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Promoting Sustainable Crop-Livestock Integration Through Farmer's Participation and Integrated Soil Fertility Management in the Sahel of West Africa

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1. Introduction

The sahelian climatic zone extends over several countries of West Africa. The "Sahel" region is charac terized by low and variable rainfall, ranging from 300 to 600 mm annually. In the Sahel of West Africa (SWA), increasing human population combined with long-term weather changes are transforming pastoralist systems based on transhumance and communal grazing of rangelands, and cropping systems based on extensive shifting cultivation, to more sedentary, intensively managed enterprises (Winrock International, 1992). As livestock husbandry becomes more settled, rangeland grazing is substituted slowly by crop residues feeding and cropland forage production, and feed shortage is becoming a major constraint for livestock production in the dry season (6-7 months) (Savadogo, 2000). As a result, most livestock in the southern SWA are integrated into mixed farming systems, involving the integration of crops and livestock.

Livestock make a major contribution to the transfer of nutrient from rangeland to cropland. However, when grazing crop residues, livestock remove more nutrients from croplands than they return in manure (Powell and Williams 1993). Farmers owing many livestock have the potential capacity to maintain soil fertility by recycling nutrients in fecal materials. But the majority of farmers practicing mixed farming in the Sahel has relatively few livestock and therefore is less capable of counteracting the soil degradation caused by livestock in their cropland. Thus, common constraints to mixed farming systems in SWA include: declining soil fertility, soil erosion and lack of access to agricultural inputs, and farmers make little use of external nutrient inputs because of scarcity of resources and inefficient fertilizer use (Powell et al. 1996). Indigenous soil fertility management strategies in SWA have therefore been driven largely by an extensive use of resources. Although farmers use many locally derived soil amendments (crop residues, manure, or termitaria), they do so more in desperation than by choice. The reasons for low fertilizer use include among others the poor natural resource base for agriculture, erratic rainfall, sub-optimal crop management practices (e.g., poor weed control), unattractive cost:benefit ratios for using external inputs (Breman and Debrah 2003).

Integrated soil fertility management (ISFM) is an integrated crop - livestock system that provides opportunities for improving soil fertility and promoting sustainable intensification of cropland and staple food production. In this respect, efficient nutrient management, including the use of manure from ruminant livestock, combined with an appropriate use of mineral fertilizers, possibly incorporating a rotation with legumes (dual-purpose cowpea), is a crucial prerequisite for sustainable mixed farming systems in the SWA. To this end, research should start with farmer's participation and include their knowledge of traditional cropping systems. Authors observed that most African farmers have a thorough knowledge of their cropping systems, and there are several examples of research using farmers' knowledge of traditional cropping systems to guide research and develop solutions suitable for their needs (Chambers et. al., 1989, Quansah et al., 2001).

The objectives of the study were to *(i)* assess farmers' knowledge of soil fertility management in the desert margin zones, *(ii)* understand the reasons behind the traditional practices in order to *(iii)* identify and adapt potential solutions for sustainable mixed crop-livestock integration in SWA.

2. Material and methods

2.1 Experimental site

Field experiments were conducted near Djibo, the main district of the Soum province of Burkina Faso located between 13°44′ and 14°50′ N (latitude), and 0°32′ and 2°07 W (longitude) (Figure 1). The experimental plots were chosen by selected sedentary pilot-farmers with livestock assets averaging 15 caws and 20 small ruminants (sheep and goat) per farm family. As such, there is a pressing need for cropland forage production. Farmers expressly choose, especially for fertilization trials, degraded land for experimental purpose, often due to expectations of increased soil fertility status on their infertile land through experimentation. Most of the experiments have been therefore conducted on infertile land.

Soil was acidic, contained 870 g kg^{-1} sand, 60 g kg^{-1} clay and 70 g kg^{-1}, and is classified as tropical ferruginous type (FAO-Unesco, 1973). The textural class is loamy-sand with low soil organic matter content and pronounced physical degradation. It's extremely coarse texture favors water infiltration, but the relatively high air temperature and low relative humidity most of the year, as well as the soil texture, do not favor soil organic matter accumulation. The main soil degradation is a result of nutrient depletion and water erosion. The topsoil (0-20 cm) at the trial sites before planting in 2003 had, on average, a pH of 5.7, an organic carbon content of 1.5 g kg-1 an available P (Bray) of 2.2 mg kg^{-1} and a CEC of 2.1 cmol kg^{-1}.

Djibo is located in the southern Sahel of Burkina Faso, characterized by a 3-month rainy season lasting from June to October, and a 8-month dry season from October to June. In 2003 and 2004, cumulative rainfall amounted to 577 and 290 mm, respectively. The region is traditionally dominated by a mixed crop-livestock farming system, including pearl millet, sorghum, cowpea and groundnut. Most of the experimental plots were located far (> 500m) from the homestead and had not received any organic inputs, except for animal droppings of grazing cattle. Prior to the experiments, fields were traditionally cropped with millet without application of manure or mineral fertilizers.

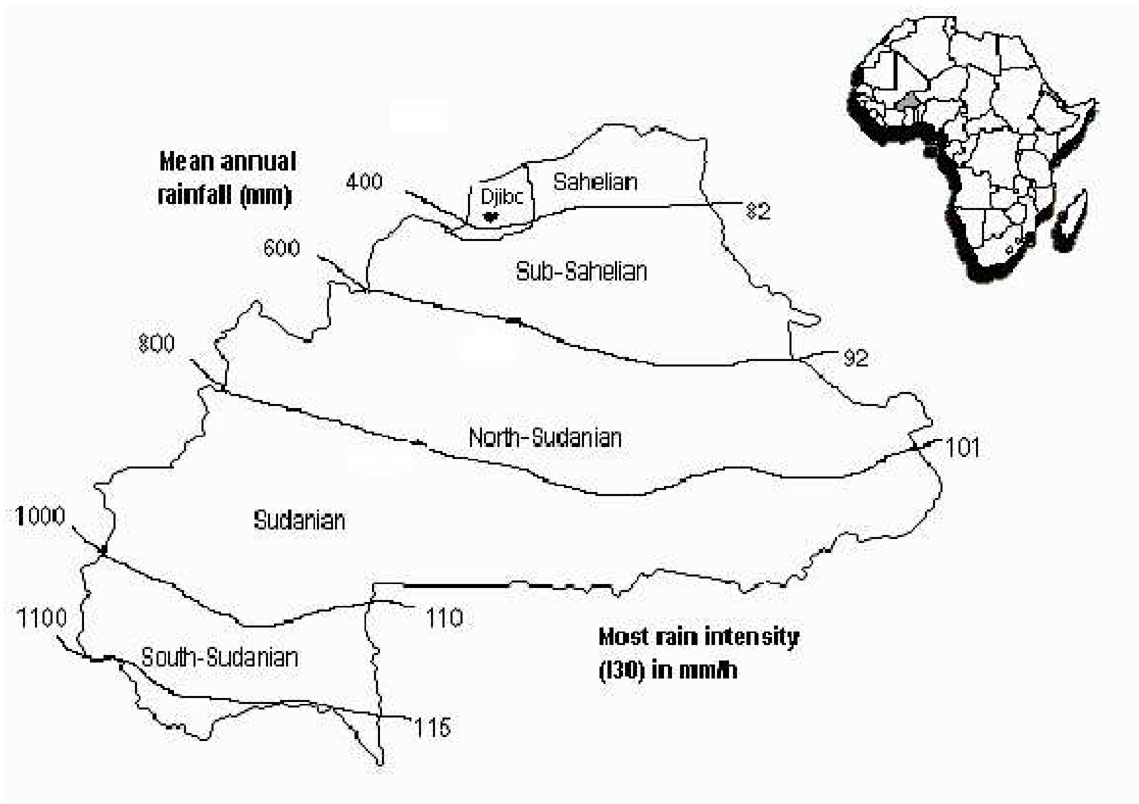

Fig. 1. Experimental site located in the Soum province (Djibo), in the north of Burkina Faso.

2.2 Farm household surveys

Farm household surveys were conducted to collect information on farmers' households including farm resources, current practices, constraints and opportunities with regard to the mixed crop-livestock system. Results were supposed to be used to set research priorities for soil fertility and livestock management options, and to identify pilot villages and farmers to collaborate with. To this end, a multi-visit participatory rural appraisal survey (PRAS) was conducted from May to December 2002 in the Soum province, located in the Sahel of Burkina Faso. This method characterized the agro-ecological zone on the basis of selected sites and extrapolated the results to a regional level (Ledoupil and Lidon, 1993). The PRAS was conducted in six (6) out of the nine (9) departments of Soum. It included 360 households living in 36 villages located in the departments of Aribinda, Baraboulé Kelbo, Nasoumbo, Pobé Mengao and Tongomayel. Farmers were selected in collaboration with national extension agents, a partner that has been involved from the start of the survey. They helped select farmers, focusing on different households that were representative of the area.

Selection criteria of departments, villages and pilot-farmers were well-defined to capture the dynamics that are so critical to the technology adoption process. Thus, the departments were chosen on the basis of herd size, population density and soil degradation. Farmers in SWA usually do not produce cropland forage and rely mainly on grazing pasture and crop residues for livestock nutrition. Pilot-villages were selected based on the soil fertility management practices including production and use of organic amendments (compost, crop residues, cover crops, manure), cropland forage and use of external inputs (fertilizer, improved variety, industrial byproducts for livestock). The PRAS concentrated on farmers owing at least ten cattle and/or small ruminants (goat or sheep), and inquired about livestock composition and dynamics, growing profitable cash crops and crops suitable for typical mixed cropping systems. Farm household information was collected with focus on human and natural resource needs and use for their activities, draught power, inputs and outputs of annual crop production on individual plots. Results of the PRAS were analyzed to distinguish production unit in different typologies defined as a household or group of households in which members work on the same fields and eat together (Samaké, 2003).

2.3 Modeling with SIMFIS (SImulating Mixed Farming In the Sahel)

The model is largely based on Struif Bontkes (1999) and composed of a number of subsystems including cropping systems, soil and livestock management. SIMFIS consists of a set of equations that are written in the Vensim language (Vensim DSS 5.3) and an EXCEL file (Struif Bontkes, 2006). The file contains general parameters pertaining to e.g. climate data, labor requirements, crops and prices. The parameters pertaining to a specific farm, e.g. number and size of fields and their soil fertility, number of animals (cattle, goat and sheep), crop and fertilizer use. The model therefore offers a way of identifying and quantifying significant interaction that occur between various components in mixed farming systems. Results of the participatory household survey were used as input data. By entering the basic data of a particular farm in an EXCEL sheet, SIMFIS can be used to quickly evaluate management alternatives that could be translated into operational support/guide for seasonal soil fertility management for an integrated crop-livestock production system. The model was used to evaluate farm management practices including crop rotation, soil organic amendments and crop residues recycling, and predict their impact on soil fertility evolution under actual soil fertility management practices.

2.4 Field experiments

Farmers were, under the supervision of extension agents, in charge of compost and manure collection/production, plot selection and for all farming operations. Participatory action research was conducted to promote ISFM options for cropland forage and cereal production. To this end, a field experiment was conducted in 2003 and 2004 by 4 pilot-farmers in Djibo. Experiment dealt with the effect of various manure types (cattle manure, mixed sheep and goat manure and compost) applied either alone or in combination of mineral compound fertilizer ($N_{15}P_{15}K_{15}$) on crop yield. Selection criteria for the pilot-villages were herd size and soil fertility management practices. The objective was, on the basis of the results of the PRAS, to promote sustainable cropland forage production for mixed farming systems through a judicious combined use of locally available resources (manure, compost, crop residues) and external inputs (seeds of improved variety, fertilizer etc.). Test crops for both experiments were millet and dual-purpose cowpea, identified by farmers as the most economically promising and suitable for mixed farming systems.

At the onset of the rainy seasons (early July), prior to land preparation and sowing, different manure types including cattle, sheep-goat and compost were distributed in the field by farmers as small heaps, applied by broadcasting and incorporated when hand ploughing. After land preparation, crops were sown in hills, distance between rows and hills within rows were 80 cm x 60 cm for millet and 75 cm x 40 cm for dual-purpose cowpea. Sowing was done in late July and all plots were weeded twice by hoeing at 15 and 45 days after sowing (DAS). To reduce/avoid damage to pods caused by aphids (*Aphids* spp.), cowpea was kept insect-free by application of Dimethoate at a rate 100 ml 20 l^{-1} of water twice at flower bud initiation and at mid-pod (50% of plants with pods).

The experiment design was a randomized complete block with 4 replicates including the application of locally available organic amendments (sheep/goat, cattle and compost) either alone at 2500 kg ha^{-1} (full recommended manure rate in Burkina Faso) or at 1250 kg ha-1 dry matter of sheep/goat manure (half of the recommended manure rate in Burkina Faso) in combination with compound fertilizer (N_{15} P_{15} K_{15}) applied at 50 kg ha^{-1} rate (half of recommended rate of 100 kg ha^{-1} $N_{15}P_{15}K_{15}$ in Burkina Faso), resulting in following treatment combinations:

- T_0: no manure and fertilizer applied (control)
- T_1: application of recommended fertilizer rate (100 kg ha^{-1} $N_{15}P_{15}K_{15}$ fertilizer)
- T_2: application of recommended manure rate of 2500 kg ha^{-1} dry matter
- T_3: ½ fertilizer rate + ½ sheep/goat rate.
- T_4 2500 kg ha^{-1} of sheep-goat manure
- T_5 2500 kg ha^{-1} of cattle manure
- T_6 2500 kg ha^{-1} of compost

The cultivars tested were IKMV 8201 for millet and KVX 745-11 P for dual-purpose cowpea, commonly grown in the Soum province. Each combination was repeated on-farm by four (4) farmers. Plot size for each treatment of experimental plots was 10 x 10 m. To confirm the results of the year 2003, treatments were once more imposed to both crops in 2004 in Djibo. But in 2004, unfortunately, most of the experimental plots were damaged by the erratic rainfall and worsen by the presence of desert locust in the sahel zone of Burkina Faso. The number of observation made was therefore not sufficient for accurate data analysis. Nevertheless, the minimum data recorded in 2004 is presented in Table 4.

2.5 Data collection and analysis

In 2003, soils samples were taken prior to land preparation (0-20 cm depth), ground to pass through a 2mm sieve, prior to chemical analysis of organic carbon, total N, pH-H_2O, pH-KCl and exchangeable Ca, K and Mg (IITA, 1982). Animal manure mixed with minor amounts of bedding and wasted feed from different cattle and sheep-goat corrals in the villages was collected in May 2003 and dried separately within feces type in the sun. Upon sample collection, the remaining quantity of manure was cleaned with a brush to remove loosely adhering soil particles. Manure samples were oven-dried to constant weight at 55^{o}C to determine total dry matter. Samples were thereafter ground to 2 mm to analyze macro nutrient (N, P and K) content. The central 36m^2 area of each plot including millet (grain and stover) and cowpea (grain and haulm) were harvested at maturity. Crop sub-samples were oven-dried at 60^{o}C, weighed and ground to pass 0.5mm and then analyzed for total N and P. Dry matter production and grain yield were expressed on a dry-weight basis. All analyses were conducted using standard methodologies in the ICRISAT laboratory in Niamey, Niger.

2.6 Statistical procedures and evaluation of economic performance

Analysis of variance (ANOVA) was carried out on grain yield and stover yield. When a significant treatment effect was found, comparison of treatment means were carried out using the least significant difference (LSD) test at the α=0.05 probability level (Gomez) and Gomez, 1984). Principal component analysis was used to classify production units in different groups, using information from the PRAS. The characteristics used to describe the profile of the smallholder mixed farming in the Soum province include age of farmer, number of compost pit, herd and farm size, and household labor unit.

The economic performance of the test crops was estimated using the value:cost ratio (VCR). VCR is calculated as followed: (yield with inputs – yield without inputs) / (cost for inputs). The inputs include NPK fertilizer, manure and seeds. The background of the millet and cowpea VCRs is as followed: the price including handling and transportation costs of 50 kg/bag of N_{15} P_{15} K_{15} fertilizers (7.5 % N, 3.3% P and 6.2% K) is 11500 F cfa; 1 kg manure is about 2 F cfa; 1 kg millet and cowpea grain is worth 90 and 145 F cfa, and 1 kg millet stover and cowpea haulm is valued at 20 and 40 F cfa, respectively.

3. Results and discussion

3.1 Participatory on-farm survey to characterize crop-livestock production systems

3.1.1 Typology of the smallholder mixed farming in the Soum province

Results of the PRAS conducted in the Soum province were used to distinguish production units (PU) of different groups. Table 1 gives an overview of the profile of households studied. Major criteria for the distinction between PU were age of farmer, number of compost pit, herd and farm size and household labor unit. Results showed three different PU with distinct characteristics that were significant (P<0.05). The typology defines farmer groups with specific combinations of land uses and resource endowment, as they are expected to react differently to specific circumstances or proposed technologies (Samaké, 2003). The following differences were observed between the production units.

	Production unit (PU)		
Characteristics per household	PU-A	PU-B	PU-C
Number of households	152	197	11
Age of farmer	48	45	42
Number of compost pits	0.7	0.6	1
Household labor units	13	6	6
Farm size (ha)	9	5	6
Number of cattle	17	4	4
Number of sheep	17	5	3
Number of goats	17	5	5
Number of pigs	0	0	23

Table 1. Typology of 360 mixed farming households, categorized by three production types, in the Soum province, Burkina Faso

The number of active persons ha^{-1} decreased from PU-A to PU-C and was 1.4 for type A, 1.2 for B and 1 for C. The average farm size were 9 ha, 5 ha and 6 ha for PU-A, PU-B and PU-C, respectively. Average number of compost pit per PU does not exceed one, indicating there is a pressing need for manure and compost production. Research should therefore promote technologies for compost and manure production. In addition, PU-A has more livestock (51) and should in principle have more manure available per unit area cultivated than PU-B (14) and PU-C (12). But manure from PU-A is scattered over the surrounding outfields and natural pastures as they are mainly pastoralists. They have large herd size and are therefore always in search of forage and drinking water for livestock, whereas those of PU-B and PU-C are characterized by regular seasonal migrations or are sedentary. There is closer integration of livestock with crop production on PU-B and PU-C farms. Thus, to facilitate the adoption of technologies for cropland forage production, the pilot-farmers selected for training came from PU-B and PU-C as livestock husbandry is more settled and feed shortages are a major constraint for livestock production on their farms

3.1.2 Farmers' perception of constraints limiting crop production

Indigenous farmers in the Soum province identified rainfall as a major limiting factor to crop production. However, poor soil fertility was implied in the problem analysis as farmers pointed out low crop yields was a major problem, linking this continuous cultivation of land, lack of soil moisture and nutrient deficiency (yellow leaves). Although it is often assumed that rainfall is the preliminary constraint to crop production in the Sahel, research in SWA demonstrated that the potential production from any given rainfall is limited by nutrient availability (Zougmoré et al., 2003; Fofana et al., 2005). Participatory research should therefore create awareness of the interaction between soil moisture and fertility. Solutions proposed by farmers to overcome declining soil fertility included use of manure (100%), compost (80%), inorganic fertilizers (56%) and crop rotation (15%) (data not presented). Irungu et al. (1996) conducted a survey in the semi-arid zone to assess soil fertility as perceived by farmers and reported that farmers' opinions considered crop vigor, invading plants, presence of earthworms and soil color. Indigenous farmers categorized soils according to their productivity. They define soil fertility by the duration under cultivation, linking continuous cultivation to soil degradation. In our survey, different soil types were classified on the basis of color and texture. White and/or sandy soils were associated with poor crop growth resulting from low soil fertility and poor water-holding capacity. Reddish and black soils were considered fertile but are known to be prone to water-logging and difficult to work. Also, farmers made associations between natural vegetation and soil fertility level. Weed species were also associated with soil fertility status, particularly *Digitaria horizontalis*, *Eragrostis tremula*, *Striga hermonthica* and *S. gesneriodes* in infertile fields and *Andropogon gayanus* in fertile outfields or natural pastures.

3.1.3 Farmers' perception of constraints limiting livestock production

Results of the survey showed two main forms of livestock production systems, i.e pastoralism and mixed crop-livestock farming. Pastoralism comprises two different movements including nomadism and transhumance. The former implies continuous movement of the herds in search of forage and drinking water, whereas the latter is characterized by more or less regular seasonal migrations from a permanent homestead

(Ayantunde, 1998). Farmer ascribed pastoralism to seasonal fluctuation in feed and water supply, the main constraint to livestock production. In the Soum province, natural pastures remain the major source of livestock feed. Thus, animals lose weight during the last months of the dry season and the beginning of the wet season (from March to July) as grazing and water resources diminish. Given the lack of alternative dry season feed, crop residues are used as vital livestock feeds rather than soil amendments. To overcome food shortage during this period, most farmers send their livestock to the southern zones of Burkina Faso where there are enough natural pastures and water reservoirs. As a consequence of the fluctuation of feed availability, manure output and distribution also vary. Hiernaux et al. (1999) reported weight losses associated with movement of animals in search of forage and drinking water. For sustainable livestock production, researchers need to investigate sustainable cropland forage production instead of rangeland grazing. This might reduce the need for constant movement, resulting in greater animal weight gains and give farmers access to more manure.

3.1.4 Nutrient sources and agricultural practices in relation to spatial variability of soil fertility

Most livestock in the Soum province are integrated with cropping systems. Traditionally, farmers in the Soum province have enriched soil fertility in the compound fields or 'infields' close to the homestead through regular application of household waste, crop residues and animal manure. Continuous cropping and grazing on fields further away from the homestead ('outfields') with little or no nutrient inputs, and use of crop residues as building materials and fuel resulted in nutrient depletion and decline in soil fertility. Farmers in the Soum province have therefore developed strategies to optimize crop production on these field types using various crops on the basis of their nutrient requirement. Pearl millet (*Pennisetum glaucum*) is grown on both field types, while sorghum (Sorghum bicolor) and rice (*Oryza sativa* or *O. glaberrima*) are grown on dark fertile soil (vertisols) in low lands. Outfields are however used for legumes and communal grazing. Farmers in the Soum province consider millet and cowpea as cash crop and cropland forage. As cowpea (*Vigna unguiculata*) and groundnut (*Arachis hypogaea*) are not manured, most of collected manure is used for pearl millet, sorghum and rice production. There is a weak link between the commonly practiced crop rotations and soil fertility improvement, apparently because of the relationship between the observed spatial variability in soil fertility and crop requirements for nutrients. Thus, farmers continuously crop cereals on infields and legumes on outfields. The observed crop sequences include pearl millet-maize-pearl millet on infields, and continuous cowpea, groundnut or Bambara- groundnut (*Voandzeia subterranean*) on outfields. Limited availability of fertile land is also considered the major cause for the lack of systematic crop rotations.

3.1.5 Soil chemical properties

Results showed large difference in natural fertility of infields and outfields. While soil pH (water and KCl) and potassium content were comparable for both fields, many other soil characteristics such as organic C, total N, total P, CEC, Bray-1 P,exchangeable Ca and Mg concentrations were significantly different (Table 2). In Mali, Samake (2003) reported C org values ranging from 5.4 to 8.5 g kg^{-1} on infields and 1.0 to 5.2 g kg^{-1} on outfields. C-org values reported by Sédogo (1993) in the Guinea Savanna zone of Burkina Faso ranged from 11-22 g kg^{-1} on infields and 2-4 g kg^{-1} on outfields. The soil properties measured clearly indicate that infields are more fertile than outfields, supporting farmers' perception of higher soil fertility status on infields. These could be ascribed to the continuous accumulation of organic amendments including all kinds of manure and household waste applied in the small ring directly surrounding the villages. The spatial variability in soil fertility between infields and those far away (outfields), was attributed to the long-term fertility management strategies of farmers.

Soil characteristic	Outfield	Infield	P value
pH – H_2O	5.7	6.1	0 .16 (ns)
pH – KCl	4.7	5.4	0.07 (ns)
K+ (cmol kg^{-1})	0.43	0.49	0.32 (ns)
Ca++ (cmol kg^{-1})	0.80	3.67	0.0001
Mg++ (cmol kg^{-1})	0.41	2.10	0.0045
CEC (cmol kg^{-1})	2.10	7.10	0.0008
C-org (g kg^{-1})	1.5	3.9	0.001
N tot (mg kg^{-1})	140	350	0.0009
P tot (mg kg^{-1})	88.6	130.4	0.0022
Bray-1 P(mg kg^{-1})	2.2	3.3	0.015
C/N ratio	11	11	1 (ns)

Significant at $P<0.05$, ns = not significant; infield is in close proximity to the homesteads while an outfield is located about 500 m and more away from the homesteads

Table 2. Average soil characteristics of eight infields and eight outfields, Soum province, Burkina Faso

3.1.6 Livestock management and soil fertility management

Livestock ownership defines the availability of manure. Results obtained showed positive correlation between access to livestock, manure availability and crop production (data not shown), depending on livestock variety and feed availability. Beside the provision of manure, cattle and donkey provide transport and draught power, giving farmers owning livestock and animal traction better access to manure and opportunity to cultivate more land. Transhumance and communal grazing systems allows for uncontrolled grazing animals on rangeland and crop residues, enabling livestock owner to "harvest" nutrient from natural pastures and fields of farmers who do not own livestock. From the 360 interviewed farmers, 50% are sedentary and integrates livestock with crop production, 34% practice transhumance, which implies seasonal migration during the later part of the dry season and early wet season (March to July), and 16% are pure pastoralists always in search of forage and water for livestock. While pure pastoralism is the major livestock production system in the northern Sahel (Powell et al., 1996), results of our survey indicate that mixed crop-livestock farming system is the dominant production system in the Soum province. There is little doubt that, especially in sub-Saharan Africa, increasing integration of crops and livestock is going to occur over at least the next 30 years (Thornton and Herrero, 2001). In such a system, there is a pressing need for more cropland forage production as crop residues including cereal stover, groundnut and cowpea hays provide vital feeds during the 6-8 month dry season. Hence, the potential of arable land to provide forage throughout the year must be enhanced. Developing ISFM-strategies for sustainable cropland forage production is a major research challenge if the important role of livestock in improving soil fertility and household welfare is to be maintained or further developed.

3.1.7 Animal manure production

The majority of farmers in the Soum province obtained manure either from their own livestock, from the livestock of other farmers, or through exchange relationship with pastoralists. There are three key methods of manure production: gathering manure from corrals, picking up manure from natural pastures and fields (infields and outfields) surrounding households, and composting. But most of interviewed farmers (80%) harvest manure from natural pastures and neighboring fields, as getting enough manure from corralling requires greater herd size than is kept on most farms. Our survey indicates an average herd size per pilot-farmer of about 8 cows, 8 sheep and 9 goats (Table 1). This indicates that most of livestock-owners may not necessary produce adequate manure to replenish nutrients harvested from cropland. Composting is mainly used by farmers who have no livestock, and in most cases crop residues are included in the compost . Manure is continuously dug out from barns and heaped in pits along with wasted feed and crop residues for composting, which is considered by farmers as labor-intensive.

3.1.8 Animal manure quality and use

Manure is the most used organic amendment in the Sahel of Burkina Faso. While the use of manure includes that from cattle, goats and donkeys, sheep manure is the most preferred and widely used. Manure quality has been defined by farmers on the basis of its source (cattle, goat or sheep), structure, color and the crop response to its application. In the Soum province, 75% of interviewed farmers distinguish and strictly separate manure on the basis of the source, 94% consider manure from goat to be the best quality followed in decreasing order by sheep, cattle and donkey. While manure from cattle and donkey are mainly used for millet and sorghum, sheep-goat manures are particularly used for maize and rice cropping. Manure is transported to the fields just prior to the start of the cropping season (May-June). Carts are the usual mode of transport, poor farmers however used wheelbarrows. The most common application method is to broadcast, although some “smart” farmers practice spot application by placing manure into sowing holes. Spot application is considered more efficient than broadcasting (Munguri et al. 1996). Prior to broadcasting, manure is distributed in the field as small heaps for uniform distribution. But exposing manure to the sun may lead to N volatilization, resulting in decreased manure quality (lower N content) (Esse et al., 2001). Broadcasting is usually done immediately prior to sowing, and manure is incorporated through hoeing.

3.1.9 Animal manure availability

The amount of rangeland needed to feed livestock and capture enough manure for subsequent application to cropland needs to take into account the high variability in the productivity of rangelands, which is assessed at various rangeland:cropland ratios (Hiernaux, 1993). Estimates of rangeland:cropland ratios typically range from 15 to 45 ha of rangeland needed to support the number of livestock that will produce sufficient manure for one hectare of cropland (van Keulen and Breman, 1990). Manure availability for cropping is mostly limited by livestock types and numbers, spatial location at manuring time, manure output per animal, efficiency of manure collection, and the amounts of feed and land resources available (Powell et al. 1996). Sedentary farmers practicing mixed crop-livestock systems in the Soum province are poor in livestock assets (Table 1). Fernandez-Rivera et al. (1995) estimated that during the 8-month period when farmers apply manure to cropland, about 300 kg DM of manure could be collected from a 300-kg cow, 60 kg from a 35-sheep and 45 kg from a 25-kg goat. Similarly manure production was reported by Matlon and Fafcahmps (1988) in northwestern Burkina Faso. Based on the above figures, the quantity of collectable manure for sedentary farmers in the Soum province (PU-B and C, Table 1) is on average 1.7 t PU^{-1} $year^{-1}$, whereas national extension agencies in Burkina Faso recommend an application rate of 5 t ha^{-1} to cropland The collectable manure of 1.7 t PU^{-1} could cover only 0.34 ha of the average 5.5 ha cultivated land area per PU, corresponding to 6% of cultivated land of each PU. These values suggest that the current soil fertility management options cannot adequately sustain the required food and fodder production in the Soum province. Therefore, research should, particularly in SWA, investigate alternative technologies to increased manure production (quantity and quality) and use.

3.1.10 Farmers' perception of good manure

The criteria used by farmers to classify manure include source, color, structure, age and the decomposition rate. Farmers accordingly defined freshly collected sheep-goat manure as being the best quality adapted to their production system because it withstands termite pests and decomposes slowly (effective for 3 years) compared to cattle manure. Thus, sheep-goat manure is directly used on field as organic fertilizer. Yet, farmers in the Soum Province widely believe that sheep-goat manure burns crops, especially when rainfall is low. The N content in fresh cattle manure is shown to be higher than in dry cattle manure, probably because of N volatilization (Powell et al., 1996). However, cattle manure is mainly composted in combination with crop residues (pit-composting) as its water content is higher, contributing to rapid decomposition of organics when pit-composting. Good compost is supposed to be whitish, not sticky, cold and have a crumby structure as it dries. The heat generated during the composting process is believed to kill weed seeds, and this has been confirmed through on-farm research that revealed a 65-70% decrease in weed seed density in manure heaped for 1-5 months (Jonga et al;, 1997).

3.1.11 Chemical manure characteristics

Results of chemical analysis of compost and manure from cattle and sheep-goat are shown in Table 3. Sheep-goat manure has a higher N content and lower C/N ratio than compost and cattle manure. The amount of faecal N that could be collected is dependent of animal diet selection, whichvaries according to the season (Ayatunde et al. 2001). Data from other studies reviewed by Diarra et al. (1995) suggested the average N concentration in cattle's diet varied from 2.0% in the mid-wet-season, 1.2% in the early-dry and 0.6% in the late-dry season. With N content of 6 g kg^{-1} in compost, 9 g kg^{-1} in cattle and 14 g kg^{-1} in sheep-goat manure (Table 3), N concentration in the three manure types were lower than the 20 and 23 g kg^{-1} respectively, reported by Brouwer and Powell (1998). These differences could be ascribed to the fact that manure collected in this study came from indigenous farmers, left in the sun and unprotected against ammonia volatilization, whereas the manure used by Brouwer and Powell (1998) were mixed with urine right at the trial site. The higher N concentration in sheep-goat manure compared to cattle manure is in line with our observations and confirms also the farmers' perception of good manure. But the observed differences in N concentrations between manure types may be due also to differences in the feed and specific physiological characteristics of both ruminant species. Schlecht et al. (1997) showed that faecal N concentrations were significantly higher for small ruminants than cattle when fed with green forage, whereas concentrations were similar for both types of ruminants with straw feeding. C/N ratio in sheep/goat manure is lower as compared to cattle. High quality of organics has generally been defined as having low C/N ratio and decomposed relatively faster, and are therefore able to release nutrients than can be utilized by growing plants in the short term.

	pH-H_2O	C Org	N Total	P Total	K^+	Ca^{2+}	Mg^{2+}	C/N
Manure type	*(1:2.5)*		*%*			*cmol+/kg*		*ratio*
Cattle	7.8	17.4	0.9	0.4	5.6	1.5	2.1	19.4
Compost[1)]	7.2	10.1	0.6	0.9	3.0	2.4	3.1	16.8
Sheep-goat	7.6	19.5	1.4	0.4	5.4	2.1	3.4	14.0

[1)]Compost is a mixture of cattle manure and all kinds of crop residues and organic wastes

Table 3. Chemical characteristics of manure and compost in the Soum province, Burkina Faso

The constraints to manure use in SWA include the lack of adequate quantities recommended, the slow or no release (N immobilization) of nutrient from low quality of organics, and the lack of water and labor for composting (Enyong et al., 1999). To overcome this constraint, on-the-job training was organized for pilot-farmers in the Soum province. The training topics include techniques of production of high quality manure and efficient use, application methods and crop nutrient requirements.

3.1.12 Mineral fertilizer use and availability

The amounts of fertilizers used by farmers in the Soum province largely depend on availability and accessibility of nutrient sources and crop requirements rather than recommendations by extension services. Most farmers do not apply fertilizers to fields (infields) that they perceive to be fertile. Also, they clearly differentiate crops on the basis of their nutrient requirements and perceive maize, rice and sorghum as having high nutrient demands compared to millet and legumes. Poor adoption of mineral fertilizers by farmers is the major highlight of soil fertility management in the Soum province and largely attributed this to the risk associated with the use of expensive fertilizers under unfavorable cropping conditions including erratic rainfall and very eroded and degraded soils (Fofana et al., 2005). Under these conditions, most farmers also believe that fertilizers burn crops. Most of the available fertilizers are used for pearl millet, sorghum and particularly for irrigated rice production. The extension services in Burkina Faso recommend 100 kg ha^{-1} and 50 kg ha^{-1} of fertilizer urea (46% N) for millet and sorghum production. While the actual fertilizer use in Burkina Faso is 7 kg ha^{-1} (Hien et al. 1994), our survey in the Sahel of Burkina Faso revealed an average fertilizer rate of about 5.6 kg ha^{-1}, including compound (mainly NPK_) and single (urea) fertilizers. Farmers traditionally mix seeds and fertilizers in the calabash and apply fertilizer simultaneously in micro-doses (i.e., in the planting hole) when sowing.

Soil fertility management practices in the Soum province indicate that current cropping systems are largely based on extensive management of resources and are not adapted for more intensive farming systems. Maintenance of soil fertility involves the replacement of nutrients removed from the soil through harvested crop products, leaching, erosion and other pathways. This concept has apparently not been built into the indigenous management practices.

3.1.13 Scenario impact assessment of current farmers' practice on soil fertility changes

Farmers in the Soum province rely mainly on manure and crop residues recycling to sustain soil fertility under current management conditions. Simulated data show decreasing soil organic matter (SOM) and total P content over time on infields, in spite of the application of animal manure and regardless of the crop rotation (Figure 2). The SOM content in the Soum province is generally less than 0.5%. Murage et al. (2000) reported that among soil organic carbon pools and fraction, total soil organic C seems to be a suitable indicator of soil quality. Giller and Cadisch (1997) reported that animal manure additions of 60 t ha^{-1} only increased soil carbon from 0.25 to 0.66 % over a period of 18 years. These studies revealed that the storage capacity for SOM in soil depends on the amount of clay content and silt in the soil. Most of upland soils in the Soum province are very sandy, have a poor aggregation and weak physical stabilization effect on SOM. Sandy soils therefore are not good at preventing SOM from microbial decomposition. This may explain the small C org content in SWA sandy soils, regardless of the quantity of soil organic amendments applied and the land use systems.

Apparently, current soil fertility management practices in the Soum province lack the capacity to maintain or increase the level of soil organic matter and total P content. The current farmer practices which are mainly based on using locally available organic resources and exploiting spatial variability of soil fertility should be complemented with options aimed at encouraging farmers to judiciously combine fertilizers with locally available and accessible soil amendments including all kind of organics (compost, manure, crop residues) and minerals (rock phosphate, dolomite etc.).

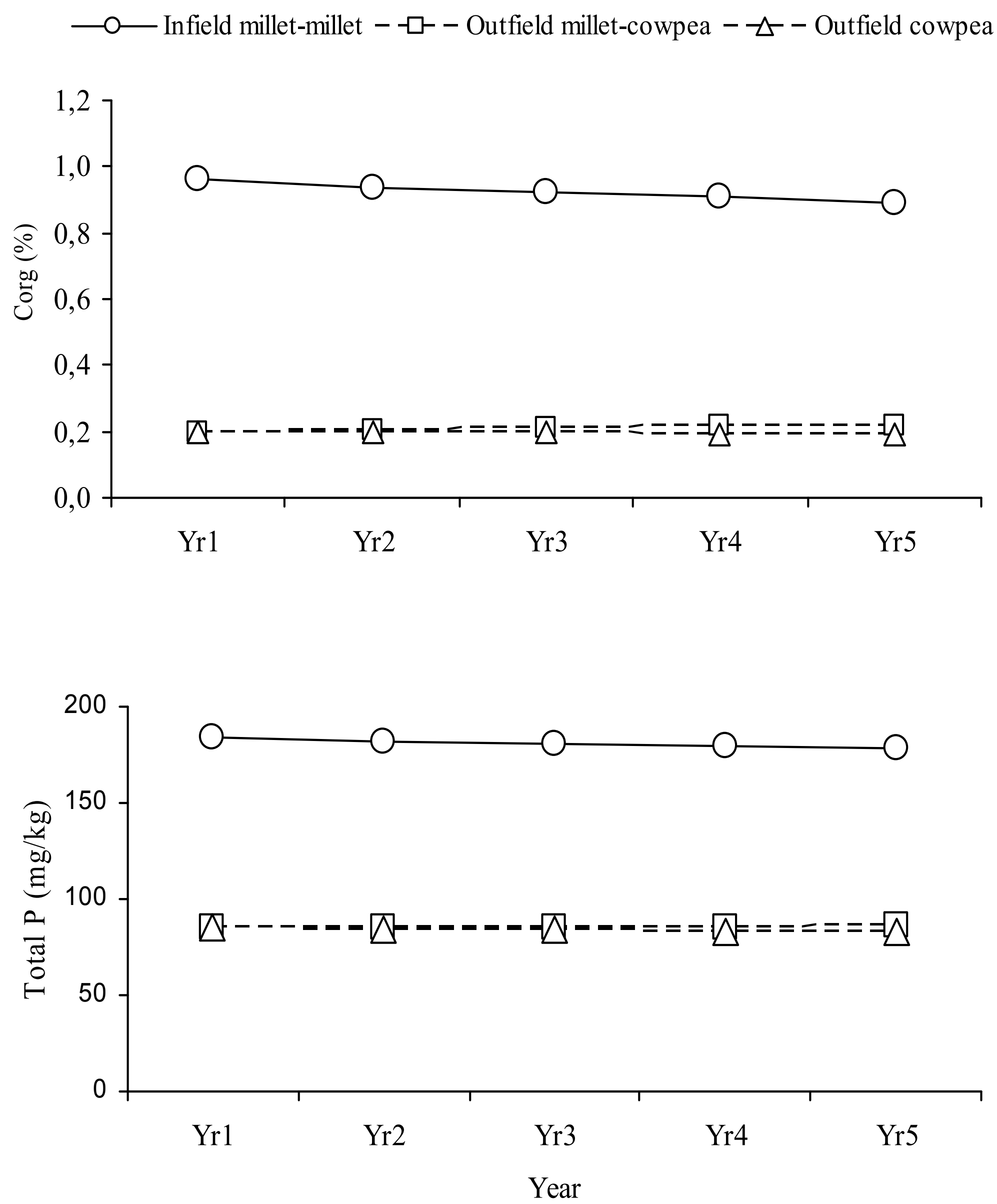

Fig. 2. Simulated evolution of soil organic matter and total P under different crop sequences on infields and outfields using the QUEFTS model (Janssen et al. 1990) (quantitative evaluation of the fertility of tropical soils). Solid lines refer to infields; dotted line to outfields, Soum province, Burkina Faso, 2004

3.2 Combining animal manure and fertilizer for sustainable and productive cropland forage production

3.2.1 Yield performance of tested ISFM technical options

Cowpea yields were significantly affected by manure and fertilizer application (Table 4). Low grain yield were obtained when sheep-goat manure was applied. Application of compost or cattle manure resulted in higher grain yield, probably because of higher P and Ca content, particularly in compost (Table 3). Authors reported higher cowpea yield performance with appropriate P, Ca and Mg fertilization (Giller et al. 1995, Bado et al., 2006). Yields were lowest without manure and fertilizer application (control). Highest yields were obtained either with fertilizer applied at recommended full rate (100 kg ha^{-1}) or with both manure (2500 kg ha^{-1}) and fertilizer (50 kg ha^{-1}) applied at half rates.

Dual-purpose cowpea							Pearl millet			
	Grain			Shoots			Grain		Shoots	
Year	2003		2004	2003		2004	2003		2003	
Treatment										
Manure (M)										
T_4	499	a	356	1989	b	1419	284	b	997	b
T_5	370	b	306	1934	b	1599	520	a	1585	a
T_6	521	a	492	2894	a	2733	549	a	1640	a
Fertilization (F) + Manure										
T0	366	c	330	1994	bc	970	367	b	1206	a
T1	508	ab	400	2710	a	1095	552	a	1578	a
T2	421	bc	350	1877	c	715	393	b	1349	a
T3 [1)]	558	a	550	2509	ab	1355	493	ab	1499	a
Probability Level										
Manure (M)	0.05			0.05			0.00		0.00	
Fertilization (F)	0.00			0.01			0.05		ns	
Interaction M x F	ns			ns			ns		ns	

Values affected by the same letters within the column are not significantly different according to $LSD_{0.05}$;
[1)] T_0: no manure and fertilizer applied (control); T_1: application of recommended fertilizer rate (100 kg ha^{-1} NPK fertilizer); T_2: application of recommended manure dry matter rate of 2500 kg ha^{-1} ;
T_3: ½ fertilizer rate + ½ sheep/goat manure rate, T_4: cattle manure at 2500 kg ha^{-1}, T_5: sheep/goat manure At 2500 kg ha^{-1}; T_6: compost including all kinds of manure and organic wastes

Table 4. Yield performance of dual-purpose cowpea and pearl millet as affected by fertilizer and manure application in the Soum province, Burkina Faso.

Manure and fertilizer application resulted also in significant millet yield increase (Table 4). Application of sheep-goat manure or compost significantly increased millet grain and shoots yields. Low yields were obtained when cattle manure was applied. Lower C/N ratio observed in compost and sheep-goat manure apparently contributed to nutrient release that meets millet nutrient requirement, resulting in increased yields. Lowest yields were recorded when no fertilizer or manure was applied. Highest yields were achieved either with NPK fertilizer applied at recommended full rate or with the combination of both manure and fertilizer at half rates. The highest yields results suggest the efficiency of integrated use of fertilizers and organic soil amendments. The crucial role of ISFM for judicious nutrient management and use has been reported by many authors (Fofana et al., 2005, Wopereis et al. 2006).

3.2.2 Economic performance of tested ISFM technical options

Calculation of the value:cost ratio (VCR) shows that combined application of manure and compound fertilizer (NPK) at half rate result in the highest economic benefits, and this is true for both dual-purpose cowpea and pearl millet production. With a VCR value of 5.9 (2.1 for millet), dual-purpose cowpea production seems to be more profitable than millet (Table 5). Higher fertilizer application rates (100 kg ha^{-1}) also resulted in relatively high VCR values for both crops. Results suggest that fertilizing dual-purpose cowpea with half of the recommended fertilizer rate and manure at recommended full rate to produce cropland forage might be profitable for sedentary farmers from PU-B and C (Table 1). A combined use of locally available phosphate rock (PR) (Kodjari) with manure (with PR-enriched compost), especially for dual-purpose cowpea, might even be more profitable than the soluble fertilizers. The VCR concept provides a rough estimate of economic profitability and could be helpful in formulating recommendation for seasonal soil fertility management in mixed farming systems. Policy instrument such as the VCR are required to institutionalize soil fertility management at the grassroots level and facilitate farmers' access to inputs including soil amendments (e.g. compost, manure etc.) and mineral fertilizers. Farmers urgently need more opportunities to connect with markets for their products, and this will give them income to invest in external inputs for their farms.

	Pearl millet					Dual-purpose cowpea				
	Grain	Shoots	TEB	TIC	VCR	Grain	Shoots	TMV	TIC	VCR
	kg ha^{-1}		F cfa ha^{-1}			kg ha^{-1}		F cfa ha^{-1}		
Tmt										
T0	367	1206				366	1994			
T1	552	1578	24094	14375	1,7	508	2710	49230	14375	3,4
T2	393	1349	5218	5000	1,0	421	1877	3263	5000	0,7
T3	493	1499	17204	8250	2,1	558	2509	48408	8250	5,9

Tmt treatment, TEB total economic benefit, TIC total input costs, VCR value cost ratio, T_0 control, T_1 fertilizer rate of 100 kg ha^{-1} NPK, T_2: sheep/goat manure at 2500 kg ha^{-1} $year^{-1}$, T_3: ½ fertilizer rate + ½ sheep/goat manure at 1250 kg ha^{-1} $year^{-1}$.

Table 5. Value-Cost Ratio (VCR) of dual-purpose cowpea and pearl millet production for different combinations of fertilizer and manure, Soum province, Burkina Faso

4. Conclusions

The results indicate that there are close links between the perceptions and indicators of soil fertility used by farmers and researcher, and that farmers use their knowledge of soil types and differences in soil nutrient status to tailor their soil fertility management practices to different situations. The PRAS indicated that farmers' decisions to grow some crops on certain portions of their farm are governed by soil fertility status but the selection of those crops also provides opportunities for crop-livestock integration. Under the current management practices, the only viable nutrient sources are manure and crop residues. However, manure (and NPK fertilizer) application rates by farmers in the Soum province are considerably less than those recommended by agricultural extension. Farmers are more likely to allocate their limited organic resources to higher value crops on more productive infields of the farm than to improve degraded soils on outfields that are becoming progressively infertile due to nutrient depletion. Constraints to soil fertility improvement on outfields include lack of adequate quantity of manure and materials (water, crop residues and manure, wheelbarrows, shovels etc.) for making compost and transporting available organic amendments (compost, manure, household waste, crop residues etc.) to outfields, shortage of labor and water for pit-composting. Results of the study indicate that efficient and sustainable use of nutrients in sandy soils should involve frequent combined application of compost at half of recommended rates (2500 kg ha-1 dry matter) and compound fertilizers (N15P15K15), which is consistent with the ISFM approach. Thus, the way forward may lie in combining the best use of locally available organic amendments with external sources of nutrients. As the quantity of collectable manure, especially for sedentary farmers of PU-B and PU-C, is not sufficient to guarantee sustainable mixed farming systems, there is a pressing need to introduce improved fodder and water harvesting technologies as to produce more manure and compost even in the drought years through sustainable increased livestock and crop residues production using ISFM. Furthermore, there is a need to promote widespread adoption/adaptation of mineral fertilizer in SWA. Flexible approaches to management of fertilizers need to be further explored and promoted, including site- and crop rotation-specific fertilizer recommendation.

Research should therefore, especially for sedentary production units that mainly rely on crop-livestock integration, identify alternative nutrient sources, promote efficient use of existing nutrient resources in combination with fertilizers and industrial byproducts so as to intensify both cropland forage production for insuring forage availability during shortage period, and settled livestock production for increasing manure production. Thanks to farmers' perception on soil fertility management practices, we started investigating the residual effect of a 3-year continuous mono-cropping of pearl millet, dual-purpose cowpea, sorghum (*Sorghum bicolor*) and andropogon, on soil physical and chemical properties and nutrient use efficiency as well. Sustainable intensification of soil fertility management on arable land for cropland forage production will increase livestock and manure production at farm gate, saving natural pastures and sparing these ecosystems from degradation. These will contribute to the maintenance of crop and animal productivity by smallholder farmers in SWA.

5. Acknowledgements

We are indebted to the 360 smallholders in the Soum province for their cooperation during the household survey and on-farm field experiment. We are grateful to L. Konfe and O. Tambora for field work, and to the national project's Coordinator Mr. A.D. Somé for his fruitful peace of advice. Financial support to the investment project was provided by the African Development Bank, the Burkina Government and USAID. Additional funding was provided through Desert Margins Program funded by the Global Environment Facility (GEF) from United Nations Environment Program.

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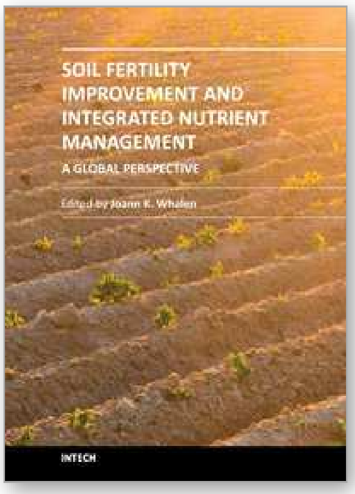

Soil Fertility Improvement and Integrated Nutrient Management - A Global Perspective
Edited by Dr. Joann Whalen

ISBN 978-953-307-945-5
Hard cover, 306 pages
Publisher InTech
Published online 24, February, 2012
Published in print edition February, 2012

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