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Soil management practices for sustaining soil health in Indi-Gangetic plain of India

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Abstract
The soil sustains most living organisms, being the ultimate source of their mineral nutrients. On croplands, tillage is the most important practice, which can have a major effect on the carbon pool, either negative with conventional plowing or positive, when No-tillage is applied. No-tillage practices claim to reverse historical carbon loss from soils, thereby reducing CO_2 in the atmosphere through storage in soil sinks-a process known as sequestration. Carbon sequestration and an increase in soil organic matter will have a direct positive impact on soil quality and fertility. There will also be major positive effects on the environment, and on the resilience and sustainability of agriculture. Moreover, Attention to NPK is desirable because 89% of Indian soils are low to medium in available N, 80% are low to medium in available P and 50% are low to medium in available K. Therefore, it is essential to apply NPK and other secondary and micronutrients in adequate and balanced amounts. This information can be used by extension and private-sector consultants to promote the use of soil management practices for sustaining soil health that result in increased soil carbon, improving soil quality and productivity in the long term and enhancing profitability of producers.

Keywords: Soil management, soil health, Indi-Gangetic plain, living, agriculture, growth

Introduction
Sustainability is generally related to soil quality, which is defined as, ‘‘the capacity of a specific kind of soil to function, within natural or managed boundaries, to sustain plant and animal productivity, maintain or enhance air and water quality and support human health and habitation’’ (Karlen *et al*., 1997) [4]. The soil’s ability to function as a component of an ecosystem may be degraded, aggraded or sustained as use-dependent properties change in response to land use and management. Therefore, to achieve sustainable higher productivity, efforts must be focused on reversing the trend in natural resource degradation by adopting efficient resource conservation technologies. One of these RCT’s is Conservation tillage. Conservation tillage practices generally result in higher amounts of soil organic matter (OM),reduced erosion, increased infiltration, increased water stable aggregates and greater microbial biomass carbon when compared to conventional tillage systems (Reeves, 1997) [8].
Maintenance of native soil fertility in the intensively cultivated regions of the country is one of the preconditions of maintaining and improving the current crop yield levels. Intensive cropping systems remove substantial quantities of plant nutrients from soil during continued agricultural production round the year. The basic principle of maintaining the fertility status of a soil under high intensity crop production systems is to annually replenish those nutrients that are removed from the field. Indeed this becomes more relevant in the absence of the measures for adequate replenishment of the depleted nutrient pools through the removal of crop residues from agricultural fields (Sanyal 2014) [11].
Conservation agriculture offer a new paradigm for agricultural research and development different from earlier one, which mainly aimed at achieving specific food grains production targets. A shift in paradigm has become a necessity in view of widespread problems of resource degradation, which accompanied past strategies to enhance production with little concern for resource integrity. Integrating concerns of productivity, resource conservation, food quality and environment is now fundamental to sustained productivity growth. Conservation Agriculture (CA) offers an opportunity for arresting and reversing downward spiral of resource degradation, decreasing cultivation costs and making agriculture more resource-use-efficient, competitive and sustainable. ‘Conserving resources-enhancing productivity’ (CREP) has to be new mission.
Food production in India must increase by 2.5 per cent each year to meet the demand of the growing population and to reduce malnutrition. A significant part of it has to come from rice

wheat crop based production systems. This assumes special challenge as the data on rice- wheat yield trends indicate plateauing or progressive productivity decline in Punjab, Haryana, and Western Uttar Pradesh. For future productivity growth to keep pace with the increasing demand, it is necessary to address the problem at various levels. It will be important to make investment in developing appropriate technologies, and enable the farmers to take advantage of these in combination with their own ingenuity and age old wisdom (Naresh *et al*., 2016) [7].

The response of soil chemical fertility to tillage is site-specific and depends on soil type, cropping systems, climate, fertilizer application and management practices. However, in general nutrient availability is related to the effects of conservation agriculture on SOC contents. The needed yield increases, production stability, reduced risks and environmental sustainability can only be achieved through management practices that result in an increased soil quality. The above outlined evidence for the improved soil quality and production sustainability with well implemented conservation agriculture systems is clear, although research remains inconclusive on some points. At the same time, the evidence for the degradation caused by tillage systems is convincing for biological and physical soil quality. Therefore, even though we do not know how to manage functional conservation agriculture systems under all conditions, the underlying principles of conservation agriculture should provide the foundation upon which the development of new practices is based, rather than be considered a parallel option to mainstream research activities that focus on improving the current tillage-based production systems.

1. Laser Land Leveling

Shrinking water resources owing to over exploitation of ground water in Punjab threatens the maintenance of agricultural productivity. As a result, the water table is falling in 90% area of the state. Most of this area falls in the Central part of the state. With the inception of Green revolution in the Sixties, the water table started declining and the area having water table below 30 feet. depth has increased from 3% in 1973 to 90% in 2004. During 1993-2003, the average fall of water table in the Central Punjab was 50cm per annum. However, in some of the areas, the fall of water table is even more than 80- 100 cm per annum. Out of 141 blocks of the state more that 100 blocks are over exploited. To arrest this dangerous trend of ground water exploitation, there is an urgent need to conserve irrigation water through various on-farm water conservation practices. Land Leveling through Laser Leveler is one such proven technology that is highly useful in conservation of irrigation water. Laser land leveling is another water-saving technology, usually appropriate for regions with uneven fields where a considerable amount of irrigation water is lost due to extensive application of flooding method of irrigation. Unevenness of fields reduces input-use efficiency and creates larger biotic and abiotic pressures on crop growth, which ultimately reduce yield potential and add to the cost of production. Laser land leveling (LLL) was first introduced in India in 2001 in western Uttar Pradesh Naresh *et al*., 2013 [6]. Laser land leveling saves farm inputs like water and fertilizers, improves crop stand and encourages uniform germination.

Fig 1: Laser land leveling

Why Laser Leveling

1. Land looks leveled but even then wide topographic variation exists
2. Wide variability in crop yields at field/ village/ block/ district/ regional level
3. For Better distribution of water
4. For Water savings
5. For Improvement in nutrient use efficiencies
6. Option for Precision Farming
7. Higher crop productivity

2. Zero or Reduced Tillage

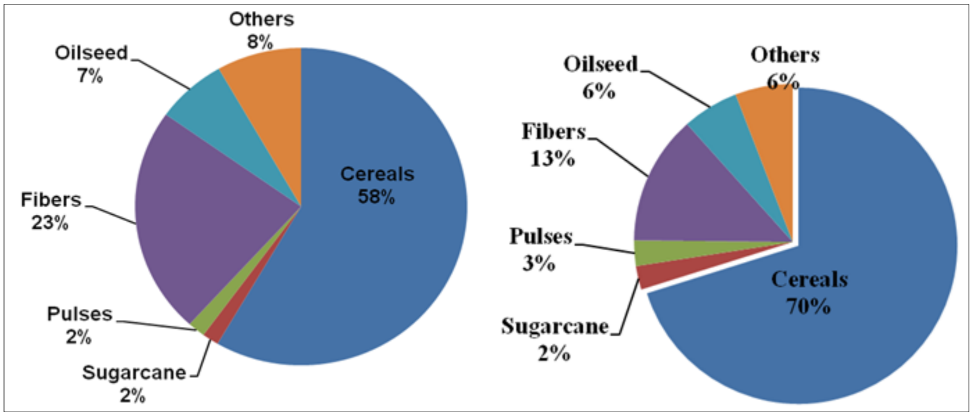

Fig.2: Contribution of various crops in residue generation
Fig.3: Surplus of various crop residues in India (Calculated from MNRE report 2009).

Reduced tillage or conservation tillage is a practice of minimising soil disturbance and allowing crop residue or stubble to remain on the ground instead of being thrown away or incorporated into the soil. Reduced tillage practices may progress from reducing the number of tillage passes to stopping tillage completely (zero tillage). Zero tillage, also known as zero till, no till, direct seeding and direct drilling, has been reported as one of the most successful resource conservation technologies in the Indo-Gangetic Plains. Zero tillage generate substantial environmental and economic benefits around 80 per cent saving in tractor-time, 60-80 per cent in fuel consumption and 20-35 per cent in irrigation water (Mehla *et al*., 2000) [5].

Reducing tillage is important from the viewpoint of environmental-farming for a number of reasons. The cover of crop residue helps prevent soil erosion by water and air, thus conserving valuable top soil. Soil structure improves because heavy machinery (which causes soil compaction) is not used and soil tilth is not tampered with artificially. With earthworms not being routinely disturbed by deep tillage, their numbers increase bringing with them the accompanying benefits of better soil aeration and improved soil fertility. Microbial activity in soil also increases for the same reason. Another important environmental effect of reduced tillage is the reduction in use of fossil fuels on the farm.

3. Trapping of CO_2: Reduction of CO_2 concentration in atmosphere

Biomass can be efficiently utilized as a source of energy and is of interest worldwide because of its environmental advantages. During recent years, there has been an increase in the usage of crop residue for energy production and as substitute for fossil fuels. It also offers an immediate solution for the reduction of CO_2 content in the atmosphere. Mitigation of CO_2 emission from agriculture can be achieved by increasing carbon sequestration in soil through manipulation of soil moisture and temperature, setting aside surplus agricultural land, and restoration of soil carbon on degraded lands. Soil management practices such as reduced tillage, manuring, residue incorporation, improving soil biodiversity, micro aggregation, and mulching can play important roles in sequestering carbon in soil.

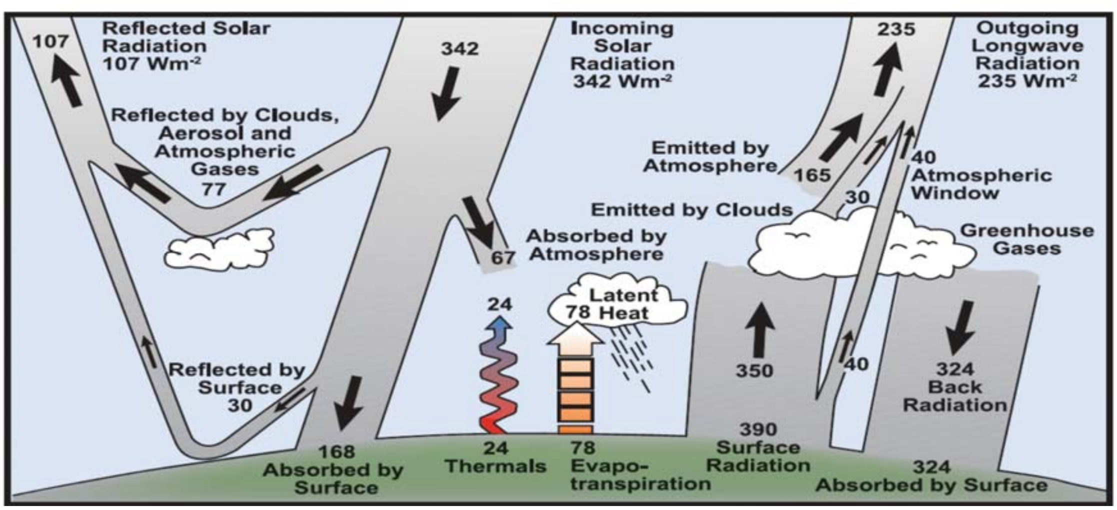

Fig. 4: Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing long wave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapo-transpiration and by long wave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates long wave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).

4. Conservation tillage and conservation agriculture

Since the 1930s, during the following 75 years, members of the farming community have been advocating a move to reduced tillage systems that use less fossil fuel, reduce run-off and erosion of soils and reverse the loss of soil organic matter. The first 50 years was the start of the conservation tillage (CT) movement and, today, a large percentage of agricultural land is cropped using these principles. However, in the book 'No-tillage seeding', Baker *et al.* (2002) [2] explained 'As soon as the modern concept of reduced tillage was recognized, everyone, it seems, invented a new name to describe the process'. The book goes on to list 14 different names for reduced tillage along with rationales for using these names. The book is also an excellent review of the mechanization and equipment needs of no-tillage technologies. Baker *et al*. (2002) [2] defined CT as:

The collective umbrella term commonly given to no-tillage, direct-drilling, minimum-tillage and/or ridge-tillage, to denote that the specific practice has a conservation goal of some nature. Usually, the retention of 30% surface cover by residues characterizes the lower limit of classification for conservation-tillage, but other conservation objectives for the practice include conservation of time, fuel, earthworms, soil water, soil structure and nutrients. Thus residue levels alone do not adequately describe all conservation tillage practices.

This has led to confusion among the agricultural scientists and, more importantly, the farming community. To add to the confusion, the term 'conservation agriculture' has recently been introduced by the Food and Agriculture Organization (see FAO web site), and others, and its goals defined by FAO as follows:

Conservation agriculture (CA) aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. It contributes to environmental conservation as well as to enhanced and sustained agricultural production. It can also be referred to as resource efficient or resource effective agriculture. (FAO)

This obviously encompasses the 'sustainable agricultural production' need that all mankind obviously wishes to achieve. But this term is often not distinguished from CT. The FAO mentions in its CA website that:

Conservation tillage is a set of practices that leave crop residues on the surface which increases water infiltration and reduces erosion. It is a practice used in conventional agriculture to reduce the effects of tillage on soil erosion. However, it still depends on tillage as the structure forming element in the soil. Never the less, conservation tillage practices such as zero tillage practices can be transition steps towards Conservation Agriculture.

5. Conservation Agriculture and Soil Characteristics

Karlen *et al*. (1997) [4] defined soil quality 'the capacity of a specific kind of soil to function, within natural managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation'. Conservation agriculture is claimed to reduce negative impacts of climate change by optimising crop yields and profits while maintaining a balance between agricultural, economic and environmental benefits. Conservation Agriculture reduces or eliminates soil tillage, maintaining soil covered by vegetation or crop residues. This protects the soil from impact of raindrops and increases infiltration, naturally improves the soil structure and fertility, reduces pollution of surface water, promotes carbon sequestration in the soil, and decreases the emission of carbon dioxide. Particularly, Conservation Agriculture greatly reduces soil erosion - over 90% with no-tillage and over 60% with minimum tillage. This ensures good quality ground and surface water bodies due to reduced sediment load, surface runoff, and the consequent reduced off-site transport of pesticides and nutrients. Soil quality can be seen as a conceptual translation of the sustainability concept towards soil.

Table 1: Example of an interpretation framework for soil health indicators under agricultural land uses

Indicator	Ranking		
	Low	**Medium**	**High**
Total organic matter content (organic C %×1.7)	Poor pore structure, hard workability (<1.7%)	friable, but poor workability (1.7-2.6%)	Extremely friable and easy workability (> 2.6%)
Light fraction organic matter	noticeable fine root fragments and weed seeds	mixtures of root and leaf litter fragments	dominated by large leaf Litter fragments.
Organomineral fraction organic matter	deep red red with discolored brown flakes of clay particles	deep red with consistent brown colored clay particles	near pitch-dark organic with mixtures of consistent red mineral flakes
Soil pH	high acid < 5.5	medium acid to neutral 5.5 to 7.0	neutral to basic 7.0 to 8.0
Soil cation exchange capacity	< 10 $mmol_c$ kg^{-1}	10 to 20 $mmol_c$ kg^{-1}	> 20 $mmol_c$ kg^{-1}
Soil aggregate stability	water stable aggregation of 50-60% indicates weak structure highly erodible	water stable aggregation of 60-80% indicates stable structure but still susceptible to erosion	water stable aggregation of >80% indicates highly stable structure and littlesusceptibility to erosion

Table 2: Effect of planting method on soil properties, grain yield, water use and water use efficiency (WUE) of wheat on a sandy loam at Delhi.

Planting method	Bulk density (0–10 cm (mg m^{-3})	Infiltration rate (cm h^{-1})	Weed density at 90 DAS (no. m^{-2})	Grain yield (t ha^{-1})	Water applied (cm)	WUE (kg grain $ha^{-1}cm^{-1}$)
Raised bed–3 rows/ bed	1.35	0.83	65	5.31	21.4	186
Conventional sowing	1.42	0.62	793	5.09	24.9	157
LSD (0.05)	0.05	NS	270	0.37	-	27

***Source*:** Aggarwal & Goswami (2003) [1].

6. Carbon sequestration

Carbon sequestration is the process involved in carbon capture and the long-term storage of atmospheric carbon dioxide. Carbon sequestration involves long-term storage of carbon dioxide or other forms of carbon to mitigate or defer global warming. It has been proposed as a way to slow the atmospheric and marine accumulation of greenhouse gases, which are released by burning fossil fuels. Carbon dioxide

(CO_2) is naturally captured from the atmosphere through biological, chemical, and physical processes. Artificial processes have been devised to produce similar effects, including large-scale, artificial capture and sequestration of industrially produced CO_2 using subsurface saline aquifers, reservoirs, ocean water, aging oil fields, or other carbon sinks. Bernoux *et al*., (2005) [3] defined carbon sequestration "soil carbon sequestration for a specific ecosystem in comparison with a reference one, should be considered as the result (for a given period of time and portion of space) of the net balance of all greenhouse gases, expressed in C-CO_2 equivalent or CO_2 equivalent, computing all emission sources at the soil-plant-atmosphere interface, and also all the indirect fluxes, gasoline, enteric emissions, etc.". Alternatively it may be defined as the storage of soil carbon in a stable form. The conservation of sufficient SOM levels is crucial for the biological, chemical and physical soil functioning in both temperate and tropical ecosystems. Appropriate levels of SOM ensure soil fertility and minimize agricultural impact on the environment through sequestration of carbon (C), reducing erosion and preserving soil biodiversity (Six *et al*., 2002). Soil carbon sequestration can be accomplished by management systems that add high amounts of biomass to the soil, cause minimal soil disturbance, conserve soil and water, improve soil structure, and enhance soil fauna activity. The impact of No-tillage practices on carbon sequestration has been of great interest in recent years.

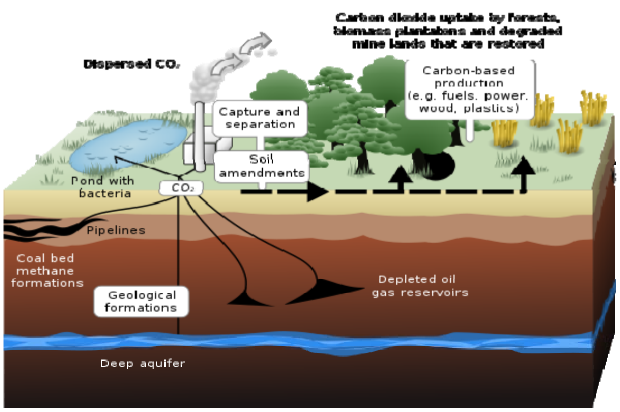

Fig 5. Schematic showing both terrestrial and geological sequestration of carbon dioxide emissions from a coal-fired plant.

7. Conservation Agriculture for offsetting Green House Gases

Rice-wheat systems produce greenhouse gases through both biological processes and burning of fuel by farm machinery. Tillage operations contribute CO_2 through the rapid organic matter decomposition due to exposure of larger surface area to increased oxygen supply.

According to the Intergovernmental Panel on Climate Change (IPCC), agriculture, deforestation, and land-use change together account for about 31% of total global anthropogenic GHG emissions (Smith *et al*., 2007) [9]. Just as agriculture and land use change has significant potential to exacerbate GHG emissions and Climate change, it also holds major potential to mitigate these impacts. Worldwide, the "technical" mitigation potential from agriculture (i.e, the biophysical capacity to mitigate GHG emissions) is estimated to be 5,500-6,000 million tons of CO_2-equivalent per year (Mt CO_2-eq/yr) by 2030 (Smith *et al*., 2007) [9].

Positive changes in agronomic practices like tillage, manuring and irrigation can help reduce greatly the release of greenhouse gases into the atmosphere. Adoption of zero tillage and controlled irrigation can drastically reduce the evolution of CO_2 and N_2O.Reduction in burning of crop residues reduces the generation of CO_2, N_2O and CH_4 to a significant extent. Saving on diesel by reduced tillage and judicious use of water pumps can have a major role to play. Changing to zero tillage would save 98 liters diesel per hectare Naresh *et al*., 2013 [6]. With each liter of diesel generating 2.6 kg, about 3.2 Mt CO_2/annum (about 0.8 MMTCE) can be reduced by zero-tillage in the 12 million ha under rice-wheat systems in the Indo-Gangetic Plains alone. Intermittent irrigation and drainage will further reduce CH_4 emission from rice paddies by 28% to 30% as per the findings at IARI (Delhi) and at Pantnagar. Use of calcium nitrate or urea instead of ammonium sulphate and deep placement instead of surface application of nitrogenous fertilizers can increase its efficiency and plant uptake thereby reducing N_2O emission. Tillage and crop residues retention have a great influence on CH_4 and N_2O emission through the changes of soil properties (e.g., soil porosity, soil temperature and soil moisture, etc.)

8. Balanced fertilization:

Attention to NPK is desirable because 89% of Indian soils are low to medium in available N, 80% are low to medium in available P and 50% are low to medium in available K (Motsara 2002) [12]. Therefore, it is essential to apply NPK and other secondary and micronutrients in adequate and balanced amounts. Focus has been given on N as the main yield-controlling nutrient at the expense of P, K, S and micronutrients (Aulakh and Malhi 2004) [15]. The efficient use of any nutrient depends on the balanced supply of other nutrients, i.e. all nutrients should be available in the right amount and at the right time. The 'Law of the Minimum' emphasizes balanced nutrition (Claupein 1993; Lægrid *et al*. 1999) [14, 13], a good example of which was presented by Johnston *et al*. (2001) [16] and the results are presented in Table 6. Ramachandrappa *et al*., (2013) [17] found that soil nitrogen balance increased with balanced nutrition and there was a net gain of 103.94 kg N/ha in the plots under recommended dose of N and K_2O + lime @ 300 kg/ha + $MgCO_3$ @ 150 kg/ha + borax @ 10 kg/ha. Higher nutrient balance was noticed in recommended dose of N and K_2O + lime @ 300 kg/ha + $MgCO_3$ @ 150 kg/ha + borax @ 10 kg/ha while lowest nutrient balance was noticed in control. The actual nutrient balance in the soil followed the same trend as that of net nutrient balance.

A continuous mismatch between nutrient removal and replenishment, even at the recommended levels of fertilizer application, was evident in the long-term studies on rice-wheat systems in the IGP reveals that in general, additions of N and P in different locations were greater than their removal by the crops. As a result, the apparent balances of N or P were positive (Table 7). On the other hand, negative K balances were noted in all the treatments at all the locations studied. The magnitude of nutrient balance varies with crop production in a given location or among the locations. However, the effect of negative K balance may not be visible on available K content of soil, owing to high K supplying capacity of the illitic minerals-dominated soils of the IGP. As these soils are moderate to high in non-exchangeable K (Sanyal *et al*. 2009b) [18] and contribution of this pool to the crop uptake is often greater than the available pool, the available K content may not be related to the decline in productivity, caused by the mining of K by the crop uptake

(Tiwari and Nigam 1985) [20]. However, continued excessive depletion of K from the interlayer space of the illitic clays may lead to an irreversible structural collapse of these minerals, thereby severely restricting the release of K from such micaceous minerals (Sarkar *et al*. 2013) [19]. This would go a long way to impair the long-term soil fertility in respect of soil K, and is thus thoroughly unwarranted. The estimates of apparent N balance, which is positive at all the locations, may not also mean a sustainable input-output relation. In rice soils, the inclusion of N losses from rhizosphere by leaching, volatilization and denitrification in the nutrient balance calculation may render the N balances negative at all the locations. This suggests that the current practices of cropping and nutrient management are exhaustive in terms of N and K withdrawals leading to depletion of these nutrients from the native soil reserves.

9. Sustainable farming methods or practices

1. **Make use of Renewable Energy Sources:** The first and the most important practice is the use of alternate sources of energy. Use of solar, hydro-power or wind-farms is ecology friendly. Farmers can use solar panels to store solar energy and use it for electrical fencing and running of pumps and heaters. Running river water can be source of hydroelectric power and can be used to run various machines on farms. Similarly, farmers can use geothermal heat pumps to dig beneath the earth and can take advantage of earth's heat.
2. **Integrated pest management:** Integrated pest management a combination pest control techniques for identifying and observing pests in the initial stages. One needs to also realize that not all pests are harmful and therefore it makes more sense to let them co-exist with the crop than spend money eliminating them. Targeted spraying works best when one need to remove specific pests only. This not only help you to spray pest on the selected areas but will also protect wildlife from getting affected.
3. **Crop Rotation:** Crop rotation is a tried and tested method used since ancient farming practices proven to keep the soil healthy and nutritious. Crop rotation has a logical explanation to it – the crops are picked in a pattern so that the crops planted this season replenishes the nutrients and salts from the soil that were absorbed by the previous crop cycle. For example, row crops are planted after grains in order to balance the used nutrients.
4. **Avoid Soil Erosion:** Healthy soil is key to a good crop. Age old techniques like tilling the land, plowing etc still work wonders. Manure, fertilizers, cover crops etc also help improve soil quality. Crop rotations prevent the occurrence of diseases in crops, as per studies conducted. Diseases such as crown rot and tan spot can be controlled. Also pests like septoria, phoma, etc can be eliminated by crop rotation techniques. Since diseases are crop specific, crop rotation can work wonders.
5. **Crop Diversity:** Farmers can grow varieties of the same crop yielding small but substantial differences among the plants. This eases financial burdening. This process is called crop diversity and its practical use is on a down slide.
6. **Natural Pest Eliminators:** Bats, birds, insects etc work as natural pest eliminators. Farmers build shelter to keep these eliminators close. Ladybugs, beetles, green lacewing larvae and fly parasites all feed on pests, including aphids, mites and pest flies. These pest eliminators are available in bulk from pest control stores or farming supply shops. Farmers can buy and release them on or around the crops and let them make the farm as their home.
7. **Managed Grazing:** A periodic shift of the grazing lands for cattle should be maintained. Moving livestock offers them a variety of grazing pastures. This means they will receive various nutrients which is good for them. The excreta of these animals serves as a natural fertilizer for the land. Change of location also prevents soil erosion as the same patch of land is not trampled upon constantly. Also by grazing in time and mowing the weeds can be gotten rid off before they produce more seeds and multiply.
8. **Save Transportation Costs:** Targeting the sales of the production in the local market saves transportation and packaging hassles. It also eliminates the need of storage space. Therefore when stuff is grown and sold in local markets, it makes a community self-sufficient, economically sound, saves energy and doesn't harm the environment in any way.
9. **Better Water Management:** The first step in water management is selection of the right crops. One must choose the local crops as they are more adaptable to the weather conditions of the region. Crops that do not command too much water must be chosen for dry areas. Irrigation systems need to be well planned otherwise they lead to other issues like river depletion, dry land and soil degradation. One can also build rainwater harvesting systems to store rainwater and use them in drought prevailing conditions. Apart from that municipal waste water can be used for irrigation after recycling.
10. **Removal of Weeds Manually:** Farmers having small farms can use their hands to remove weeds from crops where machines can't reach or where crops are too fragile. This is quite a labor intensive task and is not suitable for large farms. Apart from this, a farmer also has the option to burn the old crops so that weeds do not produce seeds and destroy rest of the crops. However, that will cause pollution in air and cal also affect the soil quality.

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