Eucalypt litter quality and sandy soils: addressing two cumulative effects on topsoil organic-matter and soil faunal activity in African plantations

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Keywords: phenolics, soluble organic matter, soil organic matter fractionation, eucalypt, acacia

Abstract

A constraint in many sandy soils is their low organic matter content. Originating mainly from litterfall in forests, soil organic matter (SOM), besides its importance for soil fertility, is the feeding resource for soil fauna, essential for soil functioning. Because eucalypt are known for their low quality litter, their influence on SOM and soil fauna on sandy soils was investigated in comparison with a loamy-clay soil (Senegal) and a clay soil (Congo) and with tree species with contrasting litter quality. For this purpose particle size fractionations at the soil-litter interface were performed, and invertebrate density was assessed with the TSBF method. Eucalypt litter has a low N content and a high phenolic content. Both soil texture and tree species controlled SOM at the soil-litter interface, and low amounts of SOM were observed in the fine particulate fraction and the organo-mineral fraction under eucalyptus on sandy soils. High phenolic content in the litter might decrease particulate SOM. Tree species and soil texture influenced earthworm density, whereas termite and ant densities were mainly dependent on soil structure. The other litter-dwelling invertebrates were mainly dependent on tree species. Eucalypts and sandy soils present together some adverse effects on soil fertility, through both organic matter and biological activity. More extensive sampling in clay soils and experimental studies on the chemical influence of litters are required for a better understanding of soil structure-SOM-soil invertebrate relationships. However silvicultural practices which are able to increase organic matter in eucalypt plantations on sandy soils are essential for their sustainability. Logging residue management are currently being studied by UR2PI (Unit de Recherché usr la Productivity Des Plantations Commercials) who also tests the input of organic matter from non-eucalypt vegetation by inter-planting acacias with eucalyptus.

Introduction

Eucalypts are extensively grown in the tropics, either as farmer forestry or as industrial plantations mainly for paper pulp production. In Africa, many eucalypt plantations are grown on sandy soils, usually nutrient poor, which however are able to support tree growth. Eucalypt plantations were tried in the semi-arid Senegal in the years 1970-80s, on sandy soil and on loamy sand soil. In the Congo, commercial plantations are grown since 1978 near Pointe Noire, covering now more than 40,000 ha on sandy soils, under a wet climate, and a few experimental plantations are also grown on clay soils.

The main constraint of African sandy soils is their low soil organic matter (SOM) content and its decrease with cultivation (Feller et al. 1991, Walker and Desanker 2004). However SOM provides exchange sites, which contribute to nutrient conservation. Besides its importance for soil fertility and structure, SOM is the primary feeding resource for most soil living organisms and especially soil invertebrates, which in turn are essential for soil functioning (Lavelle and Spain 2001). So for sustainability of fast growing tree plantations, it is of significant importance to manage sandy soils in order to increase SOM.

In a forest environment, SOM originates mainly from litterfall and litter decomposition. It is well known that the litter quality of eucalypts is low (Woods 1974). Eucalypt leaf litter contains large amounts of phenolics (Bernhard-Reversat et al. 2001) which are antibiotic and anti-feeding agent for invertebrate and vertebrate fauna (Waterman and Mole 1994; Harborne 1997). Eucalypt litter quality leads to low biological activity and results in a low litter decomposition rate in eucalypt plantations.

Whether this low decomposition rate results in SOM accumulation in the topsoil is not clearly

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understood. The observation of particulate SOM fractions at the soil litter interface could bring some useful information. SOM fraction distribution was shown to be dependent on soil texture and on vegetation (Feller et al. 1991). The aim of the present paper is to study the effect of eucalypts and soil texture on organic matter incorporation to soil, and on macro-invertebrate density which is known to be dependant on vegetation (Lavelle and Spain 2001). Planted tree species of contrasting litter quality were compared to eucalypts.

Sites and methods

The climate of the Senegalese sites is semi-arid with nine dry months, and the study was carried out over several-years that included periods of lower rainfall than the average. One site was on a loamy sand soil (mean annual rainfall 500 mm) and the other on a sandy soil (mean annual rainfall 800 mm), both being tropical ferrugineous soils. The clay content of the topsoil is 5 and 15% respectively. In both situation the native vegetation was a dry forest dominated by *Acacia seyal*. The study was conducted in experimental plantations where several tree species were grown, and *Azadiracta indica* is compared here to *Eucalyptus camaldulensis* (Table 1). Eucalypts were finally shown not to be suitable for the climatic region. *A. indica* was previously extensively planted in villages, on roadsides, and in small farmer plantations.

In the Congo, large commercial plantations are grown around Pointe Noire on a ferralic arenosols

Table 1. Vegetation of the studied sites and number of samples for soil fractionation of SOM

Country Soil	Veget	Species	nb	Age
Senegal sandy	native	*Acacia seyal*	7	
	planted	*Eucalyptus camaldulensis*	11	8-10
		Azadirachta indica	6	9
Senegal sandy-clayey	native	*Acacia seyal*	6	
	planted	*Eucalyptus camaldulensis*	5	6-7
		Azadirachta indica	2	12
Congo sandy	native	savanna	9	
	planted	*Eucalyptus PF1*	65	6-16
		Eucalyptus HS2	38	7-11
		Acacia mangium	6	6-10
		Acacia auriculiformis	3	10
Congo clayey	native	savanna	3	
	planted	*Eucalyptus PF1*	3	12
		Eucalyptus HS2	3	7
		Acacia mangium	3	8
		Acacia auriculiformis	3	8

(sandy soil), and in experimental plantations in the Niari valley on a ferralic clay soil. The clay content of topsoil is 5 and 50% respectively. Both sites have a seasonal equatorial climate (mean annual rainfall 1,250 mm) with four dry months, although atmospheric humidity remains high throughout the year. *Eucalypts* were hybrid clones resulting from the 1950-70s forestry research, *Eucalyptus* PF1 and *Eucalyptus* 12 ABL x *saligna*, here called HS2 (Delwaulle and Laplace 1988). Australian *Acacia mangium* and *Acacia auriculiformis* (Table 1) were established experimentally and are not usually planted in Congo. The Congolese eucalypt plantations area was large and comprised many plots among which many samples were collected. Only a few plots were available for the clay soil situations where the sampling was less extensive.

Litter analyses were carried out on freshly fallen leaves from various sites, and the results were averaged regardless to the soil texture, which had little influence compared to species. Litter samples were air dried before being ground at 1.5 mm. Chemical analysis methods were previously described (Bernhard-Reversat 1998). Soil sampling for particle size fractionation was made in the 0 to 1-2 cm layer. The particle size fractionation of organic matter was adapted from Feller (1979), by sieving under water and floating. Carbon analysis was performed on each fraction. In the present paper, the data of the SOM fractions were collected in order to give three fractions, a coarse particulate fraction from 0.5 to 4 mm (Senegal) or 0.5 to 2 mm (Congo), a fine particulate fraction from 0.05 mm to 0.5 mm, and the remaining organo-mineral fraction less than 0.05 mm. In Senegal samples, the coarse particulate fraction under *A. seyal* included part of the small leaflets before their decomposition. It was observed in the Congolese plantations that soil organic matter content increased with the age of plantations, regardless to logging, and the planted plots older than 12 years old were not taken into account in order to have comparable age ranges in all planted species. Carbon was analysed with a Carmhograph® (Senegalese soils) or with the Ahn method (Congolese soils). Soil C mineralisation was measured in some experiments by CO_2 release during *in vitro* incubations of humid soil at 30ºC, by the NaOH method (Bernhard-Reversat 1993).

Soil invertebrate density was estimated in the Congolese plantations, through the TSBF method (Tropical Soil Biology and Fertility Program, Anderson and Ingram, 1993) in ten soil monoliths per studied plot. On clay soils, only one plot was investigated for each species, and the results should be checked with further studies.

Comparisons were made with the non-parametric tests of Kruskal-Wallis and Mann-Whitney, with the software Statview®.

Results and discussion

Litter quality

Annual litterfall from *Eucalyptus* accounted for 2.9 to 3 t.ha^{-1} in the Senegalese plantations and approximately 5 to 7 t.ha^{-1} in the Congolese plantations (Bernhard-Reversat 1993, Laclau *et al.*, 2003). Australian *Acacia* litterfall ranged from 9 to 10 t ha^{-1}, whereas *A. seyal* litterfall was only 1.4 to 1.9 t ha^{-1}. Freshly fallen leaves of eucalypt species, compared to acacia species or other species had a low N content and had a high water-soluble organic matter and phenolic content (Table 2). However *A. seyal* seems to be an exception among leguminous plants, with also a very high phenolic content, also observed in green leaves (Breman and Kessler). Water-soluble compounds in eucalypts ranged from 20 to 40% of litter dry weight. Soluble organic matter included a great amount of water-soluble phenolics which ranged from 9 to 15% of litter dry weight. The total water soluble and methanol soluble phenolics reached 15 to 20% of litter dry weight in eucalytpt leaf litter compared to 2 to 5% in the other species studied but *A. seyal*.

Table 2. Chemical composition of fresh leaf litter from various tree species, in mg g^{-1} of litter dry weight, with standard error in brackets. Solu OM: soluble organic matter, Solu phen: soluble phenolics, N.s. phen: non-soluble phenolics, Lign: lignin

Tree	*Solu OM*	*Solu phen*	*N.s. phen*	*N*	*Lign.*
Acacia seyal	240	178	151	8.0	64
Acacia mangium	98 (7)	38 (11)	81 (9)	7.8 (0.24)	315 (17)
Acacia auriculiformis	163 (23)	39 (4)	78 (10)	9.0	283 (27)
Azadirachta indica	134	12	8	17.0	256
Eucalyptus camaldulensis	48 (22)	68 (7)	28 (8)	8.1 (0.8)	103 (12)
Eucalyptus PF1	177 (5)	88 (4)	69 (4)	5.9 (0.2)	164 (3)
Eucalyptus HS2	113	120	44	6.5	166

Soil organic matter at the soil-litter interface

Organic matter at the soil-litter interface represents the first stage of litter incorporation into the soil. The SOM particle size distribution was significantly dependent on soil texture, as previously observed by Feller *et al.*, (1991). The particulate organic fractions of SOM accounted for an average of 83% of total SOM in sandy soils, 75% in loamy sand soils, and 53% in the clay soils. Only the SOM in the organo-mineral fraction was significantly higher in the loamy sand soil than in the sandy soils. Unlike this, both fine particulate and organo-mineral fractions were significantly higher in the clay soil than in sandy soils (Figure 1). The adsorption of soluble organic compounds on the clay fraction and the formation of complexes with clay might be involved. In a laboratory experiment with Senegalese soils, 15% of added soluble C from *E. camaldulensis* litter was mineralized within 6 days in the sandy soil, and 4% in the loamy sand soil, showing the protection of the organic matter by clay.

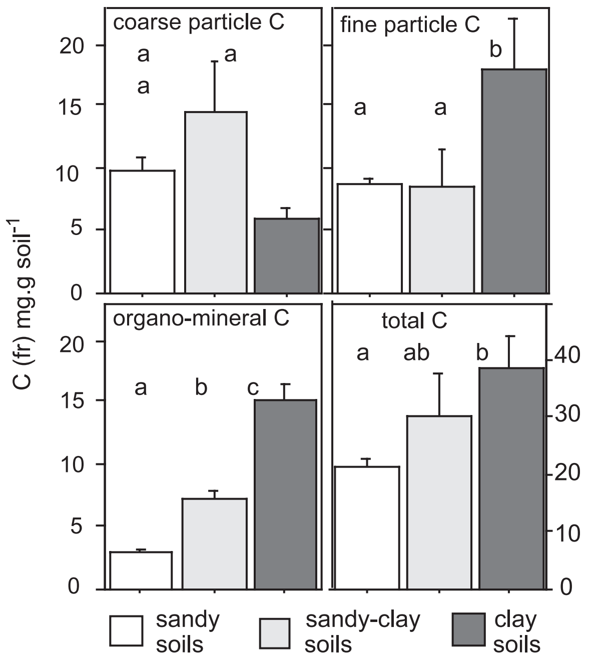

Figure 1. Carbon in the SOM particle size fractions of the 0-2 cm layer of soil, in mg g^{-1} of soil, according to soil texture, in Senegalese and Congolese tree plantations

SOM particle size distribution was also dependent on tree species. The eucalypt effect resulted in a lower amount of all SOM fractions, compared to the other tree species in the Senegalese sites (Figure 2). In the Congolese sandy soils, the fine particulate SOM fraction was lower under both eucalypt hybrids, whereas only *E.* HS2 showed this trend in the clay soil (Figure 3). Consequently, SOM accumulation was low in eucalypt plantation compared to other tree species, (comprising some species which are not presented here, as *Prosopis juliflora, Acacia laeta*, and except

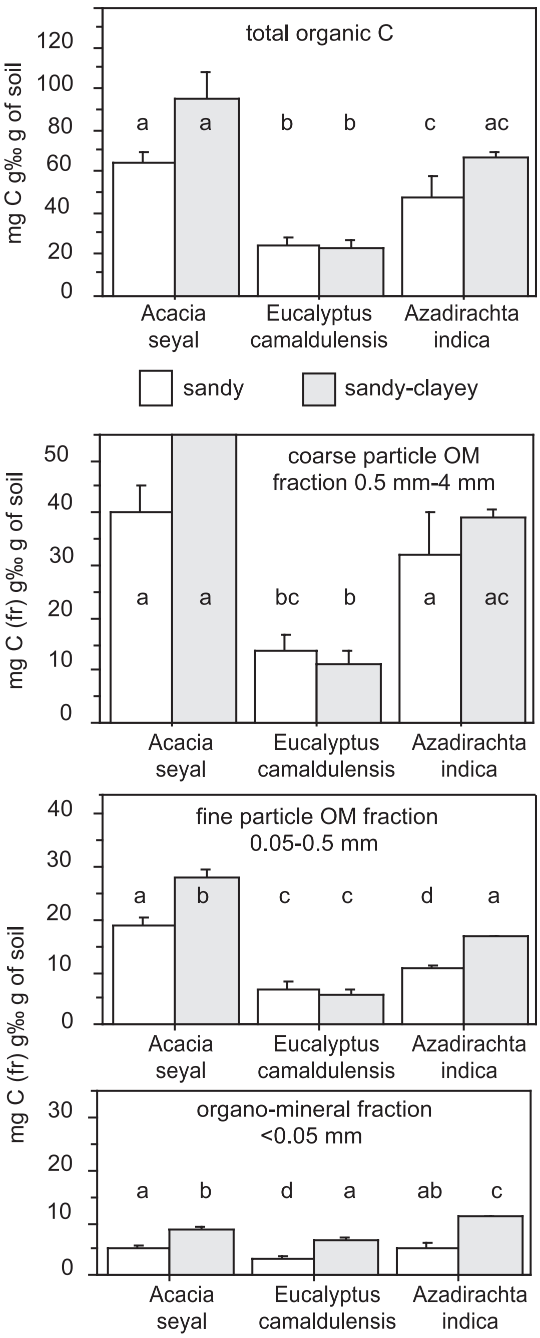

Figure 2. Carbon in the SOM particle size fractions of the 0-2 cm layer of soil, in mg g^{-1} of soil, in tree plantations and native vegetation in Senegal

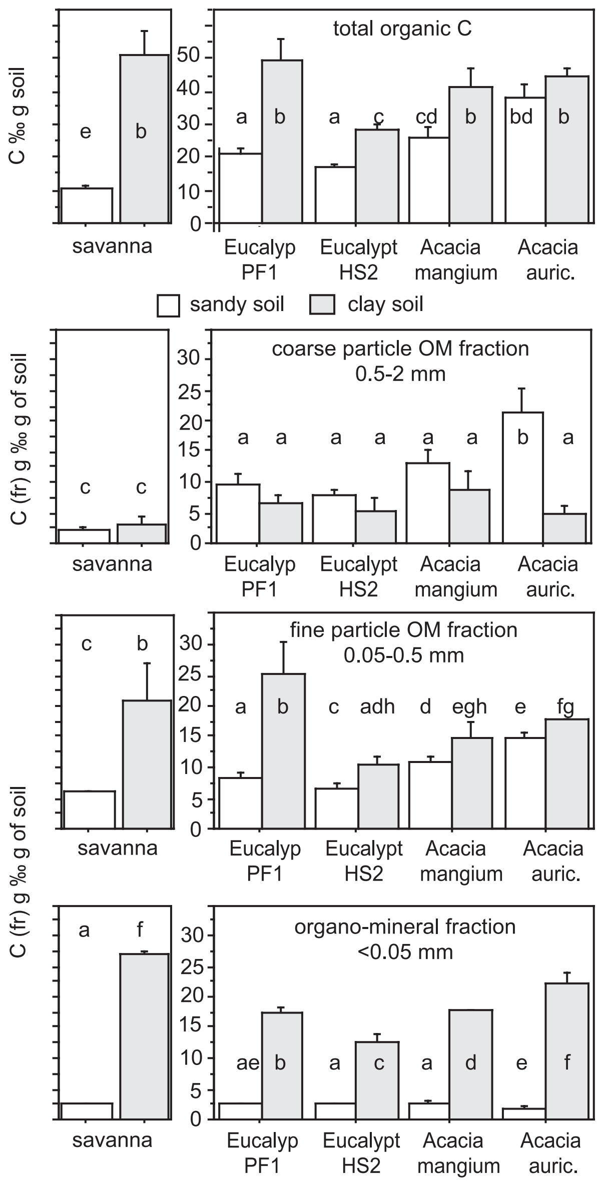

Figure 3. Carbon in the SOM particle size fractions of the 0-2 cm layer of soil, in mg g^{-1} of soil, in tree plantations and native vegetation in Congo

Pinus caribaea). This may be associated with litter quality. The lower accumulation of particulate SOM fraction under eucalypts might be related to the high non-phenolic soluble organic matter of eucalypt litter, as suggested by its significant relationship with the amount of fine particulate SOM in the species studied (Figure 4). The effect of phenolics on SOM is difficult to asses. Phenolics are known to exert an adverse effect on decomposition (Coûteaux *et al*., 1995) and thus might enhance organic matter accumulation at the soil-litter interface. Phenolics also prevent SOM accumulation (Inderjit and Mallik 1997) through the formation of soluble metal-organic complexes (Bernhard-Reversat 1999; Jansen *et al*., 2004). In the present study, the negative effect of soluble phenolics on SOM accumulation was obvious on all the component sizes of the particulate organic matter fractions (coarse and fine, Figure 3). No relationships were observed between litter quality and organo-mineral C fraction, the amount of which was highly related to soil texture.

Soil macro-invertebrates

The positive effect of soil invertebrates on soil fertility is now recognized (Lavelle and Spain 2001).

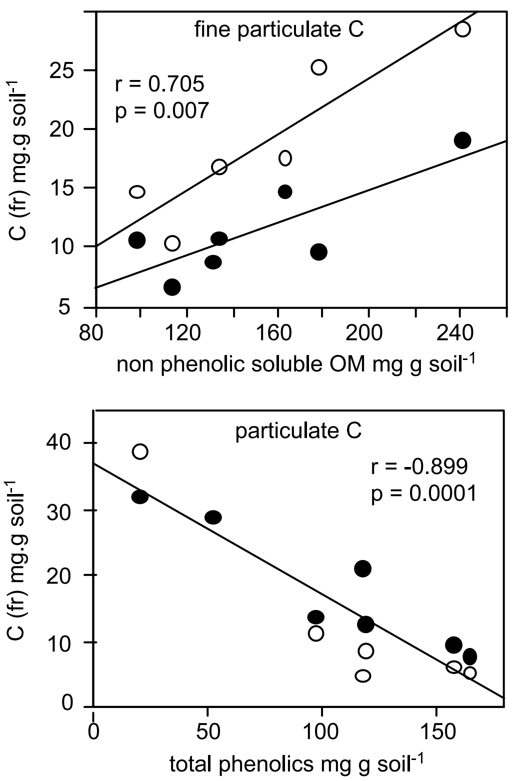

Figure 4. Relationships between the particulate organic matter of the 0-2 cm layer of soil and the litter quality of the corresponding vegetation, in Senegal and Congo. Data on *A. seyal* forests were removed from the total particulate C, because the coarse fraction contained a part of litterfall

Acacia and eucalypt plantations were compared on the Congolese soils (Mboukou *et al*., 1998). The density of earthworms was higher on clay soil than on sandy soil in eucalypt plantations, unlike what was observed in *A. mangium* plantations, where earthworms were more numerous in sandy soil (Figure 5). It appeared that soil texture effect was added to eucalypt litter effect to keep earthworm density at a low level, although Lavelle and Spain (2001) reported the influence of vegetation having a significant influence. Termite and ant density was higher in sandy soil under the two tree species. According to Jones (1989), soil texture influences termites, and Meyer *et al.*, (2000) reported the preference of some termite taxa for sandy soils. The other litter-dwelling taxa, taken together as "litter group", were much more numerous under *A. mangium*, which has a higher quality litter, than under eucalypts, but the density was not influenced by the soil texture. Although the low number of species for which we recorded invertebrate density and SOM fraction data, (four) did not allow a statistical evaluation, relationships between particulate SOM amount and termite density (r = -0.984) and earthworm density (r = 0.931) could be expected significant with more data.

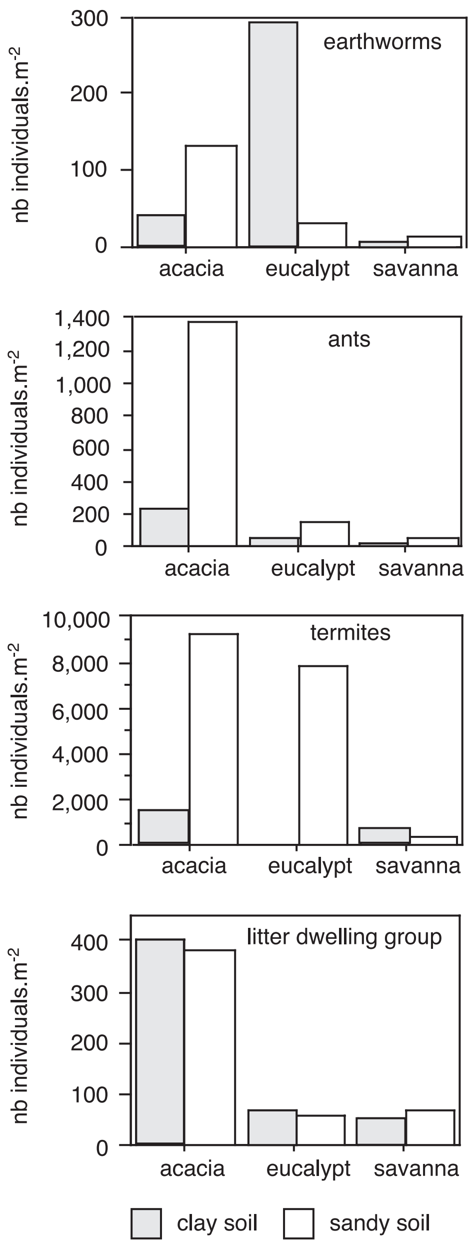

Figure 5. Density, in number of individuals per m², of some invertebrate taxa in Congolese *E*. PF1 and *A. mangium* plantations

The negative effect of soluble phenolics on termites was suggested in previous researches on Congolese sandy soils, when eucalypt litterfall leaves were considered (Mboukou-Kimbatsa and Bernhard-Reversat 2001). A weak negative effect of the insoluble phenolics from the forest floor litter on earthworms (p = 0.06) and soil-feeding termites (p = 0.05) was also suggested in another study with 27-28 TSBF samples containing the taxon from 50 samples. The depressive effect of eucalypt plantations on soil invertebrates was reported previously (Zou 1993; Maity and Joy 1999), but its relationship with sandy soil texture should be assessed with more extensive studies.

Conclusions

Eucalypts and sandy soils present together some adverse effects on soil fertility, through both organic matter and biological activity. However more extensive sampling on clay soils and experimental studies on the role of litter chemistry should provide a better understanding of these relationships. Nevertheless, silvicultural practices that may increase SOM are essential to the sustainability of eucalypt plantations on sandy soils. The management of logging residues is currently adopted in Congolese commercial plantations in order to increase organic matter and nutrient conservation, and research in this area is being conducted (Nzila *et al*., 2004). Input of organic matter from non-eucalypt vegetation would also help increase SOM and invertebrate density. This is practiced by UR2PI (Unité de Recherche sur la Productivité des Plantations Commerciales) in studies on inter-planting leguminous trees with eucalypt, in order to improve soil nitrogen in Congolese plantations, but also expected to change litter quality and soil biology.

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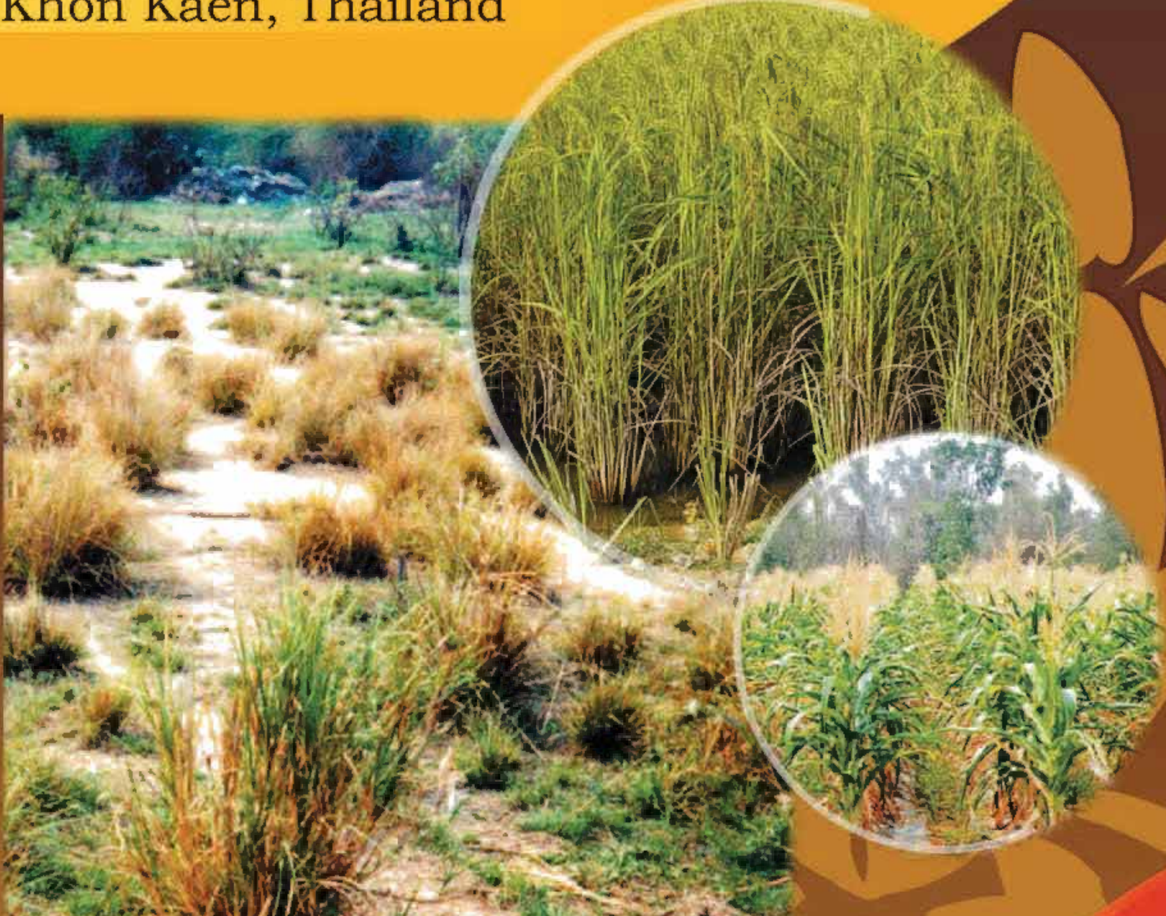

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