Managing termites and organic resources to improve soil productivity in the Sahel[1]

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Overview

Termites, widespread and abundant in drier areas in the tropics, are not only pests, but can also play an important beneficial role in recovering degraded ecosystems. They are a resource that can be used and managed, together with locally available organic resources, to counteract land degradation through their soil burrowing and feeding activities. Land degradation is a major agricultural problem in the Sahel, and one of the most spectacular demonstrations can be seen in the extension of completely bare and crusted soils. In this region, the combined effect of soil organic matter depletion, primary production decrease due to mismanagement of the fragile ecosystem, and the harsh climatic conditions has resulted in the expansion of crusted soils. These soils are characterized by:

- very low infiltration capacity
- nutrient imbalances
- reduced biodiversity and
- low to nil primary productivity.

This situation has led to increasingly miserable social conditions such as:

- decrease in per capita availability of arable land
- decrease in per capita food production
- decline of human welfare and
- social crises due to ever increasing land shortage.

Soil rehabilitation efforts have been undertaken by governments of several Sahelian countries, however these are constrained by socio-economic conditions that limit the use of machinery and fertilizers, which are unavailable and expensive in most countries. An alternative practice for rehabilitating crusted soils is through the application of various organic mulches to the soil surface that attract termites and/or increase their activity. Their bioturbating activities in the crusted soils speeds their rehabilitation by:

- breaking up of surface crusts
- reducing soil compaction
- increasing soil porosity
- improving water infiltration into the soil and
- enhancing water holding capacity in the soil.

These activities create conditions that permit:

- root penetration into the soil
- recovery of a diverse vegetative cover and
- restoration of primary productivity.

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[1] This case study is based on the results obtained by Dr. Abdoulaye Mando, as part of his PhD dissertation (Mando, 1997), under the direction of Drs. Leo Stroosnijder and Lijbert Brussaard, of the Agricultural University-Wageningen, Holland.

Work performed by Dr. Mando in Burkina Faso has demonstrated that termites, far from being only traditionally-held pests in agroecosystems, can also be extremely important in soil rehabilitation efforts, in plant production and ecosystem function, and that it is possible to manage their activities for human benefit. In the denuded areas where mulch was applied and termites invaded, within 1 year native plants re-established themselves, and crops such as cowpea could be planted, yielding modest harvests (>1 T ha^{-1} grain).

The Problem: Soil degradation in the Sahel

Soil degradation and particularly crusting is a major agricultural problem in the Sahelian zone. The combined effect of extreme and difficult climatic conditions, overgrazing and trampling by cattle, continuous cultivation and other unsustainable management practices have resulted in the spreading of bare soils with a degraded structure and a sealed surface (crusts) that impede water infiltration and root growth (*Photo* 1). Such soils constitute a threat to Sahelian agriculture and restoration efforts must be undertaken if agricultural productivity is to be restored and sustained.

Photo 1. Bare plot in September 1994. The whole site was like this picture at the beginning of the experiment.

To solve the problems that confront rural areas in the Sahel, to secure food production, and to curtail further soil degradation, a variety of measures can be taken. These range from re-evaluating and adjusting macro-economic policies to the implementation of simple measures at the farm household level. Amongst others, this requires that the productivity of the arable land increase and also that the area of land under cultivation or pasture be extended at the expense of wasteland (Kaboré, 1994, Mando, 1997). However, because the Sahel is one of the world's poorest regions, any new techniques can only be adopted if they are cheap and easily accessible. Therefore, modern techniques often used in the developed countries, such as machinery and fertilizers are not feasible.

Alternative solutions: Mulch and termite activities

The stimulation of soil fauna, especially termites, in semi-arid regions is a viable option to improve soil structure (Mando *et al*., 1996). Termites can affect the soil by their burrowing and excavation activities in search of food, or the construction of living spaces or storage chambers in the soil or above-ground. In fact, soil structure, structural stability, porosity, decomposition processes and chemical fertility are altered to a large extent by termite activities. Based on this presupposition, the role of termites and mulch in the rehabilitation of crusted soil was examined. The main hypothesis was that application of organic material on crusted soil would trigger termite activity and that termite-mediated processes would promote the rehabilitation of the degraded soil.

Materials and methods

The study site was located in Bam Province, Northern Burkina Faso, in the Western African Sahel. Rainfall in the region is irregular (400-700 mm year^{-1}) and mean temperature ranges from 20-30º C, with great diurnal variation. Native vegetation consists mostly of annual herbs and shrubs, with few annual grasses. Soils in the region are ferric and haplic lixisols and chromic cambisols (FAO-UNESCO classification). Bare spots are abundant and human pressure on the environment is high. Termites are the predominant soil fauna in the region and consist mostly of the subterranean type, that do not create mounds on the soil surface. Three species of termites were found in the experimental field: *Odontotermes smeathmani* (Fuller), *Microtermes lepidus* (Sjöst) and *Macrotermes bellicosus* (Sjöst).

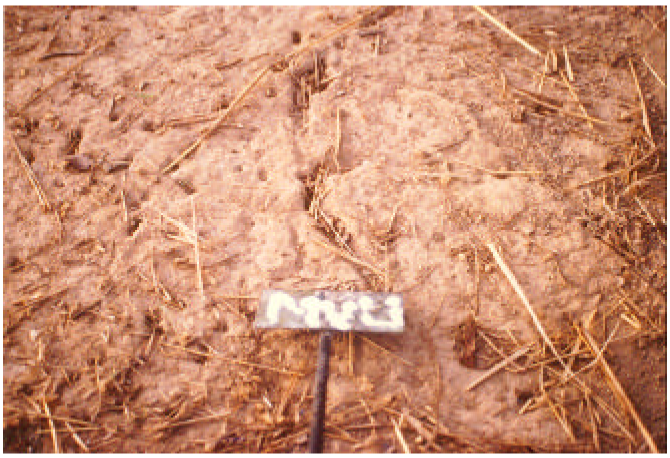
A split plot design with three replications was used to study the biological and physical role of mulch in the improvement of crusted soil and water balance during three consecutive years (1993-1995). Dieldrin (an insecticide) was used to obtain termite and non-termite infested plots. Four treatments with or without three different mulch types were randomly applied in subplots:

1. no mulch (bare plot)
2. straw of *Pennisetum pedicellatum,* at 3 tons ha^{-1}
3. woody material of *Pterocarpus lucens,* at 6 tons ha^{-1}
4. composite (woody material and straw) treatment, at 4 tons ha^{-1}.

Data on termite activity, organic matter decomposition, runoff, sediment accumulation, plant diversity and biomass of vegetation cover were collected on all plots.

In addition, another experiment with application of grass (*P. pedicellatum*) straw or cattle dung at 5 and 7 tons ha^{-1}mulch, respectively, was conducted to assess the effects of the presence/absence of mulch and/or termites on the growth and production of cowpea.

Photo 2. Termite-created voids on crusted soil after mulch application.



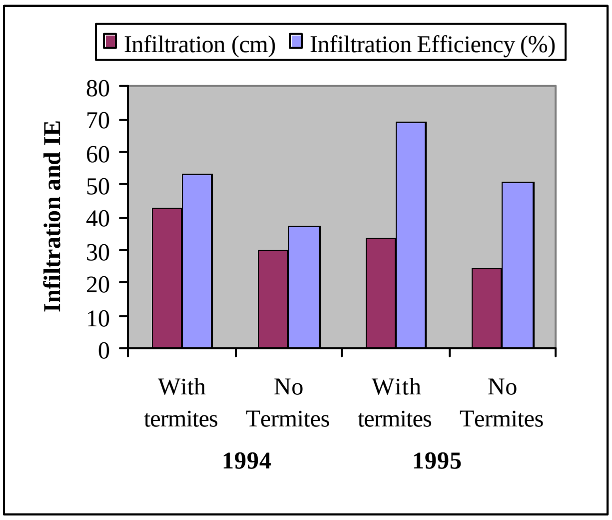
Soil rehabilitation, restoration of vegetative diversity, primary productivity and agricultural potential is stimulated through termite activities

No other soil fauna besides termites was observed on the plots, and no termite activity was observed on the plots sprayed with the insecticide. On the plots without pesticides, the application of organic materials (mulch) to the soil surface triggered termite activity, and termite colonization occurred in a relatively short time. Termite activity was similar under the different mulch types.

Termites and soil structure

Odontotermes smeathmani was the species mainly responsible for the termite-created features observed. These features included:

Figure 1. Effect of termites on soil water infiltration (cm) and infiltration efficiency (IE, %).



1. transport of material to the soil surface to construct sheathings for protection while searching for food
2. opening up of large voids on the sealed surface of the soil and throughout the entire soil profile (*Photo* 2 and 3)
3. soil aggregation, particularly below 10 cm, through the construction of bridged grains, coatings and crumbs that form the infillings of voids.

All three features had a critical influence on soil properties and processes. The transport of material to the soil surface loosened the soil enabling water to infiltrate more rapidly (Figure 1). Both termites and mulch reduced runoff and increased soil water content (storage) throughout the plant growing period. The area occupied by the large termite-created voids represented up to 12% of the topsoil (0-7 cm horizon), and accounted for 60% of the macroporosity in that horizon.

The role of mulch in improving soil water status was achieved by protecting the soil against evaporation and increasing water infiltration through its many tiny barriers. However, the differences in soil structure between plots with and without termites showed that the application of mulch alone was of much less importance in crusted-soil rehabilitation, than the effect of termites feeding on and transporting the mulch materials.

Photo 3. Cross polarized image of the microstructure of termite channels in the 0-10 cm layer of mulched plots. Note the interconnection of channels in the middle of the image (Ic).

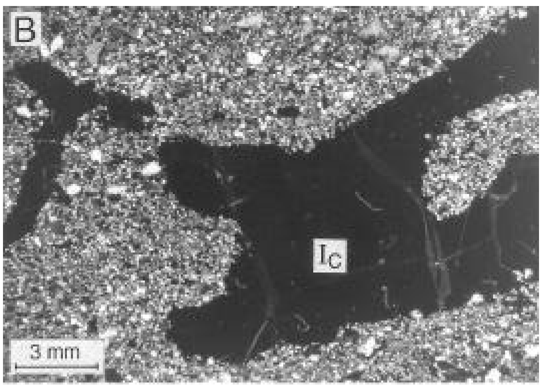
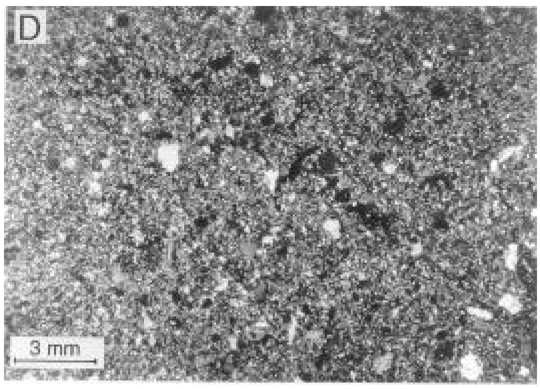


Photo 4. Cross polarized image of a compact grain microstructure in the 0-10 cm layers of a bare plot.



In the bare plots, the results of previous termite activity (voids, macropores etc.) could be seen below 30 cm, although the top 10 cm of the soil showed a compact structure, with no aggregates, and a clear inability to permit adequate water infiltration (*Photo* 4).

Termites and plant production

The mulching of a completely bare and crusted soil surface resulted, within one year, in the rehabilitation of primary production (*Photo* 5). However, plant diversity, plant cover and biomass and rainfall use efficiency of plants growing in mulched plots with termite activity (*Photo* 5) were greater than in the plots without termite activity (*Photo* 6; Table 3). Woody species only established in plots with termites.

Table 3. Effect of termites and mulch on vegetation parameters.

Treatment	Biomass (T ha^{-1})		Number of plant species			Woody plants ha^{-1}
	Year		Year			Year
	1994	1995	1993	1994	1995	1995
Straw + Termites	3.7	2.9	(3-13)	(11-25)	(26-35)	417
Wood + Termites	2.4	3.1	(1-15)	(5-11)	(18-30)	417
Composite mulch + Termites	3.3	3.9	(1-15)	(8-18)	(18-32)	665
Straw only	1.4	1.3	(1-8)	(6-10)	(8-21)	0
Wood only	1.2	0.5	(0-6)	(2-12)	(8-24)	0
Composite mulch only	1.4	1.1	(!-7)	(6-14)	(6-20)	0
Bare plot	0.0	0.0	0	(0-2)	0	0

Plant performance was best when straw and composite-mulch were applied, moderate when woody mulch was used, and worst without mulch application (bare plots) in the first year of the experiment. During the consecutive years, the performance of the vegetation in termite plots increased but this phenomenon was more apparent in wood-mulched plots compared to those that were straw-mulched. Straw had a quicker but shorter effect on vegetation performance whereas woody material had a slower but longer-lasting effect. Bare plots remained bare throughout the experimental period (*Photo* 1).

Photo 5. Termite-straw plot (TS) in September 1994. Note that the straw that was applied as a mulch had disappeared due to termite consumption, but the productivity of the soil was restored.

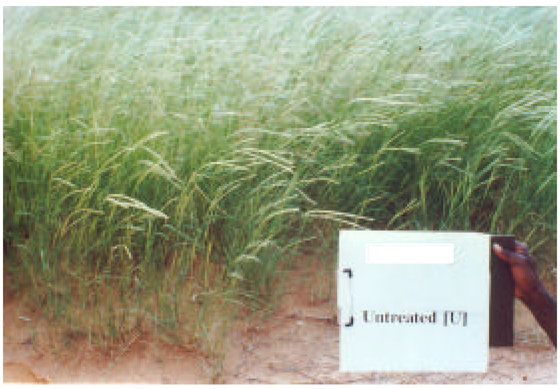


Photo 6 Non-termite straw plot (NTS) in September 1994. Note that two years after the lay out of the experiment, the straw is still not decomposed and the vegetation did not perform well, despite mulch application.

Although mulching without termites did not significantly improve plant production in already crusted soils, it had some effect on the growth of native plants by improving soil microclimatic conditions and entrapping wind-blown sediments and improving rooting conditions for plants.

Crop (cowpea) growth and yields were far better in plots with termites than in no-termite plots (*Photos* 7 and 8), and termites greatly improved the performance of the cowpea. Yields reached 1 ton ha^{-1} where manure was added and termites were present, while no cowpea grain was harvested when only straw was applied in the absence of termites (Table 4).

Table 4. Effect of termite addition to two different mulch types on cowpea yields, hydraulic conductivity and some chemical properties of a degraded Sahelian soil.

Treatments	Yield (T ha^{-1})	Mineral N (mg kg^{-1})	K (mg kg^{-1})	Total P (mg kg^{-1})	K_{sat}* (10^{-5} ms^{-1})
Cowdung + termites	1.02	21.0	87.5	130.5	1.2
Straw + termites	0.6	10.0	26.0	106.5	1.7
Cowdung only	0.01	10.5	50.4	140.2	0.9
Straw only	0.0	10.1	29.6	75.7	0.5

Ksat = Saturated hydraulic conductivity

Termites thus played the preponderant role in primary productivity, affecting vegetation growth through two main processes:

1. improvement of soil structure and water infiltration; this was the most important mechanism of termite-mediated rehabilitation of the crusted-soils;
2. enhancement of nutrient release into the soil from the mulch due to termite activity (Table 4).

In semi-arid conditions termite activity plays a key role in nutrient cycling, and the timing of mulch application is critical to optimize termite foraging period and the weather conditions necessary to synchronize nutrient release with plant demands.

Photo 7. Cowpea on termite plus cattle dung plots. Note that the termites had consumed all the cattle dung applied as a mulch without negative effects on the growing crop.

Photo 8. Cowpea on non-termite cattle dung plots. Note that 7 months after the lay out of the experiment, the cattle dung is still not decomposed and that the crop did not perform well, despite cattle dung application.

Conclusion: The potential for widespread biological soil remediation

The present study has shown how locally available organic resources (straw and woody materials, manure) can be applied to the surface of crusted soil to trigger regenerative termite activity within a few months. Despite the additional labour involved in gathering and spreading these materials (human constraints), the benefits are not only immediate, but also long-lasting. The major natural constraint on the wide-spread adoption of this technique however, would be the removal of plant material from one area to regenerate another. The amount of material removed must never reach a level where it causes degradation of the site it is being removed from or the activity defeats its purpose. But once the productive capacity of the ecosystem is restored, it is likely that the vegetation produced can act as the continuing source of food for the termites, who will then use the organic materials to continue their bioturbation activities critical to the maintenance of soil structure and plant production.

Termites, traditionally held to be pests in many occasions, can also be human friends. Termite activities repair the damage caused by soil degradation (crusting) through excavation across crusted surfaces, and the production of large voids that improve soil porosity and water infiltration into soil. Termites also enhance the decomposition of surface-applied organic materials stimulating nutrient release, which can then be used by growing plants. These results confirm that termites are not only pests, but can also be highly beneficial biological agents whose bioturbating and decomposing activities can be managed indirectly (with organic matter) to enhance primary production. Farmers in Burkina Faso and in other areas of West Africa are extensively making use of termite-mediated processes to enhance soil restoration and agricultural production in their farming systems (e.g., the zai/tassa system, where organic material is put into small holes in which termites enhance decomposition and increase water infiltration; see Roose *et al.*, 1992 and Mando *et al*., 2000).

Finally, these results also show that soil structure degradation is the result of eradicating native soil fauna (termites in this case) that were responsible for constructing and opening voids near the soil surface (top 10 cm), and counteracting the degrading processes destroying these voids. In order to avoid future land degradation, and to recover currently degraded lands, organic resources should be applied in a continued manner, to feed termites and maintain and promote their populations and their soil and plant regenerative activities.

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