Impact of Fertilizer Usage on Crop Productivity at Siguidolo

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Abstract— On a poor soil, fertilizers application is the best ways to meet crop need and restore the lost nutrients. However, its application is constrained in Mali due to the low access to fertilizers by smallholder farmers, resulting in low crop production. Today, make available to farmer’s fertilizer and information needed for its proper use is an essential asset for sustainable agriculture and food security. Before, assessing the existing fertilizer usage and it impact on yield is a prerequisite. A study was done to characterise fertiliser management practices at Siguidolo and assess the impact on millet and sorghum yields. Thus, normalized difference vegetation Index (NDVI) and visual interpretation were used to estimate vegetation cover as sources of organic matter (OM). Investigation was done to get information about manure production and areas occupied by crop production. Geographic Information System and Survey was done to obtain information on fields, fertilizer used and yields. The results showed low vegetation cover (0.02 to 0.24) indicating low source of organic matter. The mean manure produced was 14373 kg/ha/year while 69300 kg was recommended. Organic fertilizers and integrated organic and mineral fertilizers occupied greater area. About 24.1% of the area did not received fertilizer. The extremely low fertility areas tended to receive more nutrient application. Indications are that, even in those areas where fertilizers were applied, the right quantities were seldom used. Low yield for millet and sorghum was recorded ranging from 414.66 kg ha−1 to 703.80 kg ha−1 for millet and 404.12 kg ha−1 to 448.04 kg ha−1 for sorghum.

Keyword— Fertilizer, usage, crop, productivity, Siguidolo.

I. INTRODUCTION

One of the main factors limiting crop efficiency and food security in Mali is the low natural fertility of the soils and its continued decline over years of cultivation. The decline in soil fertility and low nutrient application is the leading cause of the declining per capita food production in Sub-Saharan Africa (Chianu, 2012; Bremanet al., 1983; Kihara al., 2016; IFDC, 2006; Shapouri et al., 2010; Muller et al., 2012). Food production index per capita showed a declining trend over the last decades and about 29% of the population is estimated to be undernourished (FAO stat, 2008). To reverse this trend, it is important to replenish the removed nutrients which results from crop uptake, harvest, erosion and leaching. Fertilizers application is one of the best ways to meet crop need and restore the lost nutrients (Gatti et al. 2019). Fertilizers are any material of natural or synthetic origin which, when applied to soils, provide one or more nutrients essential to plants growth and yield (Barker, 2019). They occupy a prominent position in food security challenges on poor soils (Stewart et al., 2012). However, their application is severely constrained in Mali due to the low access to fertilizer (IFDC, 2015) by the poor smallholder farmers, resulting in low agriculture production. Today in Mali, make available to farmer’s fertilizer and information needed for its proper use is an essential asset for promoting sustainable agriculture production and food security while preserving environment. Before, assessing the existing fertilizers usage and it impact on crop production and food security is a prerequisite in the identification and development of appropriate improved practice. The objective of this study was to characterise the existing fertilisers management practices at Siguidolo and assess their impact one millet and sorghum yield in order to develop an improved method.

II. MATERIALS AND METHODS

2.1 Study site

Siguidolo is located in Segou region of Mali in a depression surrounded by the plateaux. It is between -6.80399° and -6.78583° N and 12.91624° and 12.91229° W. The mean annual rainfall is 700 mm. Soils are mostly

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During the rainy season, interrill (sheet) erosion is common with intermittent rills and gullies, some of which measure up to 1.0 m deep in the relatively hilly sites. In the depressions and valleys, particularly along the streams, waterlogged conditions often prevail during the rainy season presumably due to high water table.

2.2 Vegetation cover mapping

Normalized Difference Vegetation Index (NDVI) calculation and visual interpretation were used on a Quickbird image covering the study site about 75%. NDVI is the dimensionless index that is indicative of vegetation density and is calculated by comparing the visible and near-infrared sunlight reflected by the plant surface (reflectance). The vegetation Index was used to quantify the density of green leaf vegetation by the formula:

\[
\text{NDVI} = \frac{(\text{NIR} - \text{R})}{(\text{NIR} + \text{R})}
\]

Where

NI= Near Infra;
R= Red band

When NDVI calculation is applied on an image or a pixel, the output gives a value ranging between minus one (-1) to plus one (+1). A zero value means no green vegetation and close to +1 (0.8 - 0.9) indicates the highest potential density of green leaves. The spatial distribution and the density of vegetation have significant implications on fertilizer practices in an area.

The map derived from NDVI calculation was used for ground verification. Visits were done on various locations of the study area to identify and characterise known and unknown features marked on the map.

2.3 Assessment of organic manure production capacity

Investigation was done beside the households to get information about manure production capacity and the area occupied by agriculture. Dembele (1994) showed that, the average organic manure production by livestock was 153.5 kg/head/4 months in rainy season and 182 kg/head/4 months in dry season. These data and the number of livestock were used to calculate the average organic manure production during both seasons at Siguidolo. Data were then used to estimate the availability of organic manure per year.

2.4 Fertilizer practices mapping

Global Positioning System (GPS) was used to delimit farmers’ fields. Survey was done to obtain information on the fertilizer practices used in each field. Then, GPS and survey data were combined in Geographic Information System (GIS) environment to map fertilizer practices.

2.5 Assessment of the impact of fertilizer practices on yield

Survey was conducted beside the households to find out information about the ways of fertilizer usage (spread or micro-dosing, etc.), the types and amounts of fertilizers used, and yields obtained on the sorghum (Sorghum bicolor L. Moench) and millet (Pennisetum glaucum) fields. 36 out 38 households were interviewed.

III. RESULTS

3.1 Vegetation cover mapping

Vegetation assessment resulting from NDVI processing is presented in Fig.1. The image used for NDVI calculation covered 75.5% of the study area. The vegetation index values ranged from -0.01 to 0.24. This vegetation was classified into three savannah vegetation comprising bare soil (-0.01 - 0.02), grassland with scattered trees (0.02 - 0.05), and woodland with grass cover (0.05 - 0.24). The bare soil covered 278.26 ha (31.69%) of the area. The grassland with scattered trees occupied 451.01 ha (51.36%) and comprised grasses, such as Andropogon guayanus, crop residues and shrubs, such as Pilostigm a reticulatum. The woodland had an aerial extent of 148.93 ha (16.62%) and consisted of green vegetation including Vitellaria paradoxa, Parkia biglobosa, Adansonia digitata, Tamarindus indica, Lannea microcarpa and Lannea acida on the bottom of the toposequence, then some Lannea microcarpa and acida, Ziziphus mauritiana, Guiera senegalensis, Combretum micranthum, Combretum glutinosum, Bauhinia rufescens, Bauhinia reticulate, Pennisetum pedicelatum, on the top of the toposequence.
Fig. 1: NDVI of the study area from Quick bird image in 2014

3.2 Assessment of organic manure availability

A total of 398 cattle, 274 sheep, 312 goats and 43 donkeys were identified in the village. Table 1 shows the results of the basic statistical analysis about livestock. The mean values give the general magnitude of the data and the CV show the high variability between the household concerning livestock possession (minimum 0 and maximum 42). The mean bovine per household was higher than the others animals. Some households don’t possess animal.

| livestock | Bovine | Ovine | Goat | Donkey |
|-----------|--------|-------|------|--------|
| Mean      | 11.06  | 7.61  | 8.7  | 1.19   |
| Median    | 5.00   | 3.50  | 5    | 1      |
| Minimum   | 0      | 0     | 0    | 0      |
| Maximum   | 41     | 42    | 40   | 10     |
| Coefficient of variation (CV) | 102.56 | 131.32 | 116.73 | 158.62 |

Table 1: Livestock available at Siguidolo in 2014

Organic manure production capacity is presented in Table 2. Organic manure production was high in dry season. The highest amount of organic manure was produced by bovine.

| Average production of organic manure (kg) | Bovine | Ovine | Goat | Donkey | Total |
|------------------------------------------|--------|-------|------|--------|-------|
| Rainy Season (4 months)                  | 1698   | 1168  | 1335 | 183    | 4384  |
| Dry Season’ (4months)                    | 2013   | 1385  | 1583 | 217    | 5198  |

Table 2: Organic manure production capacity at Siguidolo in 2014
The type of mineral fertilizer used in the study site in 2014 is presented in Table 3. The Complexes Cereal is the most used with the mean of 102.1 kg/ha. NPK was not used at the site in 2014.

Table 3: Mineral Fertilizers used at Siguidolo in 2014.

| Mineral fertilizer (kg/ha) | Complexes Cereal | DAP | NPK | Urea |
|----------------------------|------------------|-----|-----|------|
| Mean                       | 102.1            | 4.29| 0   | 38.21|
| Median                     | 50               | 0   | 0   | 0    |
| Minimum                    | 0                | 0   | 0   | 0    |
| Maximum                    | 500              | 50  | 0   | 150  |
| CV                         | 118.5            | 331.37| 0 | 123.66|

3.3 Fertilizer practices mapping

Fertilizer’s practices data collected on the site was overlaid on the soil fertility status map (Fig. 2) in order to understand the link between soil fertility status and farmer’s fertilizers application decision. The fertility status varied from low, to extremely low. The very low status covered the greater area. Their respective area of coverage was 42.54 ha (4.81%), 134.9 ha (15.26%) and 706.61 ha (79.93%).

The spatial distribution of the fertilizers used in 2013 is presented in Figure 3. Fertilizer used were: complex cereal (CCI), complexecoton (CCt), urea (U), DAP, NPK, Organic fertilizer (OF). The extremely low fertility area tended to receive more nutrient application.
Table 4 shows the areal coverage of fertilizers. Organic fertilizers and integrated organic and mineral fertilizers occupied the greatest area of 333.51 ha over 506 ha. About 24.1% of the area did not receive fertilizer.

Table 4: Areas covered by fertilizers in 2013.

| Fertilizers                     | Area (ha) | Area (%) |
|---------------------------------|-----------|----------|
| No fertilizer                   | 122       | 24.11    |
| Organic fertilizer              | 132.01    | 26.08    |
| Mineral fertilizer              | 50.2      | 9.90     |
| Organic and mineral fertilizer  | 201.5     | 39.93    |
| Total                           | 506       | 100%     |

Table 5 shows the soil amendments applied in 2013 and percentage area of coverage. The very low fertility areas tended to receive more nutrient application.

Table 5: Soil amendments applied in 2013 and percentage area of coverage.

| Soil amendments                      | Soil fertility status | Low | Very low | Extremely low |
|--------------------------------------|-----------------------|-----|----------|---------------|
|                                      |                       | %   | area covered | % area covered |
| No fertilizer                        |                       | 55.57 | 19.67 | 28.96 |
| Organic fertilizer                   |                       | 15.82 | 23.69 | 40.76 |
| Mineral fertilizer                   |                       | -    | 12.87 | 1.99 |
| Organic and mineral fertilizer       |                       | 28.61 | 43.77 | 28.29 |
| Total                                |                       | 100  | 100    | 100           |
3.4 **Assessment of the impact of fertilizer practices on yield**

Information on soil fertility status, spatial distribution of millet and sorghum grain yields is presented in Figures 4 and 5, respectively. The means millet grain yield was 414.66 kg ha\(^{-1}\) on soil with low nutrient status, 703.80 kg ha\(^{-1}\) on soil with very low nutrient status and 558.2 kg ha\(^{-1}\) on soil with extremely low nutrient status. The corresponding yields for sorghum were 445 kg ha\(^{-1}\), 448.04 kg ha\(^{-1}\) and 404.12 kg ha\(^{-1}\) respectively. The very low and extremely low nutrient status soils were compensated by greater amounts of fertilizer application with a consequent higher grain yield than the relatively better low fertility soils. The percentage area of the low, very low and extremely low fertility status soils that received fertilizers were 44.4, 80.33 and 71.01 respectively.

![Fig. 4: Spatial distribution of soil fertility status and millet grain yield in 2014.](image1)

![Fig. 5: Spatial distribution of soil fertility status and sorghum grain yield in 2014.](image2)
IV. DISCUSSION

Vegetation is source of organic matter (OM). OM has many beneficial effects soil (Erich et al., 2002; Sanyal et al., 1991). It improves the physical, chemical and biological properties of the soil. Thus, Maurice et al.(1998) used organic matter as an indicator of soil fertility, overall soil stability and a factor influencing the reduction of soil erosion, soil compaction and bulk density (Vorhees, W.B. 1992). Fen-Li (2006) found that the vegetation effect on soil erosion was predominant. As Soil Organic Matter increases, the quantities of N, P, K available, carbon and certain micronutrients increase (Oates, 1998, Dembele, 2017). Acquaye (1990) reported that organic matter was the main source of N, P and S for plant growth in small farms without fertilizer. Nitrogen (N) use in crop production is inevitable target (Rosner et al. 2014). In addition, soil water infiltration is more influenced by vegetal cover and soil organic matter (Sampaio Almeida, et al., 2018) as well as nutrient and water holding capacities (Lal et al., 1998, Traore, 2003; Morgan, 2005; Barmani et al., 2013). They improve soil microorganism activities (Havlín et al., 2005), soil aeration, plant root growth and elongation and pH stability. Furthermore, vegetation covers cushions the soil against the erosive forces of water and wind (Vásquez-Méndez et al., 2009,) and thereby reduce their detachment and transport capacities with a resultant reduction in erosion. Assessing the vegetation cover of the study site therefore became necessary. The effectiveness of vegetative cover in reducing erosion however depends, in part, on its density and spatial coverage, the continuity of the canopy and height (Nanko et al., 2008). NDVI at Suigidolo varied from -0.01 to 0.24 indicating low and sparse vegetative cover and very low source of organic matter. This condition has negative effects on soil fertility and influences fertilizer management strategies. Manure production capacity impacts soil fertility in Mali because small scale farmers don’t own enough money to afford mineral fertilizer at the recommended level (Jens and al., 2007; PRSP, 2002). A mean of 11.06 cattle’s, 7.61 sheep, 8.7 goats and 1.19 donkeys per household was investigated in the site which produce 14373 kg/year of organic manure. This amount is not sufficient to meet a mean of 13.86 ha/household measured in the area where 5 ha is recommended. Except Complexes Cereal, the mean of the other mineral fertilizers used in the site was significantly below the recommended rate of 50 kg/ha of DAP and 50 kg/ha of Urénat by Ouyendebé (2010). Analysis has shown that the very low fertility area tended to receive more nutrient application. Indications are that, even in those areas where fertilizers were applied, the right quantities were seldom used. Sorghum and millet yields recorded in the study site were significantly low compared to 1424 kg ha⁻¹ and 1301 kg ha⁻¹ for millet in 2013 and 2014, respectively and 1378 kg ha⁻¹ for sorghum in 2014 harvested in research station by Traore et al. (2017).

Increasing Crop production and productivity at Suigidolo area, dominated by smallholder farmers require a set of accompanying soil conservation and efficient water utilization technologies. Sound soil fertility management, as recommended by Quansah (2000), should therefore use available livestock and poultry manure and crop residues wherever practical, taking appropriate nutrient credit for these materials and using mineral fertilizers to balance the crops nutritional requirements for realistic yield goals. These include ridge furrow system, tie-ridging, circular contour bunds, zai, cereal legume rotations and residue management. In contributing to this effort, the cropping systems in the area need to be study to show trends as a basis for recommending sustainable cropping systems to improve the biophysical and socio-economic conditions of the farmers.

V. CONCLUSION

Agriculture development at Suigidolo involves the improvement of organic matter production, and the adapted agriculture technologies.

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