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Impact of Long-Term Conventional Cropping Practices on Some Soil Quality Indicators at Ethiopian Wonji Sugarcane Plantation

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Abstract

Over the last 50 years, the sugarcane yield in Wonji plantation has declined by about 40%. Perhaps one of the possible causes for the decline is soil degradation. Thus, the major soil quality indicators were evaluated for the extent of change that might occur due to long-term conventional cropping practices. To that end bio-sequential soil sampling was performed by collecting soil samples from adjacent virgin and cultivated lands of Wonji sugar cane plantation. The samples were analyzed and compared for major soil properties. The result showed that the SOM contents of cultivated land were 53% and 34% lower than the virgin land at 0 cm-30 cm and 30-60 cm depths, respectively. Total N, P Olsen, exchangeable K and soil EC of the cultivated land were also 56%, 84%, 86% and 54% lower than the virgin land at 0 cm-30 cm. The differences were also significant at 30 cm-60 cm. There was no significant change in soil pH at both depths. In general long-term conventional cropping practices depleted the SOM, total N, P Olsen and exchangeable K. However, pH and EC were in the optimum range that soil acidity, salinity and alkalinity were not a problem. As the soil type of the plantation is heavy clay, particularly, the degradation in SOM content might cause the yield decline. In order to fully identify, understand and manage the problems of soil quality deterioration further study is necessary.

Keywords: SOM; Conventional cropping; Yield decline; Soil degradation; Total N, P; Olsen; Exchangeable K; EC; pH 1

Introduction

Sugar cane production is one of the largest and most important agro-industries around the world in general and in developing countries in particular. Nowadays, sugar cane is considered as a *Dollar Earner* for tropical countries due to its immense potential to generate hard currency [1]. Therefore, achieving sustainable cane production is an increasingly important goal in recent years so as to exploit this potential. However, in several sugar cane producing countries around the world, decline in sugar cane yield appears to be the major preoccupation of the agro-industry [2-4]. Likewise, sugar cane yield decline is currently becoming the major area of attention in the Ethiopian sugar cane plantations. Although, Ethiopia is one of the countries with the highest sugar cane yield in the world [5,6] the yield has been declining already for many years. For instance over the last 50 years, the cane yield per ha in Wonji sugar cane plantation has dropped by about 40% (Figure 1). Thus, the future viability of the agro-industry will be doubtful unless the yield decline could be stopped. Therefore, identifying and understanding the cause of the yield decline has paramount importance to design and recommend appropriate management strategies. This is particularly essential in view of the current Ethiopian government ambitious plan to augment the sugar production capacity of the country.

The cause for sugar cane yield decline is a complex issue, as it results from a number of factors. According to De Wit [7] actual crop yield generally depend on growth-defining, growth-limiting and growth-reducing factors. In monoculture sugarcane farming, where long-term conventional cropping practices are widely adopted, these factors may not be sustained at the optimum level for cane growth. Particularly, upon cultivation the deterioration of soil quality is inevitable which may lead to soil degradation and consequently yield decline.

A soil with a high quality is productive and has a stable yield [8] whereas its degradation adversely affects the agronomic productivity [9]. Similarly, in sugar cane plantations, soil degradation was found to be one of the major contributors for yield decline [4,10]. The losses in soil production capacity of a sugar cane field could be mainly ascribed to long-term monoculture, uncontrolled traffic from heavy machineries, excessive tillage before planting [4] pre-harvest cane burning [11], inappropriate irrigation and drainage [12] and excessive utilization of agrochemicals [13]. These conventional cropping practices lead to change in soil biological, physical and chemical properties with concomitant decline in cane yield [13]. Similarly the aforementioned practices were also adopted in Wonji plantation over the last fifty years and May resulted in soil degradation.

Therefore, the objective of this research is to evaluate the major soil quality indicators of Wonji sugar cane plantation so as to understand the possible existence and extent of soil degradation. The approach taken was to collect soil samples from virgin and cultivated lands bio-sequential soil sampling of the sugar cane plantation and to evaluate the differences in the major soil quality indicators soil organic matter, total N, available P, exchangeable K, EC and pH.

Materials and Methods

Site description

The study was conducted between September 2009 and February 2010 in Wonji sugar estate (8°31'N and 39°12'E), which is 110 km southeast of Addis Ababa (Figure 2). The site is located at an altitude of 1540 meter above sea level. The average annual rainfall is 807 mm.

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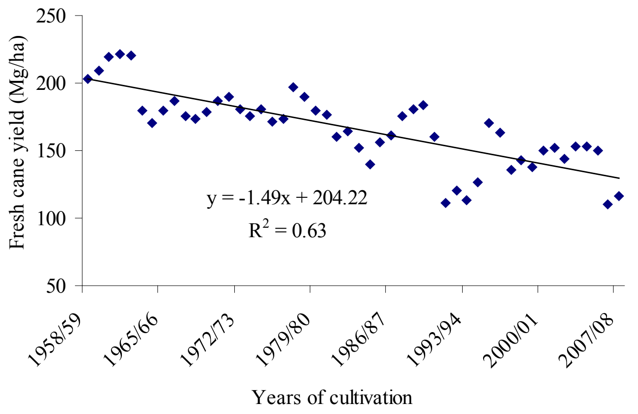

Figure 1: The yields of sugar cane over 50 years production period [1958-2008] of the Ethiopian *Wonji Sugar cane plantation.*

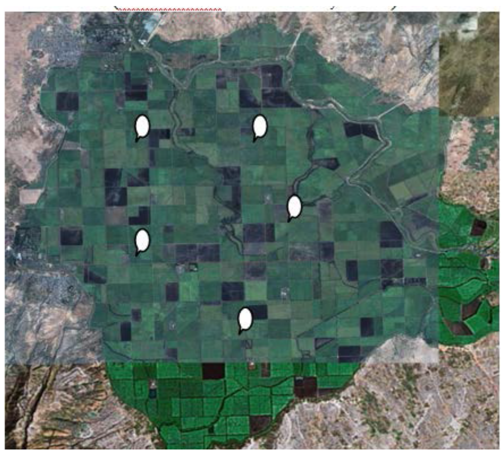

Figure 2: Field map of Wonji plantation: sites marked with white dots are the locations of bio-sequential soil sampling.

while average daily minimum and maximum temperatures are 14.3°C and 27.6°C, respectively. The soils of the study area are predominantly heavy clay. The slope of the land is very gentile and regular. Before the establishment of the estate, the Wonji plain was a sparsely populated area due to flood and malaria hazards. In 1950s the land was given to the Dutch company, HVA, for establishment of a sugar estate and in 1954 sugar production was started [14].

Soil sampling

There are two common methods of studying changes in soil properties of farmlands under long-term cultivation: chronosequential sampling or Type I data and bio-sequential sampling or Type II data [15]. The former is used to monitor soil dynamics over time at the same site while in the latter case soils of cultivated and uncultivated lands are simultaneously sampled and compared. In this study, bio-sequential soil sampling method was used and the underlying assumption was that the soils from adjacent virgin and cultivated land were originally similar and that current differences in the soil physicochemical properties are due to cultivation [15].

In order to collect the required samples, five representative sites were randmly selected from the 7000 ha of Wonji plantation fields (Figure 2). The virgin lands were located near plantation villages of the sugar estate. Each village has about one ha virgin land which was intended as entertainment place for the villages' residents since the commencement of sugar cane cultivation. Thus, the selected virgin lands were assumed to represent the original soil conditions of the site. Corresponding soil samples were also taken from the cultivated fields, near each of the selected virgin lands.

Method of soil analysis

The soil samples were analyzed in the research directorate of Ethiopian sugar development agency laboratory located in Wonji sugar estate.

Soil pH and EC were measured in a 1:2.5 soil water suspension by a glass electrode pH meter and EC meter, respectively. Total soil N was measured following Kjeldahl procedure which involved digestion of the samples in concentrated H_2SO_4 with a catalyst mixture to raise the boiling temperature and to promote the conversion from organic-N to ammonium-N. Ammonium-N from the digest was obtained by steam distillation, using excess NaOH to raise the pH. The distillate was collected in saturated H_3BO_3 and then titrated with diluted H_2SO_4 to pH 5.0 [16] Organic carbon was determined by Walkley-Black procedure which involves reduction of potassium dichromate by organic carbon compounds and subsequent determination of the unreduced dichromate by oxidation-reduction titration with ferrous ammonium sulphate. Finally, the amount of organic matter was determined according to the approximation: soil organic carbon × 1.72=SOM [17]. Available soil P was determined by sodium bicarbonate method where P was extracted with 0.5M sodium bicarbonate and measured calorimetrically [18]. Exchangeable K was determined by flame photometer after the samples were extracted with Morgan's solution [19].

Data analysis

The data were analyzed by paired samples t-test analyses at 1% probability level using Genstat software statistical packages, 12th edition. Mean comparisons were also performed.

Results and Discussion

SOM, total N, P Olsen, exchangeable K and soil EC of the cultivated land were much lower than the virgin land at both 0 cm-30 cm and 30 cm-60 cm soil depths ($P<0.01$). Nevertheless, no significant difference was observed in soil pH at both depths.

Soil Organic Matter (SOM)

The SOM content of the cultivated land was 53% and 34% lower than the virgin land at 0 cm-30 cm and 30 cm-60 cm depth, respectively (Figure 3). Thus, the SOM of the cultivated land was depleted considerably suggesting that long-term conventional cropping practices have degraded the soil. In agreement with the current result, several data from other long-term cropping systems trials also showed a decline in SOM and deterioration of soil quality under continuous cultivation as compared to native vegetation [20].

The observed differences between SOM contents of the cultivated and virgin land in Wonji sugar cane plantation at 0-30 cm depth was comparable with the differences observed in Philippines and Papua New Guinea. Alaban et al. [21] in Philippines and Hartemink et al. [22] in Papua New Guinea found the differences of 26% and 42% SOM, respectively, over a 20 years period of sugar cane cultivation. In China, Liu et al. reported that during 5, 14 and 50 year cultivation periods soil organic carbon losses were 17%, 28% and 55%, respectively. Contrastingly, Naranjo et al. [23] in Mexico and Bramley et al. [10] in

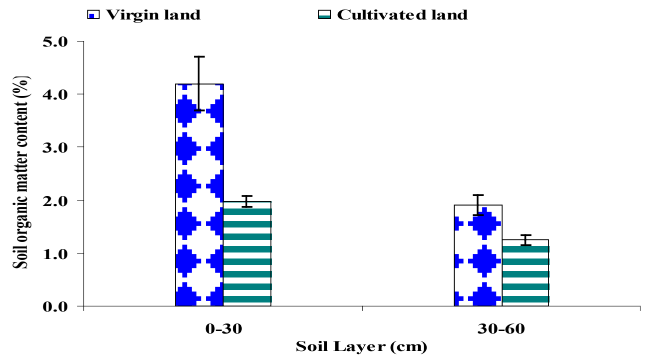

Figure 3: SOM content [%] at Wonji sugar cane plantation sampled from land areas under conventional cropping practices for 50 years and adjacent lands that were never cultivated [virgin] at 0 cm-30 cm and 30 cm-60 cm depths [means of five sampling sites]. Means of virgin and cultivated lands are significantly different at P<0.01. Vertical bars indicate ± SEM [standard error of mean].

northern Australia found non-significant differences in SOM contents after 30 and 20 years of sugar cane cultivation, respectively. This could be explained in the latter case by adoption of recommended practices which have the potential to sustain or increase SOM contents and sugar cane yield [19,23]. These practices mainly include integrated management of nutrients and sugar cane trash retention.

The absence of appropriate practices in the Wonji sugar estate played in all probability a significant role for the substantial differences observed in SOM contents of the tow soil types. For instance due to pre-harvest cane burning, about 14 ton/ha organic matter is lost up on harvesting 120 ton/ha sugar cane [24]. Additionally, excessive tillage results in 17% decline in SOM content within four months. Similar study in Australia also indicated that excessive tillage, insufficient fallowing and burning of crop residues are the major reasons for SOM decline during long-term conventional sugar cane cropping practices [4]. Moreover, the geographical location of Wonji plantation (8°31'N; near equator) might also have contributed to the observed differences. As the area is associated with high temperatures and humidity, the dynamics of SOM could be much higher than in countries like Australia (29°S-46.5°S) and Mexico (23°N) where the temperature is relatively mild. This is because of, as Sanchez and Logan [25] indicated, in tropical countries SOM decomposition rates could be up to five times higher than in temperate regions [26,27].

The main macronutrients

Total N, P Olsen and exchangeable K contents of the cultivated land were 56%, 84% and 81% lower than the virgin land at 0 cm-30 cm depth (Figure 4). The results suggest that there was depletion in the main macronutrients. Unless supplied as organic or inorganic fertilizers, the depletion of these macronutrients can cause substantial yield losses [8].

This observation was in agreement with those of Wood [28] Van Antwerpen and Meyer [2] Hartemink and Wood [15] and Hartemink [27] who reported that uncultivated land had higher levels of total N, available P and exchangeable K than cultivated land. The extent of degradation observed in our case was, however, much higher as compared to other countries. In Mexican fluvisols, after 30 years of sugar cane monoculture the N, P, and K contents of cultivated land was 14%, 43% and-5% lower than uncultivated land, respectively [23].

The significantly lower N, P and K contents of the cultivated soil than the virgin land (Figure 4) could be partly attributed to high nutrient removal by the cane itself and the lack of replenishment [27]. The practice of pre-harvest cane burning might also have played a role as it can cause 70%-95% loss of the dry matter and N from the system [28]. The finding of Alemayehu [24] also indicated that in Wonji plantation up on harvesting 120 ton/ha sugar cane about 66 kg N/ha is lost due to burning. Moreover, the continued decomposition of mineralizeable soil C and N, which is favored by the warm humid climate of the area, excessive tillage and leaching of cations could also be possible causes for the observed differences [29].

At 30 cm-60 cm depth, total N, P Olsen and exchangeable K contents of the cultivated land were 28%, 60% and 81% lower than the virgin land, respectively (Figure 4). The differences were more pronounced at the soil depth of 0 cm-30 cm than 30 cm-60 cm, because sugar cane is shallow rooted and removes little nutrients from deeper soil horizons [30]. Additionally, the extents of the differences between cultivated and virgin lands were much severe in exchangeable K at both depths (81%) and available P at 0 cm-30 cm depth (84%). This might

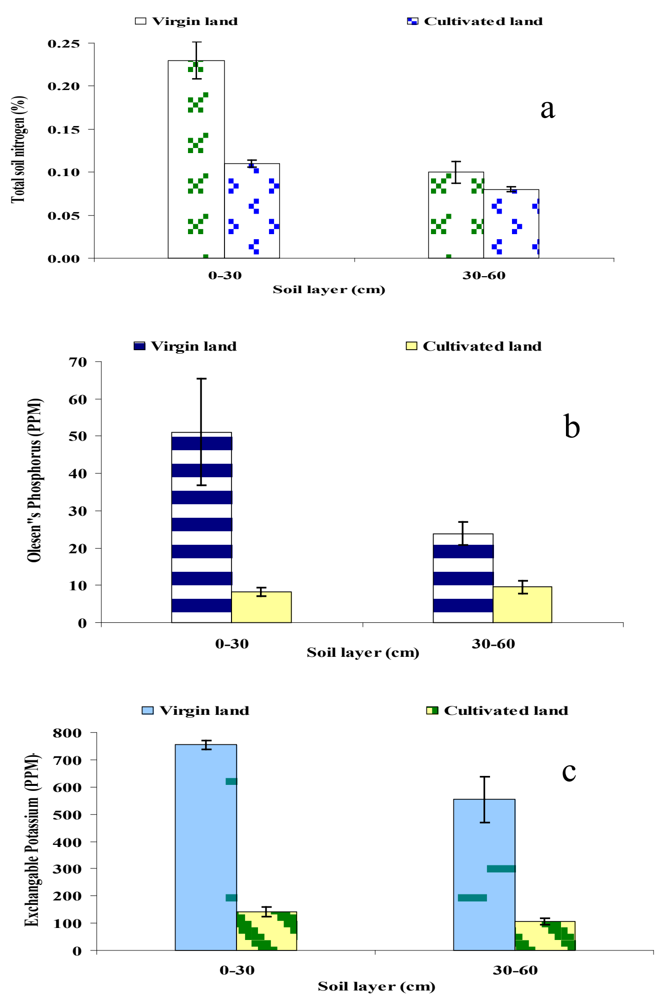

Figure 4: Total N [a], available P [b] and exchangeable K [c] contents of soils at Wonji sugar cane plantation sampled from land areas under conventional cropping practices for 50 years and adjacent lands that were never cultivated [virgin] at 0 cm-30 cm and 30 cm-60 cm depths [means of five sampling sites]. Means of virgin and cultivated lands are significantly different at P<0.01. Vertical bars indicate ± SEM [standard error of mean].

be associated with the fact that no K and P fertilizer applications have been practiced since the inception of Wonji plantation. However, the implication of the depletions of these nutrients for the observed yield decline might be of a minor role. This is because of the fact that the application of N fertilizer in Wonji increases the P and K availability in the soil [24]. Moreover the current levels of both P Olsen (8.22 ppm) and exchangeable K (142 ppm) are not in the range of deficiency. According to Landon [31] sugar cane is among the moderate P demanding crops where deficiency occurs at less than 7 ppm. For K, the critical value ranges from 78 ppm-125 ppm [32]. The values obtained in this study were above these deficiency levels. This is probably because of the cane burning practices that return P and K back to the soil and thus mitigated exhaustion of these nutrients below critical levels [33].

Soil EC

The soil EC of the cultivated land was 59% and 66% lower than the virgin land at 0-30 cm and 30-60 cm soil depths, respectively (Figure 5). This implies that the long-term conventional cropping practices resulted in reduction of the soil salt contents. The results were unexpected as the adopted long-term irrigation practices and accumulation of ashes from cane burning would result in development of salinity [33,34]. The most likely reason for the lower EC of the cultivated land than the virgin land was the good quality of irrigation water used in the plantation [35], which might leach down the salts. The torrential rainfall which used to occur during a summer season might also contribute to the leaching of salts. Thus, the current level of EC (0.51 $mScm^{-1}$) in Wonji plantation is in the category of optimum range [36].

The soil EC of both the cultivated and virgin land at 30 cm-60 cm depth were much higher than at 0 cm-30 cm depth. This might be attributed to leaching of salts from the top layer of the soil to the lower soil horizon due to the excessive irrigation [37] and rainfall.

Soil pH

The pH values of the virgin and the cultivated lands were not significantly different at both depths (Figure 6). The pH value was expected to decrease, as acid forming fertilizers have been extensively applied in the plantation (96-322 kg urea-N/ha) during the last 50 years. Hartemink and Wood [15] also stated that acid input as ammonium-N fertilizers and alkali removal as uptake of ammonium-N by the plant can result in acidification of the soil. Moreover, considerable removal of bases with the harvested sugar cane and the leaching of cations can also play a role in reduction of soil pH [38,39].

Unlike Wonji plantation, there was a decline in the soil pH in other sugar cane producing countries. For instance in Papua New Guinea, Hartemink et al. [22] reported an 11% decline during 18 years sugar cane production while in Australia, Moody and Aitken [38] reported 18% drop during 15 years cultivation. Masilaca et al. [40] also observed 14.4% drops in soil pH within 5 years production in Fiji. The invariable pH observed in Wonji plantation may be ascribed to the method of irrigation and the type of the soil in the study area. In the plantation, the major method of irrigation is blocked end furrow system. As the soil type of the plantation is heavy clay, this type of irrigation often resulted in severe water logging problem. According to Sun [41] water logging can increase the pH level of a soil through fast depletion of O_2 that leads to anaerobic conditions with concomitant reduction in Eh (redox potential). Reduction reactions use mainly H^+ and thus result in rises in pH. On the contrary, these scenarios might not have occurred in the New Guinea, Australia and Fiji studies, cited before, where the sugar cane is mainly rainfed.

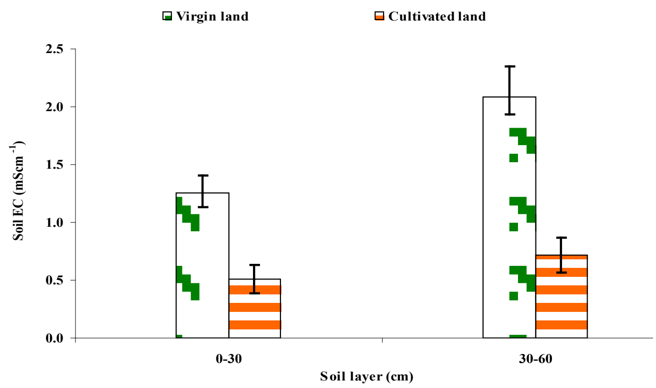

Figure 5: EC [$mScm^{-1}$] of soils at Wonji sugar cane plantation sampled from land areas under conventional cropping practices for 50 years and adjacent lands that were never cultivated [virgin] at 0 cm-30 cm and 30 cm-60 cm depths [means of five sampling sites]. Means of virgin and cultivated lands are significantly different at P<0.01. Vertical bars indicate ± SEM [standard error of mean].

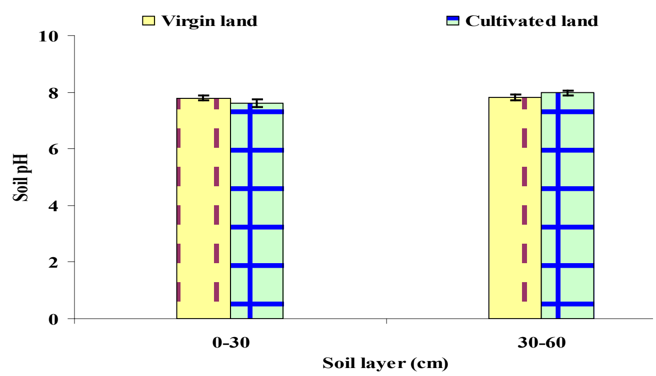

Figure 6: pH of soils at Wonji sugar cane plantation sampled from land areas under conventional cropping practices for 50 years and adjacent lands that were never cultivated [virgin] at 0 cm-30 cm and 30 cm-60 cm depths [means of five sampling sites]. Means of virgin and cultivated lands are not significantly different at P<0.01. Vertical bars indicate ± SEM [standard error of mean].

Conclusion

The long-term conventional copping practices substantially degraded the major soil quality indicators of Wonji plantation i.e., SOM, total N, available P and exchangeable K. Nevertheless, the soil pH and EC were in the optimum range that there are no problems related with soil salinity, alkalinity and acidity. As the soil of Wonji plantation is mainly heavy clay, particularly, the decline in SOM content along with the furrow irrigation system and the excessive traffic of machineries in the sugarcane plantation fields might play a role for the observed yield decline. This could be through exacerbating the detrimental effects of water logging and soil compaction. Thus, improving the SOM content could be essential in partly arresting the declining yield. Moreover an extensive multidisciplinary campaign should be further continued in order to fully identify, understand and manage the problem of soil quality deterioration.

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