Biotechnology for Natural Resource Management (NRM)

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Objectives

- To discuss and understand the importance of various biotechnologies in natural resource management (NRM) and diffuse and propagate their adoption
- To identify the most suitable biotechnologies that can be introduced into NRM and to blend them with indigenous technologies and knowledge to form a complete chain of technologies to increase production on a sustainable basis in an environment-friendly manner

What is biotechnology?

The US National Science Foundation defines biotechnology as 'the controlled use of biological agents, such as micro-organisms or cellular components, for beneficial use'.

Why is biotechnology important in NRM ?

With growing concern over food security and sustainable agriculture, the use of eco-technologies for food production has become imperative. The integrated intensive farming system (IIFS) involves agricultural intensification, diversification and value-addition methodologies (The Hindu Survey of Indian Agriculture 1996). There are two major responsibilities that confront the scientific community in developing countries. Firstly, to search for and develop new science and technology that can be blended with the wisdom of indigenous people to form a complete chain of technologies for rural people to raise their productivity. Secondly, to diffuse and propagate scientific and technological knowledge that fosters and encourages environmentally-friendly entrepreneurship among rural people, particularly the young. To be ecologically sustainable, such intensification should be based on techniques that are knowledge intensive rather than capital intensive and that replace, to the extent possible, market-purchased chemical inputs with farm-grown biological inputs (Swaminathan 1994). Biotechnologies (Table 1) being practised at farm level in many countries include micropropagation, bio-fertilizer, integrated pest management and bio-control, vermiculture, bio-energy (biogas), mushroom culture, aquaculture, etc.

In a particular ecosystem or bio-climatic zone, e.g., watershed, these technologies play an important role in making the system sustainable. There is a realisation that an integrated participatory approach is required for sustainable management.

A brief description of some of the biotechnologies is provided below.

Biofertilizer

These are natural fertilizers that are microbial inoculants of bacteria, algae or fungi individually or in combina-

Table 1: Tested and Available Rural Biotechnologies

Apiculture	Honey bee
Aquaculture	Fish, prawn
Biocontrol	Biopesticides, IPM
Bioenergy	Biogas
Biofencing	Agave, Vitex
Composting	Weed and biocomposting
Fermentation	Cheese, yogurt, alcoholic drinks
Micropropagation	Tissue culture of plants
Mushroom cultivation	Agricus, Pleurotus
Sericulture	Silk production
Vermitechnology	Use of earthworms for compost

tion that augment the availability of nutrients for plants. *Rhizobium* is the best known example. It fixes atmospheric nitrogen symbiotically with legumes. Other biofertilizers are *Azotobacter*, *Azospirillium*, blue-green algae and *Azolla*. Another good example is an actinomycetous bacteria, *Frankia*, which fixes atmospheric nitrogen in a symbiotic relationship with the roots of non-leguminous plants, e.g., *Alnus*, *Casurina*, *Myrica*, etc.

Biocontrol

It is well established that chemical pesticides pose serious threats to the environment, cause imbalance in the ecosystem, and are hazardous to humans. Biological control through the purposeful employment of natural enemies is a possible alternative. These agents are generally known as biopesticides. The term is used to include plant extracts, nematodes, micro-organisms and viral agents that are marketed as formulated products. In India, the M S Swaminathan Research Foundation is trying to make this programme ecologically and economically viable at the rural level. They have focussed on the mass culturing of *Trichogramma* sp (Figure 1), the mass production of *Helicoverpa* NPV (nuclear polyhedrosis virus) and *Spodoptera* NPV, and the production of plant extracts. One of the bio-insecticides on which extensive

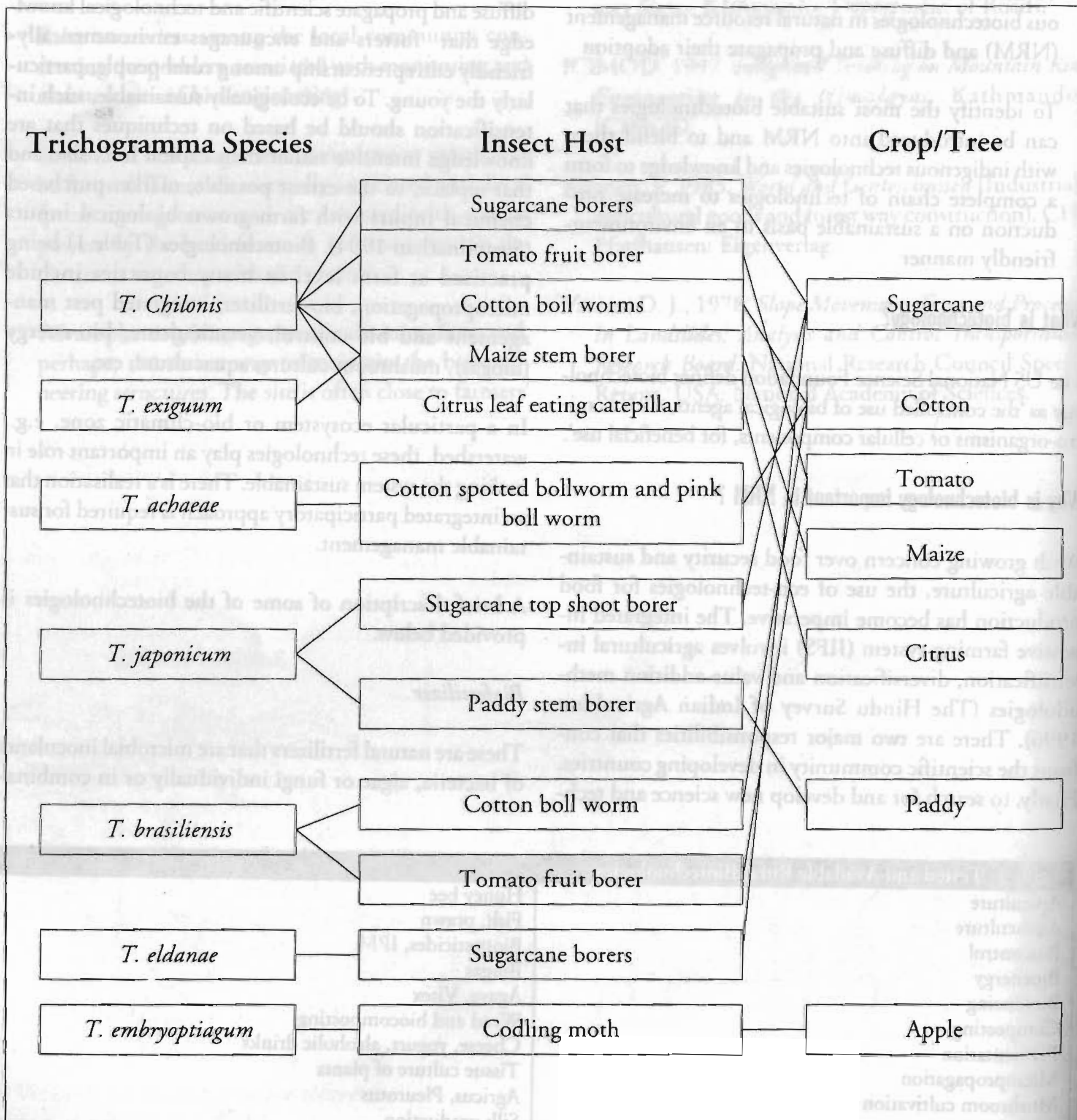


Figure 1: *Trichogramma species used for biocontrol in India (Singh et al. 1994)*

studies have been carried out is the bacterium, *Bacillus thuringiensis*. This bacterium can be used against caterpillars. Shoot-borers in cardamom, ginger and turmeric can be controlled by four sprayings of the commercial preparation of *B. thuringiensis*. At present about 75,000t of pesticides are used by the agricultural sector in India. According to recent estimates, the neem (*Adzadarichta indica*) and other plant products can replace 50 per cent of this. As of now, 86,000t of neem oil are extracted from 200,000t of neem seed kernels. Other plants of importance are *Lantana camara* (lantana), *Nicotiana tabacum* (tobacco), *Chrysanthemum cinerarifolium* (pyrethrum), *Ruta graveolens, Derris elliptica, Quassi amara* and *Ryania speciosa*. Of these, the preparations of the last four plants have already been authorised for use in organic farming for pest and disease control. Spices ,such as *Allium sativum* (garlic), *Piper nigrum* (black pepper), *Curcuma longa* (turmeric) and *Brassica nigra* (black mustard), have also been reported to have insecticidal properties.

Vermiculture

Vermiculture biotechnology harnesses earthworms as versatile natural bioreactors. Earthworms can be used for waste water treatment and solid-waste management, known as vermicomposting. Earthworms help nature in overall soil-building and plant-growth processes by particle break down. It is desirable to have 0.2 to 1.0 million earthworms per hectare to maintain the fertility of soil regularly supplied with organic matter. They are also a rich source of a protein, vermitin, and hence are being used in feed for poultry and pigs (The Hindu Survey of Indian Agriculture 1996).

Bio-energy

The generation of biogas, which is a mixture of methane and carbon dioxide, by anaerobic fermentation has long been recognised as an appropriate rural technology. The relevance of biogas technology for the subcontinent lies in the fact that it makes the best possible use of cattle dung, producing a clean cooking fuel and a valuable fertilizer. In Nepal 42,000 biogas plants are in operation; more than 60 per cent of these are located in the *Terai* region. The most immediate need is to develop cheaper designs of biogas plants and achieve better efficiency under cold climatic conditions.

Mushroom culture

Mushroom cultivation is carried out indoors and hence little land is required. It also provides employment for both educated and illiterate people. In many countries it has been accepted by rural women as an additional source of income. Mushrooms can be grown on substrates based on various agricultural wastes, which in turn are recycled. They are a good source of vitamins, niacin, pantothenic acid, and biotin. These are retained well during cooking, canning and dehydration. The most important cultivated mushrooms are white button mushrooms (*Agaricus bisporus*), paddy straw mushrooms (*Volvariella* spp), oyster mushrooms (*Pleurotus* spp) and shitake mushrooms (*Lentinus edodes*). During 1995-96 China produced 2.64 million t of mushrooms and India produced 30,000 t.

Aquaculture

Aquaculture development is gathering momentum and its credibility is growing steadily. No doubt, predicted production of 20 to 25 million t by the turn of the century will be an underestimate. In China, scientists using biotechnology produced female carp all the progeny of which are female. The sex gland of male carp develops earlier than the female and results in smaller fish.

Apiculture

Due to small land holdings and other inherent problems of mountain areas ,such as undulating physiography, cold and harsh climatic conditions, and limited sunlight, farming alone is not sufficient to make an adequate living. Bee-keeping could be a suitable off-farm, food and income-generating activity for small farmers. Apiary products are honey, beeswax, pollen, royal jelly and bee venom. Pollen, royal jelly, and bee venom are used for medicinal purposes. So far, China is the only country in the Hindu-Kush Himalayan region that has developed a technology for the commercial production of these bee products. Apiaries also enhance pollination efficiency, improve the growth of plants and increase seed output (Partap 1997).

Sericulture

Over 60 countries at present are engaged in sericulture. World silk production in 1993 was over 100,000 t. The demand for raw silk has increased significantly recently but the present production is much lower than the requirement. Moreover, the area under mulberry has not increased.

Livestock production

Improvements in the efficiency of reproduction in farm livestock, using techniques such as super-ovulation, embryo transfer and cloning are already having an impact on the livestock breeding industry. Daily growth hormone administration to young stock has been shown to increase daily live-weight gain and feed conversion in cattle, sheep and pigs; with pigs, and most probably with ruminants, the increased daily gain is associated with a higher content of protein at the expense of fat.

Micropropagation

Why is micropropagation important in the context of PIWM? Micropropagation represents optimum efficiency in terms of vegetative plant propagation and allows a large number of propagates to be produced in a relatively short period of time under controlled conditions, throughout the year, in a relatively small space. The basic tissue culture process is provided in Figures 2 and 3. Micropropagation has the following advantages.

- When classical methods of *in vivo* vegetative propagation prove inadequate, *in vitro* cloning is an important tool in speeding up propagation.

- Adult plant material that often cannot be cloned *in vivo* can sometimes be rejuvenated *in vitro* and then

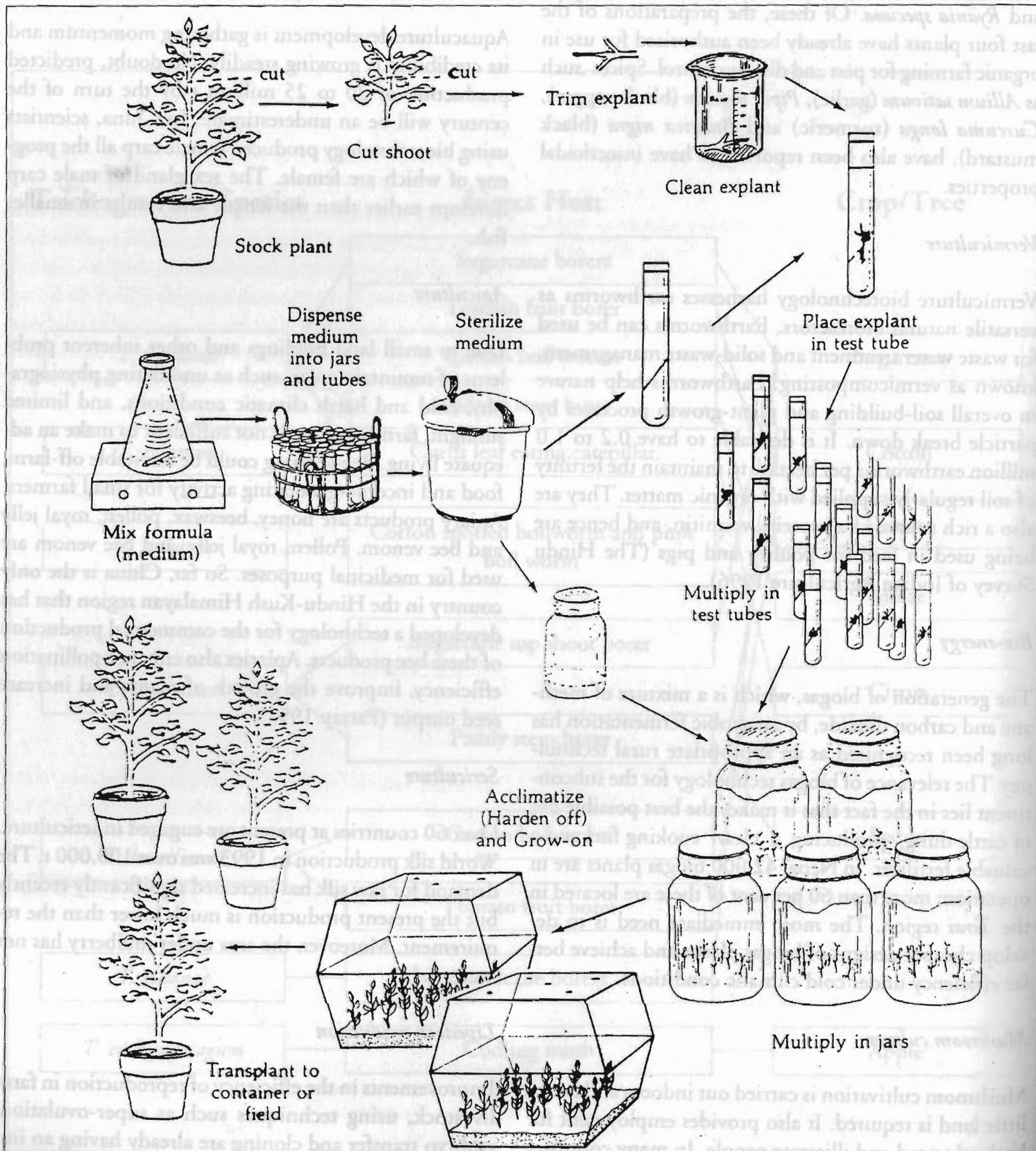


Figure 2: *Sequence of shoot tip micropropagation*

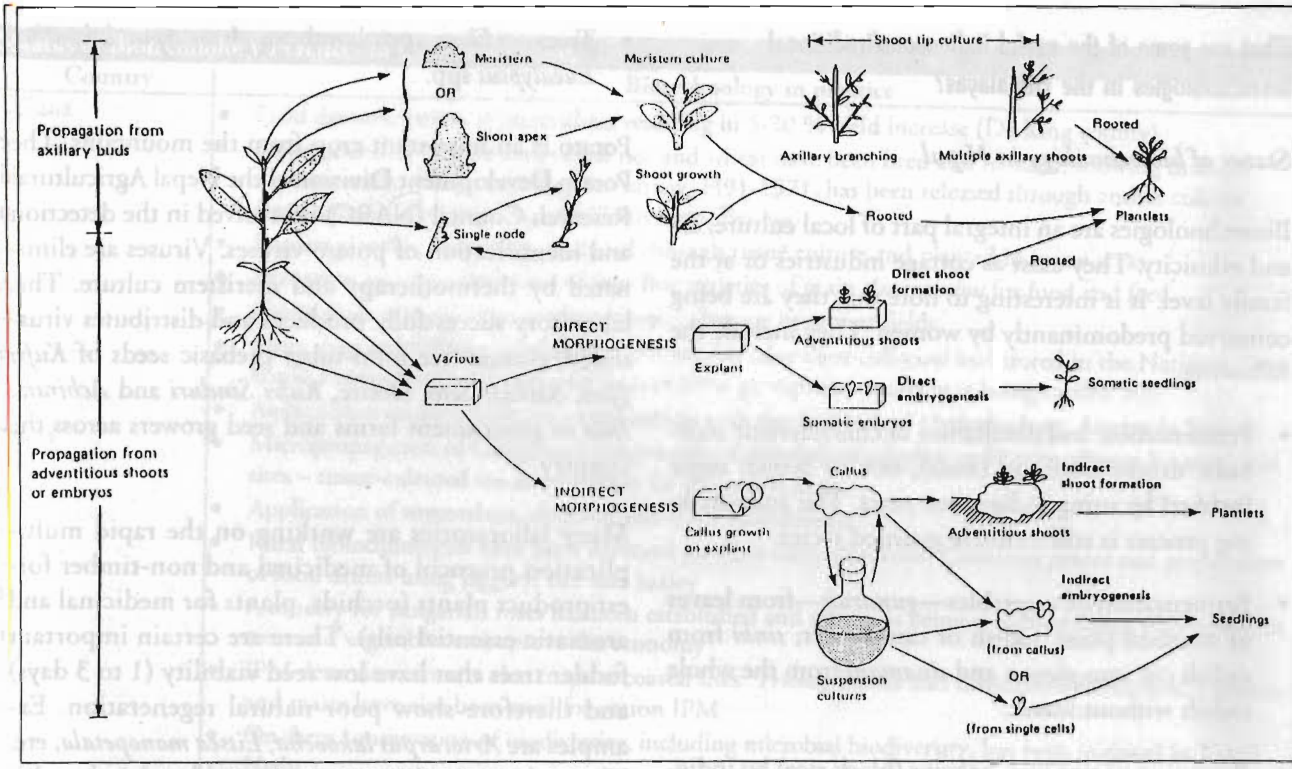


Figure 3: *Principal methods of micropropagation*

subsequently cloned. It has special significance in forestry sector.

- Growth of *in vitro* propagated plants is often stronger than in those cloned *in vivo*. This is mainly due to rejuvenation and/or the fact that they are disease free.

- When the existing methods of cloning are too slow or too complicated to be profitable, *in vitro* cloning can be applied to produce large number of plants more quickly and at a competitive price.

- By *in vitro* cloning, expensive methods such as grafting or budding on a rootstock can be rendered obsolete.

- *In vitro* cloning enables the uncovering of chimeras, and the isolation and cloning of spontaneous or induced mutants. Mutation induction and regeneration of adventitious buds *in vitro* makes it possible to obtain solid mutants.

- In contrast to *in vivo* propagation, *in vitro* cloning of herbaceous plants can be continued all year round and so become independent of the seasons.

- *In vitro* cloning enables the production of disease-free plants and thereby facilitates phytosanitory transport from country to country.

- In forestry, quality seed production and availability is difficult. Proven elite plants can be cloned to establish orchards for high-quality seeds.

Different phases in micropropagation

Phase 0: This covers correct pretreatment of the starting material, e.g., keeping the plant in a disease-free state, etc.

Phase 1: This deals with sterile isolation of a meristem, shoot tip, explant, etc. It is important to accomplish non-contaminated growth and development.

Phase 2: The primary goal in this phase is to achieve propagation without loosing the genetic stability.

Phase 3: This involves the preparation of the shoots and plants obtained in phase 2 for transfer into soil. It involves shoot elongation. Subsequent root formation must be induced, either *in vitro* or later *in vivo*.

Phase 4: This covers the transfer from test tube to soil and the establishment of plantlets (hardening).

The process of acclimatisation or hardening is the most critical phase of plant tissue culture. The process of hardening is usually done in greenhouse and hardening tunnels.

What are some of the useful indigenous/traditional biotechnologies in the Himalayas?

Status of biotechnology in Nepal

Biotechnologies are an integral part of local culture, art and ethnicity. They exist as cottage industries or at the family level. It is interesting to note that they are being conserved predominantly by women. They include the following.

- Fermentation and distillation of characteristic alcoholic drinks from rye (*kodo*), rice or brown sugar (*sakhar*) by using indigenous yeast. The yeast-making process is still a closely guarded secret.

- Fermentation of vegetables—*gundruk*—from leaves of mustard plant, radish or cauliflower; *sinki* from radish cut into pieces; and *sinamani* from the whole radish without leaves.

- Browning of rice into *hakuwa* (black rice) by indigenous techniques of fermentation.

- Pickling of fruits by fermentation.

- Production of jute from the bark of the hemp through the process of biological decortication.

- Preparation of yogurt and hard cheese (*churpi*).

- Plant materials such as *timur (Xanthoxylum indicum)* powder and *bojo* (*Acorus calamus*)/ *titepati* (*Artemesia vulgaris*) are commonly used as insect repellents in grain storage in the hills.

What are the new successful biotechnologies in Asia?

Among the new biotechnologies, tissue culture and related techniques have done quite well during the past few years. Tissue culture is now being carried out at government, non-governmental and private laboratories in many countries. The main products (crops) from different climatic zones include the following.

- Fruit—banana, strawberry, shoot-tip grafted sweet orange

- Cash crops—ginger, cardamom, sugar-cane

- Vegetables—potato

- Flowers—orchids (*Cymbidium*, *Dendrobium*, *Paphiopedilum*, etc.), carnation, chrysanthemum, African violet, etc.

- Trees— *Ficus* spp, bamboo, *Artocarpus lakoocha*, *Eucalyptus* spp.

Potato is an important crop from the mountains. The Potato Development Division at the Nepal Agricultural Research Council (NARC) is involved in the detection and identification of potato viruses. Viruses are eliminated by thermotherapy and meristem culture. This laboratory successfully produces and distributes virus-tested, disease-free mini-tuber prebasic seeds of *Kufri Jyoti*, *Sarkari Seto*, Desire, *Kufri Sinduri* and *Achirana Inta* to government farms and seed growers across the country.

Many laboratories are working on the rapid multiplication protocol of medicinal and non-timber forest product plants (orchids, plants for medicinal and aromatic essential oils). There are certain important fodder trees that have low seed viability (1 to 3 days) and therefore show poor natural regeneration. Examples are *Artocarpus lakoocha*, *Litsea monopetala*, etc. These plants can be mass-produced by clonal multiplication. Production of artificial seeds using somatic embryos could be another alternative. Important plants, such as papaya, *Choerospondias axillaris* (lapsi) and poplar, are strictly dioecious. Male and female plants produced through tissue culture may help in establishing plantations of such species.

In many countries of South and South East Asia, various tissue-cultured products are already available. Indigenous technologies and locally available substitutes have brought down prices for the farmers.

- Anther-culture-derived varieties of rice and wheat (Varieties thus generated and field-tested have shown multiple superior traits such as dwarfing, greater spikes and more grains, resistance to disease and early maturity. The yields are also higher).

- Increase in the cover of plants used for biopesticides

- Application of mycorrhiza at the rooting stage of micropropagated shoots

- Germplasm conservation for future use

Which are the priority areas for biotechnology development in future?

The following are suggested as priority areas for biotechnology. If the technologies are promising, they may be commercialised by non-government or private organizations.

Status of Biotechnology Practices in the Asian Region

Country	Biotechnology in practice
China	• Field demonstration of biofertilizer resulting in 5-30 % yield increase (Da Xing county) • Series of anther-culture varieties of rice and wheat have been bred and released, showing multiple superior traits. A high-yielding rice variety, H91-1371, has been released through anther culture (Institute of Crop Breeding and Cultivation, Beijing). • Banana plantlets have been produced through tissue culture and planted in many areas. • Extension and demonstration of four fine varieties of grain *Amaranthus* for food and feed. • Use of *Beauveria bassiana* to protect insect damage in peanut fields • More than 180,000 accessions of crop resources have been collected and stored in the National Gene Bank. Research into the characteristics of these germplasm resources is being carried out. • Aquaculture country-wide (in collaboration with the Institute of Hydrobiology, Academia Sinica).
India	• Micropropagation of *Calligonum polygonoides, Commiphora wigghtii* and *Chlorophytum* for semi-arid sites – tissue-cultured tea and bamboo for mountain areas • Application of mycorrhiza, rhizobia and other biofertilizers • Rural biotechnologies have been surveyed for fibre extraction from *Crotolaria juncea* and preparation of local drinks using jaggery, rice and barley • A nursery for Bulgarian roses has been established and saffron is being evaluated along with new fruit trees and vegetables to improve the economy • IPM demonstrations in rice crops at coastal sites. *Trichogramma* and *Chrysoperla* for cotton. Tobacco and maize have also been used for cotton IPM • On-farm conservation of biodiversity, including microbial biodiversity, has been initiated in Tamil Nadu
Nepal	• Tissue-culture protocols for more than 60 plants are available. In the *Terai* region more than 25,000 banana plants are being cultivated. This year the number is expected to reach 50,000 (Nepal Biotech Nursery, Himalayan Floratech, Microplant—all private organizations). Floriculture-related tissue-cultured plants (orchids, carnation, chrysanthemum, African violet, etc) will be marketed soon. • Site-survey activities have been initiated in association with FARM. Training of farmers' groups and workers is being done on-farm. • Mushroom production at rural level and training of women (National Agricultural Research Council) • Biofertilizer application trials on demonstration sites (National Agricultural Research Council)
Philippines	• Establishment of biotechnology village at the FARM site in Infanta Quezon. • The main technologies practised are biological nitrogen fixation, hybrid plant varieties, micropropagation by tissue culture, biopesticides, monoclonal antibodies for disease detection, aquaculture, etc.
Vietnam	• In Chieng Dong – to improve household incomes, coffee and silk work programmes have been strengthened. • 100 ha of orchards of mango, citrus, orange, banana, etc have been planted. • A target has been set to double the head of cattle by the year 2000 to increase meat production.
Thailand	• Biofertilizer application • Successful export-oriented micropropagation-based floriculture industry • Aquaculture for fish and prawns

Source: Asian Biotechnology and Biodiversity Newsletter 1995-96.

- Research and application of biotechnological tools for producing high-quality, genetically superior planting materials for biomass production, especially for wastelands.
- Conservation of elite germplasm through low temperatures or cryopreservation.
- Studies of polymorphism and molecular mapping of endangered and commercial crops.
- Selection of naturally occurring mutants among somatic cells—somaclonal variants. Mutants can be selected for tolerance/resistance to disease, unfavourable soil and environmental conditions, etc.
- Identification of medicinal plants with a proven record, e.g., *Taxus,* and study of active chemical compounds, germplasm conservation, micropropagation and biotransformation.
- Development, validation and scaling up of protocols for plant regeneration through plant tissue culture for economically important plants. A complete technology package to be handed over to the end users.

- Biotechnology programmes that benefit a target population by employment generation, upgrading of skills and improving standards of living.
- Biotechnology-based activities that involve women scientists and benefit women.
- Human resource development programmes that cover inaccessible and remote regions, facilitating training at all levels.

What are the limitations for implementing biotechnology programmes?

There are no guiding policies for setting priorities for biotechnology research that responds to national needs. Decision-makers should create a policy environment that allows biotechnology to thrive in national R & D institutions and in commercial and industrial sectors.

- There is no effective policy and legislation to protect Nepal's right to its genetic resources and to ensure any flow of benefits to the Nepalese people.
- There is no biotechnology department as such.
- Research institutions are not technically equipped.
- Lack of understanding and no inclusion of Intellectual Property Rights (IPR), Farmers' Rights (FR) and Breeders' Rights (BR) in rules and regulations (law).

Constraints in general

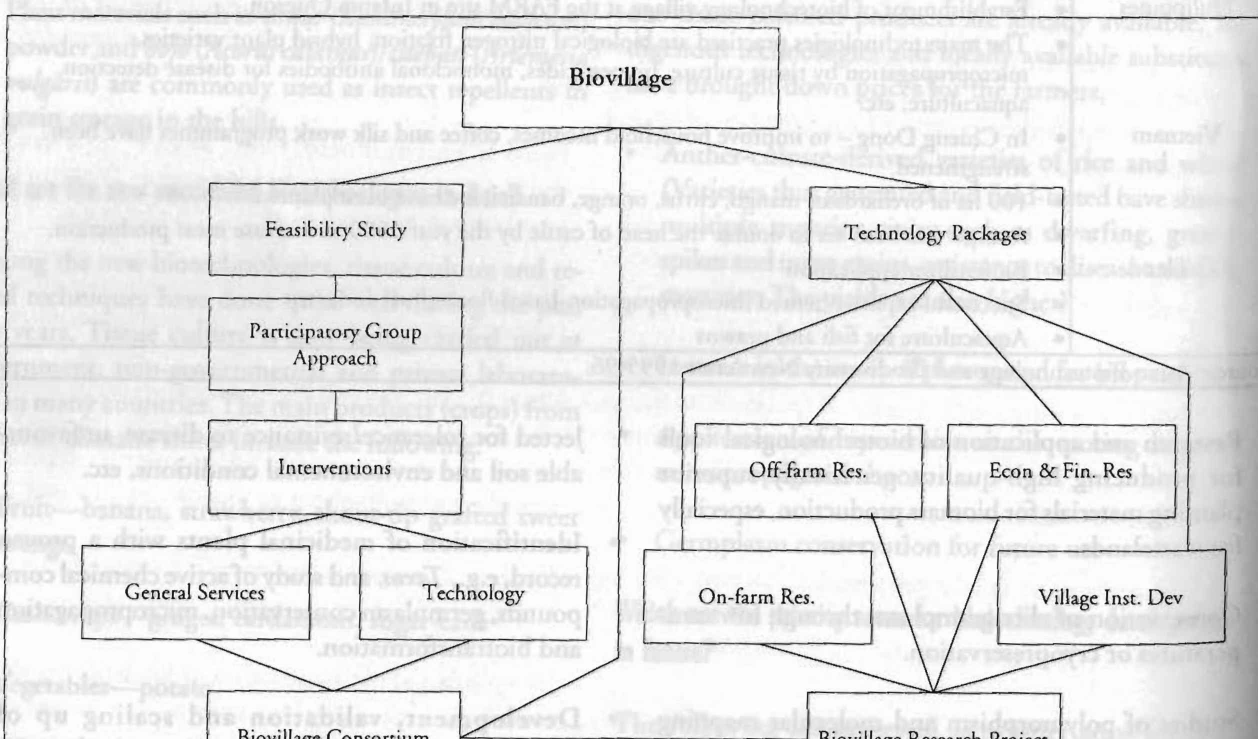
- Without the incentive of a strong market, potential private firms are unwilling to take the risk of production and marketing.
- Certain biotechnologies are expensive for farmers; research and financial mechanisms are yet to be worked out.

Can biotechnology be useful to all sections of society in the village (biovillage)? How?

The development of biotechnology should proceed with caution and critical thinking to ensure that results are responsive to end users, generate income, are ecologically sound and benefit society. A particular biotechnology in isolation is unlikely to change the situation. We need to use various technologies in an integrated fashion involving various sections of society. To propel all these efforts in the right direction political will and the support of financial institutions are necessary.

The basic paradigm of the biotechnology biovillage should include consideration of the following.

- Ecological sustainability
- Participatory research and development
- Economic efficiency with equity



Methodical Approach for Biovillage Projects (Hossain 1994)

- Employment and income generation for men and women
- Attraction and retention of educated youth in the village

A baseline survey (eco/agro/socioeconomic) through participatory research will have to be undertaken for qualitative and quantitative understanding of the resource base (physical, natural and human) and the current status of use, agroecology of farming systems, and an in-depth understanding of the constraints to sustained productivity of possible interventions. Some possible technological and institutional interventions are given in the following passages.

For assetless farmers

Value-adding activities utilising biomass available within the village (raising plant nursery, compost making, processing fruits and vegetables, feed preparation for poultry and livestock, mushroom production, micropropagation, repair workshop for agricultural machinery, etc), and development of common property resources including utilisation of wastelands, roadsides, embankments, derelict tanks and ponds, as may be available.

For marginal and small farmers

Labour-intensive production activities such as dairying and poultry raising, vegetable growing, flower production, hybrid seed production, integrated resource management systems (including waste recycling), value-added agricultural products, etc.

For medium- and large-scale farmers

Technological inventions including those that would save off-farm inputs. These may include the use of biofertilizers, biopesticides, integrated pest management systems, and inter-, multiple-, and relay cropping systems, etc.

A case study of the successful incorporation of biotechnology in a watershed is presented in Box 1.

Box 1

Successful case study of Haigad Watershed, Almora, India

The **watershed** is comprised of seven villages (1180 m to 2338 m). The total population is 1,553 with an annual growth rate of six per cent. The average family size is six persons. Twenty-nine species of medicinal plants grow in the watershed (45 % herb, 17 % shrub and 38 % trees).

Activities undertaken

1. Identification and survey assessment
2. Introduction of useful species

   a. Vegetables and fruits: use of high-yielding varieties for own consumption and income generation. Introduction of these varieties into traditional stock produced a surplus.
   b. Bulgarian rose: for oil production, market price US$ 4000/kilo. Other products are rose water and gulkand. 3,500 plants introduced.
   c. Large cardamom: 1,975 plants distributed for plantation along with *Alnus nepalensis*, *Bauhinia variegata* and *Crotolaria* sp to provide shade, enrich soil fertility by fixing nitrogen and adding leaf litter, and as a source of fodder, fuel and timber.

3. **Silvipastoral system using fodder/fuel trees:** fodder and fuel trees were planted keeping in mind the hilly terrain, geological conditions and susceptibility to erosion.

   a. Clonally raised and micropropagated plants of *D. hamiltonii* and *D. strictus* were introduced along the stream banks.
   b. A perennial grass, *Thysanolaena maxima* (broom grass) was introduced along field bunds and irrigation channels. It is a good source of fodder, useful as a soil binder and the dried inflorescence can be made into brooms.
   c. Napier grass introduction for fodder and soil conservation.
   d. High-value fodder plants, *Grewia oppositifolia*, *B. variegata* and *Morus alba,* were planted.
   e. Seeds of red clover, rye grass, lucern for cultivation along field bunds

4. **Multipurpose tree plantations:** source for wood, fuel, fodder, fibre, medicine and other products of local importance, e.g., *Sapindus mukorossi* (soap nut) *Ougeinia oojeniensis* for fuel, making utensils and fodder, *Diploknema butyracea* (Indian butter tree), etc. The butter tree provides good quality oil and is also used for the treatment of headache and arthritis.
5. **Biofencing:** *Agave* can grow on dry soils and the leaves yield fibre. Decorticated refuse is used for making paper boards.
6. **Plantation:** *Crotolaria, Alnus* and *Bauhinia* sp were planted on degraded slopes for site improvement.
7. **Bio- and weed composting:** a supplement to traditional manure and vermicomposting.
8. **Introduction of biofertilizers:** *Azotobacter, Azospirillum.*

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