"Biofertilization and 'bioirrigation' for sustainable mixed cropping of pigeon pea and finger millet (BIOFI)"

**Introduction**

The ISCB project "Biofertilization and 'bioirrigation' for sustainable mixed cropping of pigeon pea and finger millet (BIOFI)" was conceived in 2013 and started with much enthusiasm in 2014. Two of the Swiss teams had considerable experience in the ISCB from previous phases, and they strongly welcomed the new approach of the ISCB to focus on the needs of small-holder farms in India and to couple the biotechnological work with socio-economic studies. A new team of eight biotechnology groups (three Swiss, five Indian) and three socio-economic groups (two Swiss, one Indian) was assembled to study the potential of combining "biofertilization" with "bioirrigation". The concept of "biofertilization", i.e., the application of arbuscular mycorrhizal fungi (AMF) and plant growth-promoting rhizobacteria (PGPR), had already been tested and verified in previous phases of the ISCB. The novelty was the concept of "bioirrigation". According to this concept, a deep-rooted crop plant would lift water from deep soil layers to "irrigate" a shallow-rooted crop plant in its vicinity, and this would be promoted by biofertilizers, in particular AMF, which are able to interlink neighbouring plants. The two target crops of ISCB phase IV, the deep-rooted pigeon pea and the shallow-rooted finger millet, are ideally suited to test this concept. We proposed to apply biofertilization in the context of an established intercropping technique, in which pigeon pea seedlings are pre-cultivated in "polybags" some weeks before the end of the dry season and then planted into a finger millet field. The "BIOFI package" to be tested included the "polybag" pre-culture of pigeon pea, intercropping with finger millet and biofertilization by AMF and PGPR. On the side of socio-economics, the economic viability and the environmental impact of the "BIOFI package" were assessed, farmers' current practices were studied, and key constraints and opportunities for the adoption of the "BIOFI package" were identified. In addition, biofertilizer production in "eco-enterprises" was established.

**Results with respect to biotechnology**

(Outcome 1: Development of sustainable pigeon pea and finger millet inter-cropping systems based on the selection of responsive cultivars and validated processes of biofertilizers and bioirrigation.)

The results of two years of field trials in two locations in South India (Bangalore, Karnataka, and Kolli Hills, Namakkal district, Tamil Nadu) clearly showed that biofertilization can improve the yield of finger millet and pigeon pea, both in monocropping and intercropping schemes. As a rule of thumb, the yield of both finger millet and pigeon pea with biofertilization at 50% of the recommended dose of mineral fertilization (RDF) was on par with 100% RDF without biofertilization. In addition, when pigeon pea seedlings were raised in polybags inoculated with biofertilizers, they performed better than the non-inoculated ones.

The results of the experiments to examine "bioirrigation" were less clear. Experiments under controlled environments in plant growth chambers and in the greenhouse strongly supported the idea that bioirrigation by pigeon pea, mediated by biofertilization with AMF, can promote the growth and yield of finger millet. However, we still need an experimental confirmation in a field experiment in India. In the continuation of the project in Phase V, we plan to further test and validate the concept of bioirrigation in field experiments.

In all field experiments, we characterized the populations of indigenous soil bacteria and AMF to see how our treatments affected microbial diversity. We also developed molecular markers for the PGPR and AMF used in the study. This is important, both for attempts to trace the bioinoculants in the field as well as for quality control. While we have developed useful molecular markers for the PGPR, the search for markers for the AMF is still in progress. Nevertheless, we have secured IP and ownership for our BIOFI strains, and regulatory approval for scale-up and production is sought for.

We also screened and genomically characterized a large number of pigeon pea accessions for their rooting characteristics and water use efficiency to select breeding lines most suitable for the concept of bioirrigation.
Results with respect to socioeconomy

(Outcome 2: Analysis of farmers’ practices and input market; economic-environmental assessment of the “BIOFI package”)

The farmer survey showed that the "BIOFI package" differs quite strongly from farmers’ current practices. Although farmers often do intercropping, the combination of finger millet and pigeon pea is not common in either of the two research sites (Kolli Hills, Tamil Nadu, and Mandya, Karnataka). In Kolli Hills, the production of food crops tends to lose importance and is done in a low-input manner (broadcasting, mostly using saved seed and own farm yard manure). In Mandya, farmers invest more time and money in finger millet cultivation (practicing line sowing with mechanical tools and using different types of mineral fertilizers) while pigeon pea, which is mostly cultivated as a sole crop, is of limited importance.

The input market study revealed that farmers but also input suppliers and extension agents are often not aware of biofertilizers. Many of those knowing the product were sceptical about its effectiveness and stated to lack information about how to use it in the field.

According to the economic and environmental assessment in particular AMF production in eco-enterprises appears to be a profitable undertaking. The pre-culture of pigeon pea in polybags fared less well in the assessment. This part of the "BIOFI package" was considered labour-intensive, and ecologically, the single-use polybags were a burden on the balance sheet.

(Outcome 3: Participatory testing of the “BIOFI package” and improved access to biofertilizers for small and marginal farmers)

Although farmers realized higher yields in the on-farm trials, many were reluctant to adopt the "BIOFI package". Major reasons were the package’s complexity, as well as the higher input costs and labour intensity compared to current practices. Therefore, it may be meaningful to reconsider the “package approach”. Each component of the BIOFI Package could offer potential benefits to farmers and may have more impact when developed further individually and based on site-specific needs.

In this respect, the biofertilizers developed in the project and prepared in local eco-enterprises could be of considerable benefit to local small-holder farming communities. In order for biofertilizers to be successful at larger scale, there is however a need for further testing of biofertilizers under diverse farming conditions. The technology of pre-inoculated polybags is conceptually promising, but the short duration of Phase IV did not allow us to develop it further, e.g. by preparing thinner or biodegradable polybags.

Concluding remarks

(Outcome 4: Best practices in transnational and transdisciplinary research)

An important accomplishment of the BIOFI project in Phase IV is the generation of a great team spirit between the disciplines and countries. After initial difficulties to find common grounds for discussion and to work together for a common goal, the mutual understanding increased from meeting to meeting. In the third year, during an evaluation workshop, the partners concluded that it is important to continue the close collaboration with each other as well as with farmers and other stakeholders, and to allow for course corrections if the research does not correspond to the farmer’s needs. Based on this, the team was ready to go on further in order to provide ecologically and economically sound technologies for small-holder farms in India, not in the form of an entire "BIOFI package", as originally proposed, but in the form of individual solutions tailored to specific needs, including locally produced biofertilizers, well-designed pigeon pea pre-culturing systems, and resilient legume-finger millet intercropping systems, harnessing the potential of bioirrigation. The team strives to continue its collaboration, to develop the most promising aspects further, and to finish and submit the manuscripts that have been pledged to be written in the annual meetings. With more than a decade of experience in Indo-Swiss Collaboration in sustainable agriculture, the team foresees to render its expertise in potential new Indo-Swiss collaborations with a focus on skill development, education, training and innovative research in agriculture.