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Low-input technologies for increasing crop productivity and sustainability: A review

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ABSTRACT

Sustainable agriculture is an important element of the overall effort to make human activities compatible with the demands of the earth's eco-system. The low external input agriculture or low input agriculture (LIA) emphasizes the use of techniques that integrate natural processes such as nutrient recycling, biological N fixation (BNF), soil regeneration and natural enemies of pests into food production processes. Efforts are made to minimize losses from the system, such as by leaching or removal of crop residues. Yields are maintained through greater emphasis on cultural practices, integrated pest management (IPM), and utilization of on-farm resources and management. The conceptual basis of low-input agriculture includes a) adaptation of plants to the constraints, rather than eliminatrion of all constraints to meet the plant's requirements, and b) maximization of output per unit of added input. The major components of LIA are selection of most appropriate lands, use of improved (stress tolerant) bio-types, low-cost technologies for better crop establishment, management of soil-water constraints with minimum inputs, BNF, efficiently managing P fertilizers including phosphate solubilizer and identifying and correcting deficiencies of other essential plant nutriments. Improved LIAs discussed in this paper are conservation tillage, seed treatments and seed production related low cost technologies, appropriate planting time and methods, biofertilizers, better intercrops, possible *in-situ* or *ex-situ* composting, suitable agroforestry, alley cropping and other alternative farming systems. Other suitable LIAs include cover crops and green manures, effective biomass transfer techniques, improved fallows, permaculture (a land use and community building movement for harmonious integration) and IRM/IPM approaches. Future research to improve LIA should focus more on developing interventions to meet farmer realities, such as increased food security, improved cash generation, reduced risk, and enhanced quality of life.

Key words: Crop productivity, Farming systems, Integrated pest management, Low input technologies, Sustainability

The global population is predicted to reach 9.3 billion people by the year 2050, a 50% increase over the current level after which it will level off due to falling fertility rates and family size. Perhaps, 84% of these will live in developing world. This rise in population, together with a greater purchasing power through a steady increase in income, is assumed to increase food demand over the period 1990-2050 by 2.4 times in Asia, 1.9 times in Latin America and the Caribbean, and probably five fold in Africa. Moreover, the increase in production required to meet this demand will need to be realized with less water, less labour, less land, with most importantly, adversely affecting the environment (Graves *et al*., 2004).

How this can be achieved? Mainly there are three important avenues for increasing food (and other commodities) production in the world are: 1) increasing yields per unit area in presently cultivated regions, 2) opening new lands to cultivation, and 3) expanding irrigated land. The first two require the alleviation or elimination of soil constraints, while the third one eliminates water stress as the main constraint (Sanchez and Salinas, 1981). It was concluded that all three are needed although the irrigation alternative is limited to relatively small areas and is the most costly of the three (Bentley *et al*., 1980). Thus, there is very little doubt that increasing productivity in land already under cultivation is the principal avenue for increasing production of crops. This has been possible through green revolution technology where high yielding cereal varieties, together with high level of inputs such as water from irrigation systems, fertilizer has provided the necessary impetus through the nutrients needed by the varieties, and pesticides to control any associated weeds, pests and diseases. These technologies need a high capital investment, either by, or on the part of farmers, and need a well functioning economic and physical infrastructure for their effective implemenetation.

Thus, one may probably think to continue with such a high (external) input agriculture (HIA) as used in the last 2-3 decades can also be used to address the food demand for the next 40 years perhaps by raising the productivity through emerging techs such as genetic modification (Crosson and Anderson, 2002). However, it may not be possible in many situation as an estimated 30-35% of the world's population

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don't have access to such infrastructure, are remote from markets, practice subsistence farming on marginal soils, and lack access to knowledge even on how to improve their situation. Moreover, because of too many constraints, encountered making the HIA approach is unsustainable besides damage to the environment as the inputs of fertilizers and chemicals accumulate in neighbouring ecosystems. The increasing costs petroleum-related inputs and the worldwide emphasis on conserving the earth's natural resources pose additional restraints to the maximum input approach. Thus, a realistic approach could be technologies using low levels of external inputs readily available either on-farm or from nearby off-farm sources which would be more appropriate and sustainable. This approach is called as low external input agriculture or low input agriculture or simply LIA which largely emphasizes the use of techniques that integrate natural processes such as nutrient recycling, biological N fixation (BNF), soil regeneration and natural enemies of pests, into food production processes (Graves *et al.*, 2004). Here efforts are also made to minimize losses from the system, such as by leaching or removal of crop residues. Moreover, the use of non-renewable inputs such as pesticides and fertilizers that can damage the environment or harm the health of farmers and consumers is also minimized. Improved techs such as intercroping, agroforestry, cover crops and animal manure are used although such technologies are sometimes more labour intensive than HIA. Therefore, Nickel (1979) observed that if low-income consumers are to benefit, food production increases must be achieved at lower unit costs. These low unit costs can be achieved through biologically based technology that is often scale neutral.

Thus, the concept of low-input technology (LIA) is gaining momentum as it does not necessarily attempt to eliminate the use of fertilizers or amendments but rather attempts to maximize the efficiency of purchased input use through a series of practices. Thus, the basic concept of LIA is to make the most efficient use of scarce purchased inputs by planting species or varieties that are more tolerant to existing soil-water-climate constraints, thus decrease the rates of external application while attaining reasonable, but not necessarily maximum yields. Increasingly, it has been recognized that environmental deterioration in India and world over is a central factor holding back agriculture. The disappearance of forest areas accelerates land degradation. Even on gently sloping cropland, topsoil losses have been reported to range from 25 to 250 tonnes per hectare, across the region. A case study in Africa estimates that soil degradation and erosion there (in Africa) reduces the productivity of land about 1% a year (Daberkow and Reichelderfer, 1988). According to a World Bank Report, some 2.9 million hectares of forest were lost each year in sub-Saharan Africa during the 1980s, mainly due to land clearing by farmers and loggers. The Soil Reference and Information Centre (2007) in the Netherlands also estimates that 321 million hectares of African land are classified as moderate to extremely degraded.

Thus, in the existing scenario, Low input agriculture technology (LIAT) proves handy as it is concerned with production activity that uses synthetic fertilizers or pesticides below the rates that is commonly recommended. It does not mean elimination of these materials or inputs. Yields are maintained through greater emphasis on cultural practices, integrated pest management (IPM), and utilization of on-farm resources and management. Therefore, LIAT has also been termed as "low input and sustainable agriculture, LISA" by other schools of agriculture. The term in both cases applies to those systems that rely less on external, purchased inputs and more on internal resources, while sustaining the natural resources (IAASTD, 2008).

Agriculture has the potential to change from being one of the largest greenhouse gases (GHG) emitters to a net carbon sink with various options for mitigation. The solutions call for a shift to sustainable farming practices that build up carbon in the soil and use less fertiliser (Bellarby *et al.*, 2008 and Tewari and Tripathi, 2011). There are varieties of sustainable farming practices under LIA that can reduce agriculture's contribution to climate change, which are easy to implement. These include crop rotations and improved farming design, improved cropland management, nutrient and manure management, grazing-land and livestock management, maintaining fertile soils and restoration of degraded land, improved water and rice management, and set-asides, land-use change and agroforestry (Bellarby *et al.*, 2008 and Niggli *et al.*, 2008).

CONCEPTUAL BASIS OF LOW-INPUT AGRICULTURE

In a majority of constrained soil-water situations, favourable socio-economic situations do not exist, either because inputs (fertilizers, lime, etc) are expensive or not available at reasonable price, or simply because the risks are too high. The first two situations are self-explanatory. The third one can be expalined in Fig. 1 showing the response to P application by *Phaseolus vulgaris* in Columbia, USA with a high capacity to fix P. The optimum P dose is 507 kg ha^{-1} taking the residual effects of two subsequent crops. However, the

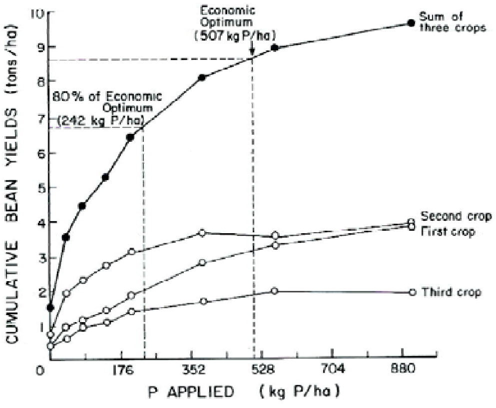

Fig. 1. Cumulative response of *Phaseolus vulgaris* grain yields to basal P applications and its residual efect to two consecutive crops (Sanchez and Salinas, 1981)

economists calculated that a total of US \$1500 ha^{-1} $crop^{-1}$ is required to be invested to get a net profit of US \$375 ha^{-1} only. Although this represents a 25% return on the investment, most farmers with limited resources are unwilling to make it considering the risk due to variability in yields caused by drought, disease, insect attacks and price flucuations. Similar is the case under Indian conditions. Thus, there are three main principles on which low-input agriculture is usually based. These are listed as under:

1. *Adaptation of plants under constraints, rather than elimination of all constraints to meet the plant's requirement;* e.g. certain varieties of rice show tolerance to Al toxicity (Colombia1 > IR5) followed by low level of soil available-P. Similarly, a differential response to lime is also observed in varieties of rice, sorghum and other crops. It is in fact more conspicuous at low rates as cultivar differences disappear at high input rates.

2. *Maximization of output per unit of added chemical or other input*; here the inputs are applied to produce higher (80% or above) or optimum yields which is considerably lower than the amount required to reach the maximum or optimum point calculated under marginal analysis. For e.g. in the above case although the P_{opt} is 507 kg ha^{-1} yet, the amount of P required is less than half i.e., 242 kg to realize 80% of optimum yield. However, marginal analysis is determined as the optimum fertilizer rates (where the optimum level is usually reached when the revenue of the last increment of fertilizer equals its added cost). Since in most instances fertilizer response curves can be chacracterized by a sharp linear increase followed by a flat horizontal line (linear approach) following liebig's law of minimum, this principle is practiced in interpretating input (fertilizer) response. Fig 2 shows a much lower recommended N rate with linear plateau model with highest fertilizer efficiency (unit crop yield per unit of fertilizer input).

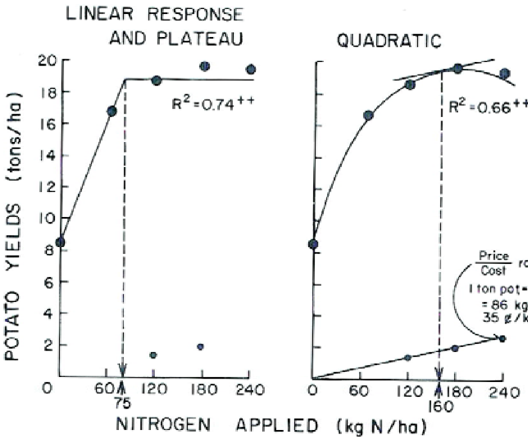

Fig. 2. N recommendation for potato in a linear plateau response model over the conventional curvilinear one (Sanchez and Salinas, 1981)

3. *Advantageous use of favourable attrubutes of (infertile/ marginal) soil-plant situation;* in an acid soil, the solubility of slowly available rock phosphate is higher than if the soil is limed, and weed growth is decreased considerably as compared to a limed and fertilized soil. Also the low effective cation exchange capacity (ECEC includes exchangeable Al, Ca, Mg and K) of the soil favours the downward movement of applied Ca and Mg to the subsoil.

MAIN COMPONENTS OF LOW-INPUT TECHNOLOGY

Several concepts or techniques are developed as building blocks for low-input technology in agriculture, some of which can be combined in a farming system approach.

1. Selection of most appropriate lands where, because of soil-water properties, landscape positions, and market accessibility, low-input technology has the comparative advantage over high-input technology. This involves avoiding the best lands in terms of high native fertility, irrigation potential, or close proximity to markets for easy and effective disposal as most of these favoured lands could be managed more effectively with high input technology. Thus, actual land selection is site-specific and land capability classification therefore is a more useful tool because it also considers climate, landscape, native vegetation, and infrastructure. Accordingly, Ramalho *et al*. (1978) redefined land capability classes in terms of high (intensive use of fertilizers, lime, mechanization and other new techs), medium (limited use of fertilizer and mechanization) and low input use (primarily manual labour and few, if any, purchased inputs). Thus, it is appropriate to select LIA for well-drained acid, infertile soils of tropics (oxisols and ultisols) with <8% slope avoiding high base status soil, and acid soils with severe physical limitations.

2. Use of improved bio-types i.e., plant species and varieties that are more tolerant to the major soil constraints as well as being adapted to climatic, insect and diseases stresses. The term acid soil tolerance covers a variety of individual tolerance to adverse soil factors and the interactions that occur among them. It includes both qualitative (under low fertilizer or lime levels) and quantitative tolerance. The quantitative assessment of plant tolerance to acid soil includes tolerance to high level of Al or Mn, and to deficiencies of Ca, Mg, P, and certain micronutrients, principally Zn and Cu. Some of the tolerant (acid soil condition) species include cassava, cowpea, peanut, pigeonpea, plantain, potato and rice. Similarly, susceptible species with acid-tolerant cultivars belong to common beans, corn, sorghum, soybean, sweet potato and wheat.

3. Use of low-cost and efficient land clearing, planting window, methodologies for plant establishment (priming, seed hardening and seed treatment), cropping systems, and other practices are made for maintaining a plant canopy over the soil. Here the principle is to develop and

maintain a plant cover over the soil for as long as possible in order to decrease erosion, compaction and leaching hazards. Further soil cover protection can be obtained by mulching annual crops and green manuring, intercropping and agroforestry.

4. Manage soil-water constraints with minimum inputs, with emphasis on promoting deep root development into the subsoil, conservation tillage, appropriate planting methods, management of soil-water constraints such as soil acidity, high basicity, hardpans and difficulty in water movements in soil profile have to be considered for overall efficiency of LIA.

Here also management of *low native soil fertility* (sometimes referred as '*Fertility deserts'*) plays a significant role in productivity optimization under LIA. Although a very low level of native soil fertility can't be eliminated as a major constraint without significant fertilizer inputs, yet several avenues are available for lowering the overall fertilizer requirements. The main LIA techs to manage the native soil fertility center on

a. Maximum use of BNF in legumes using soil constraint (e.g. acidity) tolerant *Rhizobia,*
b. Increase the efficiency of N and K fertilizers/inputs applied (main avenue for decreasing the inputs for nonlegume crops),
c. Identify and correct S and other micronutrient deficiency, and
d. Promoting nutrient recycling (mostly by crop residues)

Soil testing is sometimes of little value for N fertilization because of the mobility of NO_3 in well-drained soils. Consequently, fertilizer recommendations are based on field experience and plant uptake resulting in difficulty in actual supply for cereal and root crops in low-input strategy. However, K deficiency via soil test is straight forward as critical levels are in the range of 0.15-0.20 meq K 100 g^{-1} for most crops. In LIA, the main avenues for increasing efficiency of K is split applications and avoidance of removal of crop residues for achieving some degree of recycling.

5. Maximize the use of biological N fixation (BNF) with emphasis on tolerant *Rhizobium* strains. This is possible in presence of specific grain legumes but definitely not for cereal and root crops. Although the carryover effect of N fixed by a legume to a nonlegume either intercropped or in rotation appears to be small as most of the N is removed in the harvest, yet increasing the efficiency of N fertilization for nonlegumes can be accomplished through improved timing and placement of fertilizers.

6. Manage P fertilizers at the lowest possible cost with emphasis on increasing the efficiency of cheaper sources of P and prolonging the residual effects of applications. Efficient P management strategy under LIT includes

a. Determination of most appropriate combination of rates & placement that enhance initial and residual effects,
b. Use of improved and appropriate soil fertility evaluation methods for P recommendation,
c. Use of less costly sources such as phosphate rocks,
d. Selection of species and varieties that grow well at lower level of available P, and
e. Exploring the use of mycorrhizal inoculations to increase P uptake by plants.

7. Identify and correct deficiencies of other essential plant nutriments: Here, the critical nutrient levels in both soil and plant play a major role. The application costs are low in most cases (of course in raw form) in addition to their long residual effects (especially Zn and Cu).

LOW-INPUT TECHNOLOGIES

Many farmers in many places of the world practice low input agriculture (LIA) albeit unconsciously. Sometimes due to unaffordability of external agriculture inputs farmers have always produced crops using on-farm inputs. Some of the strategies, which are currently practiced and can be considered under LIA are given here:

1. Conservation tillage

Conservation tillage (CT) is practised on around 45 million hectares world-wide, predominantly in North and South America but its uptake is also increasing in South Africa, Australia and other semi-arid areas of the world including SE Asia. It is primarily used as a means to protect soils from erosion and compaction, to conserve moisture and reduce production costs. In Europe, the area cultivated using minimum tillage is increasing primarily in an effort to reduce production costs, but also as a way of preventing soil erosion and retain soil moisture. A large proportion (16%) of Europe's cultivated land is also prone to soil degradation but farmers and governments are being slow to recognise and address the problem, despite the widespread environmental problems that can occur when soils become degraded.

Conservation tillage can improve soil structure and stability thereby facilitating better drainage and water holding capacity that reduces the extremes of water logging and drought. These improvements to soil structure also reduce the risk of runoff and pollution of surface waters with sediment, pesticides and nutrients. Reducing the intensity of soil cultivation lowers energy consumption and the emission of carbon dioxide, while carbon sequestration is raised through the increase in soil organic matter (SOM). Under conservation tillage, a richer soil biota develops that can improve nutrient recycling and this may help combat crop pests and diseases. The greater availability of crop residues and weed seeds improves food supplies for insects, birds and small mammals.

Reduced tillage has been helpful in many cropping practices for its inherent benefits including yield advantages.

It reduces control of some key pests spending a major part of their life cycle in soils, e.g., pink bollworm (Dhawan and Sidhu, 1988 and Russel, 2004). Increasing problems of currently emerged minor pests e.g. white grubs, termites and scale insects are expected along with nematode problems unless appropriate crop rotation is practiced (Rajendran and Basu, 1999). Moreover, removal and destruction of unopened bolls from cotton stalks also helps in reducing the carry over effect of pests like pink bollworm in cotton (Jayaswal and Sundaramurthy, 1992).

2. Seed treatments and seed production technologies

***Seed hardening*:** Seed hardening and seed priming are very important simple technologies for higher germination of seed and good plant stand. For example, using of 1.0% KCl solution for hardening may confer higher germination and speed of germination in hirsutum cotton. Similarly, for hardening cotton seed, seed to solution ratio of 1:1.5 (w/v) for *G. hirsutum* and 1:1.65 (w/v) for *G. arboreum* cotton seeds with the soaking duration of 8 hours is optimum. Even simple pre-soaking of seed in water for 6 hours improves germination to a great extent and is equally effective both for rainfed and irrigated conditions.

***Seed pelleting*:** cotton seeds pelleted with finely powdered arappu (*Albizzea amara*) leaf powder @100 g kg^{-1} of seed, finely powdered DAP @ 40 g kg^{-1}, micronutrient mixture @15 g kg^{-1} and 5.0% maida solution as adhesive @ 300 ml kg^{-1} increase seed germination, seedling growth, dry matter accumulation in seedling, seedling vigour index and field emergence under excess soil moisture conditions. Elite cotton seedlings can be produced using these pelleted seeds in protrays filled with a soil mixture composed of sand + red soil + FYM (1.0:0.5:1.5 ratio) under partial shaded and open condition. These seedlings can be lifted with ball of earth and used for gap filling in the field.

***Flower (pollen) production in male parents*:** Soil application of $ZnSO_4$ alone @ 50 kg ha^{-1} or three foliar sprays of 0.5% $ZnSO_4$ at 70th, 90th, and 110th days after sowing or soil application of $ZnSO_4$ @ 50 kg ha^{-1} and boron @10 kg ha^{-1} together will increase the number of flowers plant^{-1}, pollen quantity and pollen viability in cotton (TCB 209 of *G. barbedense*) and in male parent of intra specific cotton hybrid (AICCIP, 2004).

***Halogen seed treatment*:** The halogen treatment (seeds treated with chlorine based halogen mixture @ 3 g kg^{-1} containing dehydrated $CaOCl_2$, dehydrated $CaCO_3$ and finely powdered arappu (*Albizzea amara*) leaf powder mixed in 5:3:2 ratio and packed in 700 gauge polythene bags, heat sealed and kept for 5 days) to cotton seeds may increase germination, root and shoot length of seedling, dry matter accumulation in seedling followed by seedling vigour. A reduction in electrical conductivity of seed leachate, a vital indicator of cell membrane may be observed. The observation on field emergence highlighted the efficacy of halogen seed treatment tested over 18 genotypes.

***Polymer and pesticide coating of seeds*:** Seed coating with the polymer (‘Polykote’- Acrylic Polyvinyl Alcohol Copolymer, a water soluble polymer having total solids-25%, pH - 5.5 to 6.0, specific gravity -1.05) @ 5 ml kg^{-1} was found optimum and this helped to improve germination under laboratory condition and no reduction in the field establishment.

***Inoculation of seed with microbes*:** Microbial inoculation through effective Rhizobia or phosphate solubilizing bacteria is effective on many aspects (BNF, phosphate solubilization etc.). It is also discussed elsewhere.

***Increased seed production and seed viability etc*:** Many simple technologies are available for e,g. detopping of cotton at 120 days and spraying of ethrel @ 450 g a.i. acre^{-1} at 160 days after sowing was exhibited beneficial effects of reduced plant height, increased number of bolls, boll weight, seed cotton yield and seed yield. The seeds produced were having 92 to 99 % viability. In the parental seed crop soaking of female parental seeds in succinic acid @ 0.2 % for six hours before sowing and later foliar application of boron @ 0.1 % on 60th, $MgSO_4$ @1 % on 75th or boron @ 0.1 % on 60th, 75th and 90th DAS found to be good for seed setting and production of high quality hybrid seed. A significant improvement in field emergence of up to 4–7% can be observed due to soaking of seed in succinic acid @ 0.2% solution for 6 hours followed by drying under shade to bring it to the original moisture content before sowing (AICCIP, 2004).

***Seed storage*:** Simple coating of seeds with polymer @ 5 ml kg^{-1} or polymer + carbendazim or polymer + carbendazim + imidacloprid or chlothianidine or thiamethoxam either alone or in combination prolonged the seed viability and quality up to sixteen months, conductivity of seed leachate, free sugars and seed infection may be observed. Cotton seeds treated with chlorine (5 g kg^{-1}) and iodine (3 g kg^{-1}) formulation extended the viability and vigour potential and reduced the pathogenic seed infection in seven cotton genotypes, stored under ambient condition for one, two, three and four years.

3. Planting windows

Time of planting being the most critical non-monetary input, is highly influenced in an agro-climatic region since yield formation because of delayed planting would not be realized fully by other agro-techniques. Delayed planting invariably reduces the yields, whereas planting early in the season may also not be advantageous, as the crop does not receive favorable environment at various phonological stages. Therefore, management of planting time plays a crucial role in achieving optimum yields of the crop with optimum use of scarce resources, better management of adverse situations/ pest and diseases and optimum use of seasonal precipitation.

Optimum planting time is a function of growth dynamics, moisture need and heat unit that varies with the growing conditions (irrigated/rainfed) for example, sowing of dry land crops following onset of monsoon, dry seeding in rainfed areas of Maharastra, Madhya Pradesh and Gujarat in India before onset of monsoon have yielded dividends through increased yield and quality (Rajendran and Jain, 2004). Advancing planting time either through dry seeding or through raising seedlings in nursery or polyethylene bags and transplanting these seedlings at 3-4 weeks with the onset of rain or by crow bar method under Akola, Maharashtra has also increased yield by 15-35% (AICCIP, 2004). Similarly, bidirectional sowing is helpful in many crops including cereals.

On quality front also, delayed planting usually lowered fibre quality in cotton (micronaire values, Porter *et al.,* 1996). Moreover, high incidence of pink bollworm and sucking pests especially jassids are associated with late sown condition (Rajendran and Jain, 2004). In north, staggered planting continued for 2 months due to water shortage leads to completion of 1-2 more generations by the pests leading to crop loss. Similarly, in south zone of India, high incidence of pink boll worm was observed in both early and late sown cotton crop (Dhawan *et al.,* 2004).

4. Biofertilizes

Biofertilizers, viz. *Azotobacter* and *Azospirillum* play a useful role in reducing cost of cultivation by way of increasing fertilizer use efficiency especially that of nitrogen. Seed inoculation with *Azotobacter* has resulted in saving of fertilizer to the tune of 20 kg N ha^{-1}. In cotton-chickpea sequential crop at Rahuri (India), maximum yield was realized in the combination of FYM @ 5 t ha^{-1}, GM (*Sesbania* sp.*)* buried *in situ*, *Azotobacter, Azospirillum* and seed treatment with PSB; followed by that of FYM @ 5 t ha^{-1} and *Sesbania* buried *in situ* (AICCIP, 2008). Usually, *Azospirillum* @ 3 packets (600 g) ha^{-1} and 2 kg *Azospirillum* ha^{-1} mixed with 25 kg FYM and 25 kg soil and applied on the seed line saves 25% N besides increasing the yield (CICR, 1997). Similarly, significantly higher tuber yield of potato in north-western Himalayas was recorded when vermicompost, PSB and *Azotobactor* biofertilizers were applied in combination, followed by application of vermicompost + PSB only and the physio-chemical properties of the soil were also improved with the combined application of these biofertilizers applied in conjunction (Choudhary *et al*., 2010).

5. Intercropping

The main advantages of intercropping are in reducing the risk of total crop failure, and in product diversification e.g. food crops are often mixed with cash crops to ensure both subsistence and disposable income. Evidence also suggests that microclimate in an intercropping systems, surrounding the lower crop is more conducive to plant growth than in a sole crop, and that an intercrop is more efficient at using resources such as light and water. Cereals and legumes are mixed because of BNF and dietary reasons. Farmers intercrop sorghum with cowpeas, pumpkins, cucumbers and watermelon to provide nutritional and livelihood security in Zimbabwe (Chivasa *et al*., 2000). This has the added advantage of reducing pests' attack through reduced apparency of crops in a mixed stand.

Yield advantages through intercropping are well documented (Rao and Mathuva, 2000). Maize intercropped with pigeonpea in Kenya yielded 24% more over sole maize and was 49% more profitable. Intercropping of two rows of mungbean with maize in uniform rows under 1:2 row ratio in central plain zone of Uttar Pradesh, India proved most productive, advantageous and biologically efficient system with the highest maize-equivalent yield (5314 kg ha^{-1}), production efficiency (168%), benefit: cost ratio (1.72), land equivalent ratio (1.91), weed control efficiency (44.6%) and energy productivity (361 g MJ^{-1}), followed by maize + urdbean with same planting pattern (Tripathi *et al*., 2009 and Tripathi *et al*., 2010b). Similarly, winter maize planted with potato appeared to be bilologically the most efficient and economically viable system giving the highest maize grain yield (22%), production efficiency (276%), land equivalent ratio (2.14), area-time equivalent ratio (1.91) and net realization (315%), followed by maize + pea intercropping system than sole cropping of maize (Tripathi *et al*., 2010a). In an interesting variation, sequential intercropping of rose with potato, maize and cowpea greatly increased the LER and provided large economic gains (Yaseen *et al*., 2001). Similarly, positive effects on soil fertility improvement are also observed. It is estimated that leaf abscission during the growth of pigeonpea intercrop was equivalent to 10-40 kg N ha^{-1} and the root system of the legume may also recycle N from the deper layer and build up of sub-surface NO_3 even at 1-3 m is observed (Graves *et al*., 2004). Moreover, N transfer from arrow-leaf clover to rye grass, direct transfer of N from mixed stand of legume to non-legume during the growing season is possible. Thus, soybean, pigeonpea, groundnut, bean and cowpea are promising grain legumes of South Africa for both food provision and fertility enhencement. Thus, grain legume intercrops often increase the resource use efficiency and stabilize yields of the main crop under optimal plant growing conditions (Balsubramanian *et al*., 1996). However, yield stability under adverse conditions may be more important to many farmers than high productivity under optimum condition. Thus, through careful integration of crops, livestock and trees, the long-term sustainability of the system seems possible.

6. Composting

If the soil is to continue to provide the nourishment needed by crop plants, it must be kept in good condition and its natural nutrients replaced. Artificial, chemical fertizers can't do this because they only supply the short-term needs of the plant but do not feed the soil itself-so feeding of the next crop with more, expensive chemicals becomes necessary. By returning natural wastes and animal manure to the soil, as well as feeding the plants, the farmer can also improve the structure of the soil so that it retains water more effectively. A very effective way of using vegetable wastes in this way is by making it into compost. This is made up of plant and animal residues, which have been broken down by bacteria. Since this is a natural process, compost is very easy and inexpensive to make and is an effective and long-lasting way of improving soil and crop quality. If the process is well-managed, the heat produced as the materials rot will often be enough to kill weed seeds and plant diseases. Freedom Gardens uses the trench composting system but there are many different ways of making compost, all of which have been devised to suit various waste materials and the climates in which they are used. It is essential in all methods, however, to have a mixture of different kinds of materials – some young, living material and some older, dead material - so that the final product has a good balance of natural carbon and nitrogen which the crop plants will need. The results from an experiment conducted in Guyana revealed that combination of organic fertilizers (vermicompost + vermiwash) had significance influence on the nutritional value of okra fruits and biochemical characteristics of soil with marked improvement in micronutrient contents compared to inorganic fertilizer (Ansari and Kumar, 2010).

7. Soil conservation

In order to retain the soil and avoid its loss through erosion by the wind or rain, soil conservation helps to grow plants, which bind it together. Banana plants and vetiver grass are used for this at farmers' gardens. Both of these have the additional benefit of providing either a food crop (banana) or a useful farm material in the form of mulch or animal feed (vetiver). Vetiver grass has been used very successfully in more than 50 countries for soil and water conservation. When fully established, a vetiver hedge will hold back surface water and trap any soil which is already being carried in the water.

Other methods of retaining soil include building terraces on steep slopes or using the gentler contours of the land to make flat areas in which rain water will rest until it has soaked naturally into the ground instead of running swiftly down the slope, carrying away the surface soil.

8. Agroforestry and alley cropping

This technology has great potential for soil fertility improvement, fruit tree domestication, sustainable tree seed systems and fodder for livestock production. Various leguminous tree species are used in agroforestry in Malawi. An example is *Gliricidia sepium* which is a preferred species of tree used in this technology. Its leaves are rich in nitrogen (N), sometimes up to 4% of the leaf biomass. A second quality is that the leaves provide organic matter, which help to improve the soil's fertility and structure. Research at Makoka and application of the technology at nearby farms has shown that *Gliricidia* intercropping helps to rejuvenate the soil and to improve soil fertility, without the use of fertiliser. Results indicate a definite increase in the maize crop yield using the simultaneous intercropping with *Gliricidia*. The farmer can obtain yields of up to 3-4 tonnes.

Alley cropping is an example of agroforestry practice developed in the 1970s at the IITA (International Institute of Tropical Agriculture) in Nigeria, in which hedgerows of trees and shrubs are established and annual crops are cultivated in the alleys between the hedgerows. The hedgerows are prunned before planting the crop and periodically while it is growing to prevent shading, with the prunings being applied to the soil as GM and/or mulch. Between cropping cycles, hedgerows are usually allowed to grow without pruning. Alley cropping is taken as the combination of farmers' accumulated traditional wisdom with the fficiency of modern science. In Nigeria, prunings from *Leucaena leucocephala* increased grain yields from 1.9 to 3.5 t ha^{-1} (Kang *et al*., 1981), while a *Gliricidia sepium* alley system on degraded soil increased maize grain yields from 1.74 to 2.42 t ha^{-1} (Graves *et al*., 2004). Besides shifts in weed composition (e.g. more broadleaf weeds under *Leucaena* and *dactyladenia barter)*, some control of weeds (*Gliricidia* controlling *Imperata cylindrica* biomass*)* was also achieved in alley crops if the hedgerow canopy was maintained during the fallow period.

Alley cropping does seem to have favourable effects on soil physical and chemical properties through the addition of large amounts of organic matter from the prunings. Levels of SOC, total N, extractable P, Mg, K and pH increased under alley cropping under a range of conditions (Graves *at al*., 2004). Similarly, lower BD, penetration resistance, higher infiltration rate and pore volume fraction was found under *Leucaena* alley crops in Zambia, which is ascribed to increasee levels of SOM. Thus, there is an evidence that this helps in nutrient recycling. It is successful in reducing runoff and soil erosion on sloping land. In Nigeria, reduction in soil erosion to the extent of 73 and 83% weremade under alley cropping of *Glyricidia* and *Leucaena*. Thus, alley cropping must become more versatile, capable of meeting a range of needs in response to changes in the socio-economic circumstances of the farmer including the gender considerations.

9. Alternative farming systems

There are four established approaches to alternative farming in the U.S. A common thread in all four schools is an emphasis on biological systems to supply fertility and pest control rather than chemical inputs.

a. Organic farming is the most widely recognized alternative farming system. Modern organic farming evolved as an alternative to chemical agriculture in the 1940s, largely in response to the publications of J.I. Rodale in the U.S., Lady Eve Balfour in England, and Sir Albert Howard in India. In 1980, U.S.D.A. released a landmark report titled 'Report and Recommendations on Organic Farming (USDA, 1980)' in which organic farming was defined as "a production system which avoids or largely excludes the use of synthetically compounded fertilizers, pesticides, growth regulators, and livestock feed additives". To the maximum extent feasible, organic farming systems rely upon crop rotations, crop residues, animal manures, legumes, green manures, off-farm organic wastes, mechanical cultivation, mineral-bearing rocks, and aspects of biological pest control to maintain soil productivity and tilth, to supply plant nutrients, and to control insects, weeds, and other pests (Zeisemer, 2007).

b. Biodynamic farming evolved in Europe in the 1920s following lectures on agriculture by the Austrian anthroposophist Rudolf Steiner. Biodynamic farming parallels organic farming in many ways but places greater emphasis on the integration of animals to create a closed nutrient cycle, effect of crop planting dates in relation to the calendar, and awareness of spiritual forces in nature.

A unique feature of this system is the use of eight specific preparations derived from cow manure, silica, and herbal extracts to treat compost piles, soils, and crops (Reaganold, 1993).

c. Nature farming was developed in Japan in the 1930s by Mokichi Okada, who later formed the Mokichi Okada Association (MOA). Nature farming parallels organic farming in many ways but includes special emphasis on soil health through composts rather than organic fertilizers, when possible. Kyusei nature farming, a branch group, emphasizes use of microbial preparations in addition to traditional nature farming. Nature farming is most active in the Pacific rim, including California and Hawaii.

d. In addition to these methods-based approaches to sustainable farming, regenerative agriculture is widely recognized in the U.S. and abroad. Regenerative agriculture became the preferred term of the Rodale Institute in the late 1970s and 80s under the direction of Robert Rodale. Regenerative agriculture builds on nature's own inherent capacity to cope with pests, enhance soil fertility, and increase productivity. It implies a continuing ability to recreate the resources that the system requires. In practice, regenerative agriculture uses low-input and organic farming systems as a framework to achieve these goals.

10. Cover crops and green manures

A cover crop is a crop grown to provide soil cover to prevent erosion by wind and water, regardless of whether it is later incorporated.Green manures involves essentially the incorporation of a crop while it is still mainly green into the soil for the purpose of soil improvement. These crops are generally annual, biennial or perennial plants grown in a pure or mixed stand during all or part of the year, as such can be seen as a special case of intercropping. Besides covering the ground, legume also fix N (BNF) and may also help suppress weeds and reduce insects and pests and diseases. Catch crops are again cover crops that have been planted specifically to reduce losses of nutrients by leaching following a main crop. Sometimes cover crops are buried *in situ* (or brought from outside) to act as a mulch.

Another concern with the use of GM in flooded system such as rice agriculture, which is receiving increased attention, is its influence on methane emissions into the atmosphere and subsequent contribution to global warming (Mathews *et al.*, 2000).

Mulching with *Panicum maximum* may not be useful for rainy season upland rice since the plant remain greener into maturity and are subject to more fungal attack. Instead mulching is advantageous to corn when severe drought stress occurs. However, LIT showed a definite positive effect of mulching (*Panicum maximumi*-a grass mulch and *Pueraria phaseoloides* legume mulch- Kudzu mulch) on crop yields (Wade, 1978; Table 1). The treatments did not receive the fertilizers or lime. Bare plots received 120kg N ha^{-1} crop^{-1}, 70 kg K$_2$O ha^{-1} crop^{-1}, 4 t lime ha^{-1} year^{-1} and 45 kg P$_2$O$_5$ ha^{-1} year^{-1} and gave the maximum yield. Crop mulched with *Panicum* produced 64% of maximum yield while that of *Pueraria* produced 80% without inorganic inputs. The former decreased maximum topsoil temperature by an avg. 2^{0}C on dry, hot afternoons. It also raised available soil moisture, prevented surface crusting and reduced weed growth. Although both had no effect on soil chemical properties, but because of higher yields than in the bare unfertilized plots, they promoted greater nutrient uptake by the crops.

Table 1. Overall effect of mulching and green manure incorporations in unutilized treatments relative to the yields attained in the bare, fertilized treatments in five consecutive crops[a,b]

Treatments (all unfertilized)	First crop, soybeans (1.10)	Second crop, cowpeas (0.74)	Third crop, corn (4.17)	Fourth crop, peanuts (2.88)	Fifth crop, rice (2.74)	Mean effect
Bare soil	9	59	33	55	64	44
Grass mulch	14	103	57	52	94	64
Grass incorporated	33	90	70	69	94	71
Kudzu mulch	-	97	72	63	90	80
Kudzu incorporated	109	77	88	79	99	90

[a] Source:NCSU (1976) and Wade (1978)

[b] Numbers in paremtheses are the actual yields in tonnes per hectare, which were made equal to 100.

Values in Table are percent yields in bare, high-NPKL treatments, Yurimaguas, 1974-75.

Further, it appears that kudzu green manure (not *in situ*) can be substituted for fertilizers to obtain moderate yields of continuous crops as this is essentially a trade-off between nutrients applied as fertilizers and the use of green manures. Similarly, intercropping GM crops in cereals could be better alternative because no time is wasted in growing such a crop. Sunhemp is sown @ 15 kg ha^{-1} on the reverse side of the ridge where cotton is planted and buried at 45 DAS (5 t ha^{-1} biomass) in the furrow coinciding with intercultural and earthing up operation. The ridge is formed along the cotton rows and the crop is irrigated. Combined application of GM, cotton residues and FYM in moderate quantities produced highest kapas yield over individual treatments alone (Praharaj *et al.*, 2006). *In situ* application of crop wastes/residues was also found beneficial for crop growth, development and productivity in cotton (Praharaj *et al.*, 2010).

11. Biomass transfer techniques

In most cases this has involved the use of naturally occuring biomass (tree or grass material), and rarely biomass that has been specifically planted for that purpose (Graves *et al.*, 2004). Recently, it is focussed on transfer of biomass from deliberately planted "biomass banks" of species such as *Tithonia diversifolia, Gliricidia sepium, Calliandra calothyrsus,* L. *leucocephala* as a means of providing *nutrients* for crop growth, *organic materials* for physical improvement of soil. The use of so called "cut-and –carry grasses" is another technique where biomass is harvested and transported to provide fodder to animals (Stur *et al*., 2002). The major advantge over alley cropping is that direct competition between the main crop and that used to supply the biomass is minimized, if not eliminated together.

The evidence so far suggests that biomass transfer techniques can help to increase soil fertility and sustain or increase crop yields (27% yield increase in maize by *Glyricidia* and 55% in rice by *Tephrosia* (Graves *et al*., 2004). Even addition of N and P through application of *Tithonia diversifolia* (mexican sunflower) biomass has increased yield more than the use of equivalent amount of mineral N and P (Jama *et al*., 2000). This has been further attributed to addition of K, Ca and Mg through the biomass added which might ameliorate deficiencies of these nutrients in the soil in addition to improvement in soil physical characteristics. In addition to providing nutrients, *Tithonia* has been shown to reduce P sorption and increase soil microbial biomass (Jama *et al*., 2000). Thus, biomass addition techniques should be used as a component of an INM systrem involving some external supplies of inorganic nutrients.

The disadvantages of biomass transfer is low level of farmers' adoption (as additional land etc are required) and long time-lag for improvement in soil fertility. However, there is a greater adoption of biomass transfer technique where there is some immediate benefit (milk, meat, drought power etc) to be obtained by the farmer e.g. cut-and-carry grasses as animal fodder. Therefore, processing plant biomass through animlas first to gain immediate benefits or using the biomass directly to improve soil fertility is the determining factor of whether biomass banks are adopted by the farmers or not.

12. Compost and animal manure

Compost is the aerobic, thermophilic decomposition of organic wastes to a relatively stable humus. Although the process of decomposition occurs naturally, yet the aim should be to control the condition for faster decomposition. The biophysical conditions that are required for effective composting are generally those that are required by the micro-organism at various stages of the composting process i.e., good moisture level, moderate temperature, mixed quality organic matter and a fairly neutral pH range.

Composting is not a new technique for the improvement of soil fertility and structure, and the farmers have been aware of its impact on crop yield, soil structure and fertility, crop growth and vigour (Graves *et al*., 2004). Another major benefit noted is the reduced need for the capital inputs, although some capital may be necessary for farmers to adopt the technology (Slingerland and Stork, 2000). However, the major problem associated with the use of compost is the high labour requirements that can be solved to some extent with use of modern tools and technical knowledge/technology.

The beneficial effects of animal manures on crop yields, residual benefits on following years and nutrient cycling is well documented (Graves *et al*., 2004). The benefits is also more related to improvments in physical charcateristics rather that the provision of nutrients, especially in the quantities that farmers can supply to the soil. Thus, if manure is to be extensively used to enhance soil fertility, it will need to be culturally acceptable to farmers, which is most likely to occur where livestock are an integral part of the farming system already. This is more likely to be in areas where population pressure is higher, labour availability is higher and land is scarce, such as Nepal (Graves *et al*., 2004). Thus, as with other LIA techniques, the use of manure should be seen as a component in an INM system and the importance of INM is well known.

13. Improved fallows

Shifting cultivation has traditionally alternated periods of crop production with periods of fallow in order to restore soil fertility and suppress weeds under subsistence agriculture. An 'accelerated fallow' is where specific fast-growing leguminous or non-legumnious trees, shrubs, legumes and other plants are used to improve soil fertility faster that would occur otherwise. An 'enriched fallow' is where trees and shrubs of ecoomic value are planted into the fallow so that the farmer can derive some income from them while land is regenerating (Garrity and Lai, 2000). In practice, where land is not scarce, farmers may find it more practical to improve soil fertility and structure through natural or improved fallow. Therefore, perhaps the main advantage of accelerated fallow and enriched fallow systems is that they are modifications of an existing system, requiring only minor changes to existing farmer practice.

14. Permaculture

Permaculture is a contraction of "permanent agriculture" and was coined by Bill Mollison, an Australian forest ecologist, in 1978. Permaculture is about designing ecological human habitats and food production systems. It is a land use and community building movement which strives for the harmonious integration of human dwellings, climate, annual and perennial plants, animals, soils, and water into stable, productive communities. A central theme in permaculture is the design of ecological landscapes that produce food. Emphasis is placed on multi-use plants, cultural practices such as sheet mulching and trellising, and the integration of animals to recycle nutrients and graze weeds. Permaculture can be applied to create productive ecosystems from the human- use standpoint or to help degraded ecosystems recover health and wildness. Permaculture can be applied in any ecosystem, no matter how degraded it may be. Thus, to the extent that permaculture is not a production system, per se, but rather a land use planning philosophy, it is not limited to a specific method of production. Thus, practically any site-specific ecological farming system is amenable to permaculture.

15. Irrigation scheduling

Irrigation water as a controllable factor influences significantly on productivity sustainability. Many a time a supplementary irrigation at appropriate stage may quite enough to realize the significant percent of potential yield. It also influences both status and pests' spread as pest incidence is usually low in the crop irrigated at optimum rate and time. Excess soil available moisture leads to excess vegetative growth and often attacked by white fly and other pests and may also shift the balance between the vegetative and reproductive growth, thus delaying maturity, reducing yield and GOT and promote boll shading, disease and insect damage (Surulivelu, 2006). Moreover, infection continues since excessive growth of plants hamper effective and uniform spray of the control chemical. Study under south zone reveals irrigation beyond September 30th and N beyond 100 kg ha^{-1} encourages whitefly buildup and diapausing population of pink boll worm without raising cotton yield (Jayaswal and Sundaramurthy, 1992).

16. Bio-rationals in IRM/IPM

Use of bio-rationals, viz. neem product and bio-pesticides (parasites, predators and pathogens) will help to sustain the natural enemies as long as possible especially during the early fruiting period. Neem seed kernel @ 5% or neem products at 0.5% or pongamia oil emulsion at 0.2% act as a strong oviposition deterrent and these can be used when there is low egg load of *H. armigera*. One or two release of *Trichogramma chilonis* @ 1.5 lakhs ha^{-1} help to reduce *helicoverpa (*bollworms) incidence to a greater extent it it is synchronized on the egg population of *H. armigera* and other bollworms. Spray application of HaNPV @ 500 LE ha^{-1} will help to reduce the infestation of early instar larvae of *H. armigera.* Release of *Chrysoperla carnea* @ 0.5 lakh ha^{-1} will also help to check the sucking pests and to some extent, bollworms also.

A summary of important low-input technologies (LITs), their potentials and limitations are also given in Table 2.

Table 2. A summary showing the low-input technologies (LITs), their potentials and limitations

S.No.	LITs	Potential	Limitations
1.	Conservation tillage	Very high potential worldwide with proven benefits	Very few limitations except under zero tillage.
2.	Seed treatments and seed production technologies	Have very wide potentials in seed production.These include seed hardening/ priming, seed pelleting, flower production in male parents and versatile seed treatments (halogen, polymer coating, microbial inoculation) under both rainfed and irrigated conditions.	Limitations are minimum and can be taken care of. However, the major constraint is the quality of chemical/biological materials used for seed treatments etc.
3.	Planting windows	Time of planting is the most critical non-monetary input right from placing of seed in the field.	No limitations except under certain conditions where delayed/early planting is made.Some pests problem do occur under such conditions enabling poor plant product quality.
4.	Biofertilizers, viz. *Azotobacter* and *Azospirillum*	Reduces cost and increases in fertilizer use efficiency.	Here again, the quality of biological materials available plays a cruciasl role for fixation output and efficiency.
5.	Intercropping	Reducing the risk of total crop failure, and product/income diversification.	Requirements of resources for an individual intercrops is the key for long-term sustainability and soil health.
6.	Composting	It is an inexpensive, effective and long-lasting way of improving soil health and crop quality.	May not be possible due to constraints associated with moisture, climate and infrastructure.
7.	Soil conservation	Retention of soil and avoidance of its loss through erosion processes.	No proven disadvantages.
8.	Agroforestry and alley cropping	Soil fertility improvement, fruit tree domestication, sustainable tree seed systems and livestock.	Alley cropping must be more versatile, capable of meeting a range of needs vis-a-vis socio-economics.
9.	Alternative farming systems	Organic farming and biodynamic farming are better if adopted appropriately.	No possible limitations except adoption gaps.
10.	Biomass transfer Technologies	Biomass banks for soil fertility restoration and yield enhancement	Low level of farmers' adoption and long time-lag for improvement in soil fertility.
11.	Compost and animal manure	Proven benefits are many. Should be seen as a component in integrated farming/ cropping systems.	High cost and constraints in its availability.
12.	Improved fallows	Some income from these while land is regenerating.	Requiring minor yet appropriate changes in the existing practice.
13.	Permaculture	Land use and community building movement for harmonious integration.	Permaculture is not a production system *per se*, but rather a land use planning philosophy since it is not a specific method of production.
14.	Irrigation scheduling	Many proven advantages.	It should be converted to non-menetary input for higher adoption.
15.	Bio-rationals	Use of bio-rationals, viz. neem product and bio-pesticides (parasites, predators and pathogens) will sustain the natural enemies.	Sometimes they are slow in action, which hinders its adoption on large scale.

CONCLUSIONS

Agriculture has to find ways to feed the world while being environmentally, socially and economically sustainable. Yet, it is increasingly clear that the path that agriculture has been on is not sustainable, nor can it feed the world without destroying the planet. For any agricultural system to be sustainable, regardless of whether it is classified as LIA or HIA, inputs must not be less than outputs- if they are, then mining of existing stocks occurs, and the system must deteriorate in time. Where there is constant removal of nutrients in crops harvested for human consumption and these are not returned to the system, then no such system can be sustainable without some further input from outside. No group of technologies whether based on organic or inorganic sources of nutrients can contravene this basic law of mass conservation. Thus, the future, therefore, must surely lie in the integration of the two approaches, using LIA technologies when organic sources of nutrients are available, but also being prepared to supplement these with external supplies if necessary and when it is economic to do so. Taking a system perspective is essential and the real issue is whether the supplies of these inputs are sustainable at higher scales, and whether there is sufficient labour and capital in the system for their transport and handling. Thus, there is little point in increasing crop yields *per se* if these canont be feasibly scaled up or maintained at that level for long. Therefore, future research to improve LIA should focus more on developing interventions to meet farmer realities, such as increased food security, improved cash generation, reduced risk, and enhanced quality of life.

Thus, low-input agriculture has emerged as an important issue as its popularity is motivated and supported by growing evidence of environmental and health risks from agrichemicals. The trading environment is witnessing changes due to (a) increased consumer concerns for the health and safety and (b) increased consumer consciousness regarding the environment and social issues of production and marketing. This review has shown the feasibility and adoption strategies of the low-input approach and low-input technological components.Therefore, the first priority of LIA has been to define and develop all the necessary components for a particular low-input farming system.

RESEARCH NEEDS

This review also identifies some major knowledge gaps presented as under:

1. Characterization of the critical soil test level for nutrient deficiency or toxicity in the principal soil types for plant species and varierties used in LIA. It includes also secondary and micronutrients.
2. Characterization of main varieties of promising ecotypes of main crops for their tolerance to soil-water constraints in terms of quantitative critical levels. Foan an example, for legume, plants inoculated with appropriate strain should be used.
3. Development of means for interpretating land evaluation systems in terms of requirements for low-input technology.
4. Studies on the dynamics of soil-water properties (chemical, physical and microbiological) in major cropping/farming system situations including those of sub-soil fertility/properties.
5. Various components of low-input technological management in relation to plant (species/varieties), nutrient, water and rhizobium/micorhiza etc should be integrated (put together as a package) for a specific farming system.
6. Development of novel methods for improving input use efficiency under LIA such as N fertilization in non-legumese, K fertilization to all crops and water use by all crops.

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