Systèmes de culture et dynamiques de la matière organique : le semis direct sur couverture permanente, une révolution agricole

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Station d'expérimentation (Brésil).

En agriculture tropicale, le travail du sol accélère la destruction de la matière organique. Sa restauration est possible en quelques années grâce aux systèmes de culture sans travail du sol, en semis direct sur couverture végétale permanente. Le choix des plantes de couverture est déterminant. Le taux de carbone du sol peut atteindre alors celui des écosystèmes naturels, même en partant de conditions dégradées. Grâce au semis direct, l'agriculture agit comme stockeur net de CO2 et non plus comme producteur net. Le CIRAD a travaillé sur de tels systèmes au Brésil, en Asie, à la Réunion et à Madagascar. Ce poster rapporte quelques résultats obtenus au centre-ouest du Brésil (secteur tropical humide).

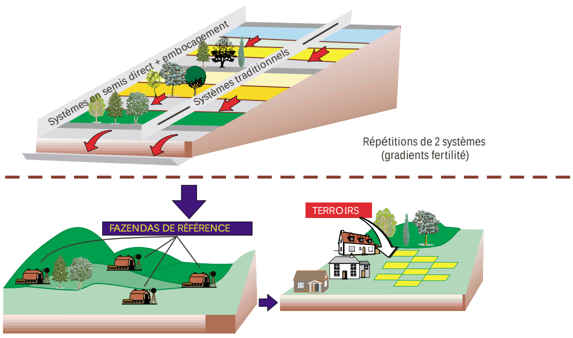
Matériel et méthodes

Le dispositif

La méthodologie est fondée sur la méthode de création-diffusion des systèmes de culture. Des unités expérimentales sont gérées par les chercheurs et les agriculteurs. Dans leurs fermes (dites de référence), les producteurs volontaires appliquent plusieurs systèmes de culture en l'état ou en les réadaptant ; l'ensemble des fermes reflète la variabilité régionale. Dans les unités expérimentales, les systèmes de culture sont organisés en matrices sur des toposéquences représentatives du milieu. Les nouveaux systèmes sont élaborés en incorporant progressivement d'autres facteurs de production. Les règles de construction des matrices (Séguy, Bouzinac, Trentini & Cortes, 1996)[1] permettent l'interprétation des effets directs et cumulés des composantes des systèmes au cours du temps. Les matrices et les fermes de référence sont des lieux d'action, de création de l'innovation et de formation. Elles constituent un laboratoires de veille, précieux pour les scientifiques et un vivier de systèmes de culture (techniques de travail du sol, nouveaux systèmes en semis direct et systèmes en semis direct plus élaborés–cultures diversifiées, élevage, agroforesterie). Trois niveaux de fertilisation sont testés : minimum (exportation par grain), le plus représenté, non limitant.

Ces dispositifs permettent d'améliorer les impacts sur l'environnement avant de les diffuser à grande échelle.

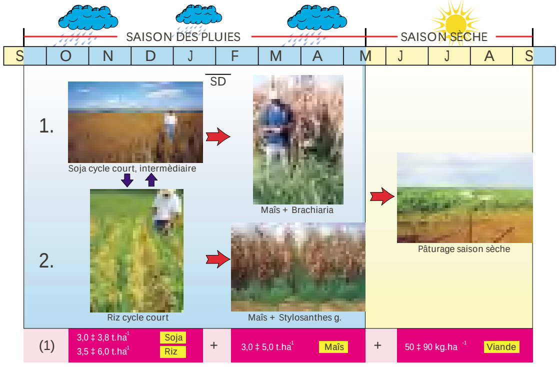
Stratégie de création – diffusion avec les agriculteurs, chercheurs et organisations professionnelles



[1] SEGUY L., BOUZINAC S., TRENTINI A. CORTES NA., 1996. L'agriculture brésilienne des fronts pionniers : I. la méthode de création-diffusion agricole. II. La gestion de la fertilité par le système de culture. III. Le semis direct, un mode de gestion agrobiologique des sols. Agriculture et développement 12 : 2-62.

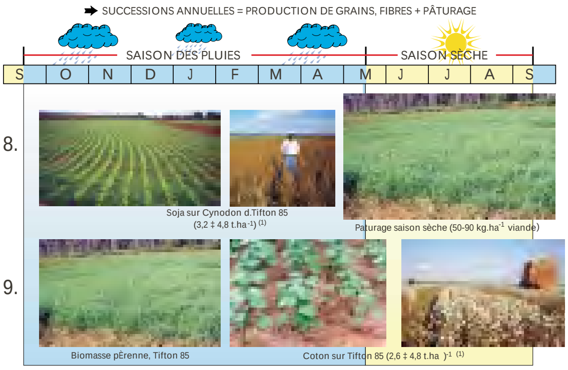
Comparaison des systèmes de culture

Dans les "Cerrados" du Brésil, le CIRAD a construit trois types de systèmes fondés sur différentes couvertures végétales permanentes. Dans les systèmes avec couverture morte (mulch), celle-ci est issue des résidus de récolte et d'une culture ou interculture de renfort fournissant une importante masse végétale, implantée avant ou après la culture principale ; elle est desséchée aux herbicides totaux avant le semis direct de la culture. Dans les systèmes avec couverture vivante permanente, cette dernière est une espèce fourragère pérenne dont la partie aérienne a été desséchée tout en préservant les organes de reproduction végétative souterrains ; elle est maintenue en vie ralentie jusqu'à ce que la culture assure un ombrage total ; après la récolte, la couverture vivante couvre à nouveau le sol et peut être pâturée. Les systèmes mixtes comportent des successions annuelles avec une culture principale et une seconde culture avec minimum d'intrants (apportant une récolte de grains et une masse végétale importante), associée à une espèce fourragère. Les cultures sont récoltées à la saison des pluies et la culture fourragère permet une production animale en saison sèche.



(1) Fonction niveau technologique - SD = Semis Direct

Semis direct sur couverture morte et plante de couverture : Système mixte avec une année de culture principale suivie d'un autre culture associée avec une espèce fourragère (2 exemples au Brésil)



(1) Fonction niveau technologique -

Semis direct sur couverture permanente : Production de grains et pâturage temporaire durant la saison sèche (2 exemples au Brésil)

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Résultats et discussions

Dynamique du carbone et des cations

Après six années de mesure, dans les trois cas, une perte de 0,2 à 1,4 Mg C/ha/an est observée en agriculture conventionnelle dans les horizons [0-10 cm] et [10-20 cm]. En semis direct sur couverture végétale, le taux de carbone du sol augmente de 0,83 à 2,4 Mg C/ha/an selon le lieu, les systèmes et les espèces de couverture. Ces résultats s'accordent avec les expérimentations de longue durée conduites aux Etats-Unis et au Brésil. L'évolution de la capacité d'échange cationique suit celle du carbone. Les systèmes en semis direct créent un pouvoir de rétention des engrais proportionnel à celui du carbone, limitant leur lixiviation.

L'importance de la séquestration du carbone dépend des systèmes de culture : les plus performants entretiennent en continu la production d'une forte biomasse aérienne et racinaire dont le rapport C/N et la teneur en lignine sont élevés, avec des systèmes racinaires très développés jusqu'en profondeur pouvant utiliser l'eau profonde et recycler les éléments nutritifs, même en saison sèche, ce qui permet d'accumuler de la matière organique.
Les racines les plus résistantes à la minéralisation comportent d'épais manchons de microagrégats protègeant la matière organique, comme *Eleusine coracana* et *Brachiaria sp.* La recharge en carbone intéresse d'abord et surtout l'horizon 0-5cm mais aussi les horizons [0-10 cm] et même [10-20 cm], avec les graminées *Eleusine* sp., *Brachiaria* sp. associées au sorgho ou mil et utilisées comme pâturage temporaire.


Coton, semis direct sur un mulch de *Brachiaria brizantha*, 20 jours après semis (Maeda, Brésil).

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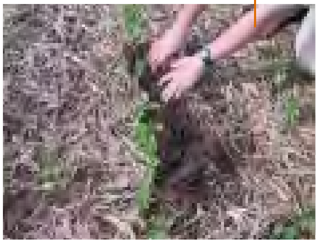
Soja : semis direct sur mulch épais de pailles de sorgho.

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Racines de *Brachiaria brizantha* (plante de couverture et fourrage).

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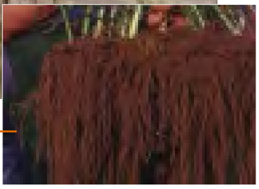
Racines d'*Eleusine* (plante de couverture et fourrage).

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Utilisation de couverture vive fourragère (Brésil)


Récolte d'*Eleusine*.

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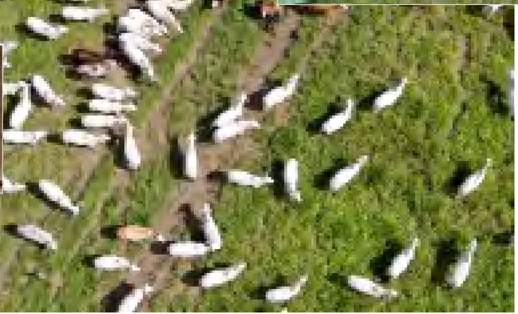
Pâturage.

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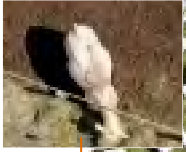
Eleusine sp. forage.

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Performances des systèmes

En zone tropicale humide du Brésil, la production de matière sèche aérienne annuelle est passée de 4-8 t/ha en 1986 à 25-28 t/ha en 2000.

Le rendement du soja est passé de 1 700 à 4 600 kg/ha entre 1986 et 2000 et celui du riz pluvial de 1 800 à 8 000 kg/ha.

Dans ces régions à l'économie fluctuante, le semis direct permet les résultats les plus stables : selon le niveau de risque choisi, les coûts de production varient entre 300 et 600 US $/ha et atteignent 1 300 US $/ha avec la culture cotonnière ; les marges nettes varient entre 100 et 500 US $/ha, selon les prix payés au producteur.
La consommation de carburant, le parc de tracteurs et de semoirs ont été divisés par deux. Dans le Centre-Ouest du Brésil, le semis direct a permis de stopper l'érosion, de produire 10 à 30 % de coton en plus et de diversifier la production, tout en maîtrisant la peste végétale *Cyperus rotondus*.


Soja sur mulch de pailles de sorgho (Brésil).

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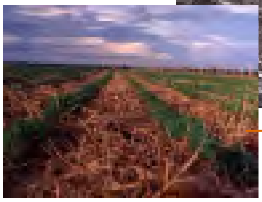
Soja sur mulch de pailles de *Brachiaria* (Brésil).

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Récolte de coton obtenu en semis direct (Maeda, Brésil).

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Culture de coton : semis direct sur couverture morte (Maeda, Brésil).

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Riz pluvial sur mulch d'*Eleusine* (Brésil).

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Cultivars de riz pluvial de haute technologie, Brésil (semis direct sur couverture permanente).

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Diagnostic agronomique et développement de techniques de semis direct

Systèmes de culture fondés sur le riz pluvial en zone montagneuse du Nord Vietnam

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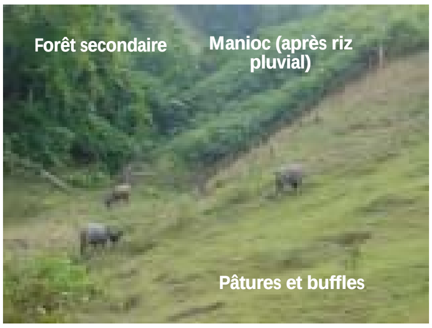
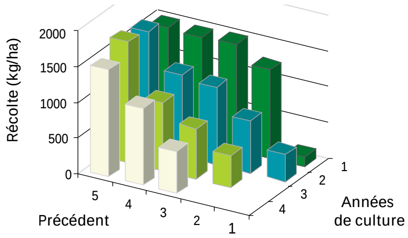
Diagnostic agronomique

Dans les montagnes du Nord Vietnam, avec une population croissant rapidement, la forte pression de l'élevage et l'évolution foncière, les systèmes traditionnels de défriche-brûlis ne sont plus durables et ont été bannis. Il est urgent de proposer aux agriculteurs des pratiques agronomiques et des systèmes de culture durables, simples, peu exigeants en intrants et permettant une sédentarisation à plus long terme après défriche de la forêt. Un diagnostic rapide mais précis a été conduit en 1998-1999. La plupart des types de culture et d'usage de la terre ont été identifiés.



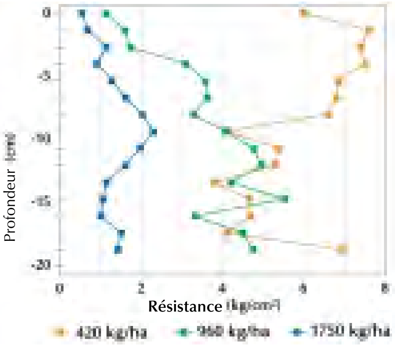
Les principaux facteurs limitants du rendement du riz pluvial ont été identifiés et classés : entre les parcelles, les variations de rendement du riz pluvial sont principalement expliquées par les précédents culturaux (ou le type de végétation défrichée) et le nombre d'années de culture depuis la défriche-brûlis de la forêt. Au sein d'une parcelle, les facteurs limitant le rendement du riz sont les caractéristiques physiques et chimiques du sol, en relation avec les bas niveaux d'activité biologique du sol.
Ces facteurs traduisent, à différents niveaux, le seuil de régénération du sol (pendant les jachères, limitées par un surpâturage et des prélèvements) ou la dégradation (particulièrement l'érosion pendant les cultures). A ces deux niveaux, les rendements sont aussi inversement proportionnels à la pression des adventices.

Rendement du riz en fonction de la végétation précédente et du nombre d'années de culture

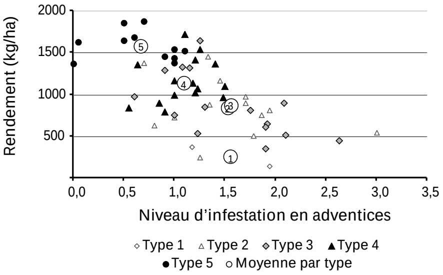


Type 1: Ancienne pâture (plus de 20 ans)
Type 2: Jachère de plus de 10 ans, ou 10-20 ans, surpâturée
Type 3: 10- 20 ans de jachère modérément pâturée ou de plus de 20 ans, surpâturée
Type 4: 10-20 ans de jachère non pâturée, ou de plus de 20 ans modérément pâturée
Type 5: Jachère de plus de 20 ans, non pâturée

Rendement du riz en fonction de la compaction du sol

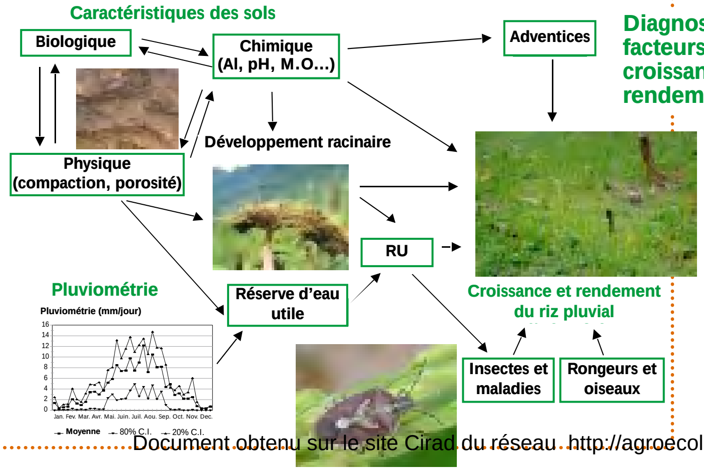


Rendement du riz en fonction de la pression des adventices et du précédent



La pluviométrie et les caractéristiques physiques du sol déterminent sa réserve en eau disponible. Les caractéristiques physiques et chimiques du sol affectent le développement racinaire. En conséquence, La réserve utile en eau (RU) est très limitée. Outre une forte pression des adventices, cela conduit à un faible développement des cultures. Les plantes chétives offrent également moins de résistances aux insectes et aux maladies. Le résultat est un rendement bas (1t/ha en moyenne) et irrégulier.

Diagnostic agronomique : facteurs limitants de la croissance et du rendement du riz



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Développement des systèmes de culture fondés sur des techniques de semis direct

Les techniques de semis direct ont été adaptées aux conditions locales parce qu'elles peuvent répondre aux causes actuelles des problèmes rencontrés, et non pas uniquement aux symptômes perçus.

En premier lieu, elles ont été testées en petites parcelles d'expérimentation. Les systèmes les plus prometteurs ont été appliqués ensuite sur de grandes parcelles, respectant la toposéquence, dans les conditions de culture des agriculteurs. Des solutions pratiques et économiques ont pu être proposées et développées avec les agriculteurs. Ces techniques sont fondées sur deux principes :

1. remplacer le labour mécanique par une amélioration biologique de la structure du sol,

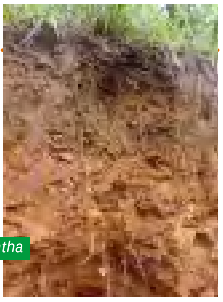
2. toujours garder le sol couvert avec une couverture vive ou morte.

Amélioration de la structure du sol par des plantes pourvues d'un fort système racinaire et favorisant le développement de l'activité biologique

Vers de terre et galleries

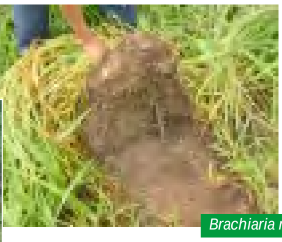
Brachiaria humidicola

Brachiaria brizantha

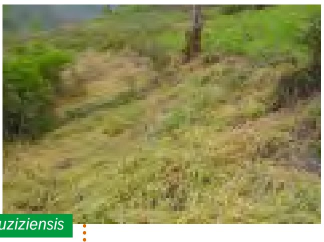


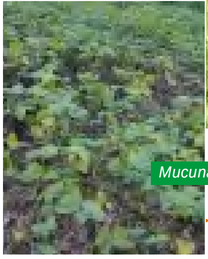
Contrôle de l'érosion et production de mulch

Sol toujours couvert avec une couverture morte ou vivante :
- empêche l'érosion
- Accroît l'infiltration
- Réduit l'évaporation
- Tempère les variations de température
- Favorise le développement des micro- et macro-organismes
- Contrôle les adventices
- Accroît les taux de matière organique et des éléments minéraux disponibles



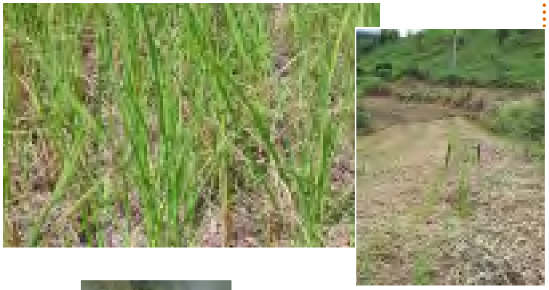
Brachiaria ruziziensis





Mucuna (Stizolobium aterinum)

Contrôle des adventices par un mulch épais



Semis direct sur mulch

Écobuage ou cuisson lente et contrôlée du sol, base d'une amélioration rapide

1,7 t/ha, année 1 sur des sols dégradés, sans fertilisation

Maïs en intercalaire et *B. ruziziensis* sur des mini-terrasses pour des fortes pentes

Rotation de cultures et diversification Maïs, soja, arachide, etc. Productions fourragères

Vietnam Agricultural Sciences Institute

Centre de coopération internationale en recherche agronomique pour le développement

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Cropping systems and organic matter dynamics: direct seeding on plant cover, an agricultural revolution

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Experimental unit (Brazil).

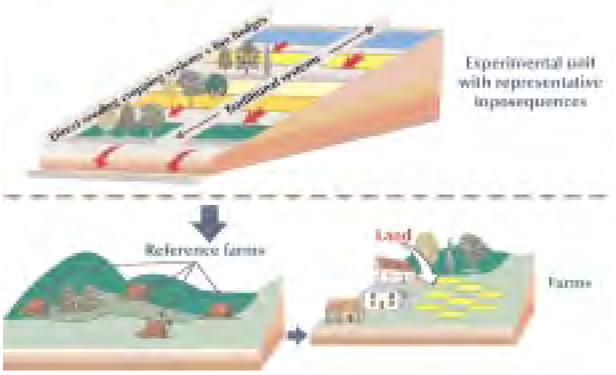
Tillage accelerates organic matter destruction under tropical agriculture conditions. No-till cropping systems involving direct seeding on permanent plant cover enable short-term soil restoration. Cover plant choices are crucial. Soil carbon can thus be boosted to levels generally found in natural ecosystems, even when starting from degraded soils. Direct seeding systems promote net CO_2 storage rather than net production. CIRAD has been working on such systems in Brazil, Asia, Réunion and Madagascar. This poster reports some results obtained in central-western Brazil (hot humid tropical area).

Material and methods

Study design

Cropping systems can be regularly improved via the **"innovation-extension strategy"**, while meeting the requirements of researchers, agricultural professionals and regional institutions (Séguy *et al.,* 1998)[1]. This experimental approach places upstream research in an *in situ* context. The experimental units were managed by researchers and farmers. Volunteer farmers—on their so-called **"reference farms"**—implemented several different cropping systems as-is or tailored them to meet their specific needs. The set of reference farms was representative of the diversity of this region. Cropping systems were set up in matrices on representative toposequences in the experimental units. New systems were developed by gradually including other production factors. Based on matrix construction rules, direct and cumulative effects of cropping system components can be interpreted over a time course. Reference farm matrices are sites of action, innovation and training. They also provide a field-monitoring laboratory for scientists, a cropping system vivarium where tillage techniques, new and highly complex (diversified crops, livestock production, agroforestry) direct seeding systems can be showcased.

Innovation-extension strategy with farmers, researchers and agricultural professionals.

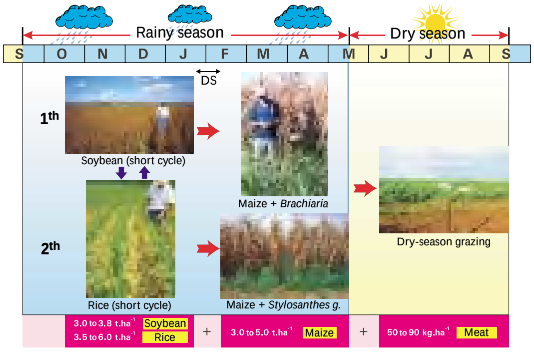


[1] SEGUY L., BOUZINAC S., TRENTINI A. CORTES NA., 1998. Brazilian frontier agriculture: I. The agricultural innovation-extension method. II. Managing soil fertility with cropping systems. III. Direct seeding, an organic soil management technique. *Agriculture et développement* Special Issue, Cirad, Montpellier, France, 64 p.

Comparison of cropping systems

In the "Cerrados" of Brazil, CIRAD has set up three types of cropping systems based on different permanent plant covers. Systems with dead cover (mulch) involve crop residue and a high biomass producing support crop—it is wilted with nonselective herbicides prior to direct seeding the crop. Systems with permanent live cover involve perennial forage species as cover crop, and the above-ground parts are wilted but the underground vegetative reproductive organs are conserved—after harvest, the live cover recolonizes the field and can thus be grazed. Mixed systems involve annual sequences with a main crop and a subsequent crop requiring minimal inputs (producing grain for harvest and high biomass), associated with a forage species. Crops are harvested in the rainy season and the forage crop can be grazed by livestock during the dry season.

Direct seeding on permanent mulch and plant cover: mixed system with annual sequences with a main crop and a subsequent crop, associated with a forage species (two exemples from Brazil).



Soybean (short cycle)

Rice (short cycle)

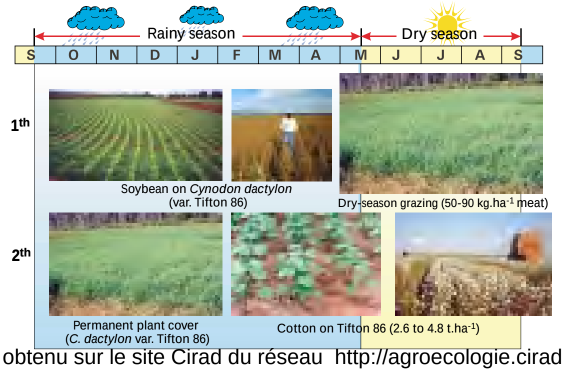
Maize + *Brachiaria*

Maize + *Stylosanthes g.*

Dry-season grazing

DS: direct seeding

Direct seeding on permanent plant cover: grain production and temporary dry-season grazings (two exemples from Brazil).



Soybean on *Cynodon dactylon* (var. Tifton 86)

Dry-season grazing (50-90 kg.ha-1 meat)

Permanent plant cover (*C. dactylon* var. Tifton 86)

Cotton on Tifton 86 (2.6 to 4.8 t.ha-1)

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Results and discussion

Carbon and cation dynamics

After 6 years of analysis, in the three cases, 0.2-1.4 Mg C/ha/year was lost under conventional farming conditions in the [0-10 cm] and [10-20 cm] soil horizons. With direct seeding on plant cover, soil carbon levels increased from 0.83 to 2.4 Mg C/ha/year, depending on the site, cropping system and cover species. Similar patterns were noted in cation and carbon exchange capacities. Direct seeding systems were found to enhance fertilizer retention to a level proportional to that of carbon, while reducing leaching.

The most efficient systems enable continuous high aerial and root biomass production, with a high C/N ratio and lignin content, extensively developed root systems that reach deep soil horizons, so plants can tap deep humidity resources and recycle nutrients, even in the dry season, thus enhancing organic matter accumulation. Roots most resistant to mineralization have thick microaggregate sheaths that protect the organic matter, e.g. *Eleusine coracana* and *Brachiaria* sp.: carbon is recycled especially in the [0-5 cm] horizon, but also in the [0-10 cm] and even [10-20 cm] horizons, with the grasses *Eleusine* sp. and *Brachiaria* sp. intercropped with sorghum or millet and used for temporary grazing.


Cotton, direct seeding in a mulch of *Brachiaria brizantha*, 20 days after seeding (Maeda, Brazil).
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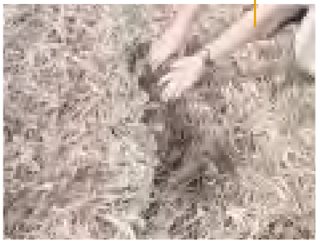
Soybean: direct seeding in thick mulch of sorghum straw.
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Brachiaria brizantha roots (as plant cover and forage).
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Eleusine sp. roots(as plant cover and forage).
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Uses of live forage covers (Brazil)


Grazing.
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Eleusine sp. harvest.
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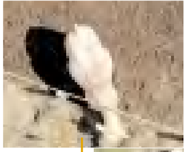
Eleusine sp. forage.
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Cropping system performance

In humid tropical areas of Brazil, annual aerial dry matter production rose from 4-8 t/ha in 1986 to 25-28 t/ha in 2000.

Soybean yields increased from 1 700 to 4 600 kg/ha between 1986 and 2000. Rainfed rice yields rising from 1 800 to 8 000 kg/ha between 1986 and 2000.

Direct seeding strategies can help stabilize incomes in these regions of highly fluctuating economies: depending on the risk level, production costs range from $US300 to $US 600/ha to as high as $US 1 300/ha for cotton crops. Net margins range from $US 100 to $US 500/ha, depending on the producer price. Fuel consumption, tractor and seeder fleets are cut by half. In central-western Brazil, the use of direct seeding systems halted erosion, increased cotton yields by 10-30%, enabled crop diversification, and control of *Cyperus rotondus* weeds.


Soybean in a sorghum straw mulch (Brazil).
© L. Seguy


Soybean in *Brachiaria* straw mulch (Brazil).
© L. Seguy


Cotton harvest after direct seeding (Maeda, Brazil).
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Cotton crops: direct seeding in mulch (Maeda, Brazil).
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Rainfed rice in *Eleusine* mulch (Brazil).
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High technology cultivars of rainfed rice, Brazil (direct seeding in a permanent plant cover).
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Agronomic diagnosis and development of direct sowing techniques

Upland rice-based cropping systems in mountainous areas of Northern Vietnam

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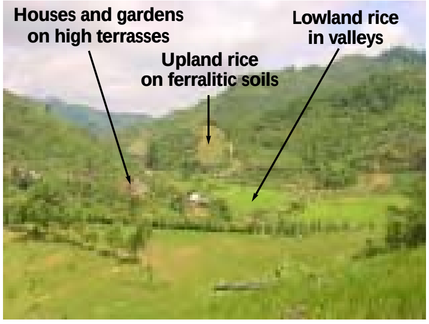
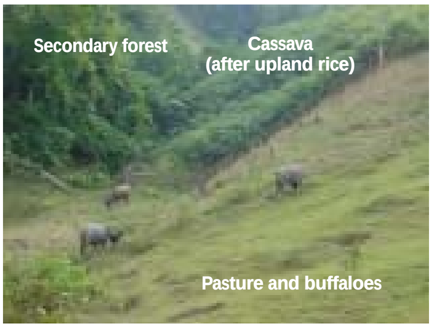
Agronomic diagnosis

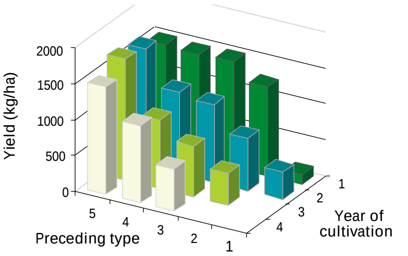
In the mountains of Northern Vietnam, with the rapid population growth, the high pressure of cattle and changes in land tenure, the traditional systems of slash-and-burn are no longer sustainable and have been banned. It is extremely urgent to propose to farmers simple, low-input, sustainable agronomic practices and cropping systems, enabling long-term settlement on field after forest clearing. A rapid but sound and clear agronomic diagnosis was conducted in 1998/1999. Major cropping situations and land use types were identified.





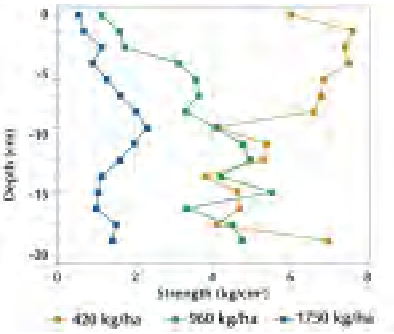
Main factors limiting upland rice yield (at various scales) were identified and ranked: Between fields, upland rice yield variations mainly are explained by preceding vegetation type and number of years of cultivation after slashing and burning the forest. Within field, major factors limiting rice yield are soil physical and chemical characteristics, in relation to poor biological activity. These factors reflect, at various scales, the level of soil regeneration (during fallow periods, but limited by intensive cattle grazing and extraction) or degradation (especially erosion during cultivation periods). At both scales, yield also can be put in relation to weed pressure.

Rice yield as a function of preceding vegetation type and number of cultivation

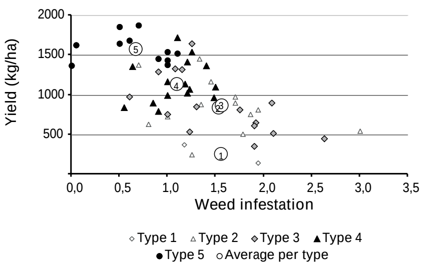


Type 1: Old pasture (over 20 years)
Type 2: Less than 10 years-old forest or 10-20 years-old forest, heavily grazed
Type 3: 10-20 y.o. forest moderately grazed or over 20 y.o. forest, heavily grazed
Type 4: 10-20 y.o. forest not grazed or over 20 y.o. forest, moderatly grazed
Type 5: Over 20 years-old forest, not grazed

Rice yield as a function of soil compaction

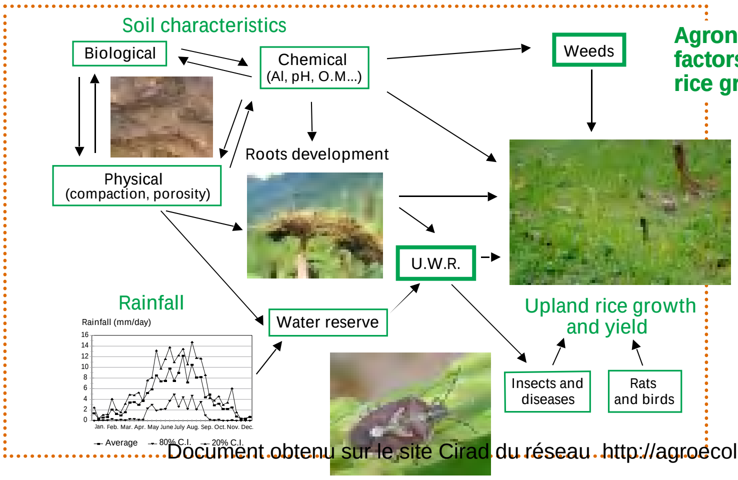


Rice yield as a function of weed pressure and preceding vegetation type



Agronomic diagnosis: factors limiting upland rice growth and yield

Rainfall and soil physical characteristics determine water reserve. Soil physical and chemical characteristics limit roots development. As a consequence, useful water reserve (UWR) is very limited. Together with high weed pressure, this leads to poor plant development. Weak plants also have low resistance to pests and diseases. As a consequence, yields are low (1 t/ha on average) and unstable.



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Development of cropping systems based on direct sowing techniques

Direct sowing techniques were adapted to local conditions as they can address the actual causes of the problems, not only the symptoms. First, they were tested in small plots. Most promising systems were then applied in large plots, across the toposequence, in farmers 'conditions. Practical and economical solutions could be proposed to and developed with farmers. These techniques are based on two main principles: 1. Replace mechanical ploughing by biological improvement of soil structure, and 2. Always keep the soil covered with living or dead mulch.

Improvement of soil structure by plants with strong root systems and development of biological activity

Earth worm and galeries

Brachiaria humidicola

Brachiaria brizantha

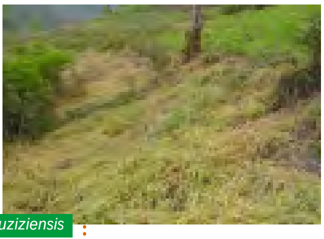
Erosion control and mulch production

Soil always covered with living or dead mulch:

- Prevents erosion
- Increases infiltration
- Reduces evaporation
- Buffers temperature
- Helps development of micro and macro organisms
- Controls weeds
- Increases organic matter content and provides nutrients

Mucuna (Stizolobium aterinum)

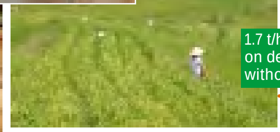
Brachiaria ruziziensis



Weeds control by a thick mulch

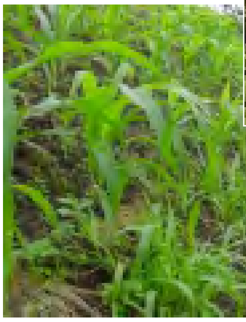
Direct sowing in mulch

Ecobuage or slow soil cooking for rapid improvement



1.7 t/ha, first year, on degraded soil, without fertiliser

Inter-cropping maize and *B. ruziensis* on mini-terraces for steep slopes



Crop rotation and diversification Maize, soyabean, peanuts, etc. Forages production

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Conservation tillage effects on runoff reduction in rainfed maize of semi-arid zones of western Mexico

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Direct sowing of maize into partial-covering maize stubble, using animal traction, Mexico.

© A. Findeling

Between 1994 and 1999, a series of studies were done to try to quantify and to modelize the effects of conservation tillage (direct drilling of seeds into a residue mulch-CT) and particularly of a partial residue mulch on water dynamics in the soil-plant-atmosphere system under semi-arid conditions of western Mexico. They showed that with even a very minimal amount of residue (1.5 t/ha), CT begins to give worthwhile improvements in productivity (Scopel, 1994; Scopel et al.*, 1999), illustrating the important role of runoff reduction (30% less than with traditional tillage) in explaining benefits of this technique. This study set out to explain the mechanisms involved in this reduction of runoff losses, trying to separate the short term effects on water movement on the soil surface and the long term effects on water infiltration capacity (Findeling 2001).*

Material and methods

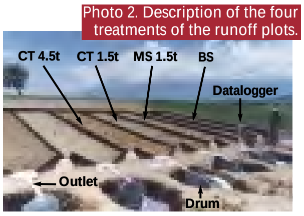
This study was conducted in 1998 in a semi-arid zone (between 400 and 600 mm of rain per year) of western Mexico, on a silty-loam soil with a 7% slope on average (Findeling 2001). On an experiment with a complete block design with two replications (each elementary plot was about 500 m^2) four treatments in particular were studied (photo 1):

- zero tillage without mulch (ZT),
- conservation tillage with 1.5 t/ha of residue mulch (CT 1.5t),
- conservation tillage with 4.5 t/ha of residue mulch (CT 4.5t),
- traditional tillage with an offset at a depth of 10 cm (TT).

A macro-fauna inventory was made. Infiltration tests were conducted with the Beer-Kan method at depths of 0, 2 and 50 cm for each treatment (Findeling 2000a).

Close to and under the same conditions as the main experiment, 20 m^2 runoff plots were established (photo 2).

Photo 2. Description of the four treatments of the runoff plots.



Four treatments in particular were studied:

- bare uncropped soil (BS),
- uncropped mulched soil with 1.5 t/ha of residue (MS 1.5t),
- CT 1.5t,
- CT 4.5t.

Photo 1. Description of the four treatments of the main plots.

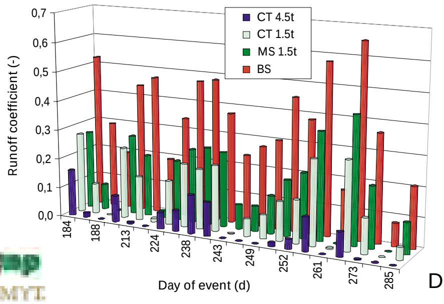

Traditional Tillage (TT).
Zero tillage, no residue (ZT).
Conservation tillage, 1.5 t/ha (CT 1.5t).
Conservation tillage, 4.5 t/ha (CT 4.5t).

Total runoff and runoff hydrograms were recorded for several rainfall events (Findeling 2000b). Velocity of runoff and friction factor were estimated for these plots during a specific experiment with artificial and constant flows of water. The tortuosity of runoff trajectories was then estimated directly, comparing the direct distance and real length of the trajectory between two points.

Results

Runoff was studied for 21 events distributed between 07/02/1998 and 10/11/1998, during the crop season. In every case, runoff coefficients on cumulated data were greater without mulch (ZT), significantly reduced with a light 1.5 t/ha mulch (30 to 50% less), and lowest with a 4.5 t/ha mulch (50 to 80% less) (fig. 1).

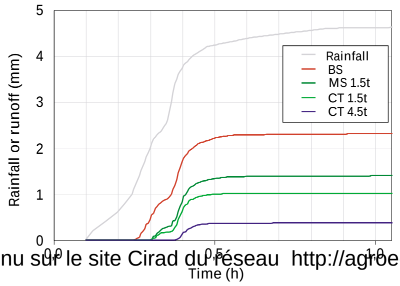
Fig. 1. Effect of treatment on cumulated runoff for 21 rainfall events distributed over the 1998 maize cycle.



On analysing all the hydrograms (fig. 2), it appears that mulch generally acts in two different ways explaining the differences between the treatments on cumulated runoff:

- by delaying the start of runoff after the beginning of the rain,
- by decreasing its intensity (lower slope for cumulated runoff in time).

Fig. 2. Effect of treatment on runoff dynamics during rainfall event 36 (08/11/1998).



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Results (following)

Part of this effect can be explained by the role of successive barriers played by small residue heaps, even with very little residue on the soil (photo 3). This is clearly illustrated by the differences between treatments in the tortuosity of the runoff pathways (photo 4), which increases with the amount of residue (table 1). The effects of mulch on runoff velocity and on friction factor (linked to superficial roughness) are also significant, but are more significant with 4.5 t/ha than with 1.5 t/ha of residue.

Table 1. Effect of treatment on tortuosity and friction factor.

Plot	Mulch biomass (t/ha)	Tortuosity	Friction factor
TT	0	1.09	0.49
ZT	0	1.09	0.27
MS-1.5t	1.5	1.28	0.38
CT-1.5t	1.5	1.28	0.38
CT-4.5t	4.5	1.46	1.15

Significant differences in infiltration velocity have been observed on the surface between treatments (fig. 3), with higher infiltration rates for mulched treatments after five years of conservation tillage. A major difference is created by the hydraulic conductivity of the 0-2 cm top layer, which tends to encrust without mulch, even in TT where the soil has been prepared mechanically at the beginning of the season.

Fig. 3. Effect of treatment on infiltration rate, after five years.

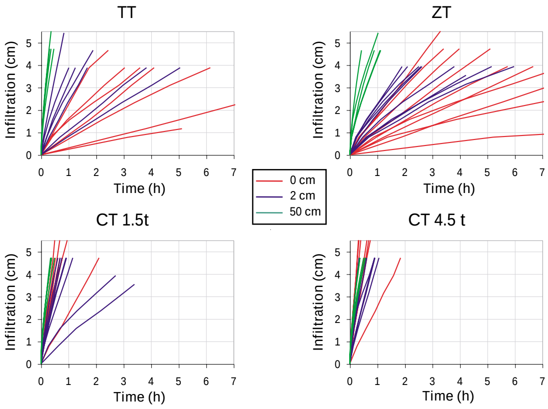


Photo 3. Experimental observation of the mulch elements dam effect on runoff (CT 4.5t).

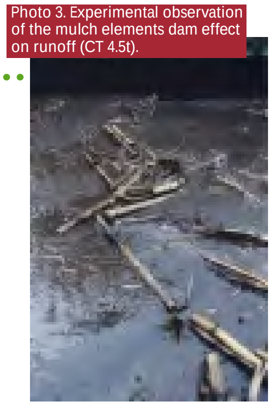


Photo 4. Experimental comparison of runoff pathways tortuosity of two contrasted treatments.

The practice of conservation tillage, with no tillage for several years and returning part of the organic biomass on the soil surface, activated the total macro-fauna population (fig. 4), whose constant activity and exchanges with the litter maintained high surface porosity (photo 5). At the same time, the intimate mixture of semi-degraded crop residue with soil in the first 2 cm helped to protect this favourable surface structure. Both phenomena explain this effect of the mulched treatments on surface hydraulic properties.

Fig. 4. Effect of treatment on total soil volumetric macro-fauna content (including earthworms, termites, and different Coleoptera larvae).

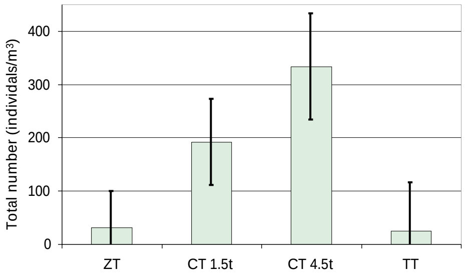
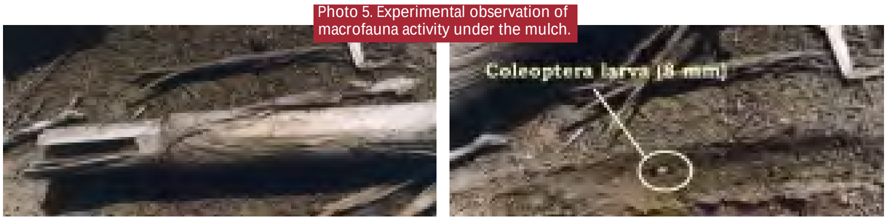


Photo 5. Experimental observation of macrofauna activity under the mulch.



Conclusion

This study confirmed the significant effects of very partial mulch on runoff reduction in conservation tillage systems, as already observed in previous studies (Scopel, 1994; Scopel *et al.,* 1998; Steiner, 1994). We demonstrated both a physical barrier effect of residue heaps and the maintenance of a high infiltration rate, by preventing crust formation on the soil surface (Findeling 2001). The first effect is continuous, which is probably why, in this context, very good yields of rainfed maize can be obtained with this technique, right from the very first years of CT application (Scopel, 1994). The second probably increases with time, accentuating the beneficial effect of mulched treatments on water storage year after year.

This mechanistic approach allowed us to better understand the benefits of CT for such semi-arid zones and opened up new prospects for modelling the effects of a partial mulch on runoff in a less empirical way than has been done before (Scopel *et al.,* 1998).

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Direct seeding on plant cover with "soil smouldering" techniques

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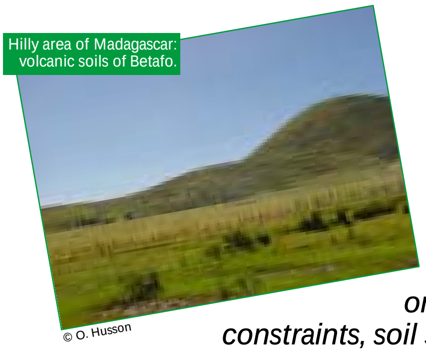

Hilly area of Madagascar: volcanic soils of Betafo.

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The soils in hilly and densely populated areas in the “Hautes-Terres” region of Madagascar are mainly ferrallitic and thus fragile, relatively infertile and prone to erosion. In addition, under low temperature conditions, organic matter breaks down very slowly and traps nutrients that are essential for crops. Direct seeding systems on plant cover offer a broad range of benefits, including erosion control and soil fertility enhancement. However, yield improvements are low because farmers —focusing chiefly on their immediate survival— apply very little fertilizer. Facing these constraints, soil smouldering, associated with direct seeding on vegetal cover, should allow a sustainable improvement of the production, with minimum inputs.

Material and methods

“Soil smouldering“ involves sluggishly burning plant matter (fuel) covered with a 10 cm layer of soil in a 20 cm deep trench, with air outlets spaced every metre. Several fuels for this purpose can be obtained in fallowed fields (e.g. dried grasses, *Aristida* sp., and *Acacia mearnsii* branches), in addition to barley straw and rice husks.

Soil smouldering was carried out in fallow fields after mowing, on ferrallitic soils (Ibity), or ploughing subsequent to the harvest of food crops on volcanic soils (Betafo). Fields where soils had been smouldered were subsequently cropped using direct seeding procedures on mulch (*Aristida* sp., 7 t.ha^{-1}).

The effects of the different fuels were assessed relative to four fertilizers adjusted according to the type of soil and crop:

- F_0 N_0 fertilized
- F_1 Manure alone
- F_2 Manure + chemical fertilizer
- F_3 Manure + chemical fertilizer + amendment.

Soil smouldering techniques

1. Trenches manual preparation.

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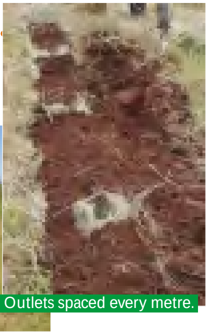

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2. Outlets spaced every metre.

4. Opened trenches after burning.

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3. Firing the outlets.

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The control treatment was carried out on bare soil after ploughing prior to sowing the crop. Another treatment, comparable to the ploughed control, was conducted with an initial application of ash (4 t.ha^{-1}) produced by open-air combustion of the same quantity of *Aristida* sp. as that used for the soil smouldering operation.

The experimental conditions were identical in all cases: split-plot design (with 3 replications), combining the main treatments, i.e. the fuels (and controls), with the fertilizers on 13.5 m^2 plots.

Rice (cvs FOFIFA 133 or 152) and soybean (cv FT10) were sown in seed holes with 10 cm spacing on pairs of rows (30 cm between paired rows), with 50 cm spacing between pairs of rows.

Crops are conducted with plowing or with direct seeding and mulch.

Results

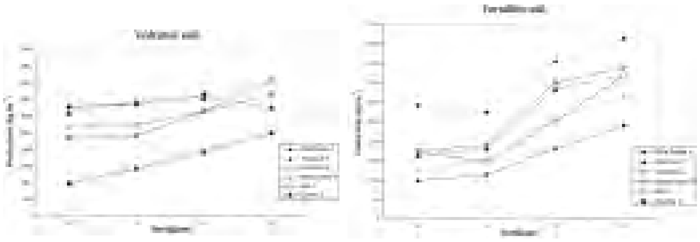
In the first year, the soil smouldering technique had spectacular effects, i.e. boosting rainfed rice yields to levels that could be achieved with high chemical fertilizer inputs—to which farmers have no access for financial reasons (Fig. 1). On the two types of soil, mean yield gains of 1-2 t.ha^{-1} were obtained, depending on the fuel, as compared to the ploughed control treatment, without any effect of the fertilization level.

The type of material used for fuel affected crop yields, with rice husk fuel giving the best results on ferrallitic soils.

Lower yield gains were achieved when applying ash produced by open-air combustion of the same quantity of *Aristida* sp. as that used for the soil smouldering operation, i.e. 0.5 t.ha^{-1} of rice on ferrallitic soils, but this input had no effect on volcanic soils.

A residual effect was observed on soybean yields in the year following the soil smouldering operation—this effect was more substantial on volcanic soils (Fig. 2).

Fig. 1. Effects of the type of fuel used for soil smouldering on rainfed rice yield.

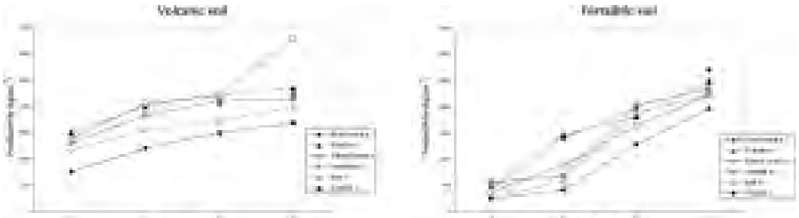


Treatments ranked by the Newman and keuls test (5% threshold)
CV fuels= 21%; CV Fertilizers= 15%, respective SDs= 580 and 428 kg.ha^{-1}

Fuel dose in t.ha^{-1} d.m.: acacia 39, aristida 54, rice husks 50, barley straw 19

Treatments ranked by the Newman and keuls test (5% threshold)
CV fuels= 18%; CV Fertilizers= 11%, respective SDs= 469 and 283 kg.ha^{-1}

Fig. 2. Residual effects of the type of fuel used for soil smouldering on soybean yield.



Treatments ranked by the Newman and keuls test (5% threshold)
CV fuels= 20%; CV Fertilizers= 19%, respective SDs= 372 and 342 kg.ha^{-1}

Treatments ranked by the Newman and keuls test (5% threshold)
CV fuels= 23%; CV Fertilizers= 34%, respective SDs= 319 and 468 kg.ha^{-1}

Acknowledgements
We thank N. Moussa and F. Rakotoniaina from the NGO Terre et Développement (TAFA) for technical assistance.

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Trophic control of tillering rate of three rice cultivars (*Oryza sativa* L. and *O. glaberrima* Steud.) under different drought levels

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Tillering capacity of rice depends on the genotype, on resources available for growth and the level of physiological stresses. The aim of this work is to examine tillering dynamics of three genetically contrasting rice cultivars: IAC47 (upland-adapted, O. sativa, japonica, low-tillering), Javaé (lowland-adapted, O. sativa, indica, high-tillering) and CG14 (broadly adapted, O. glaberrima, high-

Material and methods

The experiments involved three genetically contrasting rice cultivars:

- IAC47, a traditional, O. sativa, japonica, upland type;
- Javaé, a semidwarf, O. sativa, indica, type grown in lowland and irrigated ecosystems;
- CG14, a traditional, upland and lowland adapted, photoperiod-sensitive, O. glaberrima type.

❑ **Greenhouse experiment.** Conducted in 1997 on the EMBRAPA Research Experiment Farm (16.28° S, 49.17° W, and 823 m als), near Goiânia. Randomised complete block, using 3 cultivars, 3 water regimes with 18 replicates. The soil was a latosol. One day before sowing, a pre-mixed fertiliser and micronutrients was applied to each pot. At about panicle initiation, 85 mg N.kg^{-1} dry soil as ammonium sulphate was applied. Plants were thinned to 6 per pot at emergence, 2 per pot at the appearance of the 3rd leaf and 1 per pot at the appearance of the 7th leaf on the main stem.

Three water regimes were imposed: continuous watering to field capacity or reduced watering (moderate stress = - 0.025 MPa and severe stress = - 0.060 MPa matrix potential) from the appearance of the 3rd leaf to the appearance of the flag leaf on the main stem. The soil was kept at a constant bulk water content, weighing and watering of pots every day.

Photo 1.
IAC47, low-tillering type.

Photo 2.
CG14,
high-tillering type.

❑ **Field experiments.** In 1997 at the EMBRAPA research experiment farm. Sowing during the cold dry season (10 April) and the hot dry season (22 July) in a randomised block design with 4 replicates. Plant density: 120 plants.m^{-2} (cold dry season) and 85 plants.m^{-2} (hot dry season). The soil was a latosol. Fertiliser application according to local recommendations and plots were kept weed free. Sprinkler irrigation was used to keep the soil at field capacity.

❑ **Sampling.** For the greenhouse experiment, at each sampling, 4 to 6 plants were separated into roots and shoots, the shoot into individual tillers, and tillers into separate visible leaves (green and dead part of leaf blades), sheaths and internodes. Destructive measurements were carried out 4-5 times on field experiments on 4 sub-plots of 0.5 m^{2} per cultivar.

❑ **Number of tillers and genealogy.** Emerged tillers were counted on all plants and their genealogy was determined.

Phenological analysis

Significant differences in tiller number between cultivars under well-watered conditions were observed from 40 DAE onwards, corresponding approximately to the appearance of the nineth leaf. Javaé and CG14 significantly produced more tillers than IAC47 in all treatments. Drought effects on tillering were very small during the period of exponential growth (until ca. 40 DAE) but became very pronounced thereafter. The relative reduction in tiller number for the moderate (severe) drought treatment at the stage of flag leaf appearance was 23% (43%) for CG14, 5% (48%) for Javaé and 35% (35%) for IAC47.

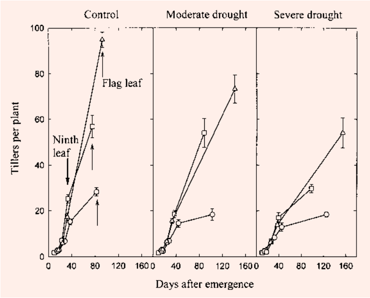

Fig. 1. Changes in number of emerged tillers for isolated plants, three drought treatments and three cultivars (○ IAC47; □ Javaé; △ CG14). Error bars indicate the standard errors (SE) for means of four to six replications.

Patterns of individual leaf blade area for the primary tillers showed a strong relationship with that of the main stem for all cultivars and drought treatment. Area of subsequently blades increased during vegetative development and then decreased. Drought had no effect on these relationships between culms. The first leaves of the tillers were more similar in size to those of a seedling.

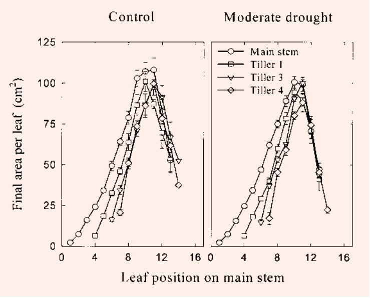

Fig. 2. Area of fully expanded leaves for the main stem (a) and the first primary tillers (b) as a function of leaf position for control and moderate drought treatments on IAC47. Error bars indicate standard errors (SE) for means of three to twenty-six replications depending of developmental stage.

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Growth analysis

In order to compare effects of growth stage (a), drought treatment (b) and cultivar (c), regressions were performed on data bulked according to these factors. A stable and uniform, linear relationship was found between RTR and RGR for two sources of variation (drought and cultivar). The intercepts on X and the slopes of the first three stages differed from the fourth stage at the 0.001 probability level.

The intercept on X for the overall regression line (RTR = - 0.014 + 0.619*RGR, R^2 = 0.84) was 0.023 g.g^{-1}.d^{-1}, indicating that no positive tillering occurred at RGR below that value. At any developmental stage, RGR of Javaé and CG14 were at least 10% higher than that of IAC47.

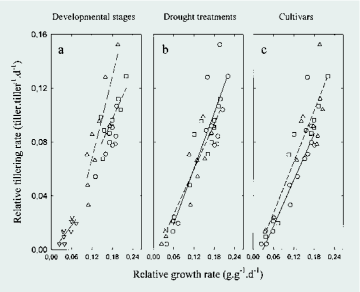

Fig. 3. Relationships between relative tillering rate and relative growth rate based on developmental stage (a: ○ stage 1, dotted; □ stage 2, short dash; △ stage 3, long dash; ▽ stage 4, solid line), drought treatments (b: ○ control, solid line; □ moderate, short dash; △ severe, dotted) and cultivars (c: ○ IAC47, solid line; □ Javaé, short dash; △ CG14, dotted). Lines indicate linear regressions.

Simulation of tiller production, using a cultivar specific relationship RTR vs RGR, gave a reasonably good fit with observations for the vegetative growth phase (from the seedling emergence to 40 days after emergence) in two-independant, well-watered, field trials. Consequently, this relationship RTR vs RGR is valid for both isolated plants and field crops.

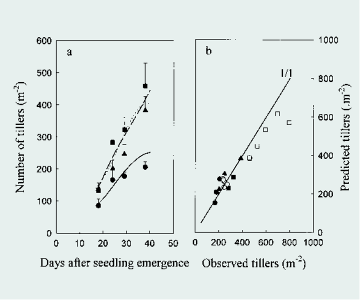

Fig. 4. Two experiments (white and black symbols) conducted under field conditions in Goiânia (Brazil). ○ IAC47; □ Javaé; △ CG14 (means of four replications).
a) Number of tillers per plant. Lines indicate simulations using a relative tillering (RTR) vs relative growth rate (RGR) relationship taken from greenhouse-based observations (solid line, IAC47; dotted line, CG14; short dash, Javaé).
b) Predicted versus observed tiller numbers.

Conclusion

- ❑ Leaf appearance is synchronized across tillers.
- ❑ New tillers repeatedly 'catch-up' with the mainstem in term of leaf size but not number.
- ❑ Tillers number depends on biomass growth and not on bud number.
- ❑ Varietal tillering capacity is due to growth rate.

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Plant covers, soil macrofauna and geranium cropping

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Geranium cropping on straw mulch.

© A. Chabanne

In the highlands of western Réunion, the abandonment of fallowing, the use of monocropping and crop rotations under bare soil conditions, and excessive application of pesticides has led to physical, chemical and biological soil degradation. The technical and socioeconomic performances of farms with geranium (Pelargonium x asperum) *as main crop have been markedly affected by these trends. They have also had a detrimental effect on the environment—already weakened by serious natural constraints. Cropping over plant covers could enhance the sustainability of such farms under these adverse conditions.*

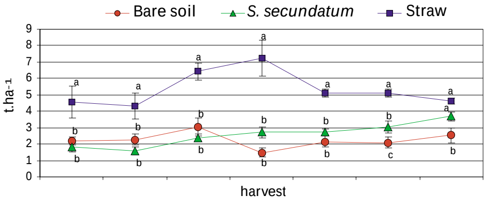
Material and methods

On a highly eroded andosol plot, an experimental block design was used with six replications. The tests were carried out by farmers over an 18-month period. Two types of cover were tested: a sugarcane *(Saccharum officinarum)* straw mulch derived from crop residue (especially leaves) obtained after sugarcane harvests; a live *Stenotaphrum secundatum* cover planted in a geranium field, kept alive and controlled with low-dose selective herbicide treatments.

Results

As compared to a control geranium crop grown on bare soil, the sugarcane straw mulch treatment led to significantly higher production of green above-ground biomass (Fig. 1).
S. secundatum only had a significant positive effect on crop yields after 1 year of cropping.

Fig. 1. Geranium green above-ground biomass production (t.ha^{-1}). Vertical bars represent the standard error.



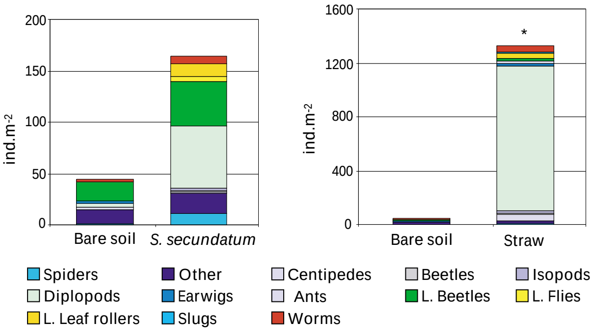
a, b, c: The same letter for the same date indicates that the difference was not significant (Newman-Keuls test; p< 0.05).

Since essential oil yields were not significantly affected by the different treatments, the resulting overall production showed the same patterns. In one crop year involving five harvests, 80 l.ha^{-1} of essential oil was yielded when cropping over sugarcane straw mulch, compared to 35 l.ha^{-1} when cropping on bare soil.

With both treatments involving plant cover, a study of mean soil macrofauna densities (Fig. 2) revealed a biodiversity renewal, especially with straw mulch (13 taxa), and a substantial increase in the number of diplopods and earthworms per square metre.

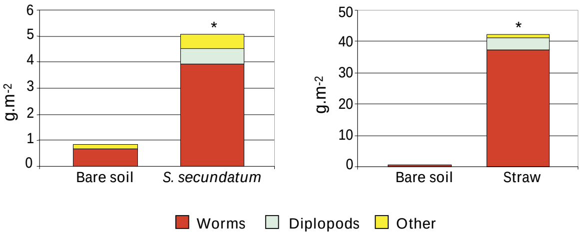
A study of mean biomass (Fig. 3) revealed that two groups markedly benefitted from the plant covers (especially the straw mulch), i.e. earthworms and diplopods, which feed on the litter layer.

Fig. 2. Mean density of the different soil macrofauna taxa.



*: Significant differences (ANOVA, p< 0.05, for mean total densities) relative to the control (bare soil).

Fig. 3. Mean biomass of the different soil macrofauna groups. Other: pools the 11 other taxa.



*: Significant differences (ANOVA, p< 0.05, for mean total densities) relative to the control (bare soil).

Conclusions

On eroded soils, sugarcane straw mulch cover quickly increased essential oil yields. The fact that soil macrofauna diversity was renewed and taxa density and biomass were increased indicated enhancement of biological soil fertility.

It takes time to establish live *S. secundatum* plant cover. This involves forming a litter layer sufficient to reactivate biological processes, especially with respect to bioregulatory cycles.

The results of this field test highlighted the technical and economic benefits of the tested proposals. Farmers are appreciative of the reduction in their labour time and herbicide inputs. Despite the phase required to establish live plant cover and the close management necessary to maintain it, this is an efficient way of building up *in situ* biomass.

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Impact of cultivation practices (cover crops) on soil macrofauna in Réunion

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Most farming practices are detrimental to soil organic matter reserves, leading to a significant decrease in biological activity and an increased risk of erosion. Soil invertebrate populations (macrofauna) are also sharply reduced in annual crop systems. The role of macrofauna in pedological processes and in the regulation of microbial activity has been fully described (Lavelle et al., *1999). Some agroecological practices and especially plant covers—straw mulch or perennial plants intercropped with annual crops—can enhance the sustainability of tropical cropping systems (Séguy* et al., *1996). This study was aimed at assessing the effects of two plant covers (greater bird's food trefoil,* **Lotus uliginosus,** *and oat,* **Avena sativa***) on soil macrofauna populations in Réunion (Indian Ocean).*

Material and Methods

Using an experimental block design with five replications, soil macrofauna was first sampled in 1999 prior to sowing the maize crop in the test plots:

- on bare soil
- with trefoil cover
- with oats (unmown).

The second sampling was done at the end of the maize crop cycle (in 2000) with three treatments:

- maize cropped on bare soil
- maize intercropped with trefoil
- maize intercropped with oat.

Macrofauna were sampled using the technique recommended in the TSBF handbook (Tropical Soil Biology and Fertility, Anderson and Ingram, 1993).

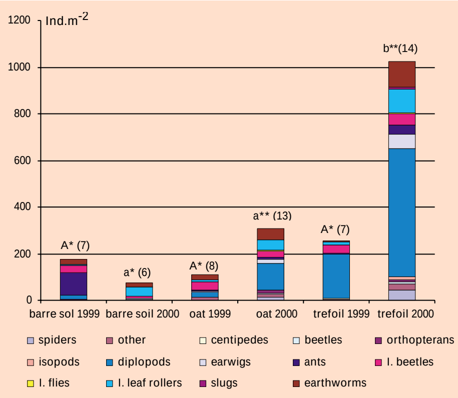


Figure 1. Mean total soil macrofauna density.

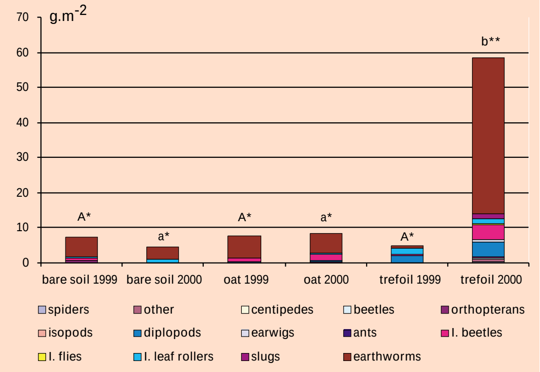
The same capital letter = a significant difference ($p < 0.05$) between three treatments for the first sampling (1999).
The same small letter = a significant difference ($p < 0.05$) between three treatments for the second sampling (2000).
The same number * = a significant difference ($p < 0.05$) between the two sampling dates for the same treatment.
In parentheses = the number of taxa.

l. = larva
Ind. = number of individuals

Figure 2. Mean total soil macrofauna biomass.

The same capital letter = a significant difference ($p < 0.05$) between three treatments for the first sampling (1999). The same small letter = a significant difference ($p < 0.05$) between three treatments for the second sampling (2000).
The same number * = a significant difference ($p < 0.05$) between the two sampling dates for the same treatment.

l. = larva
g = gramme



Results

- ❑ The results of the first sampling (1999) before sowing the maize crop, just before mowing the oat crop and under 3 month-old trefoil cover, revealed no significant differences between the three treatments with respect to soil macrofauna population density and mean total biomass (Figures 1, 2).
- ❑ At the end of the maize crop cycle (5 months, in 2000), a second sampling was carried out and a significant increase in soil macrofauna density was noted under trefoil and oat cover as compared to the control on bare soil (Figure 1). A significant increase in mean biomass was only noted under trefoil cover (Figure 2).
- ❑ For the same treatment, a comparison between the two sampling dates highlighted a significant increase in macrofauna density and biomass under trefoil (Figures 1, 2), but only in density under oat cover (Figure 1).
- ❑ For the taxa studied (14), there was a substantial increase in biological diversity under both plant covers (Figure 1).

Conclusions and Discussion

Cropping generally leads to a decrease in soil macrofauna. The use of perennial plant covers (trefoil) and mulch (oat straw) helps to restore soil macrofauna by increasing their densities, biomass and diversity.
Some of these macrofauna taxa, are more sensitive to the type of plant cover used, e.g. earthworms, whose mean biomass represents more than 50% of the total macrofauna biomass, and diplopods (phytophages, saprophages). Diplopods seem to be characteristic of trefoil since they were found in high densities under this cover. These taxa have a direct and indirect impact on fresh organic matter (litter) and on soil organic matter. Other studies have highlighted the effects of earthworms on soil nutrient dynamics and soil structure.

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Effects of direct seeding techniques on soil fertility indicators under equatorial climatic conditions

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Maize in *Mucuna* mulch.

In the Boumango agroindustrial area (2°S, 13°E) of Gabon, 2000 ha has been intensively cropped since 1980 under mechanized conditions, with an annual sequence of maize and soybean. New alternative cropping systems are now required to solve the cultivation problems that have arisen. Experiments were carried out to test systems involving direct seeding on plant cover that were initially developed in central-western Brazil. Several soil fertility indicators were monitored over a 3-year period, their evolution under three different crop management sequences and two fertilizer levels are reported.

Material and methods

Test site

The experiment has been carried out for 4 years in a large crop plot (24 ha) on ferrallitic soil. Cropping systems were compared in 0.3-1 ha subplots.

Treatments

Three crop management sequences:

- Two crops per year and one mouldboard ploughing (maize/soybean-ploughing sequence)
- Maize with direct seeding into *Calopogonium mucunoides* mulch (DS-*Calopogonium* sequence)
- Soybean with direct seeding into mulch of millet or guinea sorghum (DS-cereal sequence)

… overlaid with two fertilization levels:

- High corrective fertilization (HC)
- Progressive corrective fertilization (PC).

Measurement

Chemical parameters: soils were sampled and analyzed twice: before setting up the treatments and at the end of the 3-year test period.

Soil bulk density: it was measured at the end of each first cropping cycle in the PC subplots at 10-cm intervals in the [5-45 cm] horizon and under the initial natural cover (a wooded savanna).


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Maize in mulch.

Results and discussions

Chemical parameters

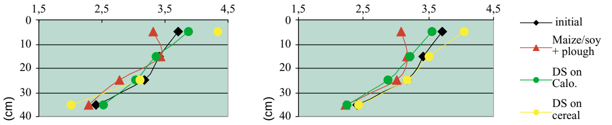
Plough tillage induced a slight drop of organic matter by 0,2-0,3 %/year at the soil surface (Fig 1). This drop was more pronounced under HC fertilization. Mechanical redistribution in the first 30 cm by ploughing and deep lixiviation reduced the efficiency of mineral inputs on acidity and nutrient availability (Figs 2, 3, 4 and 5).

Direct seeding induced pronounced improvements of chemical parameters on top soil horizon [0-10 cm] compared with ploughing and initial status:

- the organic matter level and the cationic exchange capacity stabilized and even increased (greater extent under cereal straw mulch, Figs 1 and 3);
- sharp drop in soil acidity (Fig 2);
- higher exchangeable base saturation rate (Fig 4);
- higher exchangeable phosphorus level (Fig 5).

Soil bulk density

The initial soil bulk density was around 1.3. The density fluctuated around this value with ploughing. However, sequences with plant cover induced a decrease, which was greater under cereal cover: the mean soil bulk density in the [0-30 cm] horizon reached 1.09, close to levels noted under natural cover (range 0.9-1).



Ds on cereal [10-20] : missing data on PC

Fig. 1. Soil organic matter level (%) according to depth - PC (left), HC (right) corrective fertilization.

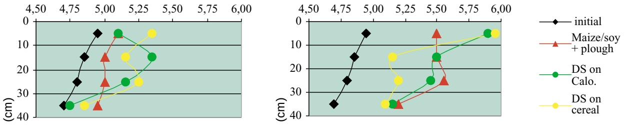


Fig. 2. pH$_{water}$ according to depth - PC (left), HC (right) corrective fertilization.

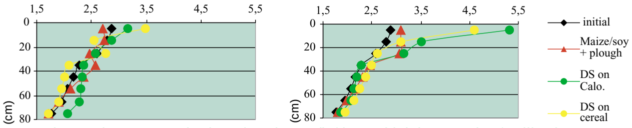


Fig .3. Cation exchange capacity (meq/100g) - PC (left), HC (right) corrective fertilization.

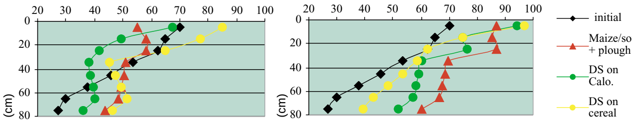


Fig. 4. Exchangeable base saturation (%) according to depth - PC (left), HC (right) corrective fertilization.

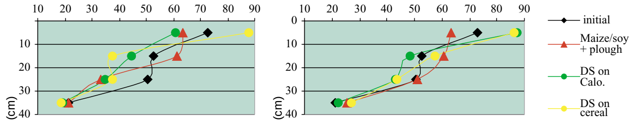


Fig. 5. Exchangeable phosphorus (ppm) according to depth - PC (left), HC (right) corrective fertilization.

Conclusion

The differentiation of soil profile under ploughing and direct seeding in plant cover are quite different:

- ploughing induced a drop of organic matter, a slight decrease in nutrient availability, which could be temporarily offset by more important inputs application; despite soil tillage physical conditions remained a constrain;
- direct seeding in plant cover had beneficial improvements for chemical indicators in top soil horizon which became more favorable for plant mineral nutrition; progressive improvements of physical conditions allowed deep root system development.

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