Lessons from Nonchemical Input Treatments Based on Scientific and Traditional Knowledge in a Long-term Experiment

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Abstract

A long-term experiment continuing at ICRISAT, Patancheru, India, since June 1999, on a rainfed Vertisol compares four crop-husbandry systems to determine the yield levels a cash-poor (but knowledge-rich) farmer could harvest by using locally available, low-cost technologies and resources. Two of the four systems are low-cost (LC1 and LC2 or T1, T2). The third (Conventional Agriculture – CA or T3) is a control that receives input types and levels as recommended by research institutions for a given crop in the region, and the fourth (CA+biomass, or T4) receives all chemical inputs as applied to CA and biomass as applied to low-cost system 2 (T2). The LC systems depend on inputs based on scientific and traditional knowledge (TK) of farmers, where crop residues, farm-waste, compost, Gliricidia *lopping, bacterial inoculants, and herbal extracts are used as nutrients and as biopesticides to manage pests. The TK items involved are cow urine, wash of composted foliage of neem and* Gliricidia*, and a curd recipe. The experiment will complete 6 years in March/April 2005. Combined yield of rainy and postrainy seasons within a year (annual productivity) of the two low-cost systems was generally similar to that of the conventional system. In some cases, high yield in the low-cost systems was due to less pest damage and not due to high crop growth. At least 5–11 t ha^{-1} of biomass was produced in-situ by the different crop-husbandry systems, which was returned to the soil in the low-cost systems. The implications of such observations are presented along with data.*

Introduction

Soil and water to a crop-production system are like flesh and blood to the human body for keeping its vital functions going. Developments in agrotechnologies, particularly in the area of soil fertility through addition of chemical fertilizers and application of synthetic pesticides for managing pests, have contributed greatly to crop production in the last five decades. These were important ingredients of the Green Revolution (GR) experienced in some developing countries, such as India and Pakistan, which transformed these countries from food-importing to self-sufficient ones. But agronomic practices and other ingredients of the GR (e.g., machinery for tillage and extracting water from deep layers of the earth) added substantially to the cost of production. Some of these inputs (e.g., chemical fertilizers) were developed after sound research and convenience for use, particularly when compared with managing natural resources, such as cattle dung (after its conversion to manure) as a major input for crop production. Interactions

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with farmers revealed some social fallouts of the ingredients of the GR. Use of chemical fertilizers, as opposed to farmyard manure, for example, is viewed as a status symbol in rural settings in India and may be true in some other countries. At times, it was reported to result in [overuse and] improper use, particularly of chemical fertilizers and pesticides. However, crop-production practices, such as use of biomass (including crop residues) as surface mulch, compost, and green manures; inclusion of legumes in cropping systems; intercropping; and biocontrol of insect pests and diseases also help enhance yields and sustain soil fertility and health (Delate and Camardella 2004, Fettell and Gill 1995, Mäder et al. 2002, Reganold et al. 1993, van Keulen 1995, Willey 1990). Appropriate use of these practices (biological approaches) has also been reported to enhance activity of soil microorganisms and macrofauna (Fatondji 2002, Kukreja et al. 1991). Almost all soil-inhabiting macrofauna, such as earthworms, and most microorganisms use plant biomass as their food or source of energy. They play an important role in releasing all necessary nutrients for plant growth through biological transformations in soil, thus making them available for crop production, and most probably in a balanced form.

In this paper, the authors share their 5-year experience from a long-term experiment initiated in June 1999 on a rainfed Vertisol, using four different crop-husbandry systems. The major objective of the study is to [learn] **ascertain** if yield comparable to conventional agriculture can be achieved by using the locally available**,** low-cost materials indicated above. Two of the four systems use these low-cost materials, involving scientific and traditional knowledge (TK) items for managing and protecting crops. Data and information on yield, plant growth, damage by diseases and insect pests, available for the first 5 years, are discussed here. Details of the data on soil properties are published elsewhere (Rupela et al. 2005), but their highlights are discussed here. Information on materials and methods (Table 1) and concept (Figure 1) of the experiment has been given in both the papers. Traditional knowledge items and information, such as "earthworms are friends of farmers," articulated with science, concepts have been emphasized where employed in the studies.

Defining concept of sustainable crop production

Use of biological approaches was visualized as an integrated soil-plant-animal system for harvesting sustainable and high yields (Fig. 1)**,** where legume and nonlegume crops can be grown as intercrops without tillage. Biomass can remain as surface mulch. Weeds (not all are harmful) known to promote crop growth can be selectively promoted to grow under the main crop. Other external inputs, where relevant and required, can be applied to soil or crop. Most such inputs visualized are herbs or soil microorganisms previously identified as having beneficial traits; e.g., biological nitrogen fixation, plant growth promotion, antagonism to disease-causing microorganisms (fungi, nematodes), and pathogens of insect pests. These can be applied to soil at sowing (along with seeds) or sprayed on plants. Cattle are an important component of this system. Only the economic yield (e.g., grain) is expected to go out of the system, while stover is returned as surface mulch. Wherever stover is needed for economic use (e.g., as cattle feed), an equivalent quantity of uneconomic biomass--e.g., foliage or loppings of shrubs or trees grown on field bunds--is returned to the field. It is hypothesized that the system will function like a single entity, where all functions in soil, plant, and soil-plant interface are highly interactive for producing high yield. The system is visualized as relevant to small and marginal farmers in developing countries of the semi-arid tropics. A census in India suggested that 78% of all farmers in 1991 were either marginal (holdings <0.4 ha) or small (holdings of 0.4–1.4 ha). The concept assumes that a practicing farmer has, or can acquire, the knowledge of the different features of the sustainable agriculture indicated here, besides having the necessary family labor (a major asset with most marginal farmers).

The long-term experiment

To examine if yields comparable to those from conventional agriculture (CA) will be possible by using the inputs suggested above, an experiment with four systems of crop husbandry (T1 to T4), according to the details given in Table 1, was initiated at ICRISAT farm, Patancheru (India) in June 1999. The four treatments were as follows: Low-cost system 1 (LC1 or T1) received microorganisms and herbal extracts to protect crops from pests and disease; legumes and compost as sources of nutrients; beneficial microorganisms and macrofauna as active partners to enhance crop growth; rice-straw (presently burnt in at least four Asian countries-- Sidhu et al. 1988) as a surface mulch; and no tillage. Low-cost system 2 (LC2 or T2) received farm waste (organic materials such as crop stubble, tree leaves, and feed waste after cattle have eaten) as surface mulch. The other inputs were the same as in T1. Conventional agriculture (CA or T3) received tillage, chemical fertilizers, compost, loppings of *Gliricidia,* and chemical pesticides as recommended for a given crop by research institutes in the region. Conventional agriculture with biomass (CA+biomass or T4) received tillage and the same quality and quantity of biomass as added to the treatment T2 above. The other inputs were the same as in T3.

The experiment is on a fully rainfed deep Vertisol of pH (in top 15 cm) ranging 8.0 to 8.2 and electrical conductivity 0.16 to 0.22 dSm^{-1}. The annual mean rainfall at Patancheru is 783 mm, which allows two crops a year as intercrops or sequential crops. To be certain of production, these crops have to be sown as intercrops during the rainy season, in June or July. Different crops were grown in each year of the experiment, but were the same across all four treatments. Annual rainfall (mm) in the different years was 580 (in 1999, year 1), 1473 (in 2000, year 2), 688 (in 2001, year 3), 628 (in 2002, year 4), 926 (in 2003, year 5), and 610 (in 2004, year 6).

It may be noted that the experiment was essentially an unreplicated study conducted on large plots (0.2 ha for each treatment, total area 1.02 ha). Studies on managing crop residues and insect pests through microorganisms were considered inappropriate on small plots, due to risk of cross-contamination across the four treatments. Therefore the biggest plot sizes possible within the 1.02-ha area available for the experiment were chosen. However, the area was split into 30 plots each of 9 m x 7.5 m in six strips of 37.5 m x 9 m, each having 5 plots. Such an approach is not new (Guldin and Heath 2001, Guthery 1987) and seems an acceptable norm under the experiment circumstances. The study provides some insights into potential effects of the treatments and should be interpreted accordingly. Observations were made from each of the 30 plots particularly for yield. For observations requiring expensive inputs, such as for soil properties, samples, though drawn from all the 30 plots, were pooled (depthwise, where relevant and stripwise) before analysis. Thus there were 30 data points (or internal replications) for parameters such as yield and six data points (internal replications) for some other parameters such as soil properties.

Two of the four treatments (T1 and T2) in this ongoing experiment receive plant biomass as their major source of crop nutrients and depend on herbal extracts and agriculturally beneficial microorganisms as soil inoculants and as biopesticides. Both the treatments (T1 and T2) are with minimum tillage, where only sowing is done by bullock-drawn implements. The concept of sustainable agriculture depicted above (Fig. 1) applies only to these two of the four treatments, occasionally referred to as "low-cost treatments." For the first 3 years, T1 received 10 t ha^{-1} rice-straw and T2 received farm waste (crop stubble, leftovers after cattle have eaten, and leaves of trees) soon after sowing, as surface mulch. The treatment T3 received 80 kg N and 20 kg P ha^{-1} per year, tillage (land preparation, sowing, and interculture) with bullock-drawn tropicultor, chemical pesticides for managing pests, manual weeding, and 1.8 t ha^{-1} compost in alternate years. The T4 plots received all the same inputs as the T3, plus 10 t ha^{-1} biomass in a year (for the first 3 years only), similar to the T2 plots. From year 4, no biomass from external sources was added to any of the four treatments, except compost (at rates given in Table 1). But, the noneconomic crop residues (e.g., leaves and stem – stover) were retained in three of the four treatments (T1, T2, and T4). Loppings of *Gliricidia sepium* grown on bunds were added twice a year from year 5 during the crop growth period to all the four treatment plots in equal quantities.

As depicted in Figure 1, foliage of *Gliricidia* and neem were composted in separate tanks and their wash (50 L ha^{-1}, at least five times in the season) was sprayed on plants in T1 and T2 during the crop growth period. The wash from neem and that from *Gliricidia* was noted to have siderophore-producing bacteria. Such organisms have been reported to promote plant growth (Kloepper et al. 1980). Bacteria (EB35 and CDB35) identified to degrade cellulose, solubilize P, promote plant growth, and suppress disease-causing fungi (Hameeda Bee, Research Scholar, ICRISAT, unpublished studies) were applied as sand-coat inoculants and sown along with seeds in T1 and T2. A bacterium (*Bacillus subtilis* strain BCB 19) and a fungus (*Metarrhizium anisopliae*), both research products of ICRISAT, with ability to kill young larvae of *Helicoverpa armigera,* a major pest of cotton and legumes, under laboratory conditions were used as biopesticides in T1 and T2, along with other low-cost materials of traditional knowledge. Cattle dung and earthworms were important ingredients of composting in the tank in Figure 1.

Crop growth and yield

Six different crops (soybean, pigeonpea, maize, sorghum, cowpea and cotton) grown in the last 6 years emerged well (including from about 10 cm thick biomass applied as surface mulch in T1 and T2). Rainfall in year 1 (crop season June 1999 to April 2000) was the lowest of the [first] 6 years of the experiment. Moisture deficiency adversely affected the yield of short-duration pigeonpea (cultivar ICPL 88039), followed by chickpea (ICCV 2) in the postrainy season (Oct-Feb). Pigeonpea yielded only 0.23 t ha^{-1} (in T2) to 0.69 t ha^{-1} (in T3). Emergence of chickpea in the postrainy season was very poor due to low soil moisture and was essentially a failure. It also highlighted the importance of intercrops (a traditional knowledge), in a rainfed system. It was therefore decided to take intercrops in future, to ensure a reasonable productivity and water-use efficiency.

A sorghum/pigeonpea intercrop was taken in year 2. Sorghum (cv ICSV 745) in the low-cost systems T1 and T2 yielded 14-34% less than in the conventional system T3 (3.29 t ha^{-1}). In the postrainy season, however, the yield of pigoenpea (cv ICPL 87119) (Table 2), in T1 and T2 was at least twice that of the conventional T3 (1.45 t ha^{-1}) About 25% of the total yield in T1 and T2 was from the second flush, an added feature of the no-till system, because there was no urgency to vacate the field for tillage while the soil was still moist. Yield of cowpea (cv C 151) in the cowpea/cotton intercrop in year 3 was only 0.14 in T2 due to extensive aphid damage and was 0.28 t ha^{-1} in T1, which was at par with the T3 (0.29 t ha^{-1}). Yield of cotton (cv NHH 44) in both the low-cost systems was at least twice that of T3 (0.44 t ha^{-1}, Table 3). The high yield was not due to good crop growth (as indicated by stover mass of T1 and T2, which was about half that of T3), but due to less damage by *Helicoverpa* (Table 4).

A maize/pigeonpea intercrop was taken in the 2002/03 cropping season (year 4). Surprisingly, the maximum yield of maize (cv Deccan 105) came from one of the two low-cost systems (T1)-- 3.80 t ha^{-1}, which was 33% higher than that of the conventional T3 (3.04 t ha^{-1}). Besides the accumulated effect of the nutrients added to T1 and T2 as plant biomass, foliar spray by wash of *Gliricidia*-compost and neem -compost may be an important contributor to yield, as the washes had 1.2×10^4 to 4.5×10^6 mL^{-1} of plant growth-promoting (siderophore-producing) bacteria. Growth of the accompanying pigeonpea (cv ICPL 87119) was greatly suppressed by good growth of maize in T1 and T2 and yielded marginally lower (8-9%) than T3. The pigeonpea cultivar in year 4 was the same as in year 2 (ICPL 87119), when up to 3 t ha^{-1} grain was harvested from comparison sorghum. This was probably due to higher competition for crop nutrients by the maize in year 4 than by sorghum in year 2.

Year 5 had cowpea/cotton intercrop. Yield of the short-duration cowpea (cv COVU 702) was generally low, but 35 to 53% higher in the low-cost systems than in the conventional agriculture (0.34 t ha^{-1}). Yield of cotton (cv TCH 44), however, was marginally lower (7–3%) in T1 and T2 than in T3 (1.42 t ha^{-1}). Insect damage to cotton in all the four crop-husbandry systems may have been low or was effectively managed by the different pesticides. Year 6 (ongoing) was again a maize/pigeonpea intercrop. Maize (cv PMH 2201 or Rana) was harvested in September /October 2004. Its yield in the low-cost systems was only 3 to 7% lower than that in control (5.27 t ha^{-1}), again suggesting the scope for harvesting a good yield of a nonlegume crop by using biological resources. The role of wash of neem and *Gliricidia* in enhancing plant growth, particularly of nonlegume crops, was considered important and needs detailed studies.

Two (T1 and T2) of the four crop-husbandry systems were solely dependent on biomass and other biological resources (agriculturally beneficial microorganisms) for crop production and protection. In the first 5 years of the experiment, biomass of 5 t ha^{-1} in cotton/cowpea to over 11 t ha^{-1} in sorghum/ pigeonpea was harvested (Table 3). This does not take into account the naturally fallen leaves from the different crops, such as cowpea, cotton, pigeonpea. These crops dropped 2.2 t ha^{-1} of leaf in cotton to 3.1 t ha^{-1} of leaf dry matter in pigeonpea. The harvested stover or sticks of crops and fallen leaves contributed significantly to the soil fertility in the low-cost systems (T1 and T2). This aspect, along with nutrient balance across all the four systems, is discussed in Rupela et al. (2005). Maize in year 4 and year 6 grew vigorously (mean stover yield 4.9 to 7.0 t ha^{-1}) and stunted the companion crop of pigeonpea. Sorghum in year 2 produced 4.6 t ha^{-1} (mean of all four systems) biomass which was only 6% lower than the stover yield of maize in year 4. Pigeonpea growth and yield was highest in year 2, and a total of 6.6 t ha^{-1} stover and 2.3 t ha^{-1} grain was harvested, with total stover yield (rainy + postrainy) of over 11 t ha^{-1} with rainfall of 1473 mm, which was the maximum received in the 6 years of the experiment.

Cowpea (cv C 151) taken as intercrop with cotton in year 3, grew vigorously (in a 1 row cotton–4 rows cowpea arrangement), and by 55 days after sowing (DAS) threatened to smother the cotton. Therefore, one row of cowpea on each side of the cotton row was removed yielding over 4 t ha^{-1} dry biomass. Climbing growth of C 151 cowpea and asynchronous maturity of pods yielded another 1.5 t ha^{-1} stover (fallen leaves not accounted). Cotton produced 5.1 t ha^{-1} sticks in the conventional system (T3), with 688 mm rain which was about twice that in T1 and T2. Cotton stick yield in T3 in year 5 was about 1 t ha^{-1} lower than that in year 3, despite higher rainfall (926 mm). This may be due to a change of cotton cultivar to Sri Tulasi in year 5. The high biomass yield of cowpea in year 3 (mean 4.9 t ha^{-1}) compared with year 5 (mean 2.1 t ha^{-1}) could be another reason. Grain yield of the two cowpea varieties in both the years was low, ranging from 0.28 to 0.39 t ha^{-1} in year 3 to 0.34 to 0.52 t ha^{-1} in year 5. But the vigorously growing variety of cowpea in year 3 grown in a 1:4 row arrangement in intercrop contributed substantially to biomass. A cultivar with vigorous growth along with synchronous pod maturity may give high yields of both grain and biomass, and we are looking for such a variety. High biomass (4.5 t ha^{-1} per annum) was harvested from year 5 onward through branches of *Gliricidia* grown on field bunds (408 m long**,** 1.5 m wide) separating the four treatments and on the boundary of the 1.02 ha field and was another important source of biomass.

Incidence of diseases and insect pests

While planning the experiment, there were apprehensions on the scope for growing crops without tilling a Vertisol with large quantity of biomass as surface mulch. Incidence of soilborne diseases (collar rot caused by *Sclerotium rolfsii*, in particular) and stem borer (*Chilo partellus*) of sorghum, in the presence of high biomass in T1, T2, and T4**,** was expected to be high. All these fears were proved wrong, at least for the first 6 years. Incidence of collar rot, caused by *Sclerotium rolfsii,* expected to be aggravated in the presence of biomass, was virtually nonexistent (at <5% mortality of seedlings) in T1 and T2 and was lower than that in T3 (up to 10% mortality of seedlings). T1 and T2 received microorganisms with ability to suppress disease-causing fungi at sowing but the disease incidence was low even in T4, which did not receive any such bacteria. Similarly, incidence of stem borer was low in sorghum and maize in all the 3 years when these were grown.

In the first 6 years, the problem of insect pests was more important than diseases. *Helicoverpa armigera,* the major pest of pigeonpea and cotton, was managed well in the first 5 years, as indicated by the yield levels (Table 2) and lower incidence of borer damage in T1 and T2 than in T4 (Table 4). Management of this insect**-**pests involved the use of six items as a protocol: two microorganisms (*Bacillus subtilis*, strain BCB 19, and *Metarrhizium anisopliae*); wash of neem and *Gliricidia* compost, which were expected to promote plant growth and protect crops from insect pests (based on laboratory studies); and cow urine and curd recipes (Amin 2002), known to help in pest management, as per farmer's traditional knowledge. There were several occasions of threats to the different crops from different insect pests, particularly in T1 and T2, which were solely dependent on biopesticides. These situations forced us to look for nonchemical answers to the different insectpests. Some recipes were taken from the magazine Honey Bee (Prof. Anil Gupta, IIM, Vastrapur, Ahmedabad, 380015, India) and used after preliminary evaluation. Aphids were a big problem of cowpea in year 3 and eventually managed by spraying 1% solution of a branded washing powder. The delay in finding a solution inflicted some damage in T1 and substantial damage in T2 in year 3. Aphids were virtually absent in T3 and T4. In subsequent years, aphids were never a threat even when noticed (in large numbers) on cotton, maize, and pigeonpea, apparently due to a timely spray of 1% soap. Due to occasional browning of leaf margins noted on cotton leaves, 0.8% soap solution was a safer option. The other insects managed with 0.8% soap were mealy bugs and cowbugs. Systematic study on managing these pests may establish use of 0.8% soap solution powder as an environmentally safe and low-cost option for farmers. Population of natural enemies of insect pests was generally higher in the low-cost systems than the other two (Table 5).

In the absence of chemical pesticides in T1 and T2, pod-sucking bugs (*Nezara viridula* in particular) in pigeonpea and cotton, red cotton bug in cotton, and *Exelastis* in pigeonpea adversely affected yield in different years. The extent of damage by these pests was not possible to assess. Eco-friendly solutions to these problems are urgently needed.

Lessons learned

The following lessons were learnt during the course of the experiment that will complete 6 years in March/April 2005. Some of these items warrant further research and therefore the results need to be interpreted with caution.

- Several crops (maize, soybean, pigeonpea, sorghum, cotton) can emerge out of thick layers of biomass placed on soil surface after their sowing.
- Soilborne diseases such as *Sclerotium rolfsii* did not cause substantial seedling damage despite the large quantity of biomass applied as surface mulch.
- Annual productivity of land did not decrease with the use of the locally available low-cost materials (plant biomass as nutrients and biopesticides as crop protectants), except in year 1. This suggested that the different nutrients (e.g., N and P) bound in the plant biomass were mineralized due to microbial activity and became available in sufficient quantity from year 2 onward.
- A large quantity of biomass could be produced in-situ. With the biomass resources produced in-situ, only 1.7t ha^{-1} of compost was added from external sources for the productivity reported here. Soil priming with 10 t ha^{-1} of external biomass for the first 3 years was, however, important and perhaps the reason for high yield (comparable with conventional agriculture), with low-cost inputs right from year 2.
- A satisfactory crop protection was possible by using microbial biopesticides, herbal extracts, and some TK items. Their use enhanced population of natural enemies of insect pests such as spiders and Coccinellids. Scientific articulation of these TK items is warranted.
- Over years, soil health and fertility improved substantially with the use of the biological approaches described here.

Rainwater runoff

Measureable rainwater runoff was noted in 2 of the 6 years (years 2 and 3). The facility to measure rainwater runoff was installed at the end of year 2 and therefore the data in year 2 were missed. Even in year 3, runoff facility in T1 was installed only at the end of the year. In years 4 to 6, there was no runoff event, although the rainfall in year 5 was greater (926 mm) than that in year 3 (688 mm). Three notable runoff events (at 42, 52, and 108 DAS) occurred in year 3,each more than 65 mm rain. Maximum runoff in all the three events was noted in the treatment with conventional agriculture (T3), followed by that in T2. Least runoff water was recorded in T4 (Figure 2), at 108 DAS, while it was absent in the previous two events (42 and 52 DAS). This strongly suggests the value of the biomass on soil surface in T1 and T2 in conserving rainwater, despite conservation tillage. Apparently, the biomass on the soil surface would have prevented raindrops falling directly on the soil surface.

Soil properties

Detailed information on soil properties is given in Rupela et al. (2005). It was apparent that despite T1 and T2 yields being comparable to T3 (conventional agriculture) without chemical fertilizers, the concentration of soil nutrients in these treatments, in a given year was higher than that in T3. The total N increased from 11 to 34% and total P from 11 to 16% in T1 and T2 over that in T3 in years 3 and 4. Soil biological properties, assessed (using soil samples from 0–0 and 10–20 cm soil profile) only once, close to crop harvest in year 5, strongly suggested that the soil in T1 and T2 treatments was microbiologically more active than that in T3. More information on soil properties is in Rupela et al. (2005).

Soil temperature

Soil temperature was measured at three points - surface, 5 cm and 10 cm depths using Hobo Data Logger (Onset Computer Corp., USA) in the crop season 2001/02. Maximum temperature at soil surface (bare soil) in general, was about 10˚C greater than the maximum air temperature on a given day. As expected, temperature reduced with depth. During summer, the maximum temperature at 5 cm depth in the T3 plots (conventional agriculture) was generally close to or even higher than that of air while at 10cm depth it was lower than air, while in the T2 plots (receiving biomass at surface mulch) the maximum temperature was generally lower at both the depths than that of air. The temperature dynamics at the three-point on a hot summer day (30 April 2002) is in Figure 3. Maximum air temperature on that day was 44.9˚C and minimum 27.5˚C. The maximum temperature was 60.5˚C at surface, 49.1˚C at 5 cm depth and 40.7˚C at 10 cm depth (Fig 3) of soil in the T3 plot. The maximum soil temperature at all the 3 points in T2 was lower than the relevant point in T3, by 4.2˚C at soil surface, by 7.3˚C at 5 cm and by 6.5˚C at 10 cm depths. This strongly suggested a more congenial soil temperature regime for microbial activity in T2 than that in T3. This has implications both for beneficial (e.g. plant growth promoting rhizosphere bacteria) as well as harmful microorganisms (e.g. soil-borne disease-causing fungi) particularly when the summer plowing (widely believed as beneficial) is absent and is an interesting researchable topic.

Conclusion

Scientific knowledge gained in the past three decades and available in the published literature was used to develop a concept of sustainable agriculture (Figure 1) for harvesting high yields using locally available biological resources. The concept or model was evaluated through a long-term field experiment. Yield of different crops in the low-cost systems (T1 and T2), the annual productivity (rainy + postrainy season yields), in particular, was comparable to that in the conventional system (T3). The low-cost systems used in the long-term experiment would probably require more labor than the conventional system, but is argued to be relevant to small and marginal farmers (78%, per 1991 census) of India, who may have readier access to labor (family members) than to cash. Some features of the low-cost systems described here, such as biopesticides for protecting crops, are also relevant to the conventional agricultural system. The low-cost systems as a whole have a great potential of employment generation in rural areas. Multilocation evaluation of the low-cost systems is strongly recommended.

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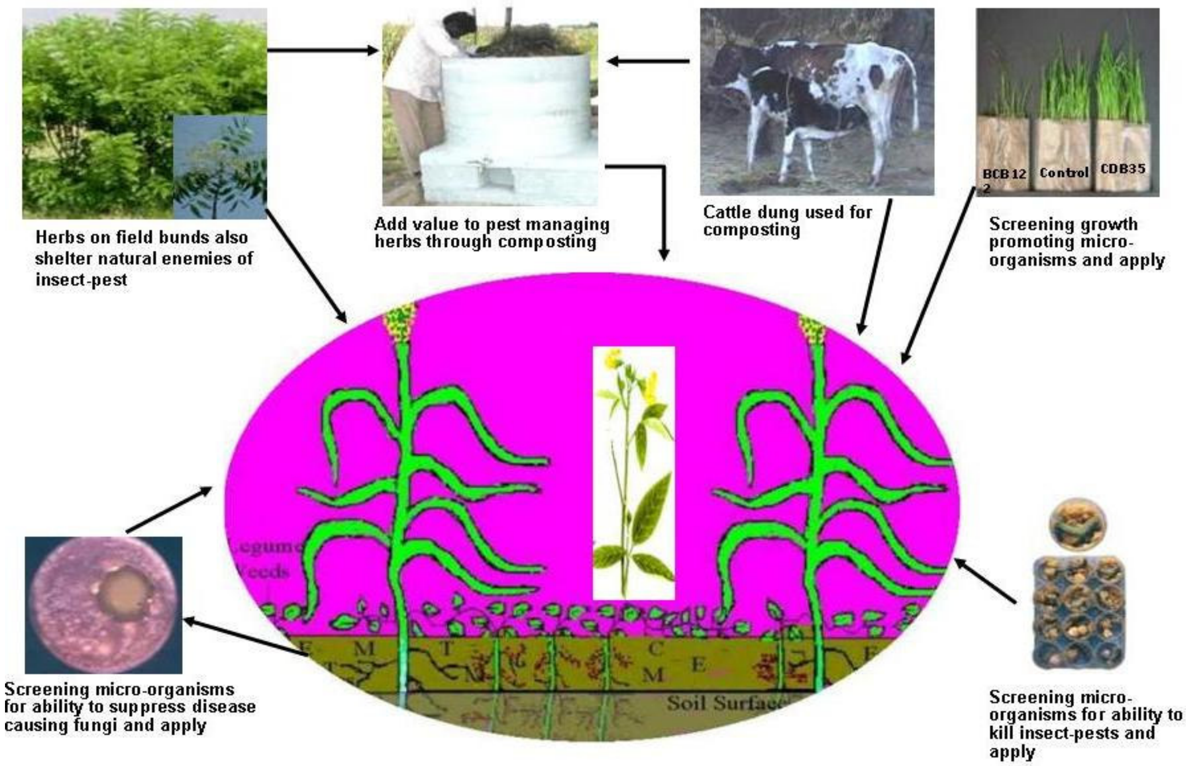

Figure 1. Schematic of an agricultural system for high yield on a rainfed Vertisol, with hypothesized relationships among earthworms (E), termites (T), collembolans (C), and beneficial microorganisms (M) in the soil system underpinning sustainable agricultural production.

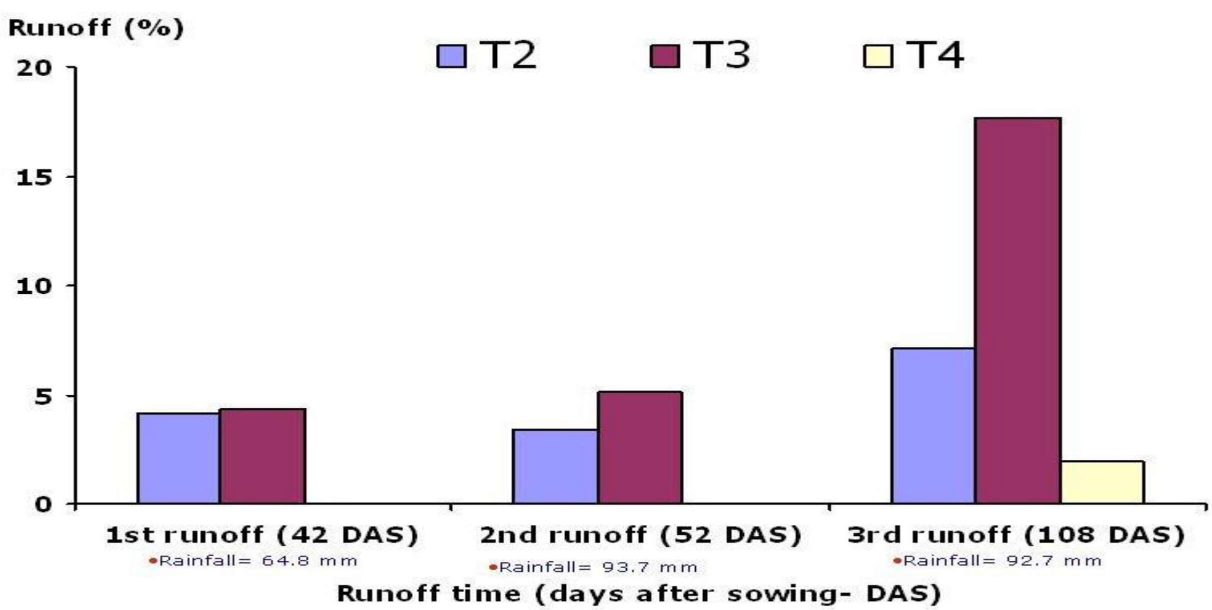

Figure 2. Rainwater runoff (% of rainfall received) recorded in year 3 in three different crop-husbandry systems in a long-germ field experiment, ICRISAT, Patancheru, India. T2= low-cost system 2: T3= conventional agriculture: T4= T3 + biomass.

Table 1. Treatments used in a continuing long-term experiment[1] at ICRISAT, Patancheru, India, June 1999 to April 2004.

	Treatment[2]			
Inputs	T1: Low-cost system I (LC1), based on rice straw	T2: Low-cost system II (LC2), based on farm waste	T3: Conventional agriculture	T4: Conventional agriculture + biomass
Land preparation	0	0	Conventional (bullock-drawn)	Conventional (bullock-drawn)
Interculture	0	0	Conventional(bullock-drawn)	Conventional(bullock-drawn)
Sowing	Bullock-drawn drill	Bullock-drawn drill	Bullock-drawn drill	Bullock-drawn drill
Microbial inoculants	Added	Added	None	None
Biomass (first 3 years only)	10 t ha^{-1} $year^{-1}$, rice straw as surface mulch	10 t ha^{-1} $year^{-1}$, farm waste, stubble, hedgerow foliage as surface mulch	None	10 t ha^{-1} farm waste, stubble, hedgerow foliage, incorporated
Compost	1.5-1.7 t ha^{-1} annually	1.5-1.7 t ha^{-1} annually	1.8 t ha^{-1} Year 2, 4, 6	1.8 t ha^{-1} Year 2, 4, 6
Fertilizer nitrogen (N)	None	None	80 kg N ha^{-1} 2 split doses annually	80 kg N ha^{-1} 2 split doses annually
Fertilizer phosphorus (P)	20 kg ha^{-1} as rock phosphate	20 kg ha^{-1} as rock phosphate	20 kg ha^{-1} as SSP[3]	20 kg ha^{-1} as SSP
Plant protection	Biopesticides	Biopesticides	Chemical pesticides	Chemical pesticides
Weeding	Manual, weeds retained	Manual, weeds retained	Manual, weeds discarded	Manual, weeds discarded

1. Crops grown in all plots: Year 1 (June 1999– May 2000) pigeonpea-chickpea sequential, Year 2 (June 2000–May 2001) sorghum/pigeonpea intercrop, Year 3 (June 2001–May 2002) cowpea/cotton intercrop, Year 4 (June 2002–May 2003) maize/pigeonpea intercrop, Year 5 (June 2003–May 2004) cowpea/cotton intercrop, Year 6 (June 2004– May 2005) maize/pigeonpea intercrop.
2. T1= low-cost system 1; T2= low-cost system 2; T3= conventional agriculture; T4= conventional agriculture + biomass (as added to T2).
3. SSP= Single super phosphate

Table 2. Yield (t ha^{-1}) of crops in different years in the field experiment with four different crop husbandry field BW3, ICRISAT, Patancheru.

	Year 2		Year 3		Year 4		Year 5		Year 6
Treatments	Rainy (S)	Postrainy (P)	Rainy (C)	Postrainy(Co)	Rainy (M)	Postrainy (P)	Rainy (C)	Postrainy(Co)	Rainy (M)
LC 1	2.82(0.140)	3.05(0.116)	0.28(0.020)	0.95 (0.018)	3.80(0.048)	0.65(0.019)	0.46(0.016)	1.32(0.039)	5.12 (0.158)
LC 2	2.16(0.113)	2.87(0.106)	0.14(0.017)*	0.90 (0.030)	3.30(0.095)	0.66(0.018)	0.52(0.015)	1.24(0.038)	4.89 (0.167)
MA	3.29(0.066)	1.45(0.124)	0.29(0.010)	0.44 (0.020)	3.04(0.055)	0.72(0.022)	0.34(0.017)	1.42(0.035)	5.27 (0.131)
MA+biomass	3.19(0.126)	1.94(0.085)	0.39(0.014)	0.68 (0.025)	3.68(0.081)	0.57(0.015)	0.38(0.015)	1.63(0.036)	6.06 (0.127)
Mean	2.87	2.33	0.27	0.74	3.46	0.65	0.43	1.40	5.34

S= Sorghum, P= Pigeonpea, C= Cowpea, Co= Cotton, M= Maize
*= extensive damage by aphids
Data in parenthesis are ± SEs

Table 3. Stover yield (t ha^{-1}) of crops in different years in the field experiment with four different crop husbandry systems, field BW3, ICRISAT, Patancheru.

	Year 2		Year 3		Year 4		Year 5		Year 6
Treatments	Rainy (S)	Postrainy (P)	Rainy (C)	Postrainy(Co)	Rainy (M)	Postrainy (P)	Rainy (C)	Postrainy(Co)	Rainy (M)
LC 1	4.37(0.165)	7.21(0.339)	5.91(0.624)	2.63 (0.058)	5.26(0.084)	1.70(0.043)	1.92(0.062)	3.83(0.095)	6.14 (0.150)
LC 2	3.74(0.108)	7.41(0.246)	5.79(0.412)	2.43 (0.060)	4.91(0.125)	1.73(0.059)	2.27(0.066)	4.04(0.103)	5.72 (0.190)
MA	5.51(0.135)	5.07(0.347)	5.19(0.456)	5.09 (0.165)	4.24(0.085)	2.04(0.042)	1.76(0.053)	4.32(0.134)	5.75 (0.110)
MA+biomass	4.65(0.176)	6.96(0.283)	6.81(0.421)	5.29 (0.317)	5.18(0.103)	1.90(0.076)	2.59(0.083)	4.38(0.091)	6.99 (0.229)
Mean	4.57	6.66	4.92	3.86	4.9	1.84	2.14	4.14	6.15

S= Sorghum, P= Pigeonpea, C= Cowpea, Co= Cotton, M= Maize
Data in parenthesis are ± SEs

Table 4. Insect pest population and damage in different years

Treatment	2000-01				2001-02		2002-03			2003-04
	Pigeonpea				Cotton		Pigeonpea			Cotton
	No of larvae (plant^{-1})	Seed damage (%)		Total	No of larvae (plant^{-1})	Boll damage (%)	Larvae (plant^{-1})	Pod damage (%)	Seed damage (%)	Boll damage (%)
		Borer	Podfly							
Low cost 1 (T1)	1.1 (0.63)	17 (1.9)	3 (0.8)	25 (2.3)	0.2(0.03)	19 (0.1)	0.7 (0.13)	39 (1.2)	20 (0.6)	24 (0.8)
Low Cost2 (T2)	0.6 (0.17)	15 (1.4)	2 (0.2)	22 (1.1)	0.2 (0.02)	19 (0.1)	0.7 (0.15)	42 (1.8)	23 (1.7)	19 (2.6)
Conventional (T3)	1.2 (0.80)	30 (3.4)	3 (0.6)	37 (3.4)	1.0 (0.11)	46 (1.1)	0.9 (0.22)	53 (2.0)	33 (1.5)	25 (1.9)
T3+Biomas (T4)	0.9 (0.54)	22 (2.2)	2 (0.1)	29 (2.2)	0.8 (0.09)	41 (1.2)	ND	57 (1.9)	35 (1.2)	26 (1.2)

ND= not determined

Table 5. Natural enemies population (numbers per plant or trap) in different years

Treatment	2000-01				2001-02 (Cotton)				
	Coccinellids (plant^{-1})		Spiders (plant^{-1})		Soil dwelling natural enemies / trap			Aireal natural enemies (plant^{-1})	
	Sorghum	Pigeonpea	Sorghum	Pigeonpea	Carabids	Crickets	Blackants	Coccinellids	Spiders
Low cost 1 (T1)	1.5 (0.24)	0.3 (0.04)	0.3 (0.04)	0.02 (0.010)	6.9 (0.02)	13.9 ((0.06)	145 (0.7)	1.58 (0.106)	0.15 (0.034)
Low Cost2 (T2)	ND	ND	ND	ND	11.9 (0.05)	11.1 (0.03)	91 (0.3)	1.23 (0.115)	0.08 (0.027)
Conventional (T3)	0.4 (0.04)	0.1 (0.02)	0.2 (0.09)	0.0 (0.00)	7.1 (0.03)	8.4 (0.03)	80 (0.3)	0.18 (0.033)	0.01 (0.006)
T3+Biomas (T4)	ND	ND	ND	ND	9.3 (0.04)	9.5 (0.03)	90 (0.4)	0.26 (0.045)	0.05 (0.019)

ND = not determine

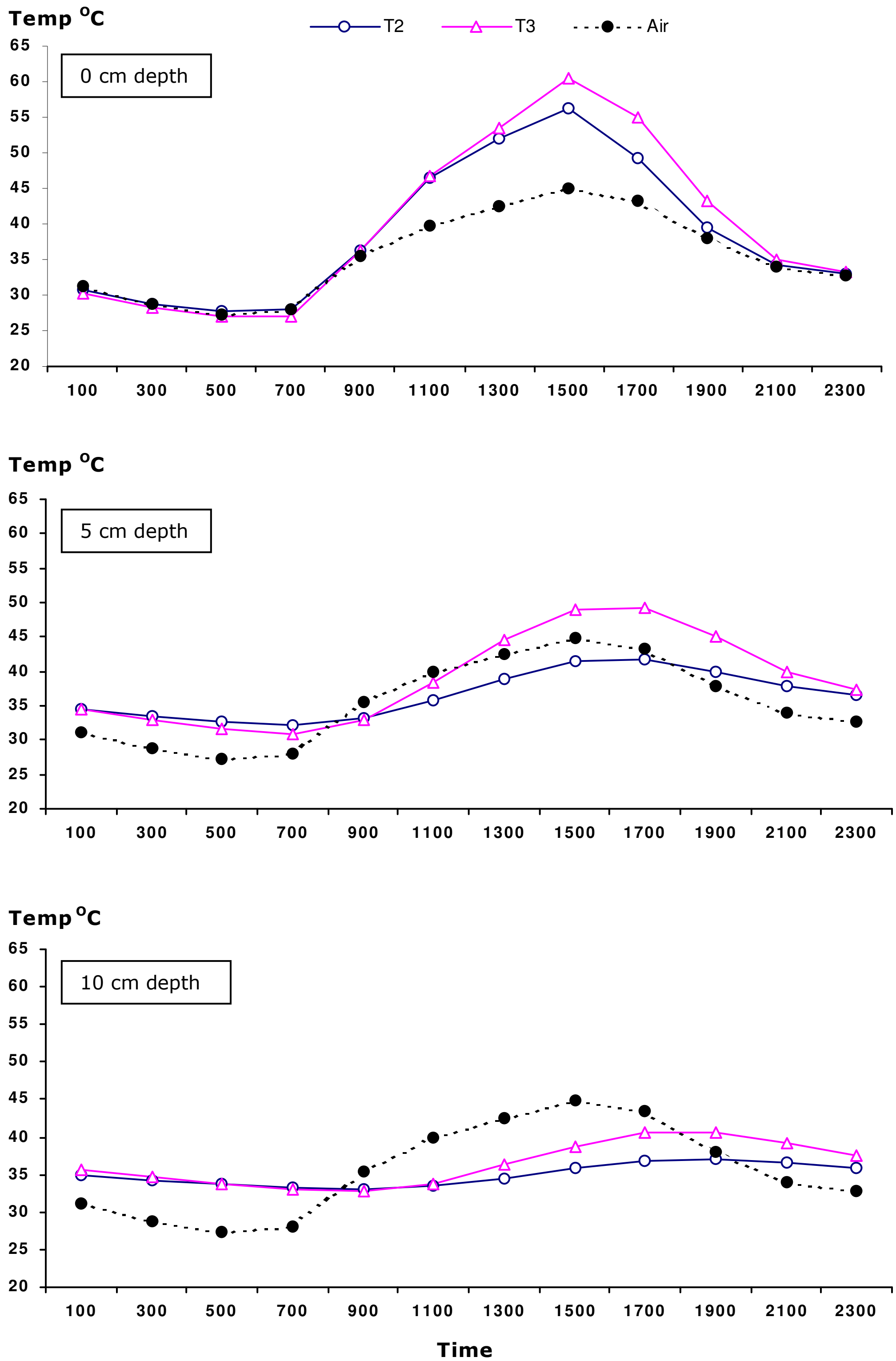

Figure 3. Diurnal changes in soil temperature at different depths on a hot day (30 April 2002), after crops have been harvested, long-term experiment, field BW3, ICRISAT Patancheru, year 2001/02.