# Identification of Plant Genetic Resources with High Potential Contribution to Soil Fertility Enhancement in the Sahel, with Special Interest in Fallow Vegetation

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**Abstract** The sandy soil in the Sahel is characterized as low inherent fertility, that is, having nutrient deficiency (total N and available P), low organic matter and high risk of erosion. Under the concept of integrated soil fertility management (ISFM), possible contribution of natural inhabitant plants to the improvement of soil fertility in the Sahel was evaluated. A broad variation in $\delta^{15}$N values was observed among the plant species commonly found in cropland and fallow land of the Sahelian zone. Annual leguminous herbs, *Cassia mimosoides* (Caesalpiniaceae) and *Alysicarpus ovalifolius* (Papilionaceae), had low $\delta^{15}$N values, showing their higher dependency on biological nitrogen fixation. They will be efficiently utilized as an extensive means of soil fertility management, for example, through more encouraged incorporation into the fallow vegetation. *Ctenium elegans*, *Eragrostis tremula* and *Schizachyrium exile*, greatly dominating annual grass species in the fallow land, though their $\delta^{15}$N values were high, would contribute to the soil fertility by supplying a significant amount of organic matter.

**Keywords** Biological nitrogen fixation · Fallow vegetation · ISFM · Leguminous plants · Soil organic matter

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## Introduction

As well as uncertain rainfall and locust outbreak, poor nutrient (carbon, nitrogen and phosphorus) status of the sandy soils is one of the causes for low and unstable productivity in agroecosystems in the Sahel. Therefore, the Sahel is very marginal for agricultural production in the world, where the success of green revolution is most wanted among the African continent.

In general, improvement of soil fertility through indigenous organic matter management is proposed with high possibility and practicality for smallholder farmers in sub-Saharan Africa (Lal, 2007). Concerning nitrogen, a most limiting factor in the soil, biological nitrogen fixation (BNF) by plant–microbe interactions (symbiotic and associative) can be efficiently utilized in croplands and fallow lands (Sanginga, 2003; Ito et al., 2005).

In croplands of the Sahel, cowpea (*Vigna unguiculata* [L.] Walp.) is the most important leguminous crop, not only for human food but also for animal fodder. Therefore, the identification of such dual-purpose cowpea cultivars which adapt well to the Sahel environment and have higher BNF ability could contribute to the improvement of soil fertility in this area. In collaboration with IITA (International Institute of Tropical Agriculture) and INRAN (Institute National de la Recherche Agronomique du Niger), a total of 140 cowpea lines were evaluated (Matsunaga et al., 2006, 2007) and best cultivars identified for dissemination to farmers of the Sahel (Matsunaga and Tobita, 2007).

Fallow systems have been locally practiced by farmers for soil fertility maintenance and restoration as an extensive means of management in the Sahel.

A. Bationo et al. (eds.), *Innovations as Key to the Green Revolution in Africa*,
DOI 10.1007/978-90-481-2543-2_71, 

However, soil N supplying ability evaluated by N uptake by pearl millet plants (*Pennisetum glaucum* L.), staple crop in the Sahel, was low from fallow lands as compared with those from other soil fertility managements, e.g. animal corralling and manure or household waste transporting (Suzuki et al., 2007). Therefore, it is strongly required to improve the fallow system for more effective soil fertility management especially in remote fields that are far away from the farmers' household.

Fallow vegetation has a role in field to retain and capture the wind-borne fertile materials from cropped area by quantitative aerodynamic observations (Herrmann, 1996; Ikazaki et al., 2007). It may lead to propose the physical improvement of fallow vegetation with temporal and spatial rearrangements.

Another aspect of the improvement of fallow vegetation could be biological, say, encouragement of plant species which contribute more to soil fertility. In this study, an attempt was made to evaluate the natural fallow plant species in the Sahel for biological nitrogen fixation as measured by natural abundance of $^{15}$N, i.e. $\delta^{15}$N (‰).

## Materials and Methods

The site of this study is located in the Fakara area in Dantiandou District of Tillaberi Prefecture (80 km east of Niamey, the capital of Niger), a typical region of the Sahel with a good mixture of cultivators and pastoralists.

Plants of higher dominance in fallow lands were photographed and collected in the dry season of 2003 and rainy season of 2004 and 2005, from fallow lands of different ages and crop fields at the Fakara region. Each plant species was identified by a scientific name from local nomenclature (Zarma and Peul) with use of the "Lexique de noms vernacularies des plantes du Niger", published by INRAN (1977), and verified by ordinary ways of plant taxonomy. This work was provisionally summarized as a pictorial dictionary of "Fakara Plants" to be accessed through the web (Miura and Tobita, 2005).

The plant samples were dried and finely powdered with use of a multi-beads shocker (Yasui Kagaku Co. Ltd., Osaka, Japan) and a vibrating sample mill (CMT, Iwaki, Japan). An adequate quantity (around 3 mg) of the samples was then introduced to an element analyser (Flash EA-1112, Carlo Erba, Milan, Italy) connected with a continuous-flow isotope ratio mass spectrometry (Delta XP$^{plus}$, ThermoFinnigan, Hamburg, Germany) connected with an element analyser (Flash EA-1112) to determine the compositional deviation of N stable isotopes ($^{15}$N to $^{14}$N) in total plant N, expressed as $\delta^{15}$N (‰). $\delta^{15}$N has been used as an indicator of their dependency on air nitrogen ($N_2$), because air and soil are exclusive sources of N and they generally have a sufficient difference in their $\delta^{15}$N values (0‰ versus +5 to +10‰). Thus, lower $\delta^{15}$N values (occasionally negative) in plants show their higher dependency on $N_2$ fixation. In this study, by means of the natural abundance method, the $\delta^{15}$N values of fallow plant species were measured for the estimation of their dependency level on BNF and its contribution to the maintenance and improvement of N fertility of the sandy soils in the Sahel.

## Results and Discussion

The principle of the $\delta^{15}$N natural abundance method is based on two prerequisites as follows (Unkovich and Pate, 2001): (i) only two N pools (soil N and air dinitrogen) for plant growth and (ii) significant difference in natural $\delta^{15}$N abundance between the two N pools. To satisfy the first requisite, all plant samples were taken from fields with no fertilizer-N application. The $\delta^{15}$N value of non-N-fixing pearl millet plants from field with no N application was +5.1‰, which was thought to reflect the $\delta^{15}$N value of the soil N. Therefore, the second requisite was also fulfilled because it deviated enough from that of air N, viz., theoretically 0‰. If the dependency of the plant on BNF is higher, $\delta^{15}$N value becomes more negative because the ratio of N from soil to N from the air is decreased.

For the plants collected in the dry season of 2003, out of 28 species comprising 12 families, the lowest $\delta^{15}$N (highest dependence on BNF) was recorded in *Cassia mimosoides* (Caesalpiniaceae), an annual leguminous herb, having –0.97‰. Young twigs of *Acacia albida* (Mimosaceae), a leguminous tree, had its $\delta^{15}$N value of +1.02‰. It is interesting that some of annual grass species such as *Ctenium elegans*, *Eragrostis tremula* and *Schizachyrium exile* (all belonging to Gramineae) had lower $\delta^{15}$N value around +2.0 to +2.5‰, especially from lands with a longer fallow duration. This may suggest a possibility of biological nitrogen fixation by associative microorganisms in non-leguminous plant species.

In rainy season, fallow vegetation was more abundant in biomass and number of plant species, as compared with dry season. Samples of a total of 45 species from 18 families were collected in August 2004. Some of them, such as *Alysicarpus ovalifolius* (Papilionaceae) and *Commelina forskalaei* (Commelinaceae), were revealed to have higher dependency on BNF, +0.57 and +1.85‰, respectively, as well as *C. mimosoides* having –1.76‰, the lowest.

In the 2005 rainy season, native plants were collected from fallow lands on which the period of fallow experiences was recognized. The vegetation of the 11-year-old fallow was dominated by annual Gramineae species, *C. elegans* and *S. exile*, and perennial shrub, *Guiera senegalensis* (Combretaceae). The $\delta^{15}$N values in this fallow vegetation ranged from –2 to +8‰ for all plant species (Fig. 1a). Three leguminous herbs, *C. mimosoides*, *A. ovalifolius* and *Indigofera pilosa*, had $\delta^{15}$N values at less than 0‰, showing higher dependency on BNF.

Samples of more number (22) of plant species were collected from the 3-year-old fallow land, where non-leguminous broad-leaf annual herbs, *Mitracarpus scaber* (Rubiaceae), *Pergularia tomentosa* (Asclepiadaceae) and *Jacquemontia tamnifolia* (Convolvulaceae), were dominant. Averages and ranges in $\delta^{15}$N values of the plants, shown in Fig. 1b, clearly demonstrate much higher dependency on BNF in leguminous plant species (*C. mimosoides*, etc.) than others. It is noteworthy that some non-leguminous *Hibiscus* sp. (a wild relative of *Hibiscus sabdarifa*), *G. senegalensis* and *S. exile* had relatively lower $\delta^{15}$N values (+3 to +4‰). This may suggest possible $N_2$ fixation by non-legumes associated with diazotrophic microorganisms in the soil of the Sahel.

In the new fallow site, a total of 27 species were collected but the total biomass was not high, because of pearl millet cultivation and weeding activity by farmers during the last season. The range of $\delta^{15}$N values shifted to more positive values, from +2 to +14‰ for all plants (Fig. 1c), as compared with those from the 11- and 3-year-old fallow lands. This could be attributed to much higher $\delta^{15}$N in soil N after several years of crop cultivation, which might be partially supported by relatively lower $\delta^{15}$N in perennial *G. senegalensis* and *Piliostigma reticulatum* (a leguminous tree). Moreover, $\delta^{15}$N values in leguminous herbs such as

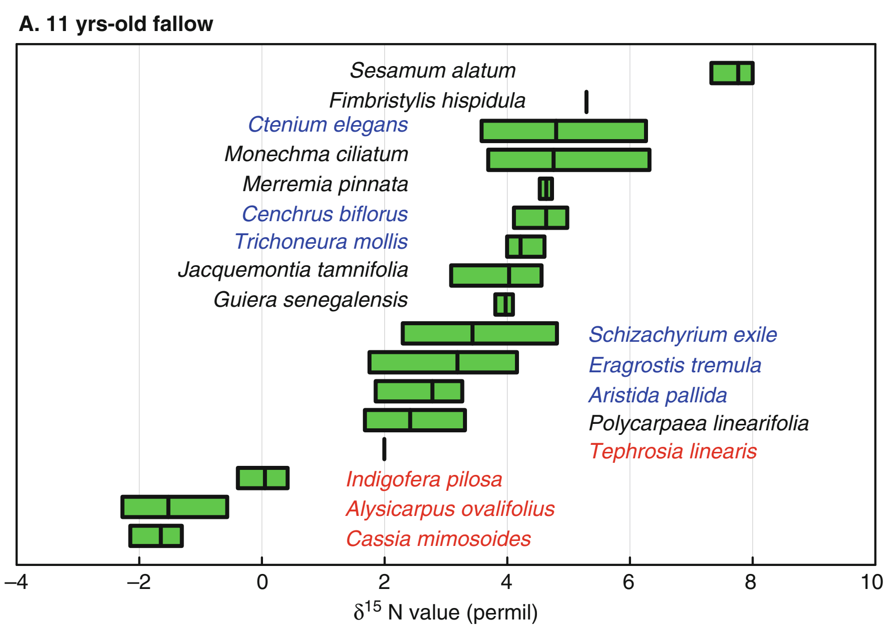


**Fig. 1** Ranges (*extent of each horizontal bar*) and averages (*vertical line in the bar*) in $\delta^{15}$N values of the native plants which were collected at the site undergoing 11-year (**a**) and 3-year (**b**) fallow periods and new fallow land (**c**). Scientific nomenclatures are written beside the bars

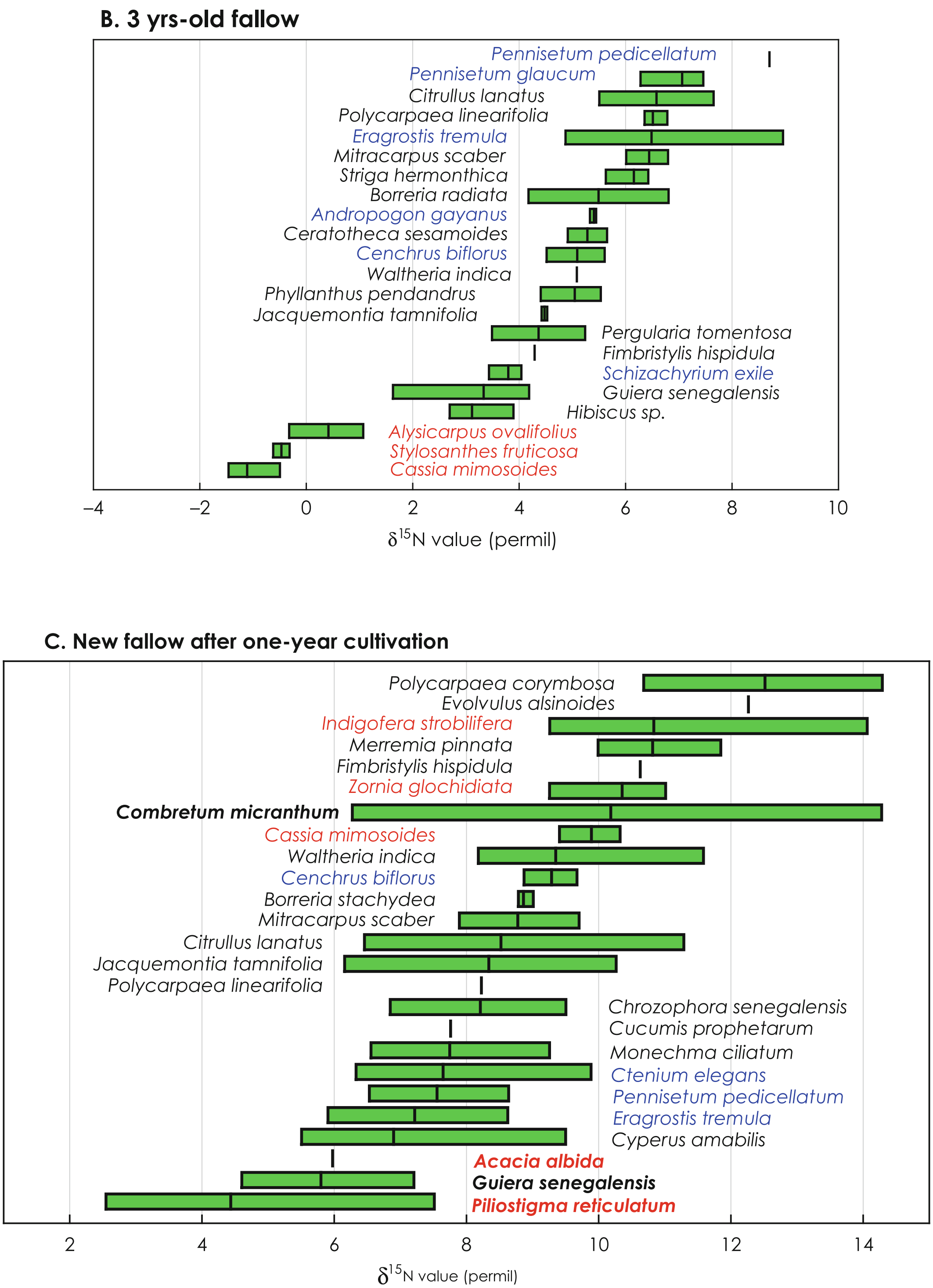


**Fig. 1** (continued)

*C. mimosoides* were higher as other non-leguminous plants in this new fallow land. It is speculated that BNF by the legumes–rhizobia symbiosis may not be fully activated in lands just after being used for intensive cropping years.

Elucidation of the N cycle with precise quantification of each flow between the agro-ecosystem components is a prerequisite for the full deployment of BNF in potential plants of the Sahel. Studies on farming systems in the wet savannah of southern Mali (Ramesch, 1999) and southern Senegal (Manlay et al., 2002) are excellent precedents of the N balance sheet work, but the contribution of BNF was not estimated. It is shown in this study that plant $\delta^{15}$N could change as affected not only by its dependency on BNF but also by the age of the fallow where it habitats. For quantitative estimation of N fixation by fallow vegetation, therefore, studies have been going on to compare $\delta^{15}$N among plant species grown on homogenous soil which has a uniform N profile in content and isotopic ratio.

Information on the ability of nitrogen acquisition from the air will be utilized for identification of fallow plant species with high potential of the contribution to soil fertility improvement, coupled with annual biomass production data through the organic matter input to the soil. Table 1 is a summarized list of natural fallow plant species with possible high contribution to the soil fertility improvement of the Sahel. They will be necessarily examined with information on ecological and livestock-related issues, say, possible interspecific competition, fodder value and grazing tolerance (Hiernaux, 1998).

On efficient utilization of limited nutrients (mostly organic matters) in sandy soils of the Sahel, Gandah et al. (2003) pointed out that the traditional fertility management ways such as cattle manure application and pearl millet stover returning had shown substantial effects on soil nutrients status, but they did not mention clearly about the contribution of fallow plants. Our concurrent activities to quantify the N budget of the agro-ecosystem in the target site, Fakara area, are showing that technology options associated with fallow system should be developed for the improvement of soil fertility in the Sahel, especially in remote fields that are far away from farmers' household. This corresponds to a part of the integrated soil fertility management (ISFM) concept (CGIAR, 2002), focusing on the utilization of nitrogen-fixing plants and soil microorganisms.

## Conclusions

Among the natural fallow plant species in the Sahel, an annual leguminous herb, *C. mimosoides* (=*Chamaecrista mimosoides*), Caesalpiniaceae, had the lowest $\delta^{15}$N value, showing its higher dependency on biological nitrogen fixation. It will be efficiently utilized as an extensive means of the soil fertility management, for example, through more encouraged incorporation into the fallow vegetation. Annual grass species, *C. elegans*, *E. tremula* and *S. exile*, were greatly dominating in the fallow land as well as a shrub

**Table 1** A list of natural fallow plant species with potential contribution to the soil fertility improvement in the Sahel, as evaluated by frequency, biomass production and dependency on BNF

| Species | Local nomenclature | Family | Frequency | Biomass | Dependency on air N |
|---|---|---|---|---|---|
| *Acacia albida* | Gao | Mimosaceae | Very high | High | High |
| *Alysicarpus ovalifolius* | Gadagi | Papilionaceae | Low | Low | High |
| *Andropogon gayanus* | Andro | Gramineae | High | High | Low |
| *Aristida longiflora* | Subu Kware | Gramineae | Very high | Very high | Low |
| *Cassia mimosoides* | Ganda bani | Caesalpiniaceae | High | High | Very high |
| *Cenchrus biflorus* | Dani | Gramineae | High | Low | Low |
| *Ctenium elegans* | Bata | Gramineae | Very high | Very high | Low |
| *Guiera senegalensis* | Sabara | Combretaceae | Very high | Very high | Low |
| *Jacquemontia tamnifolia* | Hurkutu | Convolvulaceae | Very high | High | Low |
| *Mitracarpus scaber* | Hinkini a kangi | Rubiaceae | High | Low | Low |
| *Pergularia tomentosa* | Fattakka | Asclepiadaceae | High | High | Low |
| *Schizachyrium exile* | Subu kirey | Gramineae | Very high | Very high | Low |
| *Sida cordifolia* | Kongoria | Malvaceae | High | High | Low |
| *Zornia glochidiata* | Marbku | Papilionaceae | Very high | High | High |

tree, *G. senegalensis*. Though their $\delta^{15}N$ values were high, they would contribute to the soil fertility by supplying a significant amount of organic matter into the soil.

**Acknowledgements** This study was conducted as part of the collaborative research project between JIRCAS and ICRISAT on the "Improvement of Fertility of Sandy Soils in the Semi-Arid Zone of West Africa through Organic Matter Management". The authors thank the staff of ICRISAT-WCA, especially Mr. Sodja Amadou for his assistance in Fakara area.

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