CHAPTER 5

DISCUSSION

5.1 Discussion of Statistical Analysis

5.1.1 Introduction

This study set out to investigate: 1) the quality of change and 2) the rate of change in soil fertility parameters in the CF farming system. The two main hypotheses state 1) CF fields will have overall improved soil fertility and physical parameters over ploughed fields and will be highest in fields where CF is practiced longest; and 2) these positive changes would be more concentrated inside the planting station than outside the planting station. The following results are discussed in the context of these two main objectives and hypotheses.

5.1.2 Effect of field treatment

This analysis provides a broad perspective into the quality of change and trends in field treatments as it incorporates the mean of all sampling points from one treatment group together, regardless of depth or location. For key soil parameters TC, AC, N, P, BD, and IN, CF4 and CF8 were both higher than REF; and for 9 of all 11 parameters, at least CF4 or CF8 was higher than REF with the exception of pH and K. This suggests that the CF system trends toward higher C, N, and P than ploughed fields. Physical structure trends in favor of CF with lower bulk density and improved infiltration.

These trends while useful require more information from sampling location and depth for confirmation and explanation. Caution is merited to overemphasize these results as each sampling unit (two depths and two locations) is given equal weight relative to another. The permanently enriched planting stations occupy only roughly 4-10% of a field (depending upon station size) while outside the station occupies the remaining 90% or more. In ploughed fields on the other hand, the location of fertility inputs changes with the annual shifting pattern of ridges and furrows which results in a broad and more uniform distribution of nutrients. Therefore, CF fields are favored in this analysis. Nonetheless, samples were taken adjacent to maize plants for 50% of sampling points in REF and CF fields. This analysis should therefore be interpreted more in the context of effect on maize rather than the entire field for each parameter. With this in mind, the analysis at least points toward overall better field conditions for maize production with CF than ploughing, supporting the first hypothesis that CF would show higher concentrations of nutrients and better physical conditions for crop production than in ploughed fields.

5.1.3 Effect of Sampling Depth

The analysis reveals the significant differences in the vertical distribution of chemical parameters between the two depths with the exception of sodium and BD. In general, soil chemical parameters significantly decrease with depth in all treatments. These findings are supported by Belder et. al (2007) in Zimbabwe where SOC, P, and N decreased with depth in both conventionally ploughed and CF fields.

The only exception in the current investigation is with BD that decreased but only negligibly at the lower depth (1.53 to 1.52 g/cm^3). These findings are also consistent with Joggaby and Jackson (2001) who studied over 10,000 soils globally and found that total N, extractable P, and exchangeable K were consistently higher in concentrations at the upper soil levels.

Contrary to all chemical parameters, exchangeable Mg significantly increased with depth (6.31 to 8.77 mmol/kg). Jobbagy & Jackson (2001) also found Mg to increase in subsoil depth under some soil types (e.g. Mollisols and Utisols in USDA taxonomy). One plausible explanation is the preferential retention of Mg over Ca by Al hydroxides in lower soil depths in low pH, aluminum-rich soils (Smeck et al., 1994, as cited in Jobbagy & Jackson, 2001). While the statistical analysis for depth does not differentiate between CF and REF field treatments, most results for each parameter were highly significant ($p < 0.0001$) suggesting that nutrient distribution trends by depth exist regardless of soil treatment.

5.1.4 Effect of sampling location within field treatment

This part of the statistical model highlights the following findings:

1. The strong homogeneity in ploughed fields is contrasted with strong spatial differences in CF fields.
2. The planting stations have an agronomic advantage due to concentration of nutrients.

3. Infiltration in CF fields is improved in comparison with ploughed fields.

The strong homogeneity in ploughed fields is underscored by the lack of any significant differences for all tested parameters between the ridge and furrow. This can be explained by the continual mixing of soil caused by ploughing . In contrast, for both non-ploughed groups,CF4 and CF8, P, AC, Ca, and pH were significantly higher inside the station than outside the station within their respective field treatment. The annual addition of fertilizer and organic matter to the planting station most certainly accounts for significant station amelioration since the remainder of the field (outside the station) is only enriched by crop residue retention. This is confirmed with the larger concentration range of parameters TC, AC, P, pH, BD, and IN that exists between CF stations inside and outside compared to ridge and furrow. For example, in CF8 where the largest ranges by parameter are seen, from outside station to inside station, the following percent increases occurred: TC—37%, AC—29%, N—50%, K—21%, Ca—37%, pH—18%, and a decrease in BD by 5%. Conversely in the ridge and furrow, approximately 5% or less difference exists in the same parameters, except for K which showed an 11% increase from furrow to ridge (Table 8). This clearly demonstrates that augmentation of stations is largely confined to the station and underscores the importance of striking the same hole under CF management as lateral distribution of nutrients appears limited. This supports the second hypothesis that nutrients would be concentrated in stations rather than outside the station.

The question remains as to which arrangement of nutrients provides an agronomic advantage—1) relatively uniform distribution as in ploughed fields or 2) concentrated nutrients in CF stations. Part of this may best be understood in the relative concentration of nutrients adjacent to maize plants. Larson & Oldham (2008) underscore the importance of having plant nutrients near developing maize plants, especially P due to its relative immobility. This definitely favors the CF system which shows much higher nutrient concentrations in the station than on the ridge. TC, AC, N, P, and Ca are in higher concentration for both CF treatments at the planting station than on the ridge of REF fields with significant differences for P between CF8 and REF (Table 8). The physical parameters BD and IN were also superior inside station to REF ridge or furrow. These results are validated in higher CF yields estimated in this study (Table 14).

Returning to the hypothesis posed at the beginning of this study, it is possible to state that the CF system provides higher concentrations of nutrients (C, N, P, and Ca), improved infiltration, and reduced bulk density closer to maize plants than in ploughed fields. These findings can be explained from the benefits accrued by no tillage occurring outside the stations and emphasizing residue retention. The results are confirmed by other studies showing carbon increases with long-term minimum tillage in Zimbabwe (Chivenge et al., 2007) and increased infiltration with reduced N and P run-off in conservation tillage systems (Munodawafa & Zhou, 2008).

Though not statistically significant, IN results are important at an agronomic level. The majority of rainfall will accumulate outside the stations in CF fields (since they occupy 90%+ of a field) and in the furrow of the ploughed fields (by nature of lower positioning). When comparing outside the station in CF4 to furrow of ploughed fields, CF4 infiltration was 405 mm/hr to 170 mm/hr in REF furrows—a 138% improvement in infiltration. The CF8 outside the station showed 47% increase (259 mm/hr) to REF furrow infiltration. These findings further validate that CF provides overall superior agronomic field conditions than ploughing. Interestingly, the CF4 higher infiltration results outside of the planting stations contradict reports by Belder et al. (2007) which found greater infiltration in CF stations than outside. Reconciling the difference between these two studies is difficult, but perhaps CF4's higher infiltration rate outside the stations is attributed to better field conditions accrued from additional years practiced by CF4 farmers compared to mainly 1-3 years in Belder et al. (2007).

5.1.5 Interaction of field treatment, sampling location, and depth

The interaction of depth, sampling location, and field treatment provides three findings summarized as:

1) CF fields have a higher within field variability in pH and nutrient distribution and concentration than ploughed fields.

2) P concentration in CF8 planting stations is exceptionally high relative to other sampling locations in the study and compared to soils in the region.

3) There are no significant ($p<0.05$) increases in nutrient or physical parameters between CF4 and CF8.

4) Positive change occurs relatively fast under CF, as demonstrated by the CF4 treatment group.

The spatial variation of nutrients within CF fields is more obvious in this analysis that now incorporates depth. Here, all chemical parameters inside CF stations at 0-15 cm are superior to all other sampling positions (outside station and lower depths), with the exception of K and Mg for CF8 and additionally, Na for CF4. Furthermore, the percent increase between inside stations at 0-15 cm and ridge and furrow are more elevated for all chemical parameters than in the previous analysis. This suggests nutrients are concentrated both vertically and laterally to the planting station itself. This is underscored by the significantly greater N, P, and K concentration within CF4 and CF8 stations at 0-15 cm compared to any other sampling positions within their respective treatment. This gives further credence to the hypothesis of agronomic advantages that CF provides via higher concentrations of major plant nutrients adjacent to crops.

pH range from outside to inside CF stations highlights well the spatial and vertical variability within CF fields. CF8 and CF4 pH outside the station at 15-30 cm is 4.54 and 4.94, respectively. Conversely, CF8 and CF4 pH inside the station at 0-15 cm is 6.17 and 6.18, respectively. REF pH at all sampling locations and depth range 5.58 to 5.90. The striking variability of pH within CF fields is best explained by the undisturbed soils (no mixing from ploughing) outside the stations that mimic more the native pH. The elevated pH in stations is explained by organic enrichment and lime application to permanent planting stations by CF farmers. Conversely, farmers who plough are constantly mixing organic inputs throughout the fields resulting in more uniform pH. Another explanation why there is more elevated pH in ploughed fields is that each REF field had been farmed for more than 20 years. Manure and ant heap soil have been added for over two decades with annual mixing over the entire fields.

Further work is required to establish which effect is better for maize production—uniform, slightly acid pH in REF or a broader range in CF with highest pH in planting stations. If ideal pH for maize growth is between 6.0 to 7.0 (Larson & Oldham, 2008), it can be said nutrient availability should be more optimal within planting stations at least in the early stages of maize development when roots are in the station. What happens to maize roots outside of the planting station would need to be investigated more. The implications for site specific pH improvements in CF fields can be especially strategic in regions where very acid soils reduce crop production due to limited nutrient availabiliy, phosphorous fixation, and aluminum toxicity.

One of the major findings to emerge from this study is the high level of available P reported in CF8 (50.48 mg/kg) at 0-15 cm inside the planting station (Table 3) that contrasted with significantly lower P in REF (3.42 mg/kg on the ridge). The standard deviation for P is high in CF8 (53.58 mg/kg) suggesting there is high variability within the sample set. This suggests the pattern is not uniform throughout the stations. However, the amount is still considerably higher than the 15 mg/kg threshold that is suggested for good maize production in Zimbabwe (Zingore, 2007). In a previous timeline CF study by Belder et al. (2007), no P increases were evidenced in CF over REF. The evidence of high P can be explained from the contribution of phosphorous-containing fertilizers which all CF farmers used and its relative stability in the soil compared to other elements like N. The high availability of P is perhaps best explained through the moderated pH (6.17) and higher carbon levels (0.44%) within CF stations at 0-15 cm. The significant concentration is further explained by good management practices of striking the same hole allowing for strategic station enrichment. This new finding has major implications since P is one of the most limiting nutrients for maize production in SSA.

Part of the hypothesis that is more difficult to claim is that practicing CF for eight years results in better field conditions than farmers practicing four years. There are no significant differences or trends favoring one field treatment over the other when all sampling points are considered. At 0-15 cm within stations, TC, AC, pH, and BD are nearly identical. CF4 shows 19% increase in N, 24% for Mg, and greater than 30% increase for IN. However, CF8 shows nearly 500% increase in available P, 20% increase in K, and 31% increase in exchangeable Ca. Aside from perhaps, P, this leads to the conclusion that change within CF is most evident by spatial changes within field treatments rather than temporal change. One possible explanation can be that CF8 is represented by only one field, not providing a comparable sample size. Another possibility which needs further exploration is that CF changes occur relatively fast as seen in CF4, but then slow down as nutrient accumulation beyond certain levels is difficult due to leaching and limited carbon sequestration in sandy soils (Blanchart, et al., 2005).

While no confirmation exists for a significant rate of positive change between CF8 and CF4, the findings do suggest a fast rate of change from 0-4 years. Whether reference fields or outside the station at 4 years is used as the baseline fertility, the findings show good trends in soil parameters with significant increases of N, P, and K from outside to inside the station at 0-15 cm. While Belder et al. (2007) found rapid changes especially in infiltration in 1-3 years of CF practice, there was no evidence of improved C, N, and P in CF over REF. However, in the current investigation CF4 stations at 0-15 cm had elevated TC and AC levels over REF at all positions and significantly higher N and P than all REF positions. Taken together, these results suggest that in relatively short time, CF planting stations show significant positive concentrations in major plant nutrients leading to enhanced crop production.

5.2 Active C methodology

The final hypothesis stated the more simplified carbon analysis called Active C, as outlined by Weil et al. (2003), would be a satisfactory and less expensive alternative for estimating soil quality in CF research. For certain, the AC method is far less expensive and time consuming than running samples on a C/N elemental analyzer. Aside from standard lab supplies and potassium permanganate ($KMnO_4$) solution, the only expensive equipment is a spectrophotometer, though hand-held spectrophotomers provide reliable results (Weil et al., 2003). In terms of time, 180 AC samples were prepared and analyzed in less than three days. Conversely, the C/N analyzer took around five days for grinding, weighing, and preparing samples with an estimated cost of over 3 € per sample.

Though the methodology is simple to follow, consistency during the settling time is critical to avoid introducing variability (Chapter 3). Doing 40 samples at one time resulted in error as one set of 20 samples was standing too long before reading on the spectrophotometer leading to 1.2 times higher active carbon after repeating the analysis. Therefore, 20 samples seems a maximum number to manage in one full cycle before beginning another set of samples. Another complication was that in working with low carbon soils, a significant proportion of values were negative. This resulted in using a correction factor as no support could be found in literature of how to address this. While the relative range within the study is maintained, this limits reliability of cross-referencing these results with other findings. Card (2004) raised similar concerns about the AC methodology regarding questions of normalizing the data and importance of settling time. The study concluded that running only 10 samples was best with a maximum of 17 minutes settling time.

The correlation analysis shows good correlation with TC (Pearson's Correlation Coefficient-r, 0.859) and moderate correlation with N (0.796). While the C/N analyzer provides very precise readings required for published research, the correlation results suggest AC is a good estimator of TC and N and provides a good alternative for soil labs servicing farmers and extension workers with low cost carbon analyses.

5.3 Field size and estimate maize yield

The results of this investigation show that CF demonstrably gives high yields on small pieces of land. The ploughed maize fields in the study were nearly five times the size of the combined average of the CF fields, but the yield per area nearly six times greater in CF fields. The present study confirms previous yield findings reported by Mazvimavi et al.(2008) where CF yielded five times greater than ploughed fields. These yield improvements can be explained through the higher concentration of plant nutrients and organic matter, elevated pH, and lower bulk density within planting stations and improved overall field infiltration than found in ploughed fields. The smaller field sizes in CF can be explained by the higher labor component required than in ploughing for similar size pieces of land.

The average yield for the Province where the study occurred was 0.7 t/ha in 2011-12 season and 0.5 t/ha in 2010-11 season (Zimbabwe Minister of Agriculture, Second Round Crop and Livestock Assessment Report, 2012). The combined estimated yield average from all the CF fields in the study was 4.0 t/ha. The study site region as described in Chapter 2 and 3 is characterized by low rainfall and nutrient poor sandy soils. The yield finding suggests CF is a very appropriate system for sandy soils in low rainfall regions.

An interesting finding that was not anticipated at the onset of the study was the practice by some farmers to use both ploughing and CF. Three REF farmers maintained CF plots near their homestead and had more than two times the yield of their ploughed fields (likely much higher since so much is harvested as green maize). The CF plots play a critical role in providing early, reliable maize production near their homes. Roasted green maize is one of the main food sources during the cropping season, while maize in larger fields away from the homestead develop. The homestead CF plots are easier to protect with fences and by the homestead dwellers, as earlier planting dates possible in CF exposes the emerging maize to higher grazing risk from free-ranging livestock. The role CF plays in green maize consumption appears substantial. A recommendation for future practice is to consider the promotion of CF as a homestead farming system rather than emphasizing sizes that are overly labor-demanding. This could positively affect adoption rates and promotes CF as a niche system for both small land sizes and for farming near homesteads.

5.4 Limitations within the study

The current study is limited in two main ways. First, the number of fields in the study is relatively small. The challenge in finding three CF8 farmers on the same soil proved especially difficult resulting in only one field representing CF8. This limits making strong comparisons between CF4 and CF8 field treatments. Certainly, the overall small sample size merits caution to be applied in transferring these results to other regions and soil types. The strength of the study should rest on the identified and obvious trends which support the original hypotheses regarding CF fertility development under smallholder conditions on sandy soils.

Finally, the second major limitation was the inability to control for field history when using an experimental design that used “uncontrolled” farmer fields. This type of research often is conducted on research stations or in farmer-managed research plots. This was a real-life snapshot of seven different fields. Within such a design is inherent variability. While attempts were made to minimize this effect in the field selection process, readers should understand this investigation took place on farmer fields that are subject to individual decisions, economic factors, etc.

5.5 Future Research

What is now needed are additional timeline studies on other soil types. There remains a gap in CF research when it comes to its impact on soil physical and chemical parameters. The majority of the research focuses on yield and socioeconomic factors such as labor and profitability analyses. To balance this existing research, more soil investigations are needed to appropriately quantify the type and rate of change occurring in CF fields. In particular, the presence of significant concentrations of P in planting stations merits further investigation to confirm this finding. Future research should also overcome the challenge of this study to include much larger sampling sizes. Now that CF has been practiced more than a decade, including longer timelines is recommended. The research emphasis on individual soil types will help underscore the differences soils make to fertility dynamics effecting positive outcomes in research, technology development, and promotion.

More broadly, further research might explore CF's impact outside of southern Africa to regions where smallholder land sizes are especially small (e.g. less than 0.5 ha). The ability to produce more food on smaller land size appears a critical advantage CF offers over traditional ploughing. Such a system may have merit in areas like Bangladesh or India where smallholder land sizes are particularly small. This is especially relevant given increasing population pressure and the need for farming systems that optimize fertility, soil, and water resources.