INCREASING CROP PRODUCTION *sustainably*

THE PERSPECTIVE OF *biological processes*

NOVEMBER 2009

INCREASING CROP PRODUCTION *sustainably*

THE PERSPECTIVE OF *biological processes*

NOVEMBER 2009

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS - ROME, 2009

INTRODUCTION

WITH GLOBAL POPULATION EXPECTED TO EXCEED 9 BILLION BY 2050, AGRICULTURAL PRODUCTION WOULD NEED TO GROW GLOBALLY BY 70 PERCENT OVER THE SAME PERIOD TO FEED THIS POPULATION.

This need to feed more people puts greater pressure on crop production and the resource base upon which it depends. This is exacerbated by the additional pressures of coping with an increasingly degraded environment, uncertainties arising from climate change and other stressors such as increasing urbanization and volatile food prices.

Further complicating this situation is that the global community must meet this increasing food demand in a world where ecosystem resilience is compromised, and land resources available for agricultural expansion are limited.

With land scarcity, crop production intensification rather than area expansion becomes the primary option available. Well-managed ecosystems are essential for ensuring a healthy resource base on which to intensify sustainably, to ensure that enough food is produced from now until 2050 – and beyond.

Farming practices are shifting away from heavy dependency on non-renewable inputs and chemical-based intensification, such as the use of pesticides. Instead, they are moving towards other forms of intensification, relying on natural biological processes and biodiversity to increase the productivity of agroecosystems.

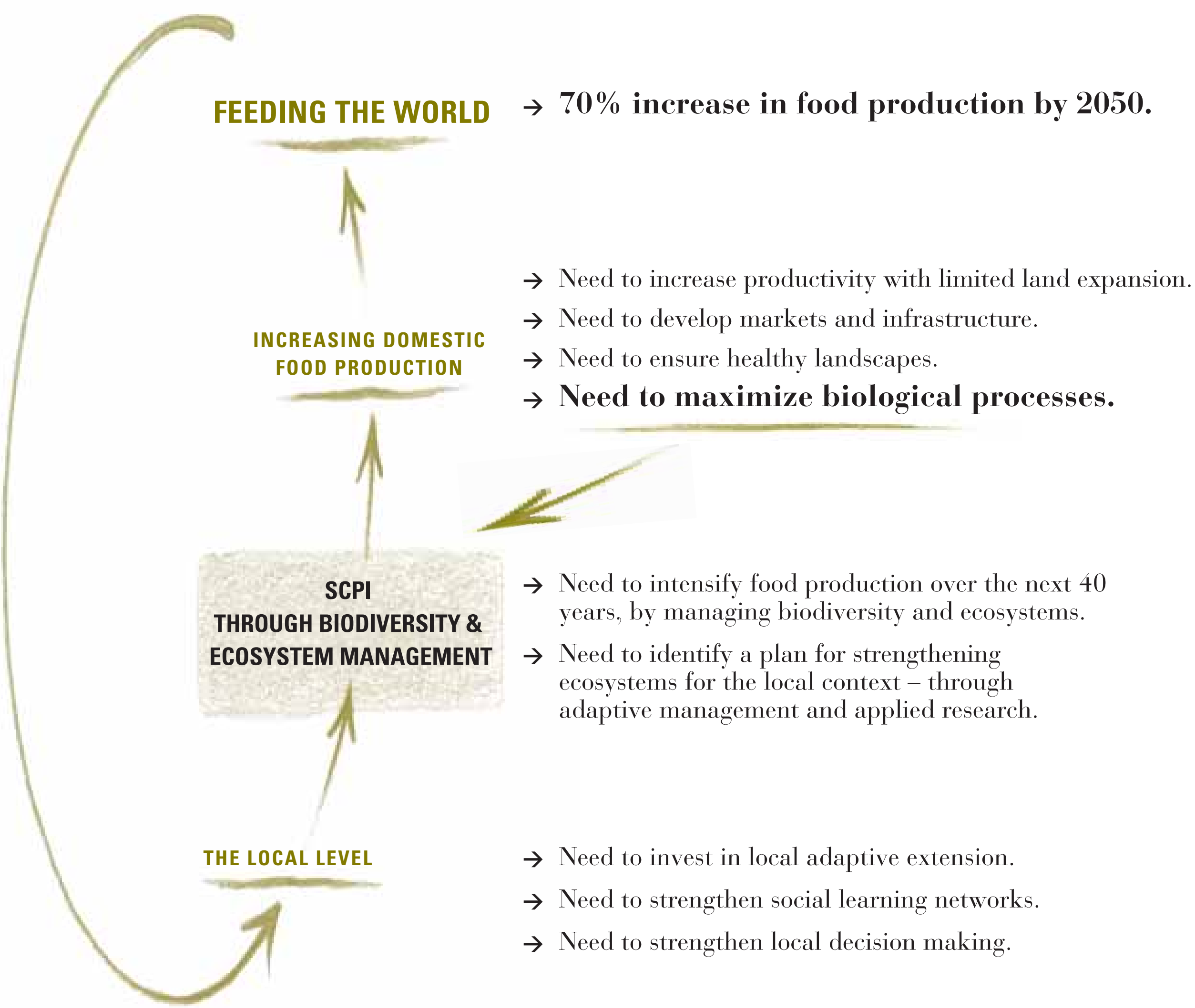
The underpinning scientific and biological principles for improving soil health, managing pollination or controlling pest populations – incorporated in farming practices – show that yields can be increased through the sustainable management of ecosystems.

HERE, THE ROLE OF FARMERS AS CUSTODIANS OF BIODIVERSITY AND AS ECOSYSTEM MANAGERS IS ESSENTIAL. At local levels, farming practices, approaches or technologies based on the management of biological processes that provide essential ecosystem goods and services, can be applied to produce higher crop yields and optimize input use while maintaining or enhancing ecosystem health. A range of options exist for good farm management practices, approaches and technologies that are based on biological processes. **Examples include: conservation agriculture; integrated plant nutrient management; integrated pest management; and pollination management.**

These farm management practices are being increasingly used to achieve sustainable crop production intensification (SCPI) which has a key role in feeding the world, today and in the future (figure 1).

To increase future food production, **CROP PRODUCTION WILL NEED TO ADAPT TO AND MITIGATE CLIMATE CHANGE**. The negative effects of climate change on productivity, which are already being felt by the agriculture sector today, can only be addressed through better understanding of the biological processes involved in farm management practices. In this regard, ecosystem management must incorporate measures of resilience and risk mitigation into agriculture – elements that are increasingly relevant under changing climates.

figure 1
FEEDING THE WORLD: A PROCESS, A CONTINUUM



Selected biological processes underpinning good farming practices for sustainable crop production intensification are illustrated in this brochure.

1 PEST REGULATION & CONTROL

RICE FARMERS FEED MORE PEOPLE THAN FARMERS OF ANY OTHER CROP. RICE IS THE PREDOMINANT FOOD CROP IN COUNTRIES WHERE THE MAJORITY OF THE WORLD'S PEOPLE LIVE. While rice production was boosted through irrigation, seeds of new varieties and fertilizer during the 1970s (the so-called "Green Revolution"), that production was threatened in the 1980s by large scale insect pest outbreaks, especially of the rice brown planthopper (BPH). Resistant rice varieties were bred by researchers and distributed by national seed systems, but as pest populations evolved they often lost their effectiveness, and insect outbreaks continued to spread, damaging rice severely or even killing plants.

Bold policy reforms in the 1990s to remove insecticide subsidies, and support for widespread farmer education through Farmer Field Schools and similar campaigns, were combined to reduce insecticide use and stop the pest outbreaks. In the Philippines, between 1996 and 2007, national rice production increased by 60 percent and rice yield per hectare increased by 12 percent. During this period numbers of both insecticide applications and total active ingredients used were reduced by more than 70 percent.

Elsewhere these trends have been sustained over several decades. For instance, in Indonesia the cost of insecticides used on rice dropped by over 75 percent while national rice production grew by more than 25 percent between 1986, when the national IPM policy was first declared, and 2001. In India, from 1994 to 2002 total food grain production rose by over 20 percent while tons of pesticides used fell by over 35 percent.

figure 2
INDONESIA: RICE PRODUCTION VS. PESTICIDE COSTS (1973–2001)

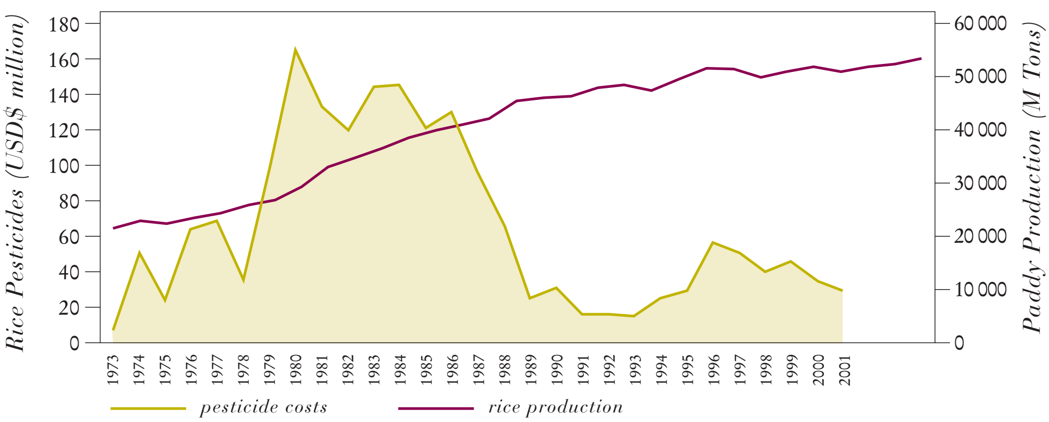
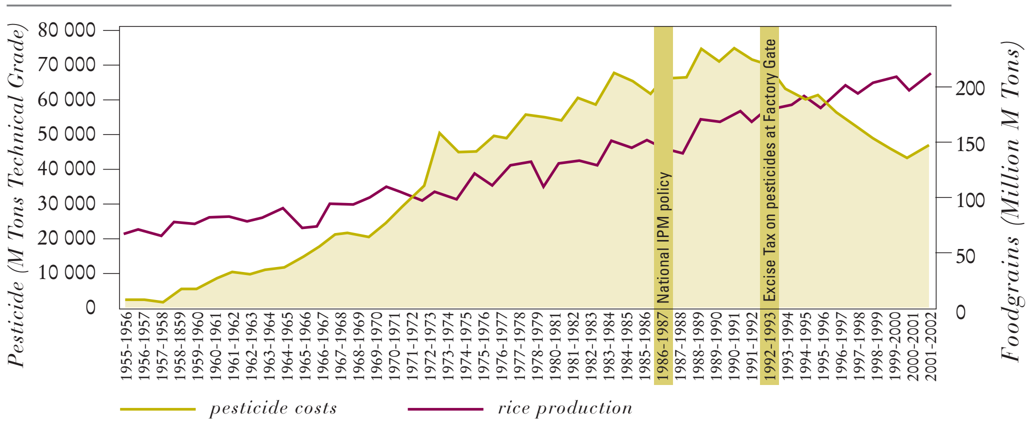


figure 3
INDIA: TOTAL ANNUAL FOODGRAINS PRODUCTION
VS. TOTAL PESTICIDE (1955 – 2002)

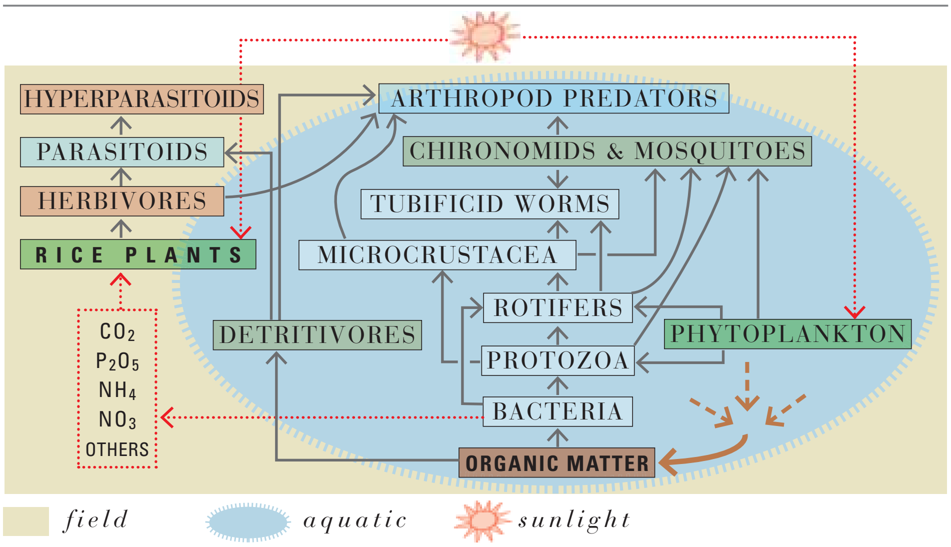


With the realization today that rice production must again be intensified to meet future demand, and widespread marketing of insecticides that are cheaper because they no longer are patent protected, farmers and policy makers must again face, and make, important decisions on how they should intensify rice production.

BIOLOGICAL PROCESSES

Flooded rice agroecosystems have evolved under human management for more than 5 000 years – or more than 50 000 generations of plant feeders (herbivores) like the BPH. When the ecosystem is not disrupted, these insects are part of a complex food web that converts sunlight and soil organic matter into energy that supports hundreds of species and millions of individual insects and spiders in every rice field: in soil, under and on top of water, and on or around plants including rice.

figure 4
AT EACH STAGE OF THEIR LIFE CYCLES, HERBIVORES ARE ATTACKED BY SPECIALIZED PREDATORS THAT LIVE IN THE RICE PADDY ECOSYSTEM




Some predators attack the eggs of the BPH, following the trail left by pregnant females when they lay their eggs in the stem of the rice plant, and sucking out each egg in a row along the stem.

Some predators live only on the surface of fresh water, such as in ponds, streams, and rice paddies.

They attack the newly hatched young BPH that fall onto the water every day.


Predatory spiders can kill and eat over 20 BPH every day, in order to mature their own eggs and produce more young predators.

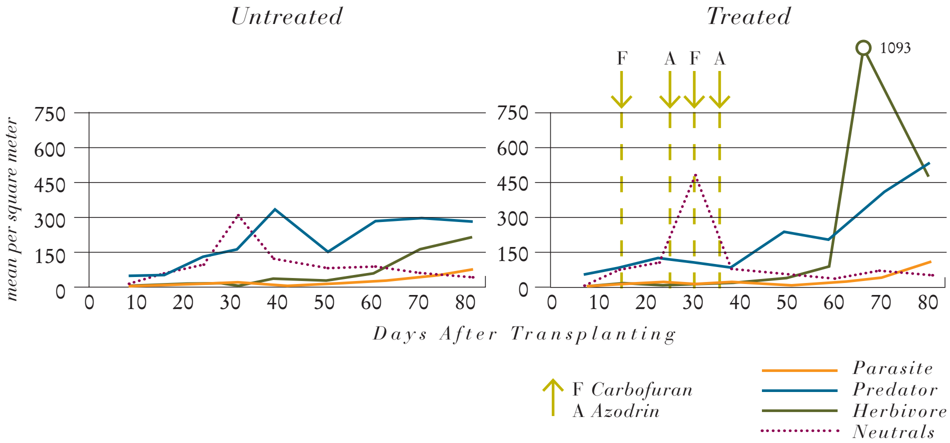
These predators, and many more like them, fulfil the ecosystem function of naturally occurring biological pest control in annual crop systems like rice. Their ecosystem function grows or shrinks as the predators multiply or leave to other fields in their search for larger populations of the pests. Their ecosystem function renews itself through the arrival and reproduction of predators in rice paddies, which depends on their food source: the pests.

By enhancing this ecosystem function, by making the rice field ecosystem healthier, more ecosystem services are provided: in this case, pest control.

PROTECTING AND ENHANCING ECOSYSTEMS WHILE INTENSIFYING PRODUCTION

When insecticides are applied to rice fields, ALL types of insects and spiders are killed, both plant feeders and predators. This allows pest eggs to hatch and survive much longer than in untreated fields. Figure 5 shows how pest numbers increased by over 600 percent in a rice field in Indonesia when insecticides were applied.

figure 5
NORTHWEST JAVA SEASON 2



This effect can be seen even in small fields, where the unsprayed part of the field is in the back of the picture, and the sprayed parts in the front are nearly dead.

Of course there are situations where the predator populations are not able to respond in time, such as after massive floods or extended drought, but the **DECISION TO APPLY INSECTICIDES SHOULD BE MADE IN EACH RICE PADDY BASED ON THE NUMBERS OF PREDATORS AS WELL AS THE CROP CONDITION AND THE NUMBERS OF PESTS**.

Making these informed decisions, optimizing and adapting management on a field-to-field basis, means that farmers must build their own knowledge systems using up-to-date ecological concepts, like predation.

FAO has worked in the field with many national agricultural systems, research, extension, academic, Non-Governmental Organizations, and farmers' community organizations to provide these ecological concepts to millions of rice farmers in hundreds of thousands of **FARMER FIELD SCHOOLS**.

Examples of Farmer Field Schools in Indonesia, in Mali and in Iran

2 POLLINATION

INCREASING CROP PRODUCTION
YIELDS AND QUALITY

Insects and other small animals provide essential pollination – and yet, the large contribution they make to agriculture is often overlooked. In agro-ecosystems, wild and domesticated pollinators are essential for orchard, horticultural and forage production, as well as for the production of seed of many root and fibre crops. **POLLINATORS SUCH AS BEES, BIRDS AND BATS AFFECT 35 PERCENT OF THE WORLD'S CROP PRODUCTION, INCREASING OUTPUTS OF 87 OF THE LEADING FOOD CROPS WORLDWIDE, PLUS MANY PLANT-DERIVED MEDICINES.**

The absence of pollination can cause significant declines in *quantity* of produce, but evidence shows that absence of pollination also has a negative effect on the *quality* of fruits and seed set. The table on the next page shows crops that can experience declines in production – by up to 90 percent – if they lack pollination.

THE ABSENCE OF POLLINATORS
CAN REDUCE PRODUCTION OF CERTAIN CROPS

REDUCED BY MORE THAN 90%	REDUCED BY 40-90%	REDUCED BY 10-40%
Kiwifruit	Coffee (robusta)	Strawberries
Cherimoya	Cashew nuts	Sesame seed
Watermelon	Cardamom	Eggplant
Squash	Canola	Fava beans
Cocoa beans	Buckwheat	Coconuts
Vanilla	Blueberries	
	Apples	
	Mangoes	
	Avocados	
	Raspberries	
	Figs	

Source: Klein, A.-M. *et al*. 2007. Importance of pollinators in changing landscapes for world crops. Proc. R. Soc. Lond. B Biol. Sci. 274, 303–313

Increased appreciation of the role of pollination in food production brings with it greater understanding of the major contribution of wild pollinators. These mainly include bees but also thrips, wasps, flies, beetles, moths and other insects, as well as birds and bats.

Maintaining this pollinator biodiversity in agricultural landscapes can ensure the provision of essential pollination, while also serving as a critical form of insurance against the risks of pests and diseases among populations of managed pollinators.

POLLINATION MANAGEMENT PRACTICES

In multiple agro-ecosystems and ecologies, pollinator-friendly management practices have been identified that serve to enhance yields, quality, diversity and resilience of crops and cropping systems. Examples include:

- → Preserving wild habitat.
- → Managing cropping systems, flower-rich field margins, buffer zones and permanent hedgerows to ensure habitat and forage.
- → Cultivating shade trees.
- → Managing for bee nest sites, e.g. by leaving standing dead trees and fallen branches undisturbed.
- → Reducing application of pesticides and associated risks.
- → Establishing landscape configurations that favour pollination services – an example of this is described, using a case study from Costa Rica.

A study (figure 6) of the value of pollination services – in terms of pollination diversity, yield, quality and economic value – on coffee farms in Costa Rica, found that the closer to forested areas the coffee farm, the greater the diversity and number of pollinators that visited the plants. For example, coffee plants closer to a forested area are visited by a greater diversity of bee communities, resulting in both increased coffee yields and improved coffee quality.

figure 6
LANDSCAPE CONFIGURATION
THAT FAVOURS POLLINATION SERVICES
– proximity to forest –

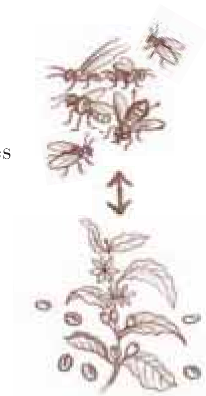
Wild pollination of coffee:
increased pollinator diversity = increased coffee yields = increased farmer income

At distances greater than 1 km from forest

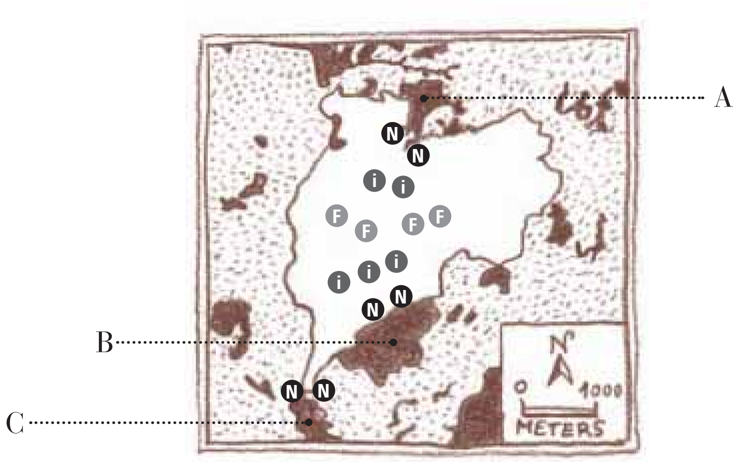
=
20% decline
in yields

For a single large farm,
pollination services
from the two largest forest patches
in the study area
represented approximately
US$60 000
ADDITIONAL INCOME
PER YEAR

Within 100 m of forest



=
Greater diversity of
pollinators



This picture summarizes the main findings of the Costa Rica study.
The study farm is shown in white;
the stippled area is a mix of coffee, pasture, and sugar cane;
and the dark areas (**A**, **B** and **C**) are forests.
Study sites are labelled **N**, **i**, and **F** for near, intermediate, and far distance classes.

Source: Ricketts *et al.* Economic value of tropical forest to coffee production.
PNAS August 24, 2004 vol. 101 no. 34 12579–12582

As the study suggests, maintaining areas that harbour pollinator nests – such as small patches of forested areas - near the farm is a favourable management practice for ensuring pollination. An additional benefit of this practice, other than higher yields and quality of coffee (and ultimately higher farmer incomes), is that in maintaining the forest, the farmer is contributing to maintaining other ecosystem services the forest itself provides, such as fuelwood, genetic resources and climate regulation.

Pollination management practices can also be undertaken to respond to climate change. Examples of how farming communities may best adapt to climate change impacts on pollinators include giving consideration to the seasonal availability of resources needed by pollinators, and ensuring connectivity of natural habitats in farming areas (allowing easier pollinator dispersal for range shifts in response to changing climates).

Pollination management practices can also be applied to mitigate climate change. Many good farming practices that sustain the ability of agroecosystems to deliver ecosystem services involve measures to increase ground cover and crop-associated biodiversity. Hence, measures to promote pollinators include providing more non-crop flowering resources in fields, such as cover crops, strip crops or hedgerows.

WHAT CAN POLICY MAKERS DO?

- → Promote policies that support pollination-friendly actions such as land use planning and, as applicable, responsible use of pesticides.
- → Build capacity for sustainably managing pollinators.
- → Raise awareness of the contribution of pollination to sustainable agriculture and livelihoods.

3 SOIL BIOLOGICAL PROCESSES

PROCESSES FOR PLANT NUTRITION (BIOLOGICAL FERTILIZATION)

HEALTHY SOIL IS CRITICAL IF AGRICULTURE IS TO THRIVE. The living part of soil, collectively referred to as **SOIL BIOTA**, includes all the various forms of life in the soil system – the flora and the fauna, the below ground root systems of vegetation, and their ecosystem functions.

Soil biota are, in turn, intricately linked to plant nutrition through biological processes such as nitrogen fixation, nutrient mobilization, nutrient storage and release, nutrient cycling and maintenance of soil pH, cation exchange capacity, structure and porosity. This is all further linked to the transformation of plant organic matter through the food webs of soil micro-organisms.

In the big picture, the ability to enhance these soil biological processes can increase nutrient availability and efficiency. Increasing available soil nutrients further serves to reduce the need for mineral fertilizer reducing both the cost of inputs and the environmental footprint of crop production.

Phosphorus (P): a major plant nutrient

P used as a fertilizer is a finite resource, mainly obtained through mining (i.e. rock phosphate). It is one of the three major elements for plant nutrition and an essential component for the functioning and development of plants. In the soil it can be easily immobilized, making it inaccessible to plant roots in most tropical soils, making it a limiting factor for crop production. It is important to find ways to mobilize P from soils and make it available to plants. This can be achieved through the promotion of *mycorrhiza* and increased associated biological activity in the soil-root system.

→ *Mycorrhiza* fungus forms a symbiotic association with the roots of plants. It can either penetrate the root cells (endomycorrhiza) or not (ectomycorrhiza), and promotes root growth and extends the root system, supplying plants with P.
→ *Mycorrhiza produces organic acids, stabilizes pH, and mobilizes immobile P, including in high pH soils.*

Nutrient pumps: deep roots help achieve nutrient balance

Soils rich in organic matter have a pool of well-balanced nutrients that contribute to crop growth and plant development. Such soils avoid the problems that result from unbalanced plant nutrition such as lower fertilizer use efficiency and reduced crop quality.

→ Balanced nutrient supply from organic matter pool is important for optimal plant growth and development.
→ Deep rooting crops act as nutrient pumps with their decaying crop residues.

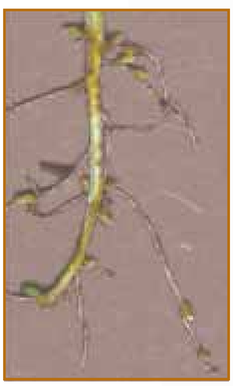
Soil organic matter also helps to store nutrients which otherwise would leach away.

Deep rooting crops, which are grown as cover crops between cash crops in sequence or in association, can recover plant nutrients from deeper soil layers and bring them to the soil surface, making them available for the next crop through the decaying of the crop residues.

Nitrogen (N): a major building block for protein

Certain bacteria convert atmospheric nitrogen into organic nitrogenous compounds which provide nutrition for plant growth and for soil microorganisms.

- There are symbiotic N-fixing bacteria, such as *rhizobia* which are found in root nodules of legumes including pulses, oil seeds, trees and shrubs, and pasture legumes.
- There are free living N-fixing bacteria such as *Azotobactor* and *Beijerinkia* that live in the soil and root rhyzosphere, the area of soil surrounding the roots of plants.



Nitrogen-fixing root nodules of legumes (such as peas, beans, clover)

These bacteria convert atmospheric nitrogen (N_2) into organic nitrogenous compounds which provide nutrition for plant growth and for soil microorganisms.

Worldwide, some 44–66 million tonnes of N_2 are fixed annually in agricultural lands by leguminous plants and other soil organisms, providing nearly half of all N used in agriculture.[1] The fixation of N_2 by legumes contributes greatly to more economically viable and environmentally friendly agriculture.

Maize grown in association with a legume intercrop for additional N supply to the soil

1 Giller, K.E. (2001) *Nitrogen Fixation in Tropical Cropping Systems*. CABI Publishing, Wallingford, UK

BIOLOGICAL NITROGEN FIXATION: THE ROLE OF LEGUME-BASED SYSTEMS

Importance of leguminous pulses and oilseeds

About 56 million tonnes of pulses, 257 million tonnes of legume oilseeds and 2 351 million tonnes of cereals were harvested globally in 2007. Grain yields of legumes are lower compared with cereals but the protein content of legume seeds is more than twice as high.

Biological Nitrogen Fixation

In agricultural systems, some types of microbes can achieve biological nitrogen fixation (BNF) as free-living organisms: heterotrophic and autotrophic bacteria and cyanobacteria. Other micro-organisms can only fix nitrogen through a symbiosis with plants, mainly legume species. In agricultural areas, about 80 percent of BNF is achieved by such a symbiotic association, between the legumes and the nodule bacteria, the *rhizobia*.

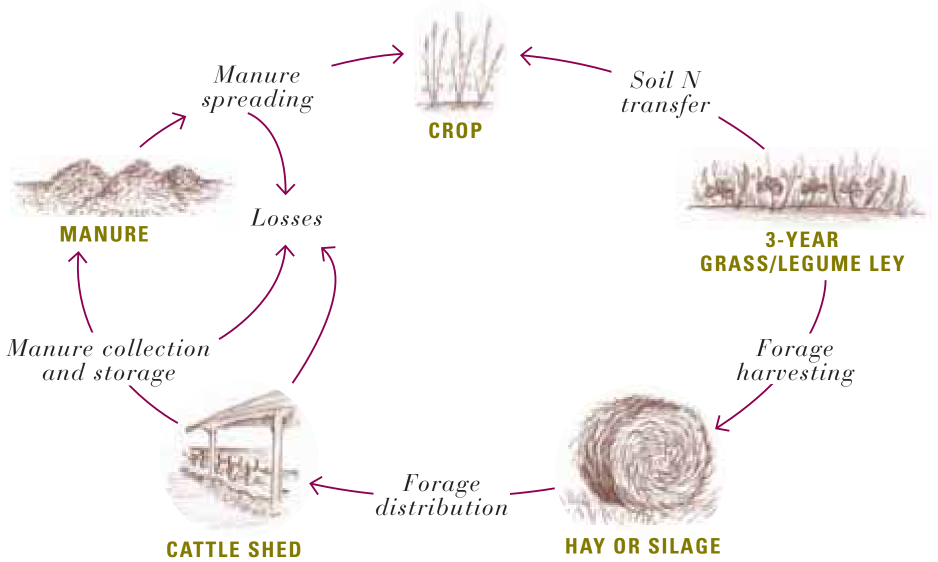
Farmers have some scope to influence BNF, through legume genotype selection, legume/grass seed proportion in forage mixtures, inoculation with bacteria such as *rhizobia*, crop nutrition (especially N and P), weed, disease and pest controls, planting time, cropping sequence and intensity, and defoliation frequency of forage swards. Some factors affecting BNF, however, cannot be controlled. These include unfavourable temperatures and droughts.

Some legume species are better at fixing nitrogen than others. In perennial temperate forage legumes, red clover and lucerne can typically fix 200–400 kg N/ha (whole plant fixation, above and below ground).

Nitrogen transfer to other crops or forages

Nitrogen fixed by legumes is harvested in the crop and partly transferred to subsequent crops increasing their yields. For instance, in forage legume/grass mixtures, nitrogen is transferred from legume to grass (e.g. 13 to 34 percent of fixed N). In cutting meadows, N is exported with silage or hay and ingested by animals. About 70–95 percent of this nitrogen is excreted by animals and the manure can then be recycled by spreading on arable land (figure 7).

figure 7
NITROGEN CYCLE IN A LEY/CROP ROTATION AND THE WHOLE MIXED FARMING SYSTEM - MAIN FLUXES

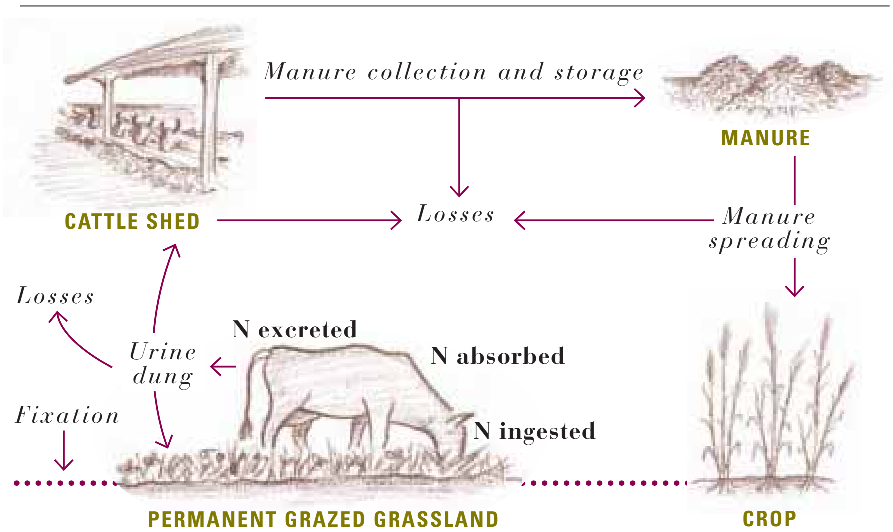


Forage legumes in temperate livestock systems

In temperate livestock systems, white clover is particularly efficient in grazed systems. It can fix 100–300 kg N/ha and has higher digestibility, crude protein, lignin, ash, calcium and magnesium contents than grasses.

White clover/grass mixtures have higher summer production and can increase animal intake compared to pure grass swards. Lucerne and red clover are very well adapted to cutting systems for the production of hay or silage. All these legumes can lead to cost reductions for farmers, increase biodiversity and shape sustainable crop/livestock production systems (figure 8).

figure 8
NITROGEN CYCLE IN A MIXED FARMING SYSTEM (LIVESTOCK/GRASSLAND/ARABLE LAND) - MAIN FLUXES



Groundnut in tropical cropping systems

N is often the most limiting element for cereal grain production. Chemical fertilizers are rarely available to smallholders. The result is that in many subsistence crop production systems, N is effectively 'mined' from soil organic matter resulting in depleted soils. Legumes can partly solve the problem, either as green manures, planted in intercropping systems, as part of a scheme of crop rotation or in agro-forestry systems.

After grain harvest of groundnut, haulms can be eaten by livestock or incorporated into the soil. In this latter case, the yield of the subsequent crop (e.g. maize or rice) can be much higher (as much as double), even if the groundnut yield is low.

Rhizobia in soybean production

The soybean (Glycine max L.) was introduced in Brazil in the late 1880s. By the 1950s, production topped 100 000 tonnes, by 1970 it had passed 1 million tonnes and now, it occupies 22 million ha with a mean yield of 2 737 kg /ha yr resulting in a production of 60 million tonnes/year. Brazilian soils originally lacked the rhizobia needed to nodulate (fix N_2) soybean effectively. However, Brazil's government recognized the importance of rhizobia and its potential contribution and has provided support through policy and research efforts. Massive inoculation with a few strains of rhizobia used in commercial inoculants during recent decades has established populations in most soybean-cropped soils. Brazil is now the world's second largest producer of soybean and applies no fertilizer nitrogen to the crop.

Impact of legume-based systems on crop production

The higher yields of crops regularly observed after legume cropping, in addition to enhanced soil N availability, are related to the:

- ability of some legume species to mobilize the low-soluble P in the soil;
- positive mechanical effect of legume tap roots on the soil structure and drainage;
- lower water use of some legume species compared to other crops; or
- beneficial effect of the legume rhizosphere (H+ excretion) on soil micro-organisms that can compete with or suppress crop pathogens.

Impact of legumes on natural resources

The direct environmental cost associated with legume-based systems is marginally lower than that of N fertilized-based systems. The risk of nitrate leaching depends very much on farming practices and is not always lower in legume-based systems. N_2O emissions seem to be comparable in both systems. However, synthesis of chemical fertilizer requires large amounts of fossil energy (at least 27 GJ/t NH_3). By contrast BNF is based on solar energy and does not emit CO_2 into the atmosphere.

The introduction of legumes (legume cover crops, grass/legume pastures, legume-based fallow or even annual legume crops) in crop rotations has proven to reduce weed infestation, disease and pest attacks.

Legume-based cropping systems contribute to maintaining biodiversity, especially of pollinators, other arthropods, soil life in general, and many of the bird and mammal species that are able to live in agricultural landscapes.

Importance of legumes for sustainable agriculture

In the context of increasing prices of fossil fuels and mineral N fertilizers, a progressive shift from N fertilizers to N-fixing legumes would seem to be highly desirable. Current BNF by crop legumes is estimated globally at about 20–22 million tonnes of N each year.[2] There is potential to harness more if the relevant biological processes are promoted within legume-based production systems.

2 Herridge, D.F, Peoples, M. B. and Boddey, R. M. (2008) Global inputs of biological nitrogen fixation by agricultural systems. *Plant Soil*, 311: 1-18

Grain (pulses and oilseeds) and various types of forage legumes occupy 12–15 percent of the earth's arable land and account for one-third of humanity's dietary protein needs. Under subsistence conditions, this can be up to two-thirds of protein needs.

PROCESSES FOR SOIL STRUCTURE (BIOLOGICAL TILLAGE)

Undisturbed soil with sufficient supply of organic matter provides a good habitat for soil fauna. Reduction of mechanical soil tillage results in increasing population of earthworms, millipedes, mites and other animals living in the soil. This macro fauna takes over the tillage task and builds soil porosity and structure. It incorporates organic matter from the soil surface; the excrements provide stable soil aggregates and the vertical macro-pores created by the worms serve as drainage channels for excess water. This makes the land less susceptible to flooding and erosion, since water infiltration deep into the ground is improved. The organic matter incorporated by soil fauna into the soil improves soil structure and water storage capacity, which in turn helps plants to survive longer during drought spells. Both are important strategies for farming **ADAPTED TO CLIMATE CHANGE**.

Increased levels of organic matter in soil also help **MITIGATE CLIMATE CHANGE** by storing carbon from atmospheric carbon dioxide in soil organic matter. The formation of stable organic matter through the process of humification is mediated by soil micro-organisms.

Building up soil health under a high biomass *Mucuna* cover crop with deep root system

Another element of biological tillage is the introduction of crops including trees and shrubs with deep penetrating tap-roots. Some of these "pioneer" crops such as lupine, jack-beans (canavalia) or radish can break subsoil compactions, if for example, planted in the crop rotation or in intercrop association as green manure cover crops.

HARNESSING SOIL BIOLOGICAL PROCESSES THROUGH CONSERVATION AGRICULTURE PRACTICES

Even though the importance of nitrogen fixation, phosphorus mobilizing *mycorrhiza* and nutrient pumps are well known to agriculturalists, these processes play a minor role in crop production.

The problem is that most agricultural soils no longer provide a suitable living environment for the micro-organisms that are so critical to these processes. Even when they are used – those such as *rhizobia* or even *mycorrhiza* may become inoculants for specific crops – they do not flourish in farming systems that rely on mechanical tillage because tillage stirs up the soil and creates a major interruption in the soil habitat which is not tolerated by most organisms that normally live in undisturbed soil.

One way to address this is to redirect soil system management towards soil biological processes that have the potential to improve soil health and function including crop nutrition and productivity.

This requires:

- → Aerobic processes in porous soils with continuous macro-pores that facilitate aeration and gaseous exchange between soil and atmosphere, and allow deep drainage of excess water to recharge groundwater storage.
- → Organic matter that provides nutrient and energy substrate for soil micro-organisms.
- → A stable environment without abrupt changes in temperature, humidity, salt concentration or pH levels.

These conditions can be met and sustained through following a set of farming practices – collectively known as Conservation Agriculture (CA) – that is based on enhancing natural biological processes above and below the ground. It also reduces interventions such as mechanical soil tillage to an absolute minimum.

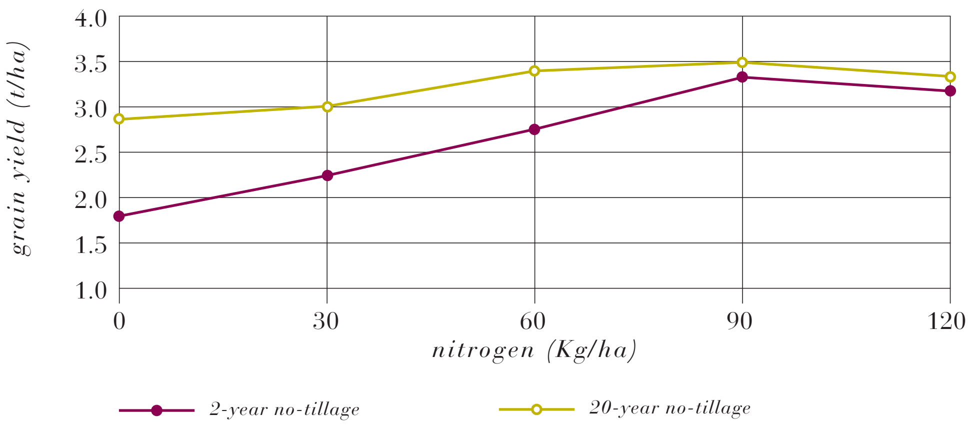
External inputs such as agrochemicals and nutrients of mineral or organic origin are applied in a manner and quantity that do not interfere with the biological processes and associated ecosystem functions.

Kenyan farmer explaining a CA crop association of maize with *Desmodium* (legume) underseed for N supply and additional action on stem borer and *striga* control

The continuous and simultaneous application of CA practices can increase soil life and soil biodiversity, enhance biological processes related to soil productive capacity and crop nutrition and, above all, provide a conducive environment that allows soil micro-organisms to flourish and create a living soil system. Although an initial inoculation might be necessary in some cases, the living soil system enhances crop productivity and ecosystem services.

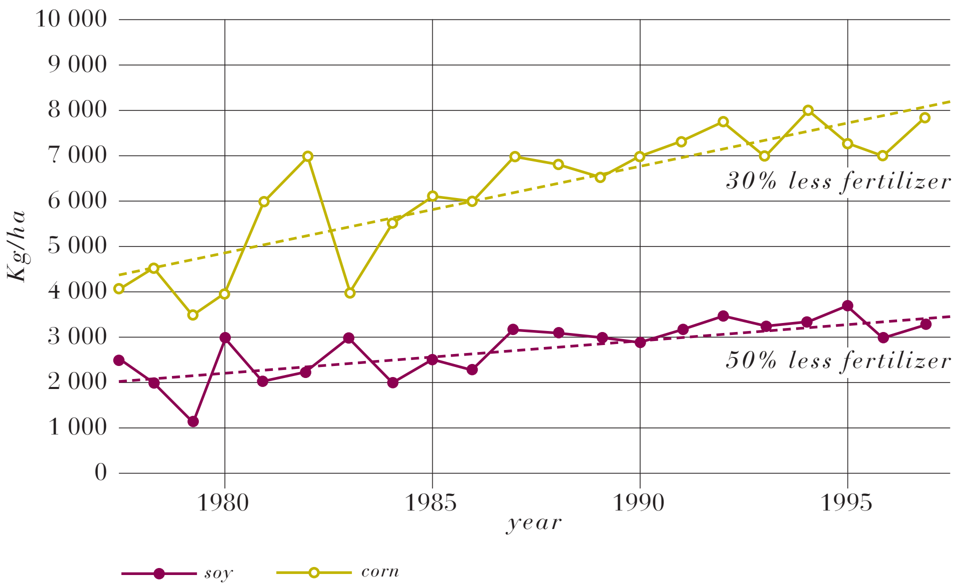
Evidence shows that mineral fertilizer requirements, particularly of N and P, in soils that have been under CA practices for an extended period of time, decrease and the problem of low availability or immobilized P in soils is ameliorated, even when the soil analysis does not show high quantities of soluble P (figures 9 and 10).

figure 9
WHEAT YIELD AND NITROGEN AMOUNT FOR DIFFERENT DURATION OF NO-TILLAGE IN CANADA 2002



Source: http://www.topcropmanager.com/content/view/4427/38

figure 10
INCREASED YIELDS FOR CORN AND SOY WITH REDUCED FERTILIZER USE OBSERVED OVER 20 YEARS PRACTICAL FARMING ON A FARM IN PONTA GROSSA, BRAZIL (FROM 1977-1998)



Source: http://www.act.org.zw/docs/actis02.pdf

In addition to this, CA practices enhance the diversity and population of soil macro fauna with its structure-building effects.

For CA practices to work effectively requires that farmers not only understand the underlying ecological principles of soil health and productivity, but are also provided with enabling policy and institutional support including participatory extension training, affordable input supply and access to adapted tools.

CA: THREE LINKED PRACTICES

- **Continuous minimum mechanical soil disturbance.**
- **Permanent organic soil cover.**
- **Diversified crop rotations in the case of annual crops or plant associations in case of perennial crops.**

4 ENABLING POLICY & INSTITUTIONAL ENVIRONMENTS

If the roles and functions of biological processes in sustainable production intensification are to be harnessed effectively on a sufficient scale to meet future food demand, **ENABLING POLICIES AND INSTITUTIONAL SUPPORT ARE NECESSARY**.

PLANNING AND AGRICULTURAL POLICIES

National agricultural development goals, strategies, policies, plans and programmes as well as laws, rules and regulations that are relevant to sustainable crop production intensification should protect and strengthen the ecological functions supporting agriculture, in order to optimize ecosystem goods and services.

For example, policy makers can promote responsible and adaptive pest management through extension and awareness campaigns. They can also influence consumption by removing subsidies from higher risks products. Policy makers have a key role in registering pesticides for sale and distribution within their jurisdiction, and so can influence the supply of agrochemicals directly. They can also check the quality of products used, and ensure they are correctly labelled, marketed and applied to minimize risks.

Another example is land use planning and land tenure. Put simply, farmers who do not have the expectation of continuing to farm at a particular location for the long term have relatively little incentive to ensure that the production practices they use are sustainable. Policy makers can address this directly through initiatives affecting land tenure.

RESEARCH

The increased recognition and use of biological processes in sustainable production intensification represents a fundamental change in production system thinking. It involves a number of elements that have until recently been unrecognised or underemphasised in production systems when considering ecosystem health and functions, or enhancing the productive capacity of the resource base. The greater incorporation of biological processes in sustainable crop production intensification therefore requires a deeper understanding of how such processes provide the ecological underpinnings of production and livelihoods.

Better understanding allows farmers to manipulate and manage the various parts of the production systems in which the aim is to optimize resource use and protect or enhance ecosystem processes in space and time over the longer-term. These are some of the features that are responsible for biologically-driven production practices being "knowledge intensive".

STAKEHOLDER MOBILISATION

Experience across many countries has shown that expanding the management of biological processes in production systems requires a change in commitment and behaviour of all concerned stakeholders. For the farmers, a mechanism (such as Farmer Field Schools) to experiment, learn and adapt is a prerequisite.

For the policy makers and institutional leaders, transformation of the unsustainable systems to improved and efficient systems requires that they fully understand the large economic, social and environmental benefits that can be harnessed by the producers and the society at large.

Enabling policy and institutional environments for sustainable crop production intensification
Some considerations:

- ***Promoting national agricultural development goals, strategies, policies, plans and programmes as well as laws, rules and regulations that are relevant to sustainable crop production intensification should protect and strengthen the ecological functions supporting agriculture, in order to optimize ecosystem goods and services.***
- ***Building capacity to sustainably manage biological processes for crop production intensification, including through training and participatory extension processes.***

- *Investing in local adaptive research especially by farmers to test, learn and apply sustainable crop production intensification as a basis for scaling and impact.*

- *Promoting strategic and applied research as well as operational research to generate knowledge, technologies and practices involving the application of biological processes that can address challenges such as climate change, water scarcity, as well as degradation of the land resource base, the environment and biodiversity.*

- *Supporting the education system at all levels in both the academic and vocational sectors to ensure that educational capacity is adequate to produce high quality graduates in the fields of conservation, ecosystem management and sustainable agriculture that is ecologically and biologically based.*

- *Strengthening local decision-making including at the rural community and village level because solutions to local challenges and opportunities must involve local ownership and leadership that can combine traditional and local knowledge with new and improved practices.*

- *Raising awareness of the contribution of ecosystems to sustainable livelihoods.*

- *Ensuring a dialogue between the agriculture and environment sectors, and between the public, private and civil society sectors.*

Figures not otherwise acknowledged are based on data from the FAO Plant Production and Protection Division.

PHOTO CREDITS:

page	**©**
cover	(main picture) FAO/G.Bizzarri
	(background) studio Bartoleschi
1	FAO/P.Pittet
4	(top) FAO/H. Null
	(below) P.Kenmore
7	(top) International Rice Research Institute (IRRI)
	(centre) P.Ooi
	(below, left) P.Ooi
	(below, right) Int. Rice Research Institute (IRRI)
8	from: www.ricehoppers.net
9	(top) FAO/G. Bizzarri
	(below) courtesy of FAO/IPM projects
10	(top) FAO/R. Pasquet
	FAO/D. Martins
	FAO/D. Martins
	(below) FAO/A. Robertson
14	FAO/R.Faidutti
	FAO/V. Belavadi
15	FAO/I. Gordon
	FAO/N. Vereecken
16	FAO/R.Messori
18	Jim Deacon
19	T. Friedrich
20	(top) M. Marzot
	(center) M. Halling
	(below) M. Halling
	(FAO/AGPC website, grassland index)
23	FAO/M.Marzot
26	FAO/A. Odoul
27	T. Friedrich
29	T. Friedrich
31	FAO/G. Bizzarri
32	FAO/G.Napolitano

Printed in Italy on recycled paper, Forest Stewardship Council (FSC) certified.

design: pietro@bartoleschi.com

THE PURPOSE OF THIS BROCHURE

IS TO ILLUSTRATE SELECTED BIOLOGICAL PROCESSES THAT ARE ESSENTIAL FOR MAINTAINING THE HEALTH OF THE LAND RESOURCE BASE, AS WELL AS OF THOSE BIOLOGICAL PROCESSES THAT CONTRIBUTE TO GOOD FARMING PRACTICES FOR SUSTAINABLE CROP PRODUCTION INTENSIFICATION.

THESE INCLUDE:

PEST REGULATION AND CONTROL

POLLINATION

SOIL BIOLOGICAL PROCESSES

THE PLANT PRODUCTION AND PROTECTION DIVISION (AGP) OF THE AGRICULTURE AND CONSUMER PROTECTION DEPARTMENT OF FAO IS THE LEAD DIVISION RESPONSIBLE FOR SUSTAINABLE CROP PRODUCTION INTENSIFICATION.

www.fao.org/agriculture/crops/core-themes/theme/spi

www.fao.org

sustainable-crop-intensification@fao.org

I1235E/1/11.09/1500