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Land-use in a mulch-based farming system of small holders in the Eastern Amazon

Vielhauer[a], Konrad, Manfred Denich[a], Tatiana D.deA. Sá[b], Osvaldo R. Kato[b], Maria do Socorro A. Kato[b], Sílvio Brienza Jr.[b] and Paul L.G. Vlek[a]

[a] University of Bonn, Center for Development Research (ZEF), Walter Flex Str. 3, 53113 Bonn, Germany, kvielhau@uni-bonn.de

[b] Agroforestry Research Center of the Eastern Amazon (Embrapa Amazônia Oriental), Tv. Dr. Eneas Pinheiro s/n, 66240 Belém - PA, Brazil

Abstract

Burning is a commonly used method to clear land for cropping, especially in regions with shifting cultivation. Due to population growth with the resulting intensified land use, it is mostly combined with a shortening of the fallow periods. Both burning and the shortened fallow period are the principal causes of declining soil fertility, and they are symptomatic for Eastern Amazonian agriculture. Based on the assumption that shifting cultivation will be maintained as the basic land-use system, these two adverse factors have to be improved in order to achieve reasonable and increased sustainable productivity.

In the framework of a bilateral German-Brazilian research project, mechanized mulching technologies were developed to carry out fire-free land clearing by cutting and chopping the tree-rich fallow vegetation creating a mulch layer. Besides preserving organic matter and mineral nutrients, mulching permits land preparation at any time of the year, as, in contrast to burning, it does not depend on the dry season.

Enriching the fallow vegetation with fast growing trees enhances the effect of mulching by increasing biomass: 25 t/ha/year as compared to natural fallow with 10 t/ha/year during the linear growth phase in the first 2 - 3 years.

When putting these technologies into practice, the demand on differently behaving nutrient stocks in mulch-based systems has to be met. On the other hand, fire-free land preparation allows for flexible, alternative land utilization practices. Both factors lead to new crop-fallow scenarios where land use is intensified whilst the basic principles of shifting cultivation are maintained. In particular: 1) fallow biomass increase by enrichment reduces the fallow period from 4 - 6 years to 2 years, 2) slow nutrient release from the mulch layer allows highly demanding crops to be planted at the end of the cropping period low mineral fertilizer input is desired, 3) an additional cropping period becomes possible and reduces the land preparation time by half, 4) independent of the dry season crops can be planted taking climate and market demands into consideration, and 5) perennial cash crops can be integrated into the crop rotation.

Introduction

The Bragantina region of Northeastern Pará (Eastern Amazonia), Brazil was exposed to an intensive colonization process end of the 19^{th} – beginning of the 20^{th} century. Settlers were given 25 ha of rectangular pieces of land located on both sides of a 330 km long railroad track connecting the capital Belém with the city of Bragança. The surrounding region was to be utilized, first by clearing the forests for timber and later through use of the land for agriculture. Food crops and meat were to provide food for the region and cash crops to generate a reasonable income for the smallholders. Consequently, the agricultural practices are a mixture of traditional shifting cultivation with modern elements of highly intensive crop production.

Due to the prevalence of low fertility Ultisols, land degradation was very rapid. Declining productivity led to an extension of the cropped fields and accelerated the crop-fallow cycles. Additionally, the growing demographic pressure fueled the vicious circle. By 1999 population density had reached the number of 41 inhabitants km^{-2} in the municipality of Igarapé-Açu, which is about tenfold of the average population density of the state of Pará (IBGE 2000). These were the reasons to choose Igarapé-Açu as a challenging research site.

Today, sustainable production of food crops is hardly viable. Upland rice, as a demanding crop, has disappeared in most of the municipalities of the Bragantina region. The most tolerant crop, cassava, is being produced on a relatively large scale as a low-input crop. The same applies to maize, which mostly serves as fodder for chickens. Cowpea is still frequently planted but requires mineral fertilizer, essentially. These crops have some impact on soil degradation due to burning at land preparation.

Perennial and semi-perennial cash crops, such as pepper and passion fruit are high-input crops and they appear and disappear as a function of (world) market prices and crop-specific governmental credits. Their impact on soil degradation, however, is considerable, mainly due to the applied tillage practices after burning. In the subsequent fallow period, the secondary vegetation becomes degraded in terms of reduced species richness and reduced growth of trees and shrubs, which in turn slows down nutrient recycling into the topsoil.

In the framework of a bilateral German-Brazilian research project ("Secondary Forests and Fallow Vegetation in Eastern Amazonia - Function and Management"), financed by BMBF and CNPq and conducted by the Center for Development Research (ZEF) of the University of Bonn and the Agroforestry Research Center of the Eastern Amazon (Embrapa Amazônia Oriental), Belém - PA, Brazil, mechanized mulching technologies are being suggested to realize fire-free land clearing by cutting and chopping the tree-rich fallow vegetation and leaving a mulch layer (chips < 2 cm) on site. In addition, fallow vegetation is enriched with fast growing leguminous trees to support the mulching effect by increasing biomass production during the fallow period.

Landscape dynamics

First, landscape dynamics were studied in different areas of the project region, distinguishing two intensities of land-use, those of long fallow periods of more than ten years and those of short fallow periods of less than four years (METZGER, 2000). In an analysis of LANDSAT TM satellite images between 1985 and 1996 it was found that fallow periods of more than ten years seem to guarantee agro-ecological sustainability based on the assumption of a zero population growth, because agricultural areas in relation to the other landscape components are not being increased in number or size.

Under the conditions of Igarapé-Açu a land utilization factor of less than 7% on the overall farm level is still adequate to avoid long-term soil degradation processes. In comparison, in areas of shorter fallow periods where the land utilization factor lies around 15%, agricultural areas are being increased at an annual rate of about 3% as a consequence of soil degradation. The latter problem-areas with a land-use factor of 0.15 (15%) have been selected for the research work

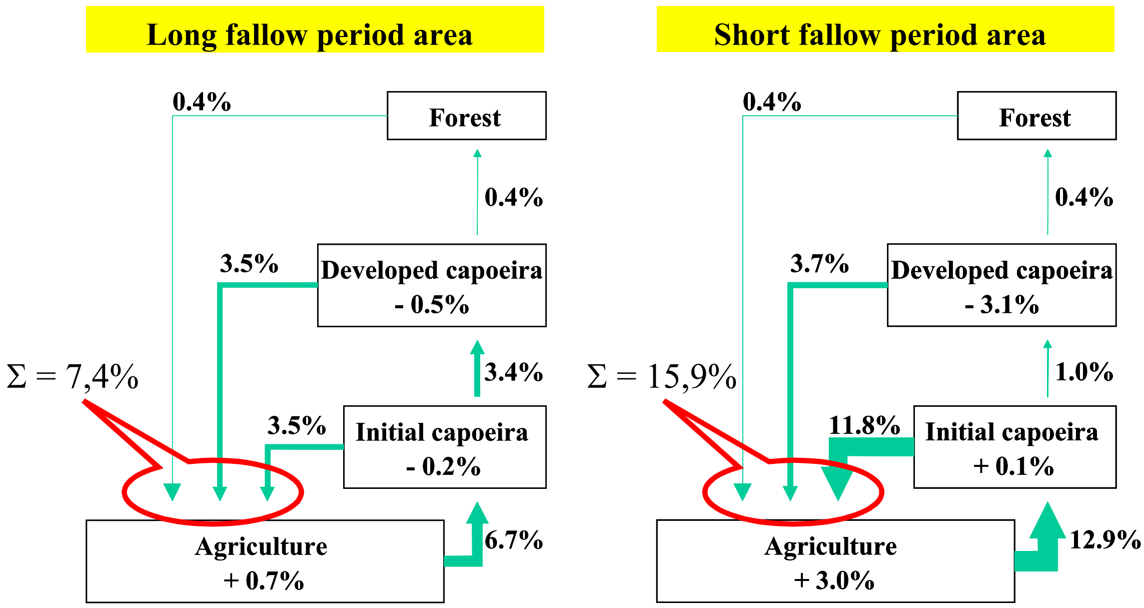

Figure 1
Agro-ecological sustainability expressed by annual flows and changes of stock of 4 different landscape components (forest, old (developed) secondary vegetation (capoeira), young (initial) capoeira, agricultural fields) in two regions typical of shifting cultivation, one with long fallow periods and another one with short fallow periods due to low and high demographic pressure, respectively (modified from METZGER 2000).

Apart from the insufficient fallow period, the major reason for the degradation processes lies in the use of slash-and-burn for land preparation, removing organic matter and nutrients from the site. Consequently, two lines of technology development are followed by the project. First, the enrichment of the fallow vegetation with fast growing tree legumes to counteract the short fallow periods through rapid biomass accumulation and, second, fire-free land preparation to preserve the organic matter and nutrients in the system. Both favor an increment of the land utilization factor even beyond the actual critical levels. Yet, shifting cultivation is being maintained as a system.

When and how is tree enrichment done?

The enrichment of the fallow vegetation by fast growing tree legumes is done as early as possible, before the fallow period starts. As an example the case of cassava shall be given: The tree seedlings are planted at a spacing of 2 m x 2 m between the cassava plants about 3 to 6 months before the cassava harvest, making sure to chose a period of sufficient rainfalls. This gives the trees a slight advantage over the remaining undergrowth but does not yet compete with the crop. At the onset of the fallow period vigorous growth of the enrichment trees takes place, followed by the species-rich secondary vegetation. Depending on the utilized species, sprouting can partially avoid replanting of the trees in later cycles.

How is fire-free land preparation done?
Since the main intention of slash-and-burn is to "clear" land for planting crops, that is, to get rid of the shrubby fallow vegetation, any alternative technology has to respect the aspect of a clear and workable land, most. But if any advantage is to be taken out of the organic matter and nutrients contained in the biomass it has to be left on site, which is why it has to be comminuted. Various methods to produce chips of the standing fallow vegetation have been tested in the project, from manual chopping to different levels of mechanization. The apparently most viable methods are tractor-propelled mobile bush choppers of different capacities. They are dimensioned to cut, chop and spread the shrubby secondary vegetation at a speed of about 0.2 ha h^{-1}. The chip sizes are to more than 50% smaller than 2 cm (BLOCK 1999).

The resulting alternative crop-fallow scenarios

Shortening of the fallow period by tree enrichment
Applying enrichment to the fallow vegetation with fast growing tree legumes shows the potentials of increased biomass accumulation of fast growing tree legumes (Figure 2). In experiment 1 it was demonstrated that the amount of biomass of a 7-year-old fallow could almost be reached within just 2 years by planting the species *Acacia auriculiformis* (SILVA 1998). In later works, experiment 2 (BRIENZA 1999) and experiment 3 (VIELHAUER unpublished data), a similar or even greater performance was achieved with *Acacia mangium*. Accompanying studies on floral diversity showed that enrichment did not influence the species richness of the natural secondary vegetation adversely (WETZEL 1997).

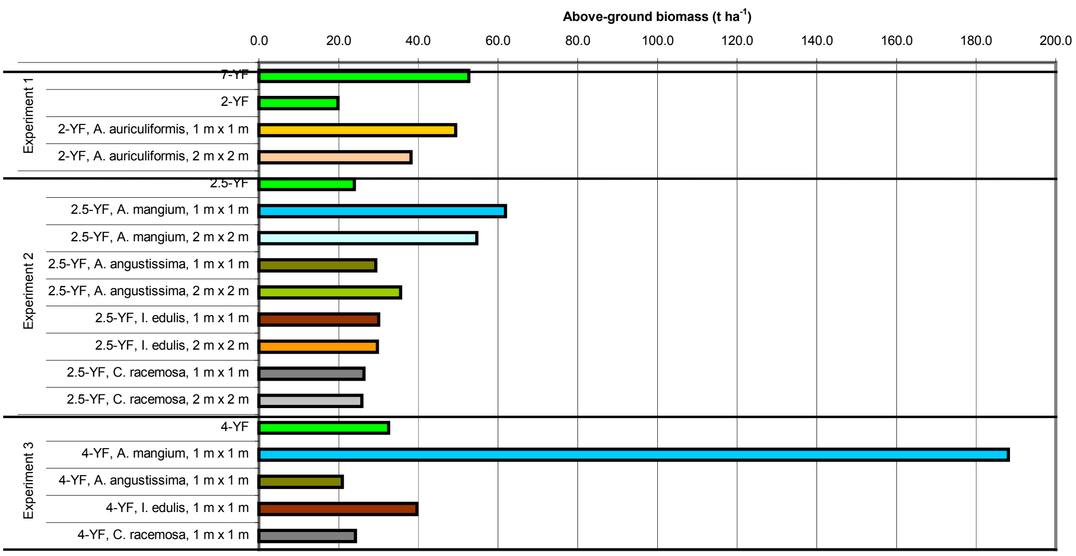

Figure 2
Above-ground biomass of fallow vegetation of 3 different experiments as a function of fallow length (7-YF = 7 years, 2-YF = 2 years, 2.5-YF = 2.5 years, 4-YF = 4 years), no enrichment and with enrichment with the tree legumes *Acacia auriculiformis*, *Acacia mangium*, *Acacia angustissima*, *Inga edulis*, *Clitoria racemosa* at two spacings (1 m x 1 m, 2 m x 2 m)

These data show that fallow biomass increase by enrichment can reduce the fallow period from between 4 and 6 years to 2 years if the appropriate enrichment species are used. This implies a possible increase of more than double of the land use factor; from R = 0.14 (14%) to R = 0.33 (33%) (Equation 1).

$$R = \frac{Cp}{Cp + Fp} \qquad R = \frac{1}{1+6} = 0.14 \;\Rightarrow\; R = \frac{1}{1+2} = 0.33$$

R = Land use factor, Cp = Cropping period (years), Fp = Fallow period (years)

Equation 1
Land use factor increment from R = 0.14 to R = 0.33 by reducing the fallow period from traditionally applied 6 years to alternatively possible 2 years on account of fallow enrichment with fast growing tree legumes

Extension of the cropping period by slash-and-mulch

Land preparation by chopping the fallow vegetation leaves behind a layer of dead mulch, which is subsequently exposed to the decomposition processes. Under the climatic conditions of the Bragantina region, natural – not enriched – material is decomposed by half, after one year (KATO, O.R. 1998, KATO, M.DOS.A. 1998). The same works show that the initial concentrations of nitrogen (KATO, O.R. 1998) and phosphorus (KATO, M.DOS.A. 1998) of the mulch are decreased rapidly during the first 60 days (N to 80%, P to 50%). These concentrations were maintained from then on during the entire first year of decomposition. This results in a nutrient release of about 86 kg N ha^{-1} and 7 kg P ha^{-1}, which should allow highly demanding crops to be planted after one year and to achieve reasonable yields even without fertilizer.

The crop yield data of KATO, O.R. (1998) and KATO, M.DOS.A. (1998) confirm this hypothesis. They are based on an experiment that was conducted to look at the effects of mulch and fertilization. The crop sequence maize, cowpea and cassava was planted twice in two consecutive cropping periods (CP_1 and CP_2), with just a short fallow in between to let the dry season go by. The results in Table 1 show that, without fertilization, mulching causes nutrient immobilization and consequently lower yields with rice and cowpea during the initial phase of the first copping period. However, in the second cropping period, this is just the opposite, the yields of the mulched treatments are as high as (rice) or higher than (cowpea) with burning in the first cropping period. This suggests securely enough that an inversion of the cropping sequence, i.e. starting with cassava followed by rice and cowpea, would guarantee the farmer the yields he is familiar with. This exceeds the expectations for a technology of which substantial effect is anticipated only in terms of long-term soil recuperation, which is thought to only then be followed by its benefits to crop production.

Looking at the fertilized treatments of the first cropping period, it can be stated that the application of mineral N, P and K (60, 47, 67 kg ha^{-1}, respectively) increases yields and evens out the differences between the two land preparation treatments (rice 2.5 t ha^{-1}, cowpea 1.5 t ha^{-1}, cassava 30 t ha^{-1}). In the second cropping period the yields of the mulched treatments are slightly above those of the burned ones, revealing the nutrient release from the mulch layer.

Being aware that in these experiments rice and cowpea had already been planted before cassava – as initial crops of the first cropping period – the fact should be recognized that without their contribution to soil nutrient depletion, i.e. with only cassava as preceding crop, rice and cowpea of the second cropping period would have done still better, which is why it is in fact more recommendable to start the cropping period with less demanding crops and end it with more demanding crops.

Summarizing, it can be said, that rearrangements in the cropping sequence in mulch-based systems can respond adequately to the specific nutrient dynamics of the decomposing organic matter, giving farmers already an easily manageable option before moving to intensification.

Table 1
Yields of three crops of two consecutive 1½-year cropping periods (CP_1 and CP_2) as a function of land preparation treatments (Burn, Mulch) and fertilizer application (without: -NPK and with: +NPK), (data from: KATO, O.R. 1998, KATO, M.DOS.A. 1998)

	Yields in t ha^{-1}				Yields in t ha^{-1} corrected by the respective land-use factors*					
	-NPK		**+NPK**		**-NPK**			**+NPK**		
	CP_1	CP_2	CP_1	CP_2	Traditional	Inverse	Intensive	Traditional	Inverse	Intensive
Rice										
Burn	1.5	1.4	2.7	2.7	0.27	0.25	0.41	0.49	0.49	0.77
Mulch	0.9	1.5	2.5	3.2	0.16	0.27	0.34	0.45	0.58	0.81
Cowpea										
Burn	0.3	0.3	1.6	1.6	0.05	0.05	0.09	0.29	0.29	0.46
Mulch	0.2	0.6	1.5	2.0	0.04	0.11	0.11	0.27	0.36	0.50
Cassava										
Burn	16.3	11.3	30.2	24.6	2.96	2.05	3.94	5.49	4.47	7.83
Mulch	17.7	17.4	28.8	26.0	3.22	3.16	5.01	5.24	4.73	7.83

* Land-use factors: Traditional (CP_1) and Inverse (CP_2) each = 0.27, i.e. 1.5 years cropping and 4 years fallow = 5.5 years total cycle; Intensive ($CP_1 + CP_2$) = 0.43, i.e. 3 years cropping and 4 years fallow = 7 years total cycle

However, intensification is even more viable than just switching crops, as is indicated in Table 1. In the already cited experiments the land use factor was lifted from 0.27 (27%) to 0.43 (43%) by moving from one cropping period of 1½ years in a 5½ year-cycle (traditional) to two cropping periods of jointly 3 years in a 7-year cycle (intensive). The overall yields – divided by the respective total cycle times to harmonize the data – show that intensification resulted in higher returns with all three crops (right part of Table 1). Moreover, the demanding crops rice and cowpea improved their yields with mulching as opposed to burning, whilst cassava reacted indifferently.

The promising results of the above-described experiments permit to further build on the land use factor established by tree enrichment, which had reached the level of 0.33 (30%). With mulching it can be further increased to 0.5 (50%) or even 0.6 (60%) as can be seen in Equation 2.

$$R = \frac{Cp}{Cp + Fp} \qquad R = \frac{1}{1+2} = 0.33 \;\Rightarrow\; R = \frac{2}{2+2} = 0.5 \;\Rightarrow\; R = \frac{3}{3+2} = 0.6$$

R = Land use factor, Cp = Cropping period (years), Fp = Fallow period (years)

Equation 2
Land use factor increment from R = 0.33 to R = 0.6 by increasing the cropping period from traditionally possible 1 year to alternatively possible 3 years on account of improved land preparation by slash-and-mulch

The increase of the land-use factor signifies increments of agricultural productivity in large steps. In addition to that, when applying two consecutive cropping periods, labor inputs can be reduced considerably by reducing land preparation by half.

Implications of the detachment of the dry season

Apart from the above-mentioned advantages of fire-free land preparation, there is one considerable additional implication to the existing customary agricultural practices. This is the detachment of the dry season for the act of field preparation, since sun drying for burning of the slashed fallow vegetation is no more required. A number of advantages can be derived from that:

- More ideal temporal placement of crops with view to climatic factors

With slash-and-burn it was not possible to make optimal use of the available natural resources such as solar radiation for maximum crop performance, because land preparation was not possible during the high rainfall months but predetermined to September, October and November, when the dry season permitted burning.

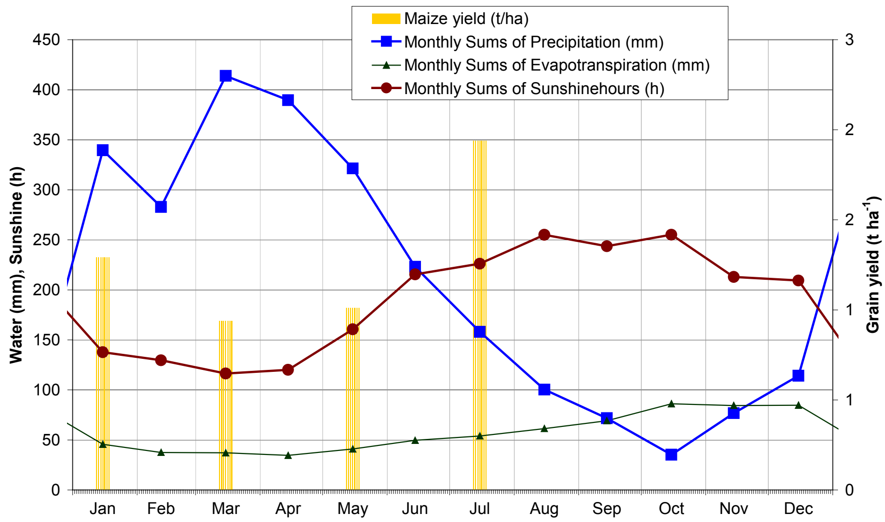

Figure 3
Annual average climate data of the years 1994-1999 of Igarapé-Açu and maize yields as a function of 4 planting dates (January, March, May, July) (data from Embrapa Amazônia Oriental, Climatic Division)

With respect to the climatic diagram of Igarapé-Açu (Figure 3) it is apparent that maize, for instance, is not placed ideally, when planting it in January, as it is traditionally done. In spite of having abundant water supply, the necessity of solar radiation is least attended during that period. It would be more adequate to plant maize in June or July, when rainfalls are still sufficiently high and solar radiation rises to its annual peak. This can be seen in Figure 3 where the maize yields are highest when planted in July. The earlier planting dates suffered either directly from the lack of sunshine in physiological terms or from humidity related external factors such as plant pathological problems, as was observed in the field.

- More flexible reaction to market demands

High market prices can be achieved by the out-of-season occurrence of products, such as the July-maize shown in Figure 3 that would come to the market in November. This means that higher yields multiply with higher prices. Certainly, this might be just of temporary character, if mulching becomes a widely spread technique. But even then, the very important asset of quick reaction to high market prices remains. In the case of great disease-caused yield losses in other regions, such as the South of Brazil, this could be reacted to ad hoc in the humid tropical regions of the North if adequate technologies would permit land preparation immediately.

- Better labor distribution over the year

One of the most intensive activities of shifting cultivation is the act of land preparation. The suggested mechanized chopping of the fallow vegetation not only reduces this part of the work substantially; it also allows distributing it more equally over the year, since land preparation during the rainy period is becoming possible by the mechanized slash-and-mulch technology. Less labor has to be hired from outside and the time set free can be applied in more valuable types of work.

Integration of perennial cash crops into the crop rotation

Traditionally, the planting of perennial cash crops is connected to intensive tillage activities, which mostly do not permit to return to shifting cultivation, because the vitality of the secondary vegetation is degraded to such an extent that regrowth remains too week to recover soil fertility effectively. By applying the technology of slash-and-mulch, however, low or no tillage can be recommended, since nutrients are supplied by the decomposition process and weeds are suppressed by the mulch layer. This allows integrating the areas of cash crops into the normal crop rotation of the farmer. Subjecting areas to perennial crops becomes thus a reversible process because the vitality of the secondary vegetation can be maintained.

Conclusions

When acquiring the new mulch-based technologies with mechanization, no negative effects are to be expected in terms of immediate visible results such as crop yields. On the contrary, considerable land use intensification and higher crop productivity can be achieved, and they go along with gradual build-up of organic matter in the soil, improving soil structure and the nutritional status. This, in turn, provides its visible long-term effects in greater future, turning the technologies not only sustainable but perhaps even incremental.

At landscape level (Figure 1) this would mean that the right flow chart with the high land-use factor of about 0.16 (16%) would move towards a dynamic equilibrium of the 4 landscape components. Agricultural areas would not have to be extended at an annual rate of 3%, young and old secondary vegetation as well as the forest would also maintain their shares. Based on the current data, there even seems to be potential for further bringing up of the land-use factor to 0.6 (60%).

Furthermore, new challenges, such as planting off-season, applying mineral fertilizer correctly and reorganizing the cropping sequence offer new opportunities in the daily life of the farmers. However, these modules are not compulsory, which permits them to be adopted gradually.

Since the above-described mulch-based technologies are primarily directed to improve soil fertility and natural vegetation vitality, they are neither very site-specific nor very crop-specific, which gives them general applicability over many different regions and cropping systems. Furthermore, they are a systems approach that remains reversible at any time, an important prerequisite for quick adoption by suspicious farmers.

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