Early evidence of improved soil quality with conservation farming under smallholder farming conditions in Zimbabwe

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Abstract
Conservation agriculture (CA) has proven to be a successful strategy to conserve soil and water through minimum or zero tillage, permanent soil cover, and crop rotations. This paper presents results of a study investigating possible changes in soil physical and chemical properties under conservation farming (CF), an adapted form of CA that is appropriate for Zimbabwe's smallholder farming systems. CF is a package of 8 components the planting basin being the central component, which is a small hole/pit, dug in an unplowed field, where seed is planted.
Soil samples were collected from 37 households in 8 districts around Zimbabwe, encompassing both high (>800 mm year^{-1}) and low rainfall regions (as low as 400 mm year^{-1}) on CF plots and conventionally managed plots, termed farmer practice (FP). Physical parameters that were determined included bulk density, water retention, and infiltration. Chemical parameters that were determined included total N, total P, pH, and soil organic carbon (SOC). Besides the soil quality measurements, maize grain yield was determined on both CF and FP plots.
Bulk density in the top 15 cm of the soil profile was 6% lower in basins than in FP soil the difference being significant. Soil water retention in the top 20 cm of the soil profile was higher in basins than in FP plots. Infiltration rate was 48% higher in basins than in FP plots and 87% higher than in areas between basins and increased with number of years that farmers had practiced CF. The chemical properties showed less changes except for soil pH in the top 20 cm that was significantly higher in basins than in FP plots. For most soil physical and chemical parameters there was no significant difference between the FP soil and soil between basins, showing that mulching had not yet improved soil quality significantly and short term yield benefits of CF were obtained by spot application of organic and inorganic fertilisers. Maize yields in CF plots were doubled compared to FP plots for the 2006/07 season and the difference was consistent across different natural regions.

Introduction
The distinguishing features of conservation agriculture (CA) are minimum or zero tillage, crop rotation, and permanent soil cover. Through the conservation of soil and water, CA is often seen as a more sustainable cultivation system than conventional tillage systems (Hobbs, 2007). CA has spread to both temperate and tropical regions and both large and small scale farming systems but mostly to more mechanized farming systems provided that farmers are convinced by the benefits of CA (Hobbs, 2007). The spread of CA in Brazil, currently the country with the largest acreage under CA, was

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partly driven by availability of cheap herbicides (Bolliger et al 2006). Spread of CA in the Indo-Gangetic plains in India was driven by availability of new farm equipment such as seed drills (Hobbs, 2007). Gowing and Palmer (2007) argue that CA is the desired approach to raise productivity in sub-Saharan African rainfed agriculture. However, to data little research work has been done on CA in sub-Saharan Africa.

Conservation farming (CF) is a modification of CA and uses hand hoes. CF has evolved in southern Africa for smallholder households that have limited or no access to draught power. Frequently these households plant late and harvest low yields. For the past several years, non-governmental organizations (NGOs) and research institutions such as the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) have been promoting CF in different areas in Zimbabwe as part of 'protracted' relief assistance. The aim of the CF promotion was to enable farmers to plant timely thereby raising household food security.

CF is a package and consists of 8 components. The central component of CF is the planting station, a small hole or pit that can be prepared with a hand hoe at the end of the dry season. This planting basin is a modification of the traditional pit systems once common in southern Africa, and is a variation on the *Zai* Pit system from West Africa. The planting station is around 15 × 15 × 15 cm and facilitates the precision application of manure or mineral basal and topdress fertiliser. CF further entails timely weeding during and after the growing season, crop rotation, and mulching of crop residues.

Many claims on improved soil quality with CA have been made, such as improved sequestration of organic carbon (Corbeels et al, 2006; Chivenge et al, 2007), improved infiltration (Fabrizzi et al 2005) and soil water storage, reduced run-off and erosion (Findeling et al 2003; Rao et al 1998), and improved soil fertility (Hobbs and Gupta, 2004). These improvements in resource use efficiency might offer the much needed improvement in crop water productivities in many of the worlds rainfed areas (Rockström and Barron, 2007). The first Millennium Development Goal agreed on by the United Nations speaks of reducing and finally eradicating absolute poverty and the 7th goal is to ensure environmental sustainability. CA and CF may play their role in addressing both goals.

CA in southern Africa has sofar been practiced in Zambia. Most research on CA took place in ecosystems that are much wetter than can be found in Zimbabwe. Positive changes on soil physical and chemical properties might occur only after several years of practicing CA (Bolliger et al, 2006). It is therefore important to know if any changes in key soil physical and chemical properties change rapidly because. Moreover, if the effect on crop yield is slow, CF package has less likelhood to be adopted by smallholder farmers who are keen to see quick returns. We used the concept of soil quality, which is defined as a measureable soil property that influences the capacity of a soil to perform a specified function (Acton and Padbury, 1993).

This study report on the effect of CF on several soil quality parameters and yield. The study also investigated the rate of change of these soil quality parameters.

Materials and methods

Soil quality is a much debated issue but in this paper refers to a set of soil physical and chemical properties such as infiltration rate, soil organic carbon (SOC), water retention, bulk density, pH, total nitrogen (N) and total phosphorus (P). These properties were determined from 37 farmers in 8 districts across Zimbabwe (see Table 1 for more details) who practiced CF but who also had a plot where they practiced conventional land management termed the farmer practice (FP). In each district a farmer was selected who practiced CF for 1, 2 or 3 years and in some districts like Masvingo, Nyanga and Nkayi two different wards were chosen with farmers practicing CF for 1-3 years. In Bindura farmers have been practicing CF up to 8 years and to capture possible changes, farmers with 2, 3, 4, 6, 7 and 8 years of continuous CF practice were sampled. Where possible, farmers were chosen in close proximity to each other to avoid differences in soil type within a ward. Statistical analysis included pair-wise comparison using the t-test, because of unbalanced number of observations for treatments and years.

{Table 1}

Soil samples were taken and infiltration measurements done in April and May 2007 just before or just after harvest of the maize crop. Since the central component of the CF package is the planting basin, all measurements were performed in the basin and area between the basins. Soil samples from FP plots were not subdivided as farmers usually do not concentrate resources around planting stations but spread them across the field.

Soil physical properties
Infiltration was determined non-destructively by inserting a steel core in the soil and adding 100 ml of water. The time to complete infiltration was recorded and subsequently converted to infiltration rate in mm per minute.
To determine soil bulk density, volumetric samples were collected at 0-5, 5-10, 10-15, 15-20, 20-30, and 30-40 cm depth using steel cores with a known internal volume of 100 cm^3 for the 5 cm depth intervals (length of core 5.0 cm) and around 170 cm^3 for the 10 cm depth intervals (length of core 10.0 cm). Samples were stored in plastic bags and taken to the laboratory for determining fresh and oven-dry (24 hours at 105°C) weights.
Water retention was determined on undisturbed soil samples, which were collected from a subset of 8 farmers located in Bindura (4) Masvingo (3) and Chivi (1). These samples were taken from 0-5, 5-10, 10-15, and 15-20 cm depth and remained undisturbed in metal cores until measurements were conducted in the laboratory. Water retention was determined using the hanging column method. Each sample was saturated and then exposed to -10, -25, -50, and -100 cm water pressure. The water released between the levels of water pressure was measured in a burette.

Soil chemical properties
For the chemical properties, samples were taken at 0-20 and 20-40 cm depth using a post-hole auger. Samples were taken from three positions across the CF or FP plot, were thoroughly mixed on a tray and then subsampled prior to laboratory analysis. For several soils it was impossible to move the auger beyond 20 cm depth and in these cases bulk density samples were used to

determine the chemical properties for the 20-40 cm sample. The chemical properties were: pH in H_2O (2.5 : 1) according to Rhoades (1982), soil organic carbon determined with the Walkley-Black method as described by Nelson and Sommers (1975), total nitrogen (N) and total phosphorus (P) as described by Anderson and Ingram (1989).

Yield

Yield was determined at the end of the 2006/'07 growing season from 50 x 20 m plots within CF and FP plots. Yield data were collected from 13 out of 37 farmers where soil samples were collected and an additional 56 farmers who were practicing CF and were interviewed for a comprehensive study on CF (Mazvimavi et al, 2007). The yield was calculated based on the number of bags that could be filled with maize cobs. Based on previous measurements, a 50 kg bag of maize cobs contains 24 kg of grain. Rainfall during the season was below average especially in Natural Regions III-V.

Results and Discussion

Soil physical properties

Bulk density and water retention

There was a significant (P=0.05) 6% reduction in bulk density in the top 15 cm of the soil profile within the basins, when compared to the soils from the FP plots (See Figure 1) and confirms results obtained under CA by Karlen et al (1994). The reduced bulk density coincides with the depth of the basin which is 15 cm. A reduced bulk density leads to an increase in porosity and enables plants to establish more easily. Improved water retention in basins was observed in Bindura and Chivi but not in Masvingo (Figure 2). There was no trend in water retention as a function of the number of years that CF was practiced in both Bindura and Masvingo.

FIGURE 1. Bulk density as function of depth in the soil profile for farmer practice, area between basins and within basins, N=37, averaged over 8 districts in Zimbabwe (bars represent standard errors)

FIGURE 2. Water retention characteristics in Bindura, farmer practice (A), area between basins (B) and in basins (C); and in Masvingo, farmer practice (D), area between basins (E) and in basins (F). Bindura data is average of 4 farmers, Masvingo data is averaged over 3 farmers. Retention based on water pressure at –10, –25, –50, and –100 cm H_2O and compared with saturation.

Infiltration rate

The changes in bulk density and water retention caused some dramatic changes in infiltration rate as can be seen in (Figures 3). Infiltration rate in basins was on average 26 mm min^{-1} which was 87% and significantly (P=0.01) higher than in areas between basins. Infiltration rate in basins was also significant (P=0.01) higher than in FP plots. Infiltration also increased with the number of years CF was practiced. This is an important finding as a higher infiltration rate in the basin leads to preferential inflow of rainwater in the planting station thus increasing the water harvesting capacity of a CF plot.

FIGURE 3. Infiltration rates in 37 farmers' fields under farmer practice, between basins and in basins as function of year that conservation farming is being practiced (bars represent standard errors)

Soil chemical properties

Soil pH
Soil pH in the top 20 cm in basins was significantly (P=0.05) higher than in areas between basins or on FP plots (Figure 4). Soil pH was lowest in Murehwa and Bindura (Table 2). Both districts are located in Natural Region II with soils that are leached to a higher degree than the soils in Natural Regions III-V (Nyamapfene, 1991).

FIGURE 4. Soil pH of farmer practice, between basin and in basins from 37 farmers across Zimbabwe (bars represent standard errors)

{Table 2}

TABLE xx

Nitrogen, phosphorus and soil organic carbon
There was an increase in total % N in the top 20 cm in basins as compared to soil between basins. There was, however, no increase in total % N and P in basins as compared to FP (Figures 5-6). Soil organic carbon (SOC), likewise, was significantly higher in the top 20 cm of the soil in basins than between basins but no significant differences occurred between basins and the FP (Figure 7). The higher %SOC in the basins can possibly be attributed to precision application of manure and inorganic fertiliser and decomposition of roots. The increase in SOC in the basins could then also explain the amelioration of soil pH, as SOC increases the cation exchange capacity and so creates a buffer.
We found large differences in SOC even across small distances in the field, indicating that land use history and practices play a dominant role in SOC dynamics as observed by Zingore et al (2007). However, as of yet there were no major changes in total N and P in contrast to the more noticeable changes in soil physical properties.

FIGURE 5. Percentage N in soil from in farmer practice, between basin, and in basin from 37 farmers across Zimbabwe (bars represent standard errors)

FIGURE 6. Percentage P in soil from in farmer practice, between basin, and in basin from 37 farmers across Zimbabwe (bars represent standard errors)

FIGURE 7. Percentage soil organic carbon in soil from in farmer practice, between basin, and in basin from 37 farmers across Zimbabwe (bars represent standard errors)

Yield

Maize grain yield was higher with CF than FP across all natural regions (Table 3). Maize grain yield was significantly enhanced by N top dress application but much more so with CF than current farmer practice (Table 4). Table 3 also shows that without topdressing with N, benefits of CF are much lower, showing the importance of precision application of topdress N fertiliser to improve yields as included in the CF package.

{Table 3+4}

Conclusions

CF has led to improvement in porosity, water retention and infiltration in the basins. It was somewhat surprising that these improvements occurred quite rapid after implementation of CF and indicate the status of soil degradation in many soils around Zimbabwe. Improved infiltration rate and water retention leads to more effective use of rainfall and a lower bulk density enables better root growth. The precision application of manure and fertilizer to the basins as well as decomposing roots builds soil organic carbon. In degraded soils such as prevalent in many communal farming areas in Zimbabwe, building up SOC is of paramount importance to revert further soil degradation. Further investigations are required to determine if CF leads to higher availability of important nutrients as N and P, and the effect of CF on water retention across agro-ecosystems. Higher yields were realised irrespective of agro-ecological zones and soil types. CF therefore looks like a promising strategy to raise productivity under rainfed conditions and early results on labour use and profitability show that CF is more profitable than the FP (Mazvimavi et al, 2007).

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TABLE 1. Sampling details of detailed soil sampling on 37 farmers' fields

District	Ward	Natural Region[a)]	Soil type[b)]	Years of CF	Total number of farmers sampled
Bindura[c)]	10-12	II	5G/E,5AE,6G	2,3,4,6,7,8	6
Murehwa	14	II	5G/E,5AE,6G	1-3	3
Chirumanzu	8	III	5G/M, 6G, 4E	1	1
Masvingo	12	III	7G	1-3	3
Masvingo	14	III	7G	1-3	5
Chirumanzu	7	IV	5G, (4M/S/E)	2-3	3
Mangwe	2	IV	5G (4M/S/E)	1-3	3
Nyanga	3	IV	5G,(4M/S/E)	1-3	3
Nyanga	17	IV	5G,(4M/S/E)	1-2	2
Nkayi	3	IV	1,(2)	1-3	3
Nkayi	14	IV	1,(2)	1-2	2
Chivi	5	V	5G, 4P, 2, 4M	1-2	2
Chivi	19	V	5G, 4P, 2, 4M	3	1

[a)] Natural regions classified by annual rainfall; II→750-1000 mm, III→680-800 IV→450-650 mm (inconsitent rainfall), V→<650 mm (highly inconsistent rainfall) (Vincent and Thomas, 1960)
[b)] Zimbabwe soil classification as published by Nyamapfene (1991)
[c)] Wards 10 and 12 in Bindura were adjacent to each other and considered as one ward

TABLE 2. Average, minimum and maximum soil pH in samples taken from basins, between basins and the farmer practice plot at 0-20 cm and 20-40 cm from 37 farmers across the 8 sampling districts

District	Average	Minimum	Maximum
Murehwa	3.6	2.3	4.5
Bindura	3.8	2.4	5.7
Nkayi	4.8	3.8	6.8
Nyanga	5.1	4.1	7.2
Chivi	5.1	3.5	7.0
Masvingo	5.1	3.6	6.8
Mangwe	5.1	4.3	5.9
Chirumhanzu	5.2	4.0	6.9

TABLE 3. Maize yield (kg ha^{-1}) in 2006/'07 season obtained with conservation farming and farmer practice in 3 natural regions in Zimbabwe (N=69)

Natural region[a)]	Conservation farming	Farmer practice
II	1950 ± 257[a)]	920 ± 580
III	1590 ± 234	698 ± 204
IV	1356 ± 123	864 ± 77

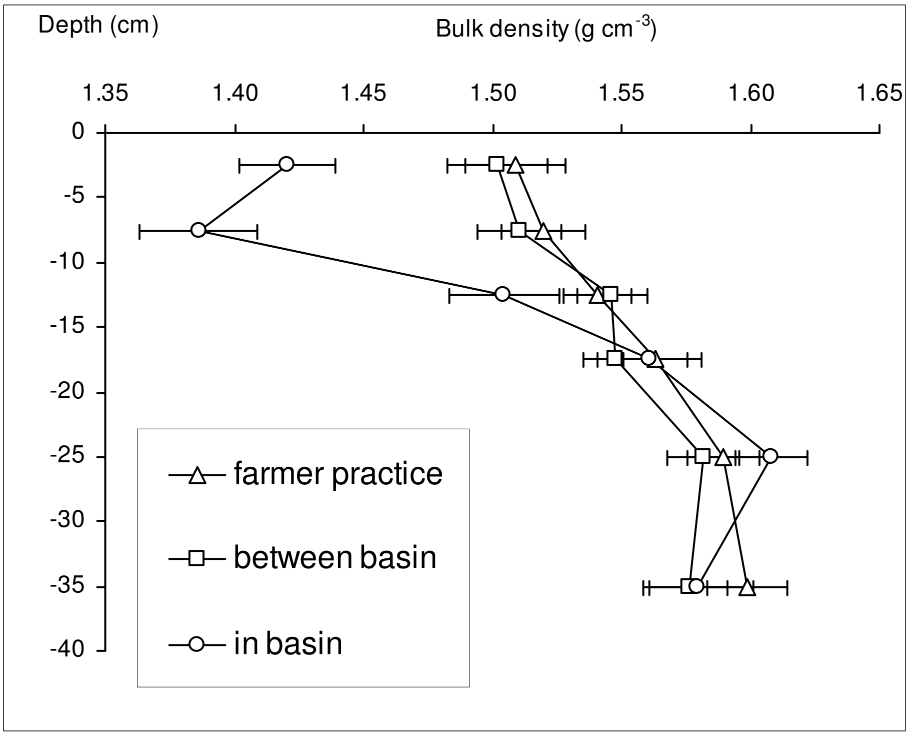
[a)] standard error
(source: Mazvimavi et al, 2007)

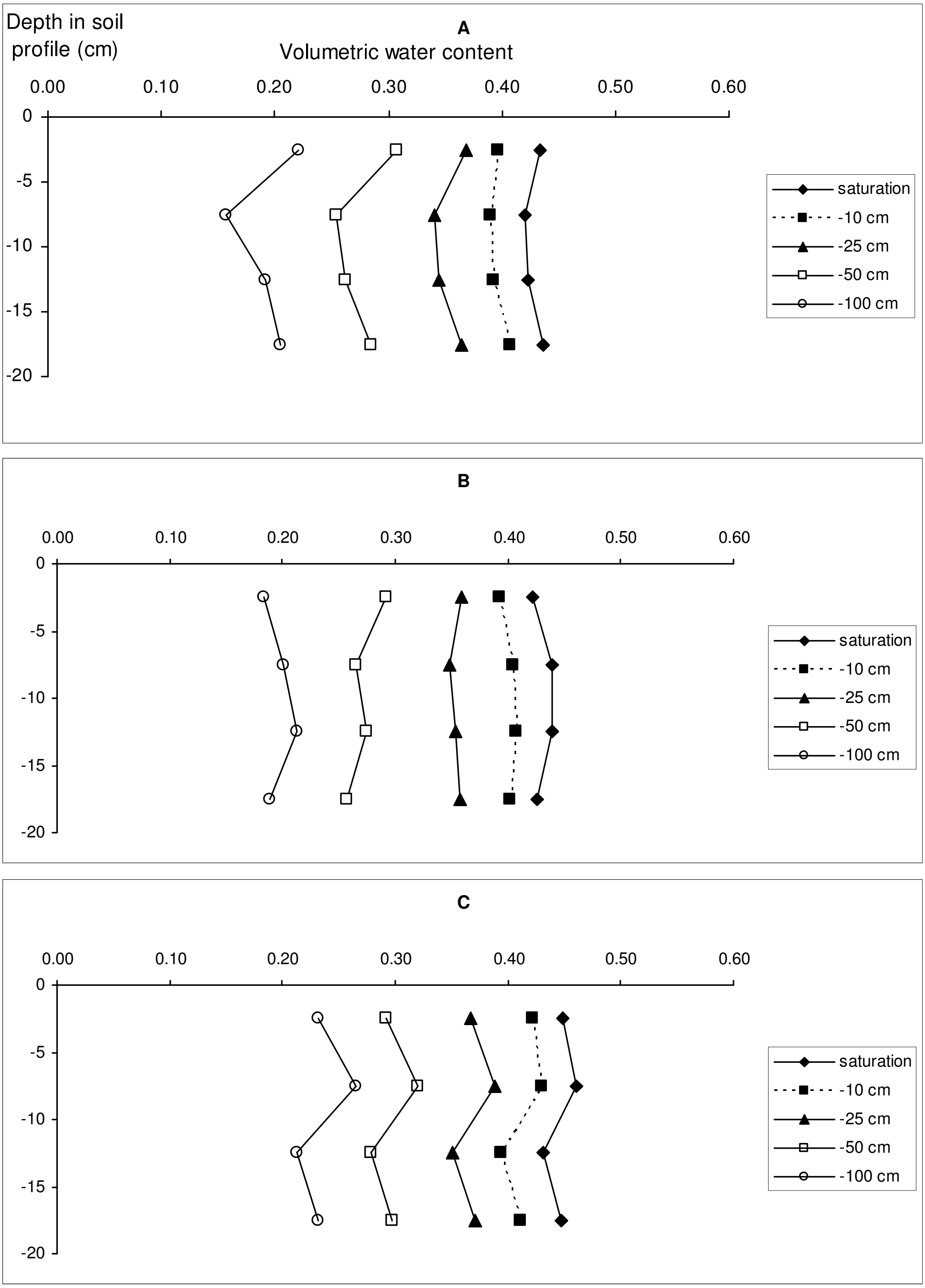
TABLE 4. Maize yield (kg ha^{-1}) in 2006/'07 season obtained with conservation farming and farmer practice as function of topdress fertiliser application (N=41)

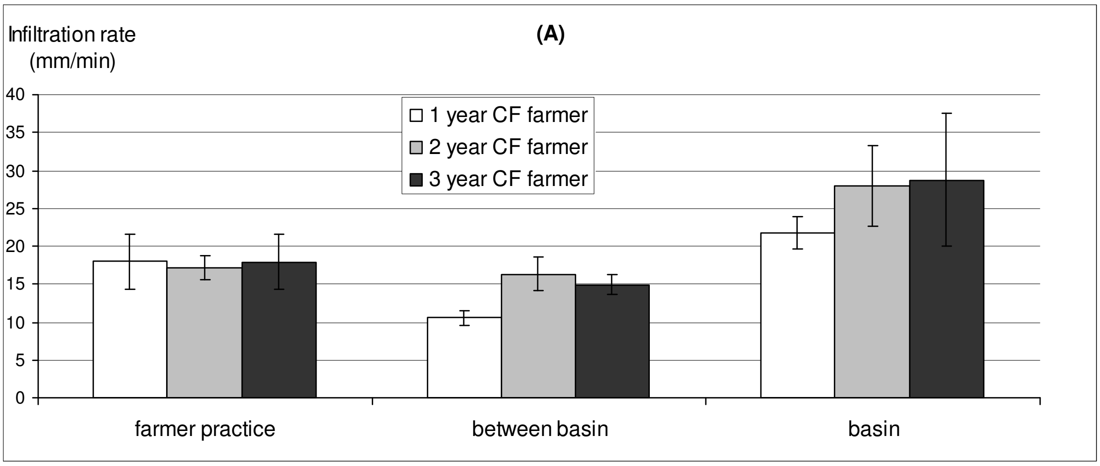
Topdress fertiliser applied	Conservation farming	Farmer practice
no	846 ± 283[a)]	642 ± 93
yes	1595 ± 180	874 ± 229

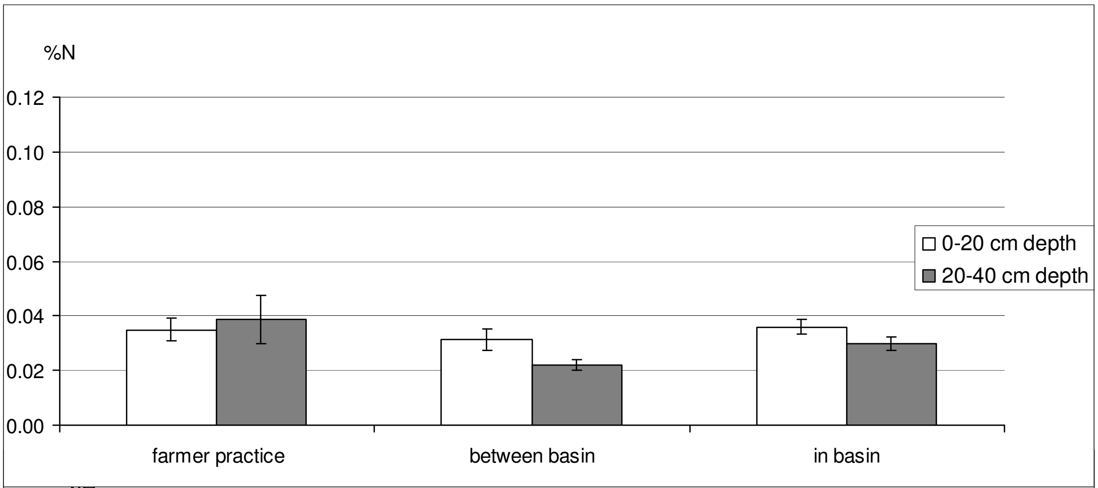
[a)] standard error

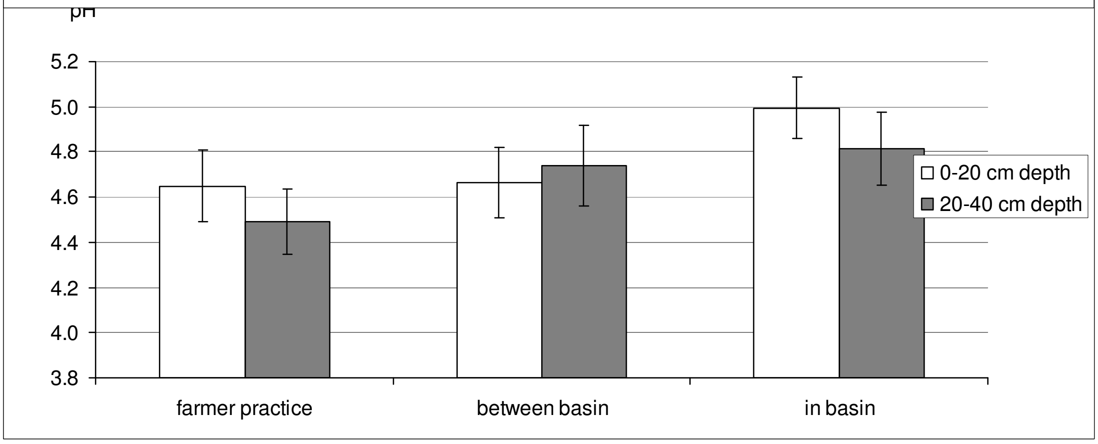
(source: Mazvimavi et al, 2007)

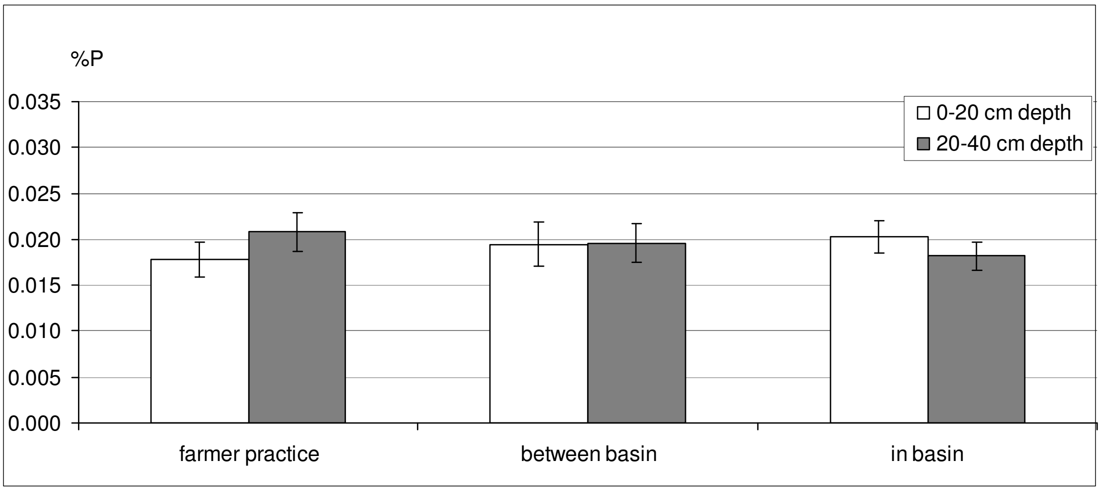

Depth (cm)
Bulk density (g cm-3)
1.35
1.40
1.45
1.50
1.55
1.60
1.65
0
-5
-10
-15
-20
-25
-30
-35
-40
farmer practice
between basin
in basin

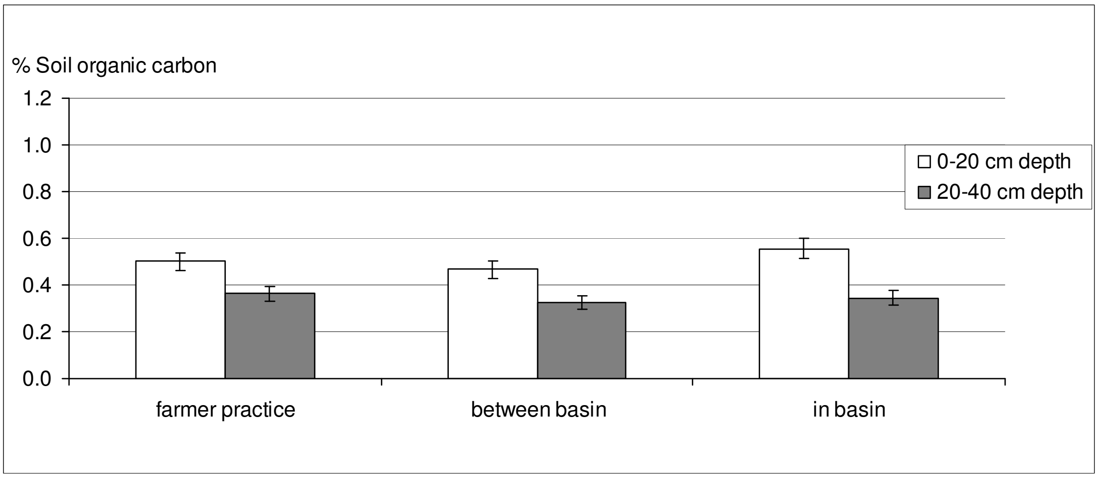

Depth in soil profile (cm)
A
Volumetric water content
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0
-5
-10
-15
-20
saturation
-10 cm
-25 cm
-50 cm
-100 cm
B
C


Infiltration rate
(mm/min)
(A)
40
35
30
25
20
15
10
5
0
1 year CF farmer
2 year CF farmer
3 year CF farmer
farmer practice
between basin
basin


%N
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0-20 cm depth
20-40 cm depth
farmer practice
between basin
in basin


pH
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
0-20 cm depth
20-40 cm depth
farmer practice
between basin
in basin


%P
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0-20 cm depth
20-40 cm depth
farmer practice
between basin
in basin


% Soil organic carbon
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0-20 cm depth
20-40 cm depth
farmer practice
between basin
in basin