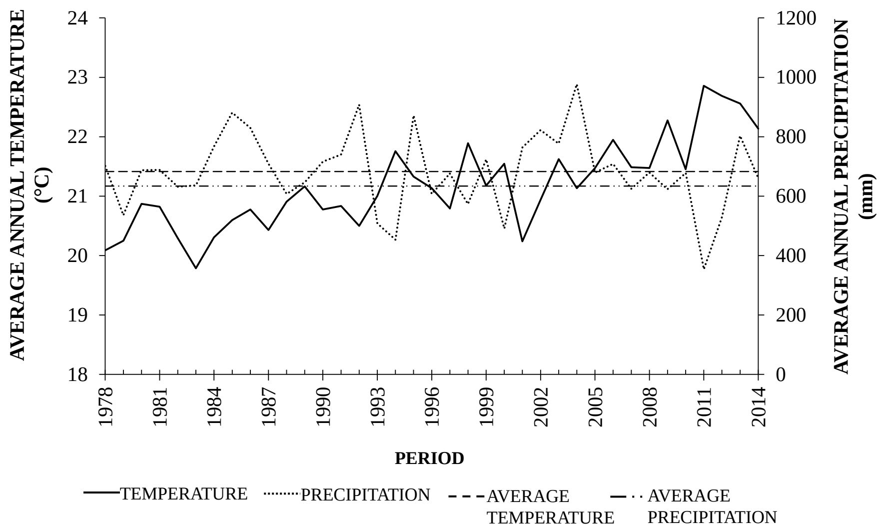

Figure 3. Historical analysis of precipitation and temperature, Juchipila weather station.

In Juchipila station, the maximum temperature was 32.4 °C and minimum 10.1 °C having an average of 21.17 °C. In this case on the temperature we observed a better stability, only in 2001 it decreased 0.93 °C above the average. On these 36 years of study only 2.05 °C increased which means a rate of 0.057 °C per year.

In precipitation, is not possible to establish a trend in this variable. Since 1993, there are considerable increases and decreases compared to the average 682.96 mm, having a drought on 2011 of 353.88 mm.

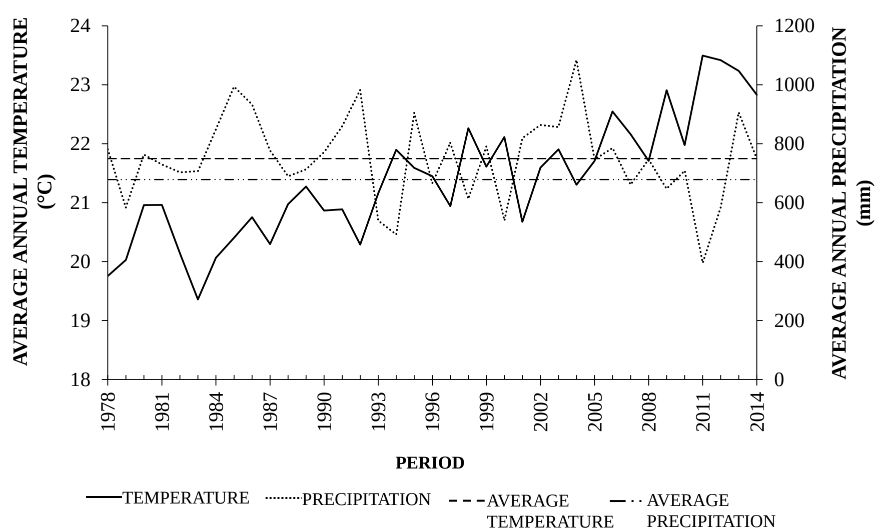

Figure 4. Historical analysis of precipitation and temperature, La Villita weather station.

La Villita station according to the temperature data throws 33.2 °C in the maximum, 9.9 °C minimum and 21.39 °C in average. From 1978 to 2014 it increased 3.07 °C which means an annual rate of 0.085 °C. Is observed an increase in temperature above the mean, growing apace with time since 1993, earlier the average temperature ranged at 20.17° C.

On the other hand, it is difficult to set a trend in the precipitation. It is noted that there are considerable causalities after 1993; i.e. very wet or dry years, as 2011 with 353.77 mm under the mean 749.72 mm, or above as in the case of 2004 with 334.65 mm.

The predictions resulted from the mean of the GCMs for each station of precipitation, maximum and minimum temperature are shown in Table 2, Table 3 and Table 4 and the mean values are shown in Table 5.

In maximum temperature (Table 2) the predictions of the three weather stations projected that using the average of the three scenarios, in December on the period 2015-2030, there will be an average increase of 0.90 °C for Jalpa, 0.95 °C for Juchipila and 1.27 °C for La Villita; on 2046-2065 2.15 °C, 1.67 °C and 2.07 °C; and for 2080-2099 it will grow 3.45 °C, 3.03 °C and 3.41 °C respectively.

By averaging the three scenarios, the minimum temperature predictions (Table 3) showed that for Jalpa weather station in November (2015-2030) it will increase 1.29 °C, 1.34 °C in Juchipila and 1.10 °C in La Villita, on the next period (2046-2065) March will increase 2.09 °C, 2.00 °C and 1.94 °C, and on the last period (2080-2099) April will grow 3.16 °C, 3.36 °C and 3.38 °C respectively.

The average annual precipitation predictions (Table 4) shows a little variation between scenarios. Based on the average historical (1978-2014) on the period 2015-2030 the rainfall will decrease 102.55 mm in Jalpa station, 63.19 mm in Juchipila and 67.19 mm in La Villita; by the period 2046-2065 it will fall 136.27 mm, 87.51 mm, 137.42 mm; and by 2080-2099 129.80 mm, 155.39 mm, 173.68 mm respectively.

Table 2. Monthly average of maximum temperature predictions based on the period, the scenario and weather station

MAXIMUM TEMPERATURE (°C)														
Weather Station	**Period**	**Scenarios**	**Months**											
			J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
JALPA	***Historic***		***26.5***	***28.5***	***31.1***	***34.0***	***35.4***	***33.7***	***30.1***	***30.2***	***29.8***	***29.9***	***28.6***	***26.5***
	2015-2030	***A1B***	27.1	28.7	32.2	34.7	36.0	34.1	31.0	30.7	30.6	30.3	29.4	27.4
		A2	27.2	28.6	32.2	34.6	36.0	34.1	30.9	30.6	30.6	30.3	29.4	27.4
		B1	27.2	28.6	32.2	34.5	35.9	34.1	30.9	30.7	30.6	30.2	29.4	27.5
		MEAN	**27.2**	**28.6**	**32.2**	**34.6**	**36.0**	**34.1**	**30.9**	**30.7**	**30.6**	**30.3**	**29.4**	**27.4**
	2046-2065	***A1B***	27.5	29.0	32.0	34.3	36.1	34.6	31.1	30.8	30.6	30.4	29.7	28.1
		A2	27.5	29.0	32.0	34.3	36.0	34.5	31.0	30.8	30.6	30.4	29.7	28.1
		B1	27.6	29.1	32.0	34.2	36.0	34.5	31.0	30.8	30.6	30.3	29.7	28.1
		MEAN	**27.5**	**29.0**	**32.0**	**34.3**	**36.0**	**34.5**	**31.0**	**30.8**	**30.6**	**30.4**	**29.7**	**28.1**
	2080-2099	***A1B***	27.5	29.2	32.4	34.8	36.4	34.2	30.9	30.5	30.4	30.4	29.7	28.5
		A2	27.6	29.2	32.3	34.8	36.4	34.1	30.8	30.4	30.3	30.4	29.7	28.5
		B1	27.6	29.3	32.3	34.7	36.3	34.1	30.9	30.5	30.3	30.4	29.6	28.6
		MEAN	**27.6**	**29.2**	**32.3**	**34.7**	**36.4**	**34.1**	**30.9**	**30.5**	**30.3**	**30.4**	**29.7**	**28.5**
JUCHIPILA	***Historic***		***26.8***	***28.9***	***31.2***	***33.9***	***35.6***	***33.9***	***30.2***	***30.2***	***29.9***	***29.9***	***28.8***	***27.2***
	2015-2030	***A1B***	28.3	30.2	33.4	36.0	37.2	35.3	32.3	31.9	31.4	31.3	30.4	28.8
		A2	28.4	30.3	33.5	36.0	37.2	35.2	32.1	31.8	31.4	31.3	30.4	28.8
		B1	28.0	29.8	32.9	35.4	36.7	35.0	31.9	31.6	31.1	30.9	30.0	28.4
		MEAN	**28.2**	**30.1**	**33.3**	**35.8**	**37.0**	**35.2**	**32.1**	**31.8**	**31.3**	**31.2**	**30.3**	**28.7**
	2046-2065	***A1B***	28.8	30.7	33.1	35.7	37.4	35.7	32.2	32.0	31.4	31.7	30.7	28.9
		A2	28.8	30.7	33.1	35.7	37.3	35.6	32.0	31.9	31.4	31.7	30.7	29.0
		B1	28.4	30.2	32.6	35.2	36.9	35.3	31.8	31.7	31.1	31.4	30.3	28.6
		MEAN	**28.7**	**30.5**	**32.9**	**35.5**	**37.2**	**35.5**	**32.0**	**31.9**	**31.3**	**31.6**	**30.6**	**28.8**
	2080-2099	***A1B***	28.9	30.5	33.3	35.9	37.8	35.4	32.0	31.8	31.6	31.6	30.8	29.4
		A2	28.9	30.6	33.4	36.0	37.8	35.3	31.9	31.7	31.6	31.6	30.9	29.5
		B1	28.6	30.1	32.8	35.4	37.3	35.0	31.7	31.5	31.3	31.3	30.5	29.1
		MEAN	**28.8**	**30.4**	**33.2**	**35.8**	**37.6**	**35.3**	**31.9**	**31.6**	**31.5**	**31.5**	**30.7**	**29.3**
LA VILLITA	***Historic***		***27.0***	***29.0***	***31.4***	***34.1***	***35.8***	***33.8***	***30.1***	***30.1***	***29.8***	***29.9***	***28.8***	***27.3***
	2015-2030	***A1B***	29.3	31.6	34.6	37.3	38.3	36.9	33.5	33.1	32.6	32.9	31.6	30.0
		A2	30.1	32.4	35.5	38.2	39.2	37.8	34.4	33.9	33.4	33.7	32.4	30.8
		B1	28.5	30.6	33.5	36.1	37.2	35.9	32.6	32.2	31.6	31.9	30.6	29.1
		MEAN	**29.3**	**31.5**	**34.5**	**37.2**	**38.2**	**36.9**	**33.5**	**33.1**	**32.6**	**32.8**	**31.5**	**30.0**
	2046-2065	***A1B***	29.8	31.8	34.6	37.2	38.9	36.9	33.4	33.3	33.0	32.9	31.8	30.2
		A2	30.6	32.6	35.4	38.2	39.8	37.8	34.2	34.0	33.7	33.6	32.5	31.0
		B1	28.9	30.9	33.5	36.1	37.8	36.0	32.4	32.3	32.0	31.9	30.8	29.3
		MEAN	**29.7**	**31.8**	**34.5**	**37.2**	**38.8**	**36.9**	**33.3**	**33.2**	**32.9**	**32.8**	**31.7**	**30.2**
	2080-2099	***A1B***	29.9	32.0	34.6	37.2	39.1	37.0	33.3	33.1	32.6	32.9	32.0	30.7
		A2	30.8	32.8	35.5	38.2	40.1	37.8	34.1	33.9	33.3	33.6	32.7	31.5
		B1	29.1	31.1	33.6	36.0	38.0	36.0	32.4	32.2	31.6	31.9	31.0	29.8
		MEAN	**29.9**	**31.9**	**34.6**	**37.1**	**39.1**	**36.9**	**33.3**	**33.1**	**32.5**	**32.8**	**31.9**	**30.7**

Table 3. Monthly average of minimum temperature predictions based on the period, the scenario and weather station

MINIMUM TEMPERATURE (°C)															
Weather Station	**Period**	**Scenarios**	**Months**												
			J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
JALPA	***Historic***		***5.0***	***6.5***	***8.3***	***11.6***	***14.7***	***17.2***	***16.5***	***15.9***	***15.2***	***11.8***	***7.7***	***6.3***
	2015-2030	***A1B***	5.5	6.8	9.0	12.4	15.4	15.4	17.1	16.5	16.5	12.4	8.9	7.0
		A2	5.6	6.7	9.0	12.3	15.4	17.4	17.0	16.5	15.6	12.4	9.0	7.1
		B1	5.6	6.7	8.9	12.2	15.4	17.4	17.0	16.5	15.5	12.4	9.0	7.1
		MEAN	**5.6**	**6.7**	**9.0**	**12.3**	**15.4**	**16.7**	**17.0**	**16.5**	**15.9**	**12.4**	**9.0**	**7.1**
	2046-2065	***A1B***	6.3	7.9	10.6	13.6	16.6	18.9	18.0	17.4	16.9	13.4	9.7	8.0
		A2	6.5	8.0	10.7	13.7	16.6	18.8	18.0	17.4	16.9	13.5	9.8	8.1
		B1	6.0	7.5	10.1	13.1	16.1	18.5	17.7	17.1	16.5	13.1	9.3	7.6
		MEAN	**6.3**	**7.8**	**10.4**	**13.4**	**16.4**	**18.7**	**17.9**	**17.3**	**16.8**	**13.3**	**9.6**	**7.9**
	2080-2099	***A1B***	7.8	9.2	11.4	14.7	17.8	20.0	19.4	18.7	17.7	14.3	10.8	8.9
		A2	8.9	10.3	12.5	15.8	18.9	21.1	20.4	19.6	18.6	15.3	11.7	9.8
		B1	7.0	8.4	10.4	13.6	16.8	19.1	18.5	17.9	16.8	13.4	9.9	8.0
		MEAN	**7.9**	**9.3**	**11.4**	**14.7**	**17.8**	**20.1**	**19.4**	**18.7**	**17.7**	**14.3**	**10.8**	**8.9**
JUCHIPILA	***Historic***		***5.6***	***7.0***	***8.9***	***11.7***	***14.6***	***17.6***	***16.9***	***16.4***	***15.9***	***12.5***	***8.4***	***6.6***
	2015-2030	***A1B***	6.3	7.5	9.4	12.2	15.3	18.0	17.4	17.0	16.4	13.0	9.8	7.3
		A2	6.4	7.5	9.4	12.3	15.3	18.0	17.4	17.0	16.4	13.0	9.8	7.3
		B1	6.3	7.5	9.4	12.2	15.2	18.0	17.4	17.0	16.4	12.9	9.7	7.3
		MEAN	**6.3**	**7.5**	**9.4**	**12.2**	**15.3**	**18.0**	**17.4**	**17.0**	**16.4**	**13.0**	**9.8**	**7.3**
	2046-2065	***A1B***	7.1	8.5	11.0	13.7	16.4	19.1	18.5	18.1	17.5	14.0	10.2	8.3
		A2	7.2	8.7	11.1	13.7	16.4	19.1	18.5	18.1	17.6	14.1	10.3	8.4
		B1	6.7	8.2	10.5	13.1	15.9	18.8	18.2	17.8	17.2	13.7	9.9	7.9
		MEAN	**7.0**	**8.5**	**10.9**	**13.5**	**16.2**	**19.0**	**18.4**	**18.0**	**17.5**	**13.9**	**10.1**	**8.2**
	2080-2099	***A1B***	8.0	9.7	12.1	15.1	17.9	20.6	19.7	19.2	18.4	15.3	11.4	8.9
		A2	9.0	10.8	13.2	16.2	18.9	21.6	20.6	20.1	19.3	16.2	12.4	9.9
		B1	7.2	8.9	11.1	13.9	16.8	19.6	18.8	18.3	17.5	14.4	10.6	8.0
		MEAN	**8.0**	**9.8**	**12.2**	**15.1**	**17.8**	**20.6**	**19.7**	**19.2**	**18.4**	**15.3**	**11.5**	**8.9**
LA VILLITA	***Historic***		***6.4***	***7.6***	***9.4***	***12.3***	***15.1***	***17.6***	***17.0***	***16.5***	***16.1***	***12.7***	***8.8***	***7.0***
	2015-2030	***A1B***	6.9	8.0	10.2	13.0	16.0	18.0	17.6	17.1	16.5	13.0	9.9	7.7
		A2	7.0	8.1	10.2	13.0	16.0	18.0	17.6	17.1	16.5	13.0	10.0	7.7
		B1	6.9	8.0	10.2	12.9	15.9	18.0	17.6	17.1	16.5	12.9	9.9	7.7
		MEAN	**6.9**	**8.0**	**10.2**	**13.0**	**15.9**	**18.0**	**17.6**	**17.1**	**16.5**	**13.0**	**9.9**	**7.7**
	2046-2065	***A1B***	7.9	9.2	11.4	14.4	16.9	19.3	18.7	18.2	17.5	14.4	10.7	8.8
		A2	8.0	9.3	11.6	14.5	16.9	19.3	18.6	18.2	17.6	14.5	10.8	8.9
		B1	7.5	8.8	10.9	13.9	16.5	18.9	18.3	17.9	17.1	14.1	10.4	8.4
		MEAN	**7.8**	**9.1**	**11.3**	**14.2**	**16.8**	**19.2**	**18.5**	**18.1**	**17.4**	**14.3**	**10.6**	**8.7**
	2080-2099	***A1B***	8.6	10.0	12.4	15.7	18.4	20.7	19.9	19.2	18.6	15.3	12.0	10.1
		A2	9.6	11.1	13.5	16.8	19.4	21.7	20.9	20.1	19.5	16.2	13.0	11.1
		B1	7.8	9.2	11.4	14.6	17.3	19.8	19.1	18.4	17.8	14.4	11.2	9.3
		MEAN	**8.6**	**10.1**	**12.4**	**15.7**	**18.4**	**20.7**	**20.0**	**19.3**	**18.6**	**15.3**	**12.1**	**10.2**

Table 4. Average annual precipitation predictions of each period, scenario and weather station

PRECIPITATION (mm year $^{-1}$)				
Scenario	**Period**	**Weather Station**		
		Jalpa	**Juchipila**	**La Villita**
Historic	***1978-2014***	***664.46***	***682.96***	***749.72***
A1B	*2015-2030*	560.25	618.06	679.45
A2		566.60	624.53	687.52
B1		558.88	616.70	680.65
MEAN		**561.91**	**619.76**	**682.54**
A1B	*2046-2065*	524.87	591.99	609.09
A2		529.85	597.18	613.91
B1		529.85	597.18	613.91
MEAN		**528.19**	**595.45**	**612.30**
A1B	*2080-2099*	528.24	521.52	569.20
A2		536.21	529.67	577.45
B1		539.53	531.50	581.47
MEAN		**534.66**	**527.57**	**576.04**

Table 5. Comparison of historical values and average predictions precipitation, minimum and maximum temperature.

Scenario	**Period**	**Weather Station**								
		Jalpa			**Juchipila**			**La Villita**		
		T_{MIN} °C	T_{MAX} °C	*P mm*	T_{MIN} °C	T_{MAX} °C	*P mm*	T_{MIN} °C	T_{MAX} °C	*P mm*
	1978-2014	**11.39**	**30.36**	**664.46**	**11.84**	**30.54**	**682.96**	**12.23**	**30.61**	**749.72**
A1B	*2015-2030*	11.92	31.02	560.25	12.46	31.18	618.06	12.82	31.24	679.45
	2046-2065	13.10	32.21	524.87	13.54	32.35	591.99	13.94	32.43	609.09
	2080-2099	14.23	33.48	528.24	14.67	33.65	521.52	15.08	33.72	569.20
A2	*2015-2030*	12.01	30.99	566.60	12.49	31.16	624.53	12.84	31.22	687.52
	2046-2065	13.17	32.20	529.85	13.60	32.33	597.18	14.01	32.41	613.91
	2080-2099	15.24	34.31	536.21	15.67	34.46	529.67	16.08	34.53	577.45
B1	*2015-2030*	11.98	30.99	558.88	12.45	31.16	616.70	12.80	31.22	680.65
	2046-2065	12.72	31.82	529.85	13.16	31.96	597.18	13.56	32.04	613.91
	2080-2099	13.32	32.47	539.53	13.76	32.65	531.50	14.17	32.71	581.47

Comparing average annual precipitation, maximum and minimum temperatures predictions with the average annual historical, in general terms follows that, Jalpa, Juchipila and La Villita will experiment a decrease in precipitation and an increase in minimum and maximum temperature, in 2015-2030, 77.64 mm, 0.60 °C and 0.63 °C; in 2046-2065, 120.40mm, 1.60 °C and 1.69 °C, and by 2080-2099, 152.96 mm, 2.87 °C and 3.05 °C respectively.

Conclusion

The predictions of minimum and maximum temperatures and precipitation were obtained based on LARS- WG5 generator, in 2099 the study area will experiment a decrease in precipitation and an increase in minimum and maximum temperature around 100 mm, 1.7 °C and 1.8 °C respectively. Following those predictions, agriculture of the region could suffer changes in crop water requirements. In consequence, strategies as reservoir construction are necessary to satisfy such variations.

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Farmer's perspective on adaptation and up-scaling of conservation agriculture based management practices in Indo-Gangetic plains of India

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Food security, resource conservation and soil health engrossed farmers worldwide towards conservation agriculture. Globally, in last 10 years CA cropland area has expanded at an average rate of around 8.3 M ha per year, from 72 to 157 M ha (Kassam et al., 2015). However, despite of economic, agronomic and environmental benifits the adoptation rate of CA is still trickling in South Asia (Sapkota et al., 2015). The Indo-Gangetic Plains (IGP) of India accounts about 15.8% of the total geographical area and 37.4% of the population of the country and spreads across five states *i.e.* Punjab, Haryana, Delhi, Utter Pradesh, Bihar and West Bengal (Pal et al., 2009). In the Indian IGP, rice-wheat is the dominant cropping system, occupying about 10.3 mha (almost 53%) of total area under rice and wheat crops in India (Ladha et al., 2003). Rice-wheat monocropping system of the most fertile Indo-Gangetic Plains region of India is under stress due to depletion of native nutrient reserves, emergence of multi-nutrient deficiencies, and consequent decline in factor productivity of applied nutrients (Shukla et al., 2005). Trans and Upper IGP having fertile alluvial soils witnessed green revolution with improved high yielding seed, enormous fertilizer, weedicide and pesticide application.The repurcussions of drastic hike in productivity bounces back as soil salinity, poor water quality, stagnation in productivity and ultimately possess threat to food and livelihood security (Bhan and Behera, 2014 and Sapkota et al., 2015).

Understanding the farmer's perspective has traditionally been seen as critical to influencing the adoption and up-scaling of CA-based climate-resilient practices. The objective of this study was to investigate the biophysical, socioeconomic, and technical constraints in the adoption of CA by farmers in the Trans- and Lower-IGP.

1. Materials and methods

1.1 Location and climate of the study area

The study was conducted in Karnal district of Haryana (Trans-Gangetic Plains) and Samastipur district of Bihar (Eastern Gangetic Plains) based on agro-ecology, socio-economic, population density and cropping intensity. The climate of Karnal is semiarid, with average annual rainfall of 700 mm (75–80% of which is received during June–September), daily minimum temperature of 0–4 ˚C in January, daily maximum temperature of 41–44 ˚C in June, and relative humidity of 50–90% throughout the year. However, the climate of Samastipur is characterized by hot and humid summers and cold winters with an average rainfall of 1200 mm, 70 percent (941 mm) of which occurs during July-September. Frequent droughts and floods are common in this region.

1.2 Sampling procedure and data collection

The study was conducted in 6 (Sagga, Kutail, Unchsmana, Taraori, Baloo and Sambhali) and 7 (Srirampur Ayodhya, Kubauliram, Bishanpur Dimangra, Repura, Waini, Shahpur Baghauni and Chandauli) villages that practice CA technologies in Karnal and Samastipur were purposely chosen in this study. A total of 100 randomly selected farmers were interviewed from the 13 villages of the IGP. Structured questionnaire based survey and key informant interviews were mainly used for data collection. A structured questionnaire with both open ended and closed question was used to obtain quantitative data from the sampled respondents. The survey was used to collect demographic, CA adoption, agronomic practices, weed and pest control, irrigation, crop production and marketing, socio-economic, livelihood, livestock, soil health, and climate change factors from the sampled respondents. The questionnaire was pre-tested and corrections were made accordingly in one village in Karnal, and one village in Samastipur and adjustments were made before its final field observation. A multi-stage sampling technique was employed to get households from different villages. Key informants interviews were conducted to fill gaps from the questionnaire survey and verification of the results. The study involved a wide range of stakeholders from farmers, key village and district leaders and officials, and members of NGOs that operate in the study areas. Descriptive analyses were used to determine factors that influence the adoption. The questionnaire survey data was analysed using SPSS statistical package and MS Excel software.

2. Results

In this study we categoried farmers on the basis of acrage of total land holdings (small (<1), marginal (1-5), medium (>5-10) and large (>10)). Total land holdings among the farmers was much higher in Karnal (40 % large farmers) as compared to Samastipur (only 4 % large farmers). Majority of farmers in Samastipur (70 %) falls under marginal whereas in karnal only 22 % farmers was having less than 5 acres of land holdings (Figure 1a). Analysis of farmers response reveled that about 76.8 % and 32.5 % of total cultivated land was under CA in Karnal and Samastipur, respectively, till 2015 (Figure 1b).

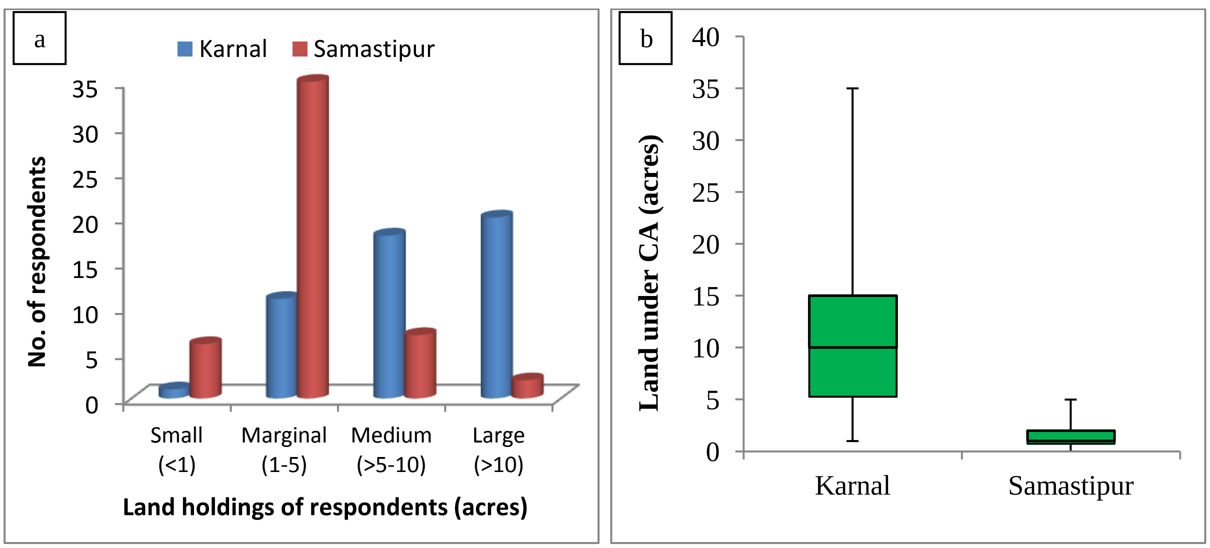

Figure 1. Land holdings and area allocation under CA in Karnal and Samastipur

Resource poor farmers with limited landholding sizes had allocated less land to CA because they are more vulnarable to risk averse in the wake of prioritizing food security concerns. Total land holding, duration of practicing CA, and district significantly influence farmers extent of CA adoption. Extent is measured by the amount of land allocated to CA relative to total cultivated land per household. Total land holdings was positive and significantly ($p<0.05$) correlated with land allocation for CA in both the study sites (r=0.912** in Karnal and r=0.667** in Samastipur) suggesting that the more available land in total, the more land is allocated to CA (Table 1). This study finds total land holding to be significant negatively influenced farmers decisions in extending their land to CA practices in Samastipur, suggesting that the more available land in total, the more land is allocated to CA. However, no such correlation was observed in Karnal. In case of Samastipur, the duration that farmers have practiced CA had a positive and significant ($p<0.01$) impact on land under CA. In contrast, there was no such findings for Karnal (Table 1).

Table 1. Correlation between Total land and land allocated for CA, Extent of CA and years of CA practices among the households of Karnal and Samastipur

Variables	'r' combinations	Calculated 'r' values	
		Karnal	Samastipur
Total land and land allocated for CA	(X_1Y_1)	0.912**	0.667**
Total land and Extent of CA	(X_1Y_2)	-0.189	-0.455**
Total land and years of CA practices	(X_1Y_3)	0.233	0.259
land allocated and years of CA practices	(X_2Y_3)	0.200	0.552**
Extent and years of CA practices	(X_3Y_3)	0.014	0.317*
Extent and land allocated for CA	(X_3Y_1)	0.076	0.306*

Significant at P < 0.01, *Significant at P < 0.05. **Notes: X_1 = Total land per household; X_2 = Land allocated for CA and X_3 = Extent of CA adoption, Y_1 = land allocated for CA; Y_2 = Extent of CA and Y_3 = years of CA practices.

Economic, technical and biophysical characteristics of the household directly or indirectly influence the adoption of different CA techniques. Major techniques adopted by farmers in Karnal was zero tillage (100 %), crop residue retention/incorporation (48 %), and crop diversification (44 %), whereas their counterparts in Samastipur mainly adopted crop diversification (100 %), minimum tillage (92 %) and permanent bed planting (60 %) as shown in Figure 2a. Results of adoption of CA techniques with corresponding crop is shown in Figure 2b. In Karnal wheat crop was planted across all the CA technologies, on average about 74.8 % of the households planted wheat, followed by pulses (47.8 %), rice (37.8 %) and maize (19.4 %). However, in Samastipur maize planted across all the CA technologies, on average about 43.6 % of the households planted maize, followed by wheat (41.4%), pulses rice (27.0 %) and rice (3.0 %).

CA is knowledge intensive and highly mechanised, hence availability of proper mechaniries and skill to handle those mechaneries played a crucial role in scaling up the CA adoption. Mechaneries availability were higher in Karnal as compared to Samastipur (Figure 3a). Dependency on others i.e renting for irrigation was 68.8 % higher in Samastipur than Karnal and hence they mostly suffer from yield penality and food security (Figure 3b).

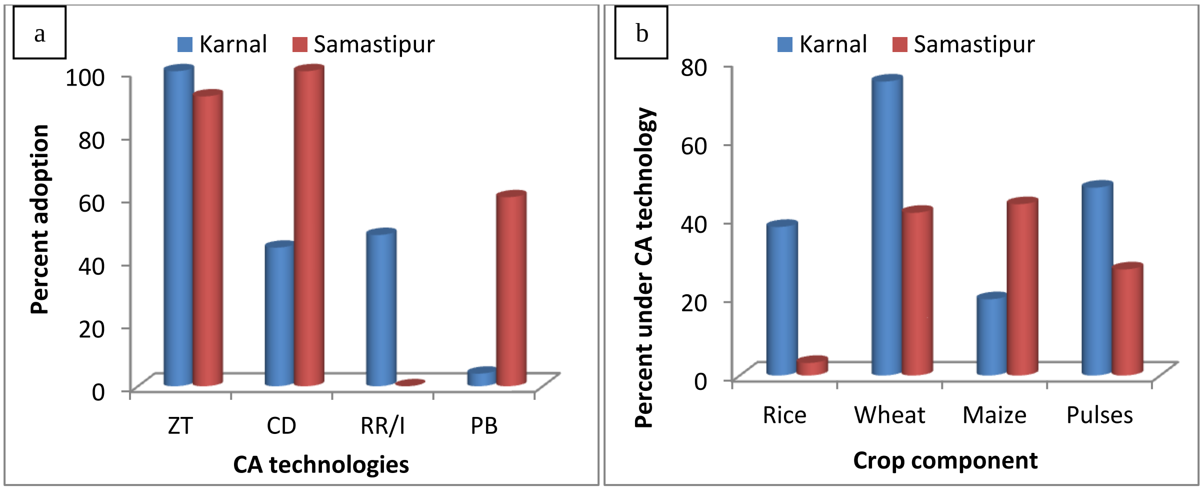

Figure 2. Farmers adoption of CA technologies and relative proportion of crop component at both the study area

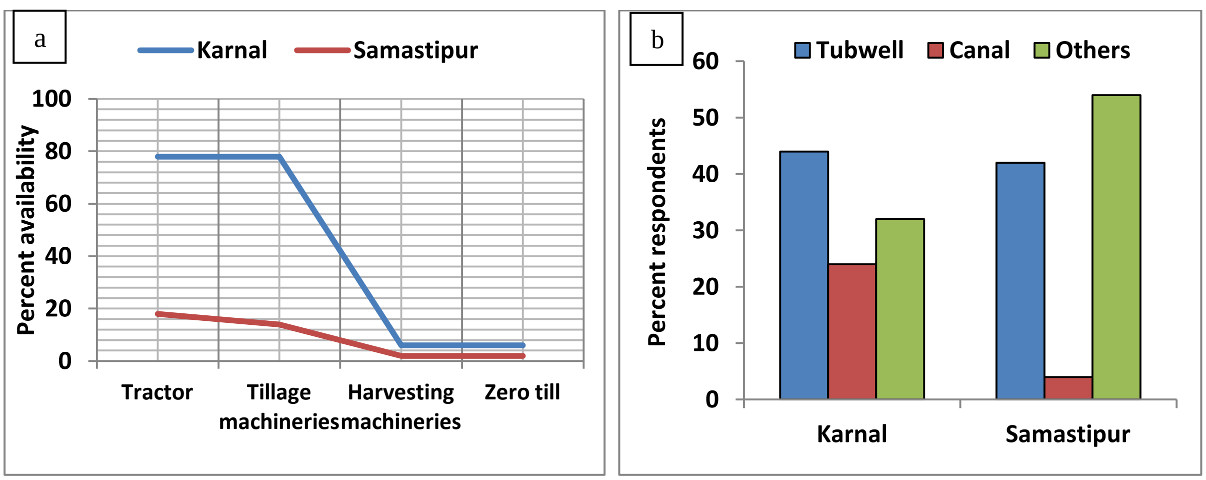

Figure 3. Mechanization and irrigation options available to the households in both the study area

3. Discussion

Indo-Gangetic plains of South Asia with 13.5 million ha of continuous rice-wheat (RW) intensive tillage cropping system has resulted in over exploitation of resources, a decline of productivity, loss of soil fertility and biodiversity, and a decline of resource use efficiency (Bhan and Behera, 2014). Adoption and scaling up of conservation agriculture require a paradigm shift from conventional agriculture in terms of bio-physical, socio-economic, agronomic intervention and soil-nutrient management (Jat et al., 2013), mechanisation (Kassam et al., 2014), mind set transformation (Sapkota et al., 2015), policy and institutional framework (Bhan and Behera, 2014 and Kassam et al., 2014) and extension of CA innovation from lab to land. Site specific CA management practices should be promoted for achieving long term sustainability with in the indiginous regime of the area. The problems for adoption of CA changes, however, from the intensive systems in the Northwest IGP to those in the Eastern IGP (Balasubramanian et al., 2012), which are characterized by smaller farms, land fragmentation, inadequate irrigation infrastructure, weaker institutions, including markets, and greater poverty (Laik et al., 2014). Total land holding and its allocation to CA governed by many factors, a case study in malwi showed that smallholders are less able to invest in new equipment and are more risk averse then large scale farmers (Ngwira et al., 2014). Similarly as shown in Figure 2b, smallholders in Samastipur affraid of failure of the new technology and averse of food security. Allocation of land in CA increased with the duration of practice with statistically significant correlation (r=0.552**) in Samastipur (Table 1) suggesting increased knowledge, skill and experiences gained on CA, might be the likelihood of allocating more land to CA, as farmers respond to yield gains, labor savings, and soil quality improvement (Ngwira et al., 2014). Results from Karnal and samastipur regions (Figure 2a) imply that more adoption of zero-tillage in IGP, as one of the components of CA, may be primarily due to lower cost of production and increased profit (Erenstein et al. 2012). Wheat (74.8 %) and maize (43.6 %) being the most adopted under major components of CA in Karnal and Samastipur, respectively (Figure 3b). This may be due to low cost and ease in field preparation when compared to conventional agriculture. Sapkota et al. (2015) reported 23 % reduction in average total cost of wheat production under zero tillage with and without residue retention as compared to conventional tillage system from participatory trials on 40 farmers' fields in Haryana for three consecutive years. Lack of proper equipment in Samastipur slowed the adoption of CA however, this can be overcomed by making farmers group in Karnal (Figure 3a). Availability, advancement and site specific modification in equipment and related skills/training are crucial for adoption and scaling up CA (Kassam et al., 2014 and Sapkota et al., 2015). The rapid increase in the number of tube wells during last four decades in north-western IGP has resulted in improved irrigation, however in Eastern IGP still irrigation is biggest challenge for sustaining agricutureand most of the area is rainfed (Figure 3b). Irrigation in Haryana was under Govt. subsidy, however there was no such scheme in Bihar that lead to slow CA adoption.

Conclusion

The findings of this survey revealed that 24 % farmers in Karnal and 82% in Samastipur belong to marginal and small (<5 acres). Karnal having 40 % large farms have more flexibility in decision making, more oppurtinity to test with new farming technologies, and more ability and willingness to deal with risk and survive crop failure due to pests and/or other natural disasters. Wheat (74.8 %) and maize (43.6 %) being the most adopted under major components of CA in Karnal and Samastipur, respectively. These crops being cost effective and ease in management and hence now increased drastically under CA. Adoption and scaling up of CA technologies should be targeted as per the biophysical, socio-economic, site specific agroecosystem management and encouraged for better networking as common participatory platform mode between the farmers, the local government officials and other stakeholders.

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Short-term green manure legume cover crops and maize rotation system effects on selected soil properties in a Rhodic Ferralsol

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Introduction

The use of green manure legumes cover crops (GMLCC) in rotation with cereal crops such as maize improves soil productivity through improvement of soil properties. This benefit is particularly critical on smallholder farms of most developing countries, which are characterized by moderate to severe soil degradation due to inappropriate soil management practices. The improvement in soil conditions as a result of build-up of organic matter through incorporation of legume green manure or crop residues is associated with a decreased bulk density, increased porosity, water stable aggregates and hydraulic conductivity of the soil (Ogbodo, 2010). Soil aggregation and aggregate dynamics are important in facilitating water infiltration (Franzluebbers 2002). The continued existence of macro pores in the soil that favour high infiltration rates and aeration depends on the stability of macro aggregates (Madari et al. 2005). Evaluation of chemical soil properties such as pH, electrical conductivity, organic carbon and total nitrogen contents are essential for assessing the effects of organic amendments on soil properties. These chemical aspects are important because they provide a measure of the ability of soil to supply nutrients and to buffer against chemical additives or amendments.

Despite the use of GMLCC to improve soil fertility being a well-known practice in the tropics and subtropics, it is apparently not very widespread among the smallholder farmers in Limpopo province of South Africa and there's limited information on the effect of GLMCC on soil properties in the region. Therefore, the objective of this study was to determine the effect of a two-year GMLCC-maize rotation system on soil aggregate stability, infiltration, pH, organic carbon, available phosphorus, and total nitrogen of highly weathered soils in semi-arid Limpopo province of South Africa.

1. Material and Methods

Site description

This study was conducted at Thohoyandou, approximately 22°35'14.0" S and 30°15'50.3" E, and 595 m asl, in Limpopo province of South Africa. The site is characterized by deep well-drained clay soil (Soil Classification Workgroup, 1991) with 62% clay, 27% silt, 11% sand and pH of 5.75. The annual rainfall is ~500 mm and falls in summer (October to April). The temperature ranges from 10°C during winter to 40°C during summer. Pre-sowing analysis of selected chemical properties of soil samples obtained from the trial site indicated 2.09% organic carbon, 0.052% total N, while available P (Bray-1) level was 3.49 mg kg^{-1}. The levels of exchangeable Na, K, Ca and Mg were 0.11, 0.31, 4.43 and 1.85 $cmol_c$ kg^{-1} soil, respectively.

Field experiment set-up

The rotation system consisted of three GMLCC, viz. mucuna (*Mucuna pruriens*), lablab (*Lablab purpureus*) and sunhemp (*Crotalaria juncea*), and a fallow plot, followed by maize (*Zea mays*) for two seasons (2007/8 and 2008/9 seasons). The three legumes were planted in December 2006 in plots measuring 5 m × 5 m. The treatments were arranged in a randomized complete block with three replications. In March 2007, cover crop growth was terminated by slashing the above-ground biomass and leaving it on the surface. In September 2007 (beginning of 2007/8 planting season), the plots were ploughed by hand-hoes to avoid mixing of the residues from different plots and maize was planted in all the plots. The experiment was repeated in 2008/9 season in the same plots using the same methodology except that the GMLCC were planted in April 2008, their growth terminated in August 2008 and maize planted in October 2008. At the end of the two seasons, the following soil properties were determined; soil aggregate stability, infiltration, pH, organic carbon, available phosphorus, and total nitrogen.

Determination of cumulative infiltration and aggregate stability

Cumulative infiltration was determined by the double ring infiltrometer method (Bouwer 1982). Aggregate stability was determined as described by Kemper and Rosenau (1986).

Soil analysis

At the end of the two-year rotation, one composite soil sample was collected from the 0-20 cm depth from each plot and analyzed for pH, organic C, available P, and total N. Soil pH was determined in water (1:2.5 soil: water ratio). Available phosphorus was determined using the Bray 1 method. Total N and organic C were determined by the Kjeldahl and Walkley-Black methods, respectively (Bremner and Mulvaney 1982; Nelson and Sommers 1982).

Statistical Analysis

Using randomized complete block design model, analysis of variance was conducted using the general linear model (GLM) procedure of SAS software version 9.4 (SAS Institute, Inc., 2013). The Least Significant Difference (LSD) test was used to separate statistically different treatment means.

2. Results

Aggregate stability and cumulative infiltration

There were no differences in water stable aggregates among the treatments at both 0-10 and 10-20 cm depths (Figure 1). The percent water stable aggregates ranged from 62% in fallow plots to 76% in sunhemp plots in the 0-10 cm depth. In the 10-20 cm depth, percent water stable aggregates ranged from 64% in fallow to 70% in lablab plots.

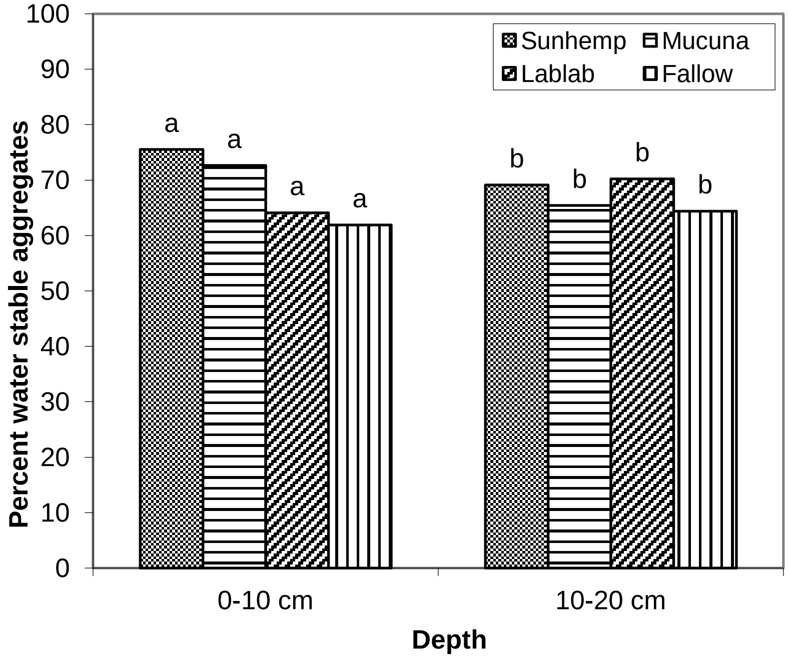

Figure 1. Percent water stable aggregates at 0-10 and 10-20 cm depths.

Cumulative infiltration (mm) after three (3) hours was 146, 178, 193 and 183 mm in the fallow control, lablab, mucuna, and sunhemp rotation plots, respectively (Figure 2). Lablab, mucuna and sunhemp rotation plots had 21.7, 31.6 and 25.3% greater cumulative infiltration, respectively, after three hours than the fallow control plot, with cumulative infiltration for the mucuna rotation plot being significantly ($p < 0.05$) higher than the fallow control.

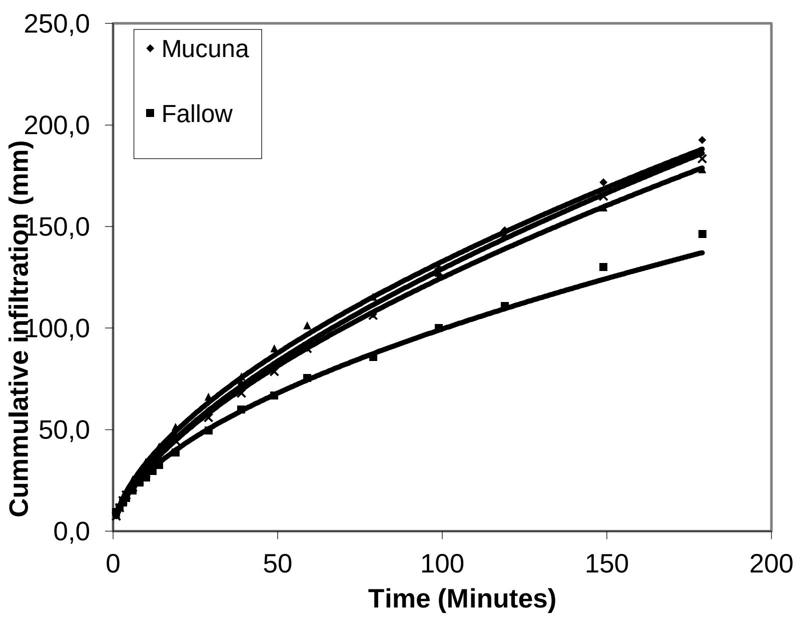

Figure 2. Cumulative water infiltration after 3 hours.

Soil pH, organic C, available P and total N

There were no significant differences ($p < 0.05$) in soil pH among the treatments (Table 1). Soil pH ranged from 6.02 in sunnhemp to 6.24 in lablab plots. Organic C content in the sunnhemp plot was 2.20% and significantly ($p < 0.05$) more than the fallow plot (1.88%) (Table1). There were no differences in plant available soil P content among the treatments (Table 1). Total N content in sunhemp rotation plots (0.07%) was significantly higher than in all other treatments (Table 1).

Table 1. Soil pH, organic carbon, available phosphorus and total nitrogen levels at the end of the two-year green manure legume -maize rotation system.

Rotation	pH	Organic C	Available P	Total N
		%	**mg kg^{-1}**	**%**
MUC-MZ-MUC-MZ	6.03a	2.14ab	1.68ab	0.058b
LL-MZ-LL-MZ	6.24a	2.08ab	1.65ab	0.057b
SH-MZ-SH-MZ	6.02a	2.20a	1.62ab	0.073a
FAL-MZ-FAL-MZ	6.08a	1.88b	2.12a	0.056bc

MZ = Maize; MUC = Mucuna; LL = Lablab; SH = Sunnhemp; FAL = Fallow

Means followed by the same letters are not significantly different at $p<0.05$.

3. Discussion

Aggregate stability and cumulative infiltration

Green manure legumes improve soil properties such as aggregate stability and infiltration rate. However, the results of this study indicated no differences in aggregate stability among treatments at 0-10 and 10-20 cm depths after a 2-yr green manure cover crop-maize rotation. There are contradicting reports on the short-term effect of crop rotation involving cover crops on structural stability. Mupambwa and Wakindiki (2012) noted a significant increase in aggregate stability only under monoculture but not biculture cover crops based on the mean weight diameter (MWD) in a hardsetting soil in Eastern Cape Province, South Africa. Other researchers (Mbah et al. 2007, Bhattacharyya et al. 2012) reported that cover crops improved aggregate stability by contributing organic matter, which in turn contain active soil-binding agents (Liu et al. 2005, Mbah et al 2007, So et al. 2009). Castro Filho et al. (2002) observed no effect of crop rotations on aggregate stability indices in a latosol (Rhodic Ferralsol) from southern Brazil. These inconsistent results suggest confounding influences possibly because of specific soil and/or environmental characteristics.

Green manure rotation plots had greater cumulative infiltration than the fallow plot. Given that the infiltration process is greatly affected by pore clogging (Baumhardt and Jones 2002, Verhulst et al. 2010), it was plausible to attribute infiltration results (Figure 2) to the nature of the root system and ability of the cover crops to add soil organic carbon and lower soil strength (Mupambwa and Wakindiki, 2012). The fact that the mucuna rotation plots had significant cumulative infiltration rate than the fallow control indicate that possibly it produced much more dense root mass than the other green manure legume crops and thus leaving intact channels after decomposition. The results of the present study agree with those of Roldan et al. (2003) and Astier et al. (2006) who observed higher infiltration rates under different green manure legume cover crop residues compared to a weedy control.

Soil pH, organic C, available P and total N

The results of this study showed no differences in pH between the treatments. Contradicting reports on the effect of green manure on soil pH have been reported. While Astier et al. (2006) noted that green manure addition decreased soil pH, Kiiya et al. (2010) reported that incorporation of legumes significantly raised soil pH in the second and third seasons of the field experiment. Malero et al. (2007) reported that organic amendments have only a little effect on soil pH values which reflects the importance of the variations in quality or initial chemical composition of the decomposing material.

Soil organic matter, nitrogen and available P are major determinants of productivity and sustainability of agricultural production systems (Kifuko et al. 2007). The significantly higher organic C content under sunhemp implies that it has the potential to improve soil organic C content within a shorter period of time compared to the other two legumes, mucuna and lablab.

The incorporation of crop residues may increase plant available soil P either directly by the presence of decomposition and release of P from biomass or indirectly by increase in amount of soluble organic matter which are mainly organic acids that increase the rate of desorption of phosphate and, thus, improve the available P content in the soil (Nziguheba et al. 1998). This increase in plant available P may however not be immediate following green manure incorporation since microbial biomass and soil sorption processes compete for available P. In this study, the lack of differences in plant available soil P between the fallow and green manure legume treatment plots may be attributed to P fixation due to the highly weathered nature and high P fixation capacity of the soil. Other researchers (Sharma et al., 2001; Singh and Sharma, 2000) found slight or no increase in plant available soil P in the soils treated with rice or wheat straw residues. The lower available P under the green manure treatments compared with the control treatment could be attributed to the utilization of residual P by green manure legumes in the rotation.

The significantly higher amount of total N in sunnhemp plots could be attributed to the higher sunnhemp biomass produced in both seasons which were also associated with a high tissue total N content as reported by Odhiambo et al. (2010) in a related study on the effect of green manure legume – maize rotation on maize yield and weed infestation. The high sunnhemp biomass and, therefore, possibly more extensive root system may have contributed to increased N levels as compared with the other green manure legumes.

Conclusions

In conclusion, the use of GMLCC in rotation with maize significantly improved infiltration rate. Use of sunnhemp in the rotation system led to higher total N content and soil organic carbon, indicating that it may be the most suitable green manure legume for this region. This study therefore demonstrates the potential of green manure legumes, particularly sunhemp, to improve soil properties when used in rotation with maize in these highly weathered soils.

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Soil biogenity and productivity of strawberry as affected by different fertiliser type

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Introduction

Strawberry (Fragaria × ananassa Duch.) production is on a constant increase, primarily due to increased consumption of the fruit and its high profitability. Fertilization is one of the most important cultural practices used in modern strawberry production. Intensive farming practices that result in high yield and quality also require extensive use of chemical fertilisers, which are costly and create environmental problems. An extensive body of research shows that the continuous use of mineral fertilisers leads to environmental contamination, with more than 50% of applied mineral fertilisers remaining unabsorbed, resulting in loss of minerals, and thus posing a serious threat to the environment (Bockman et al. 1990). Therefore, proper use and partial or complete substitution of mineral fertilisers with microbial inoculants i.e. biofertilisers can help overcome environmental problems caused by the overuse of mineral fertilisers.

1. Material and methods

1. 1. Plant material

The open field trial was conducted at the experimental plantation of the Fruit Research Institute, Cacak (Republic of Serbia, 43º53' N latitude, 20º20' E longitude, 225 m above sea level). Soil physical–chemical analysis was performed prior to trial establishment. The content of macro-nutrients in soil was determined according to standard laboratory protocols and methods. Trial was conducted on alluvial soil with sandy-loam texture (51.9% sand and 48.1% loam), pH_{KCl}– 5.48, humus –3.95%, N_{TOT} – 0.20%, easily-accessible potassium – 27.00 mg g^{-1}; easily-accessible phosphorus – 22.95 mg g^{-1}). The field was planted in July 2011 in double rows on beds covered with black polyethylene foil. Certified frigo plants (A^+ class) of the three newly introduced short day strawberry cultivars ‘Clery’, ‘Joly’ and ‘Dely’ (Consorzio Italiano Vivaisti, Ferrara, Italy) were planted. Planting distance was 30 x 30 cm.

1. 2. Experimental design

The layout of the experiment was a completely randomized design. The experiment was conducted in 2011–2013, including 4 treatments: MF – mineral fertilisers with different formulation ratios; B1 – biofertiliser 1 (microbial fertiliser consisting of a combination of bacteria of the genera *Azotobacter*, *Azospirillum*, *Bacillus* and *Pseudomonas*); B2 – biofertiliser 2 (an inoculum obtained from the liquid culture of diazotrophic bacteria *Klebsiella planticola TSHA-91*); C – control, irrigation without fertilisation with 20 plants in each treatment in 3 replications. Mineral fertilisers were applied according to the phenological stage of the plant, as follows: immediately after planting, starter fertiliser *NPK Poly-Feed Drip* 11-44-11 with micronutrients at a rate of 1 g per plant; during intensive plant growth and flower bud emergence, 2 applications of *NPK Poly-Feed Drip* 20-20-20 with micronutrients at a 7-day interval, at a rate of 1.5 g per plant; during flowering, fruit set, growth and ripening, 5 applications of the complex mineral fertiliser *NPK Poly-Feed Drip* 16-8-32+2*MgO* at 10-day intervals at a rate of 1 g per plant; during intensive fruit growth and ripening, in addition to the former formulation, 2 applications of *Multi-Cal* (15.5% *N* and 26.5% *CaO*) and *Multi-KMg* (12% *N*; 43% *K* and 2% *MgO*) at a 10-day interval, at a rate of 1.5 *g* per plant. Microbiological fertilization involved soaking strawberry roots in the liquid inoculum at planting, followed by fertigation with 10-12 l ha^{-1} of the inoculum 3 times per month during the growing season in each experimental year. The bacterial titer in the inoculum was 20–40 x 10^6 cm^{-3}. The control involved irrigation without fertilisation.

1. 3. Generative potential and productivity of strawberry

The generative potential of the strawberry plants was determined by establishing the number of fruiting stalks, flowers and fruits set the per plant and fruits set per fruiting stalk. Fruiting stalks, flowers and fruits set were counted at each plant. Yield per plant and yield per square meter were obtained by collecting and weighing fruit (g/plant; kg/m^2) during the harvesting seasons (2012–2013).

1. 4. Soil biogenity

The microbiological analysis included determination of the total microbial count, numbers of fungi, ammonifiers, actinomycetes, azotobacter and oligonitrophils, using an indirect method of dilutions on appropriate nutrient media (*Pochon* & *Tardieux*, 1962). Analyses of the counts of different systematic and physiological groups of soil microorganisms were conducted in all three experimental years (2011–2013).

2. Results

2. 1. The generative potential and yield of strawberry

Table 1. The influence of fertiliser type on the generative potential of strawberry

FACTOR		Number of fruiting stalks per plant		Number of flowers per plant		Number of fruits set per fruiting stalks		Number of fruits set per plant	
		2012	2013	2012	2013	2012	2013	2012	2013
FERTILISER	MF	4,5 ± 0,4 a	8,2 ± 0,3 a	29,3 ± 2,2 a	60,3 ± 4,5 a	6,6 ± 0,5 a	7,6 ± 0,6 a	25,9 ± 2,7 a	51,7 ± 4.1 a
	B1	4.1 ± 0.5 a	7.8 ± 0.4 ab	25.6 ± 1.3 b	52.1± 4.9 ab	5.6 ± 0.5 b	8.3 ± 0.8 a	22.0 ± 1.3 bc	51.2 ± 3.6 a
	B2	4.3 ± 0.4 a	7.4 ± 0.5 b	26.9 ± 1.3 ab	47.0 ± 2.7 b	5.5 ± 0.5 bc	8.6 ± 0.6 a	24.1 ± 1.5 ab	45.3 ± 2.2 b
	C	4.0 ± 0.5 a	5.8 ± 0.5 c	24.3 ± 1.4 b	35.0 ± 3.2 c	5.1 ± 0.4 c	9.3 ± 0.8 a	18.6 ± 1.6 c	33.6 ± 2.7 c

MF – mineral fertilisers, B1 – biofertiliser 1, B2 – biofertiliser 2, C – control. The different small letter(s) in column indicate significant differences among means within each fertiliser at $P \leq 0.05$ by LSD test.

Table 2. The influence of fertiliser type on the yield of strawberry

FACTOR		Yield per plant (g)		Yield per m^2 (kg)	
		2012	2013	2012	2013
FERTILISER	MF	715,0 ± 78,6 a	868,7 ± 66,1 a	5,7 ± 0,6 a	6,9 ± 0,5 a
	B1	555,2 ± 63,5 b	867,5 ± 52,1 a	4,4 ± 0,5 b	6,9 ± 0,4 a
	B2	570,5 ± 80,1 b	739,4 ± 28,5 b	4,5 ± 0,6 b	5,9 ± 0,3 b
	C	453,8 ± 88,5 b	517,0 ± 24,3 c	4,0 ± 0,7 b	4,9 ± 0,2 c

MF – mineral fertilisers, B1 – biofertiliser 1, B2 – biofertiliser 2, C – control. The different small letter(s) in column indicate significant differences among means within each fertiliser at $P \leq 0.05$ by LSD test.

2.2. The counts of different systematic and physiological groups of soil microorganisms

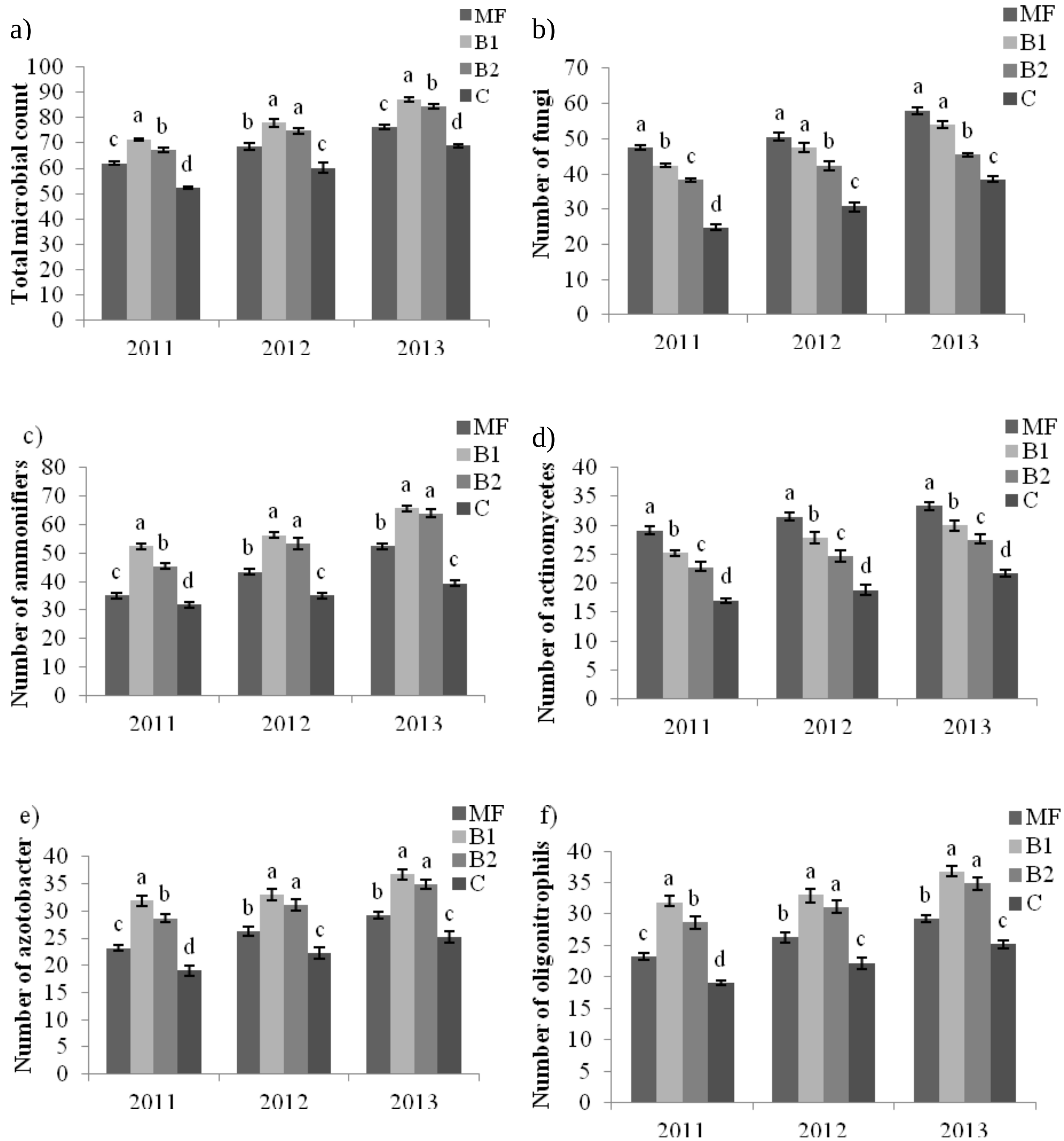

Figure 1. Influence of different fertiliser applications on total microbial count (a), number of fungi (b), ammonifiers (c), actionomycetes (d), azotobacter (e) and oligonitrophils (f); MF – mineral fertilisers, B1 – biofertiliser 1, B2 – biofertiliser 2, C – control.

3. Discussion

3. 1. The generative potential and yield of strawberry

Generative development of strawberry is genetically controlled and determined by environmental factors (*Battey et al*., 1998). In addition to the length of the day and temperature, differentitation of the flower buds in strawberry was also influenced by other factors including humidity, adequate nutrition, as well as large and healthy leaf surface (*Galletta & Bringhurst*, 1990). Higher generative potential and better production traits of the tested cultivars were obtained in the second year of fruiting. In 2012, the generative potential and fruit yield increased after mineral fertilization, whereas in 2013 these parameters were positively affected not only by mineral fertiliser, but also by biofertiliser 1.

3. 2. The counts of different systematic and physiological groups of soil microorganisms

Hole et al. (2005) state that change in the number of individual systematic and physiological groups of microorganisms in the soil, as well as their activity, may be used as indicators of thee soil's potential and actual productive capacity. There are obvious differences in the presence of certain groups of microorganisms in the soil in the respective years of study. Namely, the smallest number of all of the studied groups of microorganisms including the total number, was observed in the first year of the experiment. However, it is important to point that with every new year of the experiment there was a gradual increase – both within values of individual groups of microorganisms and overall presence of microorganisms in the soil – reaching their peak in 2013. The lower numbers of microorganisms in the first year of the experiment can be attributed to the fact that following the introduction of biofertilisers in the soil, the microorganisms contained in the biofertilsier require a certain time to adapt and establish their dominance. According to *Higa* & *Parr* (1994), after introducing inoculants in the soil, there is a possibility of their impact on indigenous microorganisms and vice versa, wherein the type of the impact depends on the interactions that exist within and among the indigenous populations, as well as on the type of the plant and soil.

The positive effect of biofertiliser 1 on total microbial count and numbers of azotobacter, ammonifiers and oligonitrophils was observed in all three experimental years. In the second and third year of stud, the frequent application of high-density inoculants (biofertilisers 1 and 2), secured a higher probabilitly of their successful establishment, which was reflected in both the total microbial count and the numbers of azotobacter, ammonifiers and oligonitrophils in the soil of the experimental plantation. The increased biological activity of the soil may be a consequence of the marked azotofixan capacity of the bacteria strains present in the applied biofertilsiers, as well as of the cumulative action of multiple effects such as inhibition of phytopathogenic development and phytohormones synthesis (*Sukhovitskaja et al*., 2004), detoxication of heavy metals and synthesis of exocellular polysaccharides (*Park et al*., 2005; *Biari et al.*, 2008). However, the use of microbe inoculants did not contribute to an increase in the counts of fungi and acytnomyces in this study, as opposed to the use of mineral fertiliser, which contributed to the highest counts of these microorganisms in the soil of the experimental plantation in all three years of the study. The results of this study are in accordance with the results obtained by *Đukić* (1991 a,b), *Barabasz et al*. (2002) and *Pešaković* (2007) stating that implementation of mineral fertiliser leads to an increase primarily in the numbers of actinmyces and numbers of fungi in the soil.

Conclusion

- In 2012, the generative potential and fruit yield increased after mineral fertilization, whereas in 2013 these parameters were positively affected not only by mineral fertiliser, but also by biofertiliser 1.
- The positive effect of biofertiliser 1 on total microbial count and numbers of azotobacter, ammonifiers and oligonitrophils was observed in all three experimental years, while in 2012 and 2013 the positive effect was also exerted by biofertiliser 2.
- The use of microbiological fertilisers as supplements to mineral fertilisers or even their substitutes can be considered an appropriate practice to ensure safe strawberry fruit production and enhance soil biological activity, which has an indirect positive effect on the production characteristics of the tested strawberry cultivars.

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Soil erosion and conservation agricultural systems research in South African smallholder farms

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Abstract

There has been a flurry of scientific and developmental projects on conservation agriculture (CA) targeting smallholder farms in sub-Saharan Africa. However, much of the research over-emphasizes crop yield and economic benefits and focuses less on the gains in soil health and productivity. Livestock systems, which are an integral part of smallholder farming in Africa are often ignored. Meanwhile, soil erosion contributes to about 84% of land degradation mainly due to overgrazing. In South Africa alone, 12.6 tons of fertile topsoil is lost annually from each cultivated hectare, which is twice the world average. The current review shows that soil erosion is often not the target objective and livestock systems are viewed as inhibitors of CA. Soil erosion projects in South Africa continue to follow a dichotomous approach: mapping and zoning of degraded areas, and to a lesser extent studying the underlying mechanisms and processes. The review concludes that soil erosion research should be a preferred objective in future CA projects so as to increase soil health and productivity in South African smallholder farms. Secondly, livestock systems should be part of CA.

Introduction

Soil erosion is the most severe form of soil degradation (FEW Resources, 2016). According to the FAO (2008), about 50 tons per hectare of topsoil is lost annually in sub-Saharan Africa, which is almost ten times higher than the global average (Wilkinson and McElroy, 2007). The smallholder farming sector is particularly vulnerable to soil erosion because of an array of challenges such as limited access to improved farm inputs and production technology (Lal, 1998). Technologies such as conservation agriculture (CA) have been prescribed as a possible practical solution for resource-poor smallholder farmers in sub-Saharan Africa (FAO, 2008). Consequently, there has been a flurry of scientific and developmental projects on CA in the region (Rusinamhodzi et al., 2011). Regrettably, adoption of CA by smallholder farmers in sub-Saharan Africa is poor, despite more than two decades of research having been conducted (Corbeels et al., 2014a). On-farm experimental results obtained so far are inconclusive (Giller et al., 2009; Esser, 2016). Nonetheless, CA is being aggressively promoted by international research and development organizations to the extent of stifling debate (Giller et al., 2009; Esser, 2016). This review aims to examine to what extent CA has been applied to control soil erosion in South African smallholder farms.

1. The nature and extent of soil erosion in South African smallholder farms

Soil erosion is the most important form of soil degradation (Figure 1).

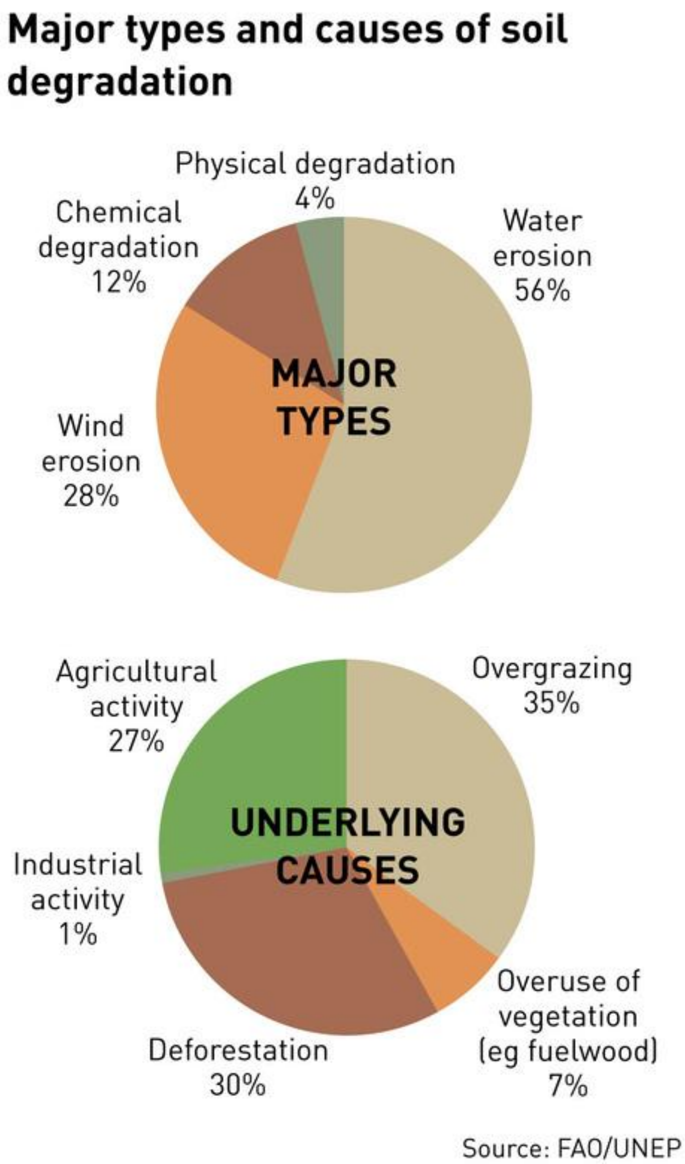

Figure 1. Major types and causes of soil degradation (source: FEW Resources, 2016)

South African smallholder farmers are concentrated in areas of land with inherently low productivity, with little or no infrastructural support. Years of over-exploitation and the inherently poor soils have led to massive soil erosion. Consequently, South Africa loses 12 t ha^{-1} of soil each year (Le Roux et al., 2007). Much of the reported soil loss is due to water on pastureland and less on wind erosion.

2. Control and management of soil erosion in South Africa

The earliest intervention to control soil erosion was the contour or bench terracing, a labour intensive method prescribed and enforced by the colonial government. Unfortunately, these structures failed because the smallholder African farmers detested them (Dreyer, 1997). In other instances, no proper soil investigation was done so the soil structure collapsed when excess water infiltrated (Laker, 2004). Cooper (1996) also castigated the soil conservation policy. Recently, a promising in-field rainwater harvesting technique was introduced (Vohland and Barry, 2009). This technique involves localized generation of runoff, which is collected in mulched, no-tilled infiltration ditches for crop production.

3. Soil erosion research in South Africa

Soil erosion studies were not common in South Africa until the late 1970s (Mulibana, 2001; Laker, 2004; Nciizah and Wakindiki, 2015). Most soil erosion work involved in situ studies on long-term runoff plots using either natural or simulated rainfall. Early investigations also extended to cover sediment yield in rivers and examination of aerial photographs (Laker, 2004; Garland et al., 2000). Nciizah and Wakindiki (2015) summarized the findings of major soil erosion research work from South Africa in Table 1.

Table 1. Soil erosion studies in South Africa

Author/date	Location	Description	Key findings
Talbot (1947)	Swartland/Sandveld, Western Cape	Air photo analysis of extent and type of erosion	Poor farming practices had resulted in wind and water erosion
Scott (1951)	KwaZulu-Natal Drakensberg	Soil loss measurements from runoff plots	Average soil loss values for grazed land established
Menne and Kriel (1959)	Pretoria	Measurements of erosion from runoff plots	Effect of slope on erosion is modified by land-use
Haylett (1960)	Pretoria	Long-term erosion from runoff plots	Average soil loss values for veld and graze/burn combinations established
Marker and Evers (1976)	Mpumalanga	Geomorphological/ archaeological	Iron age land-use had promoted soil erosion
Murgatroyd (1979)	Tugela catchment	Topographic and volumetric analysis of rates of erosion through geological time	Current rates of erosion are 28 times the long-term geological norm
Rooseboom (1976)	Orange River	Measurement of sediment accumulation in dams over 40 years	Sediment yield of Orange River is decreasing
Schulze (1979)	KwaZulu-Natal Drakensberg	SLEMSA used in modelling soil loss	SLEMSA gave reasonably good results but overestimated soil loss in some situations
Snyman and Van Rensburg (1986)	Free State	USLE applied to natural veld area under simulated rainfall conditions	No difference obtained between measured and predicted results
Rowntree (1988)	Karoo	Review of erosion	Erosion itself may not represent degradation, as the cycle of erosion and deposition are part of the dynamic equilibrium of landscape
Meadows and Asnal (1996)	Western Cape	Sedimentological/ geochemical study	Sedimentary analysis shows that land degradation was human induced at Verlorenvlei
Pile (1996)	KwaZulu-Natal Comfields	Interview/questionnaire survey with poor rural community	Some community awareness of soil erosion in community; erosion ranked quite low in importance compared with other community problems
Pretorius (1998)	South Africa	Development of predicted water erosion map	Mapped erosion by integrating the main erosion contributing factors of the USLE in a geographical information system (GIS), the sediment yield map and green vegetation cover map to account for rainfall, soil-slope and vegetation factors
Wessels et al. (2001)	Mpumalanga and Gauteng	Natural resource auditing	Mapped erosion by application of RUSLE in a GIS
Strohmenger et al. (2004)	Eastern Cape and KwaZulu-Natal	Integrated Sustainable Development Strategy nodes	Mapped erosion by application of RUSLE in a GIS

(Source: Nciizah and Wakindiki, 2015)

4. Soil erosion research in African smallholder farms involving CA

CA research in smallholder farms in sub-Saharan Africa started in the 1980s (Corbeels et al., 2015). CA has increasingly gained recognition in the region but its full-scale adoption by smallholder farmers is hindered by several problems such as inadequate knowledge and skills, competing uses for crop residues, affordability and accessibility of equipment and inputs (FAO, 2010). Despite these challenges, significant work has been done as evidenced by the number of review papers (Wall et al., 2013). However, most of the reviewed articles focused more on crop response and less on soil erosion control. For instance, Rusinamhodzi et al. (2011) carried a meta-analysis of long-term effects of CA on maize grain yield under rain-fed conditions in southern Africa. Corbeels et al. (2014a) reviewed ten projects but none focused on soil erosion control. Corbeels et al. (2014b) carried out yet another meta-analysis of crop responses to CA, whilst Wall et al. (2013) highlighted the effect of CA practices on maize yields in eastern and southern Africa. In all these studies the focus was on ascertaining the benefits of CA with regard to crop yield. Dube et al. (2013) studied CA effects on plant nutrients and maize grain yield after four years of maize-winter cover crop rotations.

There are a few published reports on CA research aimed at reducing soil erosion in South Africa. For instance, Mupangwa and Hewitt (2011) simulated the impact of no-till systems on field water fluxes and maize productivity under semi-arid conditions and observed significantly higher surface runoff from the conventional system compared to the no-till system. This observation suggested the potential of no-till systems for reducing surface runoff from smallholder fields. A similar study by Kosgei et al. (2007) on the influence of tillage on field scale water fluxes and maize yields in semi-arid environments also showed nearly twice as much runoff from conventional tillage when compared to no-till plots. Meanwhile, Mchunu et al. (2011) carried out a study on the effects of no-till on soil erosion and soil organic carbon under crop residue scarcity conditions. They observed 68% and 52% less soil and SOC losses, respectively, under no-till compared to conventional tillage. However, Mzezewa and van Rensburg (2011) studied tillage from a different perspective. They sought to understand rainfall-runoff processes under two tillage practices, no-till and conventional tillage, with regard to the potential of in-field rainwater harvesting. The rainwater harvesting production technique outperformed the conventional system in harnessing runoff. The system also had the potential of reducing soil loss.

Conclusions

Soil erosion research in South Africa is monotonically about mapping and zoning of affected areas, with few studies focusing on the underlying mechanisms and processes. Equally, many studies that are said to be investigating CA only address some aspect of it such as tillage, crop mix and/or retention of biomass. Comprehensive on-farm CA trials are scant because of the complexity of smallholders. It is necessary that future CA trials focusing on smallholder farmers should consider livestock systems because most soil erosion is caused by overgrazing.

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