

# Climate Smart Management Options for Improving the Soil Fertility and Farm Productivity in the Middle Hills of Nepal

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**Abstract** Increasing food demand and climate change pose a major challenge to the sustainability of food production systems and safeguarding environmental health. Nepal's economy is primarily reliant on agriculture which is highly sensitive to climate variability. Key concerns in the middle hills of Nepal include declining soil fertility and soil degradation, changing temperature and precipitation patterns, and pest and disease outbreaks, all of which are affecting productivity, prices, incomes, and ultimately livelihoods. This paper describes some simple, farmer-friendly climate smart management options, and analyses their importance, effectiveness and impacts on improving soil fertility and farm productivity. Simple and widely-adopted sustainable soil management and agronomic practices, which are based on efficient use of local resources, include improvement in preparation and management of farmyard manure (FYM) and compost, systematic collection of cattle urine and its use as a base for botanical pesticide and liquid fertilizer, integrating legumes and fodder crops into cropping systems, small-scale collection of rain and run-off water, and improved water use efficiency. These practices have resulted in a statistically significant increase in soil organic matter levels, and have improved soil fertility and structure, workability, and moisture characteristics. Soil organic matter reached a mean of 3.77% from 3.32% after adoption of sustainable soil management practices over the period of 1-3 years in 337 farm sites. The nitrogen content of topsoil significantly increased overall (0.17% to 0.2%) and in 3 of 5 time series. Similarly, nitrogen content of improved FYM significantly increased in 3 of 5 series and overall on 350 farmer's fields over a period of 1 to 3 years. 18.6 kg additional N was annually gained from a mature cattle with improved farmyard manure management techniques and systematic collection of urine. Additional benefits include enhanced soil carbon storage, and improved crop resilience to changes in weather patterns. Adoption of these practices has contributed to increased productivity, enhanced income, improved food security, and a beneficial impact on the workload of women.

**Keywords** Climate Change, Food Security, Farmyard Manure, Soil Fertility, Sustainable Soil Management, Soil Organic Matter

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## 1. Introduction

The most prominent current challenges of the Nepalese agriculture sector are achieving food security and responding to climate change. Food security and sustainable agricultural production, linked to economic growth, livelihood improvement and poverty reduction, are central to the new Agriculture Development Strategy (ADS, 2013). In many areas of the world, where agricultural productivity is already low and means of coping with adverse events are limited, climate change is expected to reduce productivity and make production more erratic (Stern, 2006; FAO, 2010).

Decreased rates of farmyard manure (FYM) application (Shah and Schreier, 1991), poor soil nutrient and water management, inadequate replacement of nutrients removed in harvested materials or loss through erosion, leaching and gaseous emissions, has caused decline in soil organic matter (SOM) levels and soil fertility (Kaini, 2004). Jaishy and Subedi (2000) found SOM levels were low in about two thirds of 9,800 arable topsoils sampled throughout Nepal. Total nitrogen (N) was also low in about half and available phosphorous (P) and potassium (K) in about one third of all samples. Consequently, production of major cereals has been virtually stagnant over the past 15-20 years and the national average yields of maize, wheat and rice are well below the attainable and experimental yield - indeed, they are well below those reported in neighbouring countries (Kaini, 2004).

Sustainable soil management received strong support at the Rio Summit (1992), in Agenda 21 (UNCED, 1992), UN Framework Convention on Climate Change (UNFCCC,



### 3. Soil and Water Management

#### 3.1. Improving FYM Quality and Retaining Fertilizer Value of Cattle Urine

A mature cow/buffalo under normal mid-hill farming condition produces 1,825 kg fresh dung and 1,460 litres urine per annum (Subedit *et al.*, 2010). The majority of N (up to 97%) that is ingested by cattle is excreted in the form of urea and organic N in urine and faeces (McCrorry and Hobbs, 2001). The urea form of N is highly volatile and losses from urine are faster and higher than from faeces. To maximize N retention in urine and FYM, it is important to minimize losses from ammonia emission and nitrate leaching during storage and land-spreading (Figure 2).



Figure 2. Traditional method of FYM storage: Both FYM and urine isn't systematically managed and used



Figure 3a. Improved management practice: FYM heap protected from sun exposure, rainfall and leaching

Improved FYM management techniques involves careful collection, layering and moistening of raw materials, shading the heap from sunlight to minimize N-volatilization, protecting the heap from rainfall to reduce leaching and

erosion, no drying of FYM before carrying to the field and immediate mixing into soil, and systematic collection and use of cattle urine as a liquid fertilizer and a base for botanical pesticide (Figures 3a, 3b).



Figure 3b. Systematic collection of cattle urine

#### Evidence of Improvement from FYM Analysis Results

Monitoring of N-content in FYM before and after improved practices were introduced to 350 farmers' fields over a period of 1 to 3 years showed a significant but inconsistent improvement in FYM quality. Increase in N-content of FYM after adoption of improved technique was substantial and significant in 3 of 5 series, and overall (Figure 4). The largest increase was for the series starting in 2000 but this may be exaggerated by unduly low pre-adoption values. Adoption effects in the series 2003-2006 were also positive, but were smaller and non-significant. Systematic collection of cattle urine added a significant amount of N (Table 1).

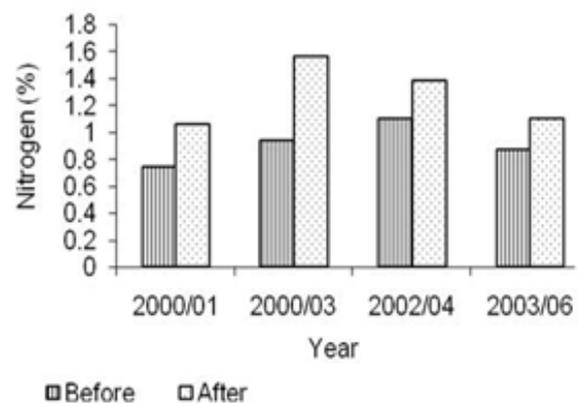


Figure 4. N-content in FYM before and after adoption of improved management practices

**Table 1.** Comparison of N gain from FYM and cattle urine - with and without improved management techniques

From FYM, N gain/year		Additional N gain/year	From cattle urine, N gain/year		Additional N gain/year
Traditionally managed	Managed with improved techniques	Managed with improved techniques	Without systematic collection	With systematic collection	With systematic collection
15 kg	21 kg	6 kg	4.2 kg	16.8 kg	12.6 kg

### 3.2. Composting and Crop Residue Management

Farmers are coached to compost on-farm, using crop residues and vegetation from terrace raisers and other farm areas as livestock bedding which is later incorporated into the FYM or compost pits, and to avoid biomass burning and uprooting of legumes. This has helped to reverse the situation of continued biomass removal from soils and to supplement SOM and plant nutrients.

### 3.3. Integrated Plant Nutrient Management System (IPNS)

IPNS is a holistic approach that integrates all components of soil, plant and nutrient management to achieve higher crop yields and improved soil fertility. The Farmer Field School (FFS) approach was adopted to disseminate the concept of IPNS. Evaluation of 54 FFSs recorded an increase in crop yield of 26%. The results of soil analyses showed an increase in soil fertility, particularly SOM, N, P and K as compared to the base year over a 3 year period (Regmi *et al.*, 2005).

### 3.4. Preparation and Use of Botanical Pesticides for Managing Crop Pests

SSM options for insect pest and disease management include environment-friendly preparation of urine-based botanical pesticide, crop rotation, mixed cropping and measures that are based on local resources, knowledge and skill. Cattle excreta, both urine and FYM, are mixed with milk to control diseases and insects. Different plants, such as *Justicia adhatoda*, *Artemisia vulgaris*, *Eupatorium adenophorum*, *Azadirachta indica*, *Melia azedarach*, *Tagetes erecta*, *Urtica dioica*, *Acorus calamus* etc., that possess

pesticidal properties are used to prepare botanical pesticides.



**Figure 5a.** On-farm research trial on botanical pesticide for managing crop pests



**Figure 5b.** Farmer-led experiments on botanical pesticides for managing crop pests

On-farm studies and FLEs (Figure 5a and 5b) proved the effectiveness of bio-pesticides in managing insect pests and diseases (Table 2) with no or minimum damage to the local agro-ecosystem. Bio-pesticides often have an ameliorating effect on the plant-soil environment and beneficial organisms, supplying several essential nutrients, adding organic matter to the soil, and acting as a plant tonic (i.e. cattle urine contains up to 1% N), thus enhancing crop growth and production.

**Table 2.** Effectiveness of various botanical pesticides in controlling crop pests: results from farmer-led experiments

Insect pests or diseases	Botanical pesticides	References
Late blight (tomato, potato), fruit fly (cucumber), borer (tomato, brinjal)	Urine-based botanical pesticide: 10 kg each of <i>Artemisia vulgaris</i> , <i>Justicia adhatoda</i> , <i>Eupatorium adenophorum</i> , <i>Melia azedarach</i> mixed with 4 litres urine and 4 kg fresh FYM, fermented for 30 days.	Bodhraj Aryal, Farmer, Syangja
Caterpillar, aphid	1 kg stinging nettle soaked in 8 litres water for 12 hours in summer and 24 hours in winter, applied within 24 hours of preparation.	Keshav Sharma, Farmer, Syangja
Red ant	500 gm stinging nettle soaked in 1 litre water for 24 hours. Green chilli (3 fruits) ground and mixed with 1 litre water, again mixed with 2-3 litres soap-water and 200 gm of ground <i>Artemisia vulgaris</i> shoots mixed together, applied after mixing with water in ratio 1:3-1:5.	R.B. Siris and P.B. Naisa, Farmers, Baglung Purushottam Lamichhane, Farmer, Syangja
Viral diseases	Cow milk mixed with 4-5 part of water and sprayed at 7-15 days interval.	B.B. Thapa, Farmer, Baglung

### 3.5. Mulching/Cover Crops

Farmers and stakeholders in the programme districts perceived mulching as effective in conserving soil moisture in times of drought, and suppressing weed growth. It is most commonly undertaken in seed beds and for crops like potato, cucurbits, ginger and turmeric. Mulching creates a conducive environment for soil microorganisms, adds to the SOM reserve, and often improves quality of produce. It is effective in reducing evapotranspiration and increasing crop growth and yield (Allen et al., 1998).

### 3.6. Water Management Strategies

Farmers in the programme districts have experienced a complete lack of or late occurrence of winter rain, and more intense but less frequent monsoon rain. In one recent survey, 100% of respondents reported increased drought conditions and 95% perceived decreased frequency but increased intensity of rainfall. The rainfall records (1999-2008) also verified the farmer's perceptions. Since the mid-hill farmers almost entirely rely on rainfall for their crops, water management strategies are essential to ensure survival of both winter and summer crops in water-deficient periods.

#### a. Water Collection Pond

Waste/grey water, surface and roof run-off water can be collected and led to small plastic or earthen ponds at household level, from where water is provided to nearby cash crops during droughty periods (Figure 6a, 6b). These water harvesting technologies have been effective in reducing risks associated with water shortage in the mid-hill region.



**Figure 6a.** Waste water from drinking water tap collected in plastic-lined pond to feed plants next to the pond



**Figure 6b.** Silpaulin-lined water harvesting pond that accumulates runoff water channeled via a plastic-lined canal

### b. Irrigation Methods to Improve Water Use Efficiency

Proper and timely water application method, such as drip irrigation, has been identified as one of the best methods to increase water use efficiency. It requires less water than flooding or sprinkling. Khanal *et al.* (2013) reported that drip irrigation, as compared to conventional (bucket) irrigation, resulted in 31 % water saving in cauliflower, and increased cauliflower production/area by 46% with the same source of water. Moreover, average production per plant increased by 14%, it reduced irrigation labour costs by 40% and that for weeding and earthing-up by 33%. Ngigi (2009) also reported that shifting from surface irrigation to drip irrigation increased irrigable area by 200%, improving irrigation efficiency by between 25 and 75% using the same volume of water. Regmi *et al.* (2009) also reported that the local communities in Kaski district of Nepal found drip irrigation saved water, improved yields and reduced losses during droughts, thereby combatting water shortage. Similarly, sprinkling on coffee plants induced flowering when the rain failed in the flowering season, and sprinkling warm water on plants in coffee nurseries maintained heat.

## 4. Crop Management

### 4.1. Inclusion of Legumes into Cropping System



Figure 7. Integrating cowpea into the cropping pattern

Legumes improve N levels in cultivated soil through biological N fixation and scavenging residual soil N, making it available for subsequent crops. Legumes also supply organic matter to soil, suppressing weeds and breaking pest cycles (Peet, 1996; Magdoff, 1998). Growing legumes along with cereals leads to nutrient recycling. Legumes are prolific leaf shredders, and act as a natural manure to conserve soil moisture and maintain soil fertility (Tiwari, 2001). SSMP strongly encourages inclusion of legumes into the cropping system as a sole crop (Figure 7), as a mixed, relay or catch crop, as a cover and green manuring crop, in mixed cropping

systems and as forage crops to improve livestock nutrition. It also provides additional cash income for farmers, and compensates the farmers in case the major crop fails.

### 4.2. Growing Drought Tolerant Crops/Cultivars

Some crops and cultivars can withstand drought conditions better than others, and thus reduce the risk of total crop failure. Grain legumes, like horse gram and rice gram can better withstand drought condition relative to other grams and legumes. Some cultivars of rice available in Nepal, such as Sukkha Dhan 1, Sukkha Dhan 2, Sukkha Dhan 3, Radha 4, Radha 7, Radha 11, Bindeshwari, Janaki, Makawanpur 1 are recommended for rainfed conditions, and the wheat variety WK 1204 and maize variety Deuti are reported to be relatively drought tolerant. The nature of such crops and varieties indicates that these are not only important for the food security of people living in harsh and difficult terrain but also for those living in other areas which are prone to the adverse effects of climate change.

### 4.3. System of Rice Intensification (SRI)

One aspect of SRI is the alternate wetting and drying of soil during the rice cropping season rather than continuous flooding. Cooper *et al.* (2013) reported that flooded rice consumes nearly 40% of all irrigation water. It also produces about 10% of all methane produced by human activities; methane is 25 times more potent than carbon dioxide as a GHG. Allowing the soil to dry out intermittently lets air in, preventing build-up of anaerobic bacteria responsible for methane production. SRI has shown reductions in methane emissions by up to 50%, and reductions in water use by up to 40%. SRI brings immediate benefits to the farmers in terms of increased yield, while building long-term resilience by reducing the amount of water use, reducing emissions of GHG, and sequestering carbon in the soil.

## 5. Agro-forestry

### 5.1. Fodder and Forage Crops

Fodder and forage crops provide livestock with improved feed, re-cyclable nutrients, and builds resilience of local agro-ecosystems. SSMP promotes planting of both fodder and forage crops on terrace risers or ridges, wasteland around the farm (which often accounts for 25% of farm areas), and for inclusion in crop rotations (Figure 8). It also encourages stall feeding and reduces women's workload, significantly decreasing time and energy in collecting fodder. It also reduces evaporation and provides biomass for fuel, binds soil, thereby protecting land from erosion, and acts as a home for beneficial insects and birds.



**Figure 8.** Forage/fodder production on terrace risers

Cooper et. al.(2013) also reported that fodder and forage improves soil structure and fertility, thus rain soaks into the soil more readily resulting in water table replenishment (especially in desert and dry areas), thereby making water more accessible to plants, livestock and people. Other advantages include increasing the resilience of farming systems to extreme weather events, diversifying sources of food and income, protecting land and water resources, and sequestering carbon in the soil, root and biomass. Regmi et al. (2009) also found that the farmers were able to cope with the invasion of new grass species by growing fodder and forage, which also improved resilience to climatic stresses like drought and flooding Effect of Climate Smart Practices on Soil Fertility

337 farm sites were monitored before and after SSM practices in terms of SOM and topsoil nutrient contents. An increase in SOM was reported in each of the time series (Figure 9).

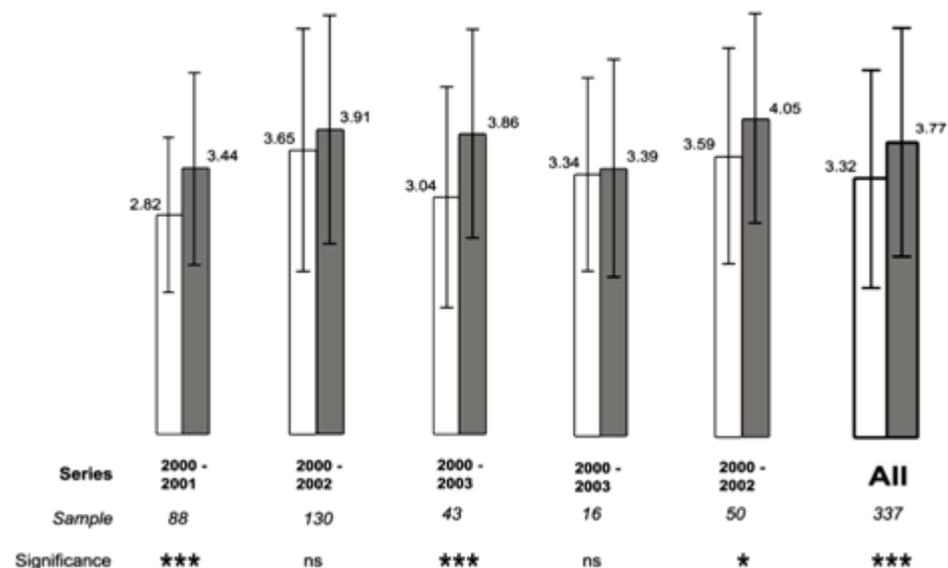
Wilcoxon comparisons showed significant increases in soil N overall and in 3 of 5 individual time series (Table 3). The topsoil N content increased in parallel with SOM, but the effect was slightly less consistent, with significant increases recorded overall and in 3 of 5 time series. The effect on available P in topsoil was inconsistent, with significant increases overall and in 2 series, and insignificant decreases in the other 2 series.

There were significant decreases in soil K overall and in 3 series, with a small but insignificant increase in another one. The decrease may be exaggerated by inflated pre-adoption values. However, a decrease was also reported

in other series, suggesting that the effect is real. Soil pH values varied little, with insignificant effects from improved practices.

Another study undertaken in four districts during 2009-2010 revealed that the effect of soil management on SOC were most marked in the 0-15 cm horizon, but continued to be significant well into the subsoil. SOC in topsoils treated with SSM practices was similar to those under forest, although the forest subsoil had substantially but insignificantly higher levels of SOC. SOC levels were significantly higher in the treated soils than in the non-treated topsoil, and substantial differences continued into the subsoil but were less significant. N is the major nutrient associated with SOM and its pattern was similar to that of SOC, with significantly higher content in the treated soils, particularly in the topsoil (Dahal and Bajracharya, 2012).

Since SOC levels are very sensitive to soil management practices, SSM technologies clearly and significantly contribute to increased SOC. Several long-term studies have also shown the benefits of manuring, adequate fertilization and crop rotation in maintaining productivity and in increasing carbon input into the soil (Mitchell et al., 1996; Reeves, 1997). Two randomized long-term trials comparing organic and conventional farming practices for over 20 years showed remarkable higher carbon contents in organic plots. Evidence from other research (eg. Grandy et al., 2007; Hepperly et al., 2006) also reveal that climate smart management options as described in this paper can sequester more carbon into the soil.



**Figure 9.** Effects of climate smart practices on soil organic carbon in monitored soils

**Table 3.** Effect of SSM technologies on nutrient fertility attributes in monitored topsoils

Series	Duration (year)	n	Total N (%)			Available P (mg/kg)			Available K (mg/kg)			Soil pH		
			Start mean	End mean	Increase % & significance	Start mean	End mean	Increase % & significance	Start mean	End mean	Increase % & significance	Start mean	End mean	Increase % & significance
2000-2001	1	88	0.14	0.18	25***	26.21	39.02	49***	481	388	-19**	5.99	5.94	-1ns
2000-2002	2	130	0.19	0.2	4ns	35.37	36.21	2ns	472	501	6ns	5.94	6.04	2*
2000-2003	3	43	0.16	0.23	43*	21.59	17.64	-18ns	468	373	-20*	5.41	5.94	10***
2002-2005	3	16	0.18	0.17	-6*	26.88	24.46	-9ns	363	309	-15ns	5.87	5.74	-2ns
2003-2006	3	50	0.18	0.2	12**	28.73	37.51	31**	334	235	-30**	5.77	5.67	-2ns
All	1-3	327	0.17	0.2	16***	29.77	34.16	15*	448	404	-10*	5.85	5.93	1ns

Significance of difference between pre- and post-SSM means (\*\*\*p <0.001, \*\*p <0.01, \*p <0.05, ns p >0.05).

Climate smart agricultural practices include the application of organic manure, biological pest control, legume integration, mulching, and crop rotation, make the best use of local resources, and are environmentally sound (Muller-Lindenlauf, 2009). These practices also assist in reducing the emissions from mineral fertilizer production, which are reported to contribute 1% of global anthropogenic greenhouse gas emissions (FAOSTAT; EFMA; Williams, 2006).

### **Climate Smart Practices: Improving Farm Productivity and Income**

The practices described in this paper contribute to increased production of cereals, seasonal and off-season vegetables and cash crops, thus increasing income and food security. Many farmers who have been adopting such practices over the past 5 years have doubled the yields of cereals, vegetables and cash crops (SSMP, 2010b). Adoption of SSM practices has resulted in better soil aggregation and easier tillage, decreased crusting and clodding, and increased moisture availability. On average, adoption of such practices has increased crop yields by up to 30% as compared to traditional practices. Some farmers mentioned improved crop yield in dry years.

A number of factors are responsible for increased crop yield; improved SOM levels and soil structure, and increased nutrient supply from organic sources. The increase in SOM improves crop yield and conserves water. Potential crop yield increases of about 12% for every 1% of organic matter have been reported (Magdoff, 1998). Quiroga et al. (2006) found that crop yields in similarly textured soils depend on total SOM content and an increase in SOM significantly increases nitrate availability.

Climate smart management options, such as legume integration, FYM improvement, systematic collection & use of cattle urine, combined with integrated livestock production increases the SOM, thereby increasing the water capturing capacity of the agricultural system and lowering the risk of soil erosion. Hence, the risk, of yield losses by extreme weather events is also lowered (Lotter, 2003). Since these practices do not rely on external inputs, it increases the agricultural productivity and livelihoods of rural communities who have no or little access to inputs, It can promote food availability and increase the income of small scale farmers (Zundel et al., 2007; FAO 2009). A growing demand for organically produced food can offer access to premium prices and hence higher income (Willer et al., 2009). Impact of Climate Smart Options on Women's Workload

Increasing outmigration of males from rural areas in search of gainful off-farm employment has resulted in an increased workload for women, the feminization of the agriculture sector. Agricultural technologies/practices need therefore to pay due consideration to this major social change.

Initially, adoption of improved FYM management

practices and cattle urine collection, demand some additional labour, but it is observed that in the long run, it significantly reduces workload in terms of collecting materials, cleaning cattle-sheds, carrying manure to field (well-prepared manure is lighter), and land preparation. Field studies indicated that after adoption of such improved practices, often with little capital outlay, men have started helping with work, such as FYM management, urine collection and bio-pesticide spraying, tasks previously considered as women's responsibility, especially in remote rural areas. This uptake by men is encouraged by improving the cattle-shed design for easier urine collection (through better drainage and piping the urine to the pit or tank), and the use of a manuring fork to simplify collection. Other practices that have reduced women's workload include: promotion of on-farm fodder and forage, integrating legumes into the cropping system, water collection and conservation strategies, and composting (Bishwakarma, 2013).

### **Mainstreaming Climate Smart Practices in Governmental Policies and Programmes**

Recent policies and programmes of the Government of Nepal in regard to adoption and promotion of climate smart agricultural practices are promising.

1. Recognition and internalization of climate smart practices as sustainable soil and crop management strategies by the Ministry of Agriculture Development and its reflection in policy and programmes: support is now provided to farmers in 33 districts outside the current SSMP-working districts for promotion of improved cattle-sheds and FYM management.
2. Establishment of Agriculture, Forestry and Environment Committees (AFECs) at the village level and mobilization of locally-developed Experienced Leader Farmers (ELFs) as extension agents, all of whom have been trained in these climate smart technologies.
3. Mandate from the Ministry of Federal Affairs and Local Development to allocate at least 15% of the VDC grants for sustainable agricultural technologies - the VDC is the lowest rung of the administrative structure in Nepal.
4. Increased focus on promotion of organic products.
5. Recognition of organic manure as a fertilizer (Fertilizer Act 2001), and provision of subsidies to establish organic fertilizer factories, and support reduced prices of bio-fertilizers.
6. Climate Change Policy (2011) and the framework on National Adaptation Programme of Action (NAPA) and Local Adaptation Plan of Action (LAPA) have also focused on formulating local adaptation plans for the agriculture sector.

## **6. Support Needed for Farmers**

In the context of a global and competitive market

economy, increasing pressure on agricultural production, ever-increasing outmigration of youth, and food security and sustainable land management, Nepalese farmers need political, economic and social commitment and incentives to adopt climate smart and sustainable soil management strategies. Smallholder farmers require direct incentives to encourage the adoption of climate smart management options and income-generating production technologies.

Supporting cattle-shed improvement is a good strategy to substitute chemical fertilizer and encourage farmers to best use locally available resources. Return on investment for a simple redesigned-cattle-shed, costing NRs. 7,000-12,000 (approx. \$70-120), is covered within a short period as an additional 19 kg N derives from a single cattle each year - thus such investment is both environmentally and financially sound.

## 7. Conclusions

The agricultural sector in Nepal must become climate smart to successfully tackle the current challenges of food security deficits and climate change. The practices described here are climate smart options, which increase farm productivity, strengthen farmer's resilience, reduce GHG emissions and increase carbon sequestration. They strengthen food security and deliver both financial and environmental benefits. Practices that do not involve imported inputs or cash outlays and concerned with improving FYM quality offer a bottom-up, boot-strapping way to reverse the downward spiral of declining soil fertility. Socio-political commitment, and policy and programme initiatives are therefore required to directly support the smallholder farmers to adopt such agricultural options on a wider scale. If agriculture is to be part of the solution to climate change, and at the same time, continue to contribute to food security and poverty alleviation, there will be a need for a significant increase in investment in climate-smart agricultural policies and practices. Since failure in making this shift would put future food security at risk, greater emphasis needs to be placed on agriculture in climate change policy discussions. This will ensure that agriculture fully contributes to future adaptation and mitigation efforts without undermining food production and the fight against poverty.

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