Consilience: The Journal of Sustainable Development
Vol. 12, Iss. 1 (2014), Pp. 95 – 122

Ecological Agriculture and Sustainable Adaptation to Climate Change: A Practical and Holistic Strategy for Indian Smallholders

Remy N. Bargout
College of Social and Applied Human Sciences
& Ontario Agricultural College
University of Guelph, Ontario
rbargout@uoguelph.ca

Abstract

The largest demographic in India suffering from the adverse impacts of global climate change are small farmers. India's rural population is approximately 800 million, with the majority being households dependent on small-scale agriculture. For these smallholders, facing a common rural reality of disempowerment and limited disposable household capital, the agro-ecological results of climate volatility will have catastrophic costs. In a single growing season, even moderate climate abnormalities in temperature regime or moisture regime have shown to disrupt farm agro-ecology and diminish harvests over time. Using a precautionary principle to identify sustainable adaptation solutions, ecological farming offers the most practical and holistic traits of resilience, particularly in the areas of soil, water, and biodiversity. When acknowledging ecological agriculture as an empowering adaptation strategy for smallholders, the evident sustainability of this approach is also apparent alongside key structural dynamics limiting its adoption.

Author's Note

Remy is a fifth-year undergraduate candidate in International Development Studies, specializing in rural agricultural development, and plant science. For their guidance and hospitality throughout the research process, acknowledgements and gratitude are kindly given to Dr. E. Ann Clark (Retd.), Dr. J. Christopher Hall, Dr. Vandana Shiva, and the team members at Navdanya's Bija Vidyapeeth trial farm.

Keywords: Agriculture, Sustainability, Smallholders, Climate Change Adaptation, India

1.0 Agro-ecological Impact of Global Climate Change

1.1 Overview of Impacts

The most adverse agro-ecological impacts of global climate change are in the thermal regime (temperature) and moisture regime. In regards to tropical and subtropical agriculture, increases in temperature and decreases in available moisture are the fundamental changes limiting plant production.

Crop ecologists commonly acknowledge, based on a study from the U.S. National Academy of Sciences, that, for every degree Celsius above the normal temperature range, a 10 percent yield reduction will likely occur in maize (*Zea mays*

L.), rice (*Oryza sativa*), and wheat (*Triticum spp.*) cropping systems (Brown, 2009).

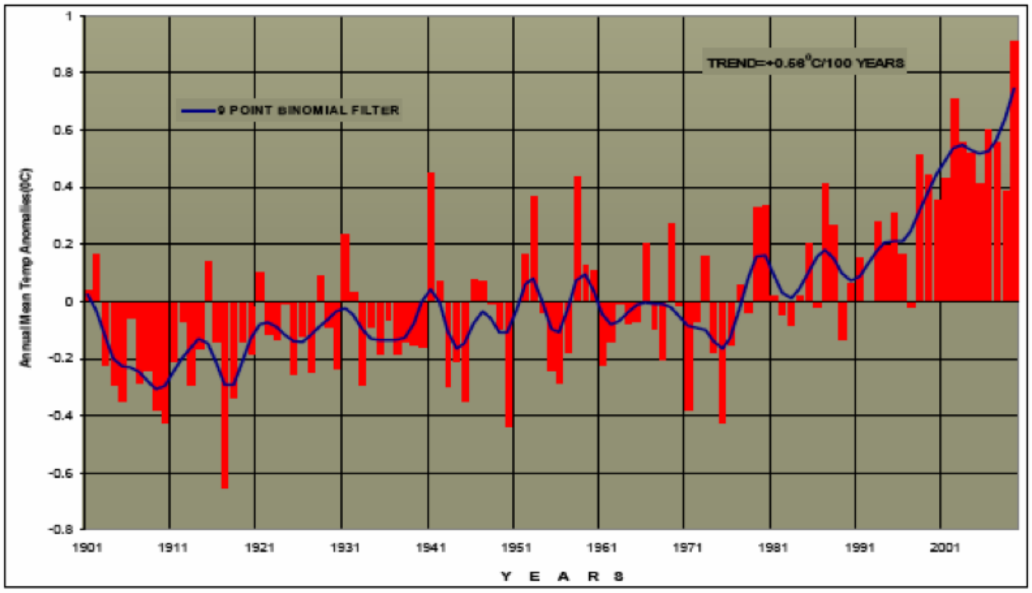

Figure 1: Mean Annual Temperature Anomalies in India from 1901 to 2005. An increasing trend begins near 1981. X-axis is in years from 1901 to 2005 and Y-axis is in degrees Celsius from -0.8 to 0.8 (Indian Institute of Tropical Meteorology, 2010).

For plant species that have determinant traits – oilseeds, pulses, and cereals – higher temperatures hasten development in the plant lifecycle. This is characterized by a shorter growing period, premature adulthood, and smaller harvests (Pankaj and Rakshit, 2008). For tropical climates, temperature increases cause Soil Organic Matter (SOM) to decompose at higher rates and, if not managed accordingly, expedite the leaching of nutrients, resulting in acidic soil (Pankaj and Rakshit, 2008). SOM is an integral component of healthy soil and leaching is only one of many agro-ecological catastrophes that can occur from its loss.

Temperature imbalance is a catalyst for biophysical disruption, and has the ripple effect of creating other negative feedbacks. In all aspects of agro-ecology, the most devastating feedbacks are those caused by disruption in the hydrological system. Temperatures have an impact on moisture regimes by increasing evaporation and creating a soil moisture deficit (Parry and Swaminathan, 1992). Additionally, insufficient rainfall results in dry spells and drought periods, which put stress on plants and lower plant productivity, especially during key growth periods in the plant life cycle (Gadgil, 1995).

1.2 Temperature Changes in India

The Intergovernmental Panel on Climate Change (IPCC) has warned that India will continue to experience more extreme temperature variation with increases in mean annual temperature. Temperature increases range from 3 to 5 degrees Celsius when using a severe climate scenario and from 2.5 to 4 degrees under more modest predictions (Sathaye *et al*, 2006).

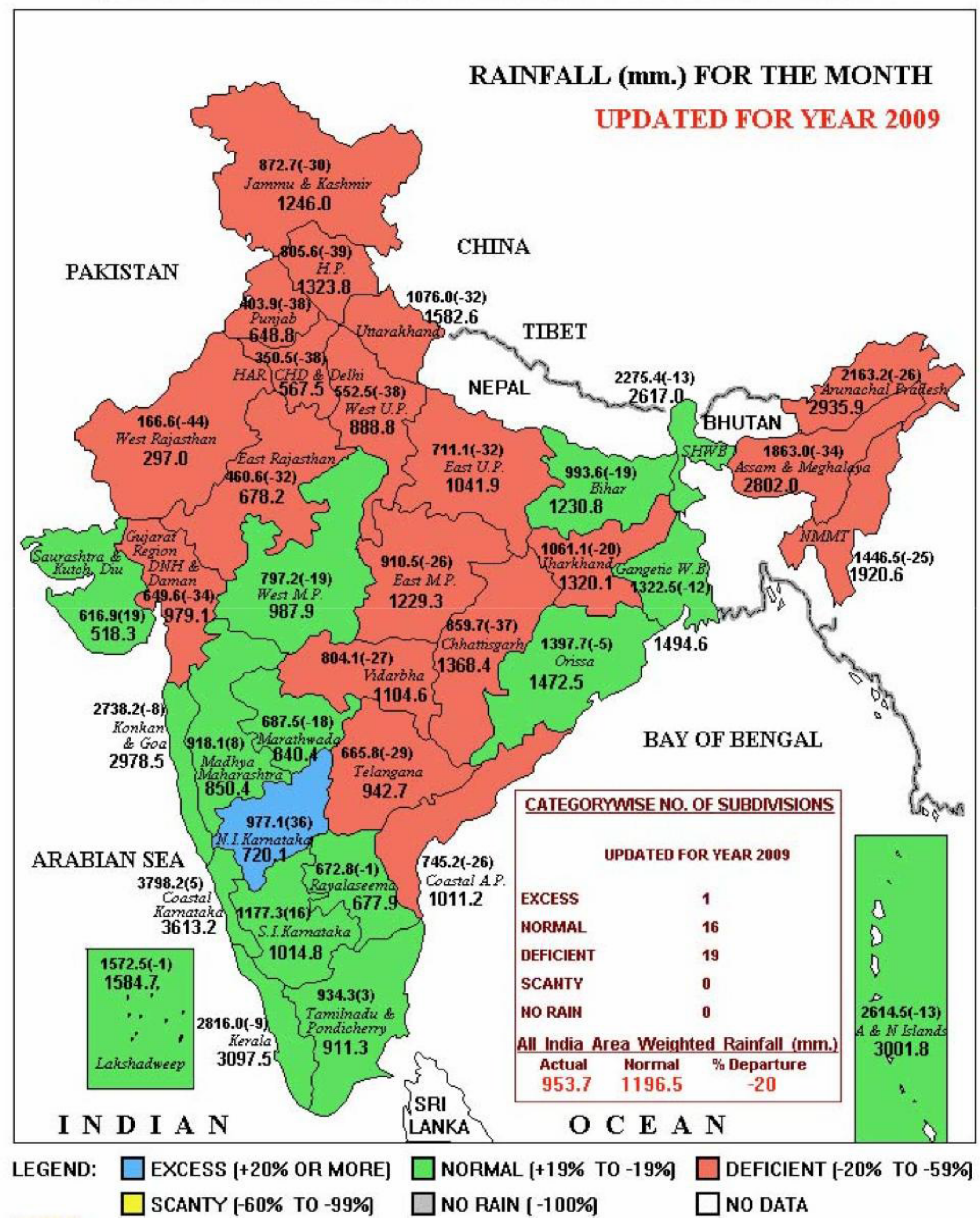

Figure 2: Based on mean monthly rainfall in 2009, 19 out of the India's 35 states and union territories experienced water deficiencies, and 1 state experienced a water surplus (India Meteorological Department, 2010b).

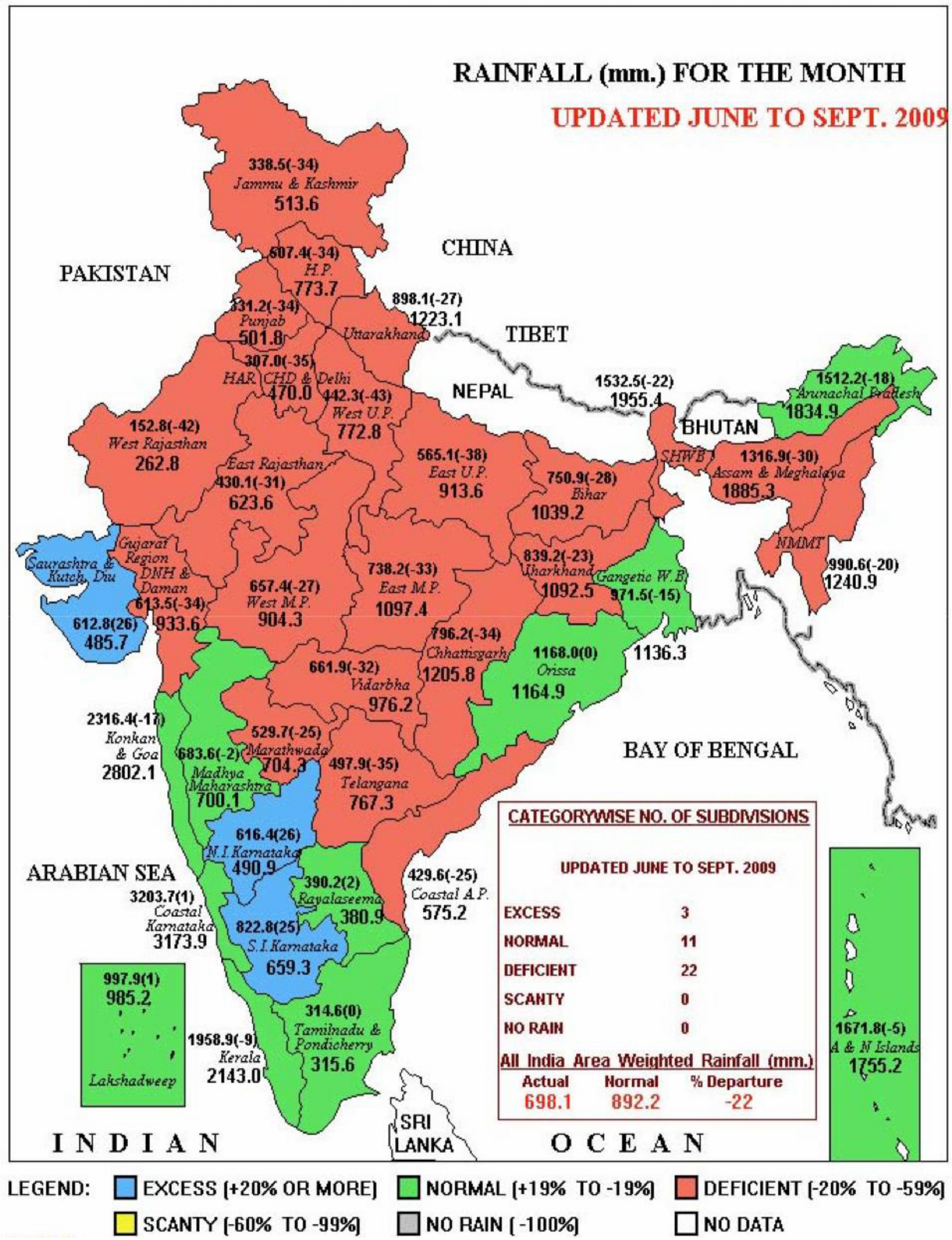

Figure 3: Based on mean monthly rainfall for the monsoon season in 2009, 22 out 35 states and union territories experienced water deficiency, and 3 states experienced water surpluses (India Meteorological Department, 2010a).

There is already evidence of such temperature increases. Half of the years from 1990 to 2010 have been characterized climatically as abnormally hot periods, and seven of these hot years have occurred in the last decade [Figure 1] (Indian

Institute of Tropical Meteorology, 2010). Another study showed that deviations from India's mean annual temperature have been increasing, both in their incidence and intensity by a mean of 0.4 degrees Celsius (Kothyari and Singh, 1996).

1.3 3 Hydrological Changes in India

A publication by the Indian Institute of Tropical Meteorology and the Ministry of Earth Sciences shows variation in the millimeters of mean annual rainfall, seasonal rainfall, and monthly rainfall from 1901 to 2006. The data determined that annual rainfall has a decreasing trend for 68.1% of the country's major 15 climate regions and 49 minor sub-regions, an increasing trend for 22.4%, with 9.5% showing no trend (Sontakke *et al*, 2008). In 2009, the Indian Meteorological Department documented some of the most severe moisture deficits characteristic of this trend [Figure 2 & 3] (India Meteorological Department, 2010a; 2010b).

Although the majority of farms will receive less total rainfall throughout the year, summer precipitation during the monsoon season is also expected to increase in intensity and incidence (Gadgil, 1995). In other words, not only do farms receive less total rainfall, the rain that is received increasingly comes from bouts of torrential downpour.

The forceful impact of intense precipitation can damage or wash away a future crop during the period of germination or the initial phases of adolescence. A surplus of wet periods will facilitate the spread of pests and diseases during crucial growth periods. Increased incidents of pathogens also pose a threat to post-harvest storage, a household source of calories, and seeds for the next crop.

Regularly waterlogged soil can act as an anaerobic host to soil-born diseases. It will also create more opportunity for soil compaction, reduce soil aeration, and place excessive stress on the root system of dry land plants (Gadgil, 1995). More importantly, stronger monsoons bring larger volumes of water, which increase flooding and soil erosion (Pankaj and Rakshit, 2008). Soil erosion creates complications through the combined losses of macro-nutrients, micro-nutrients, essential colloidal particles, residue sources (i.e. dead foliage, manure), and their resulting soil aggregates (i.e. clay, humus).

1.4 Impact of Climate Change on Indian Smallholders

A 'smallholder' can be defined by commonly used parameters of 1) a consolidated or dispersed area equal to or less than two hectares (approximately five acres), and 2) rain-fed plant production (dependent on precipitation for irrigation). Approximately 800 million people make up India's rural population, the majority of whom are smallholder households that rely on small-scale agriculture for their livelihoods and, often, their very subsistence (Sathaye *et al*, 2006).

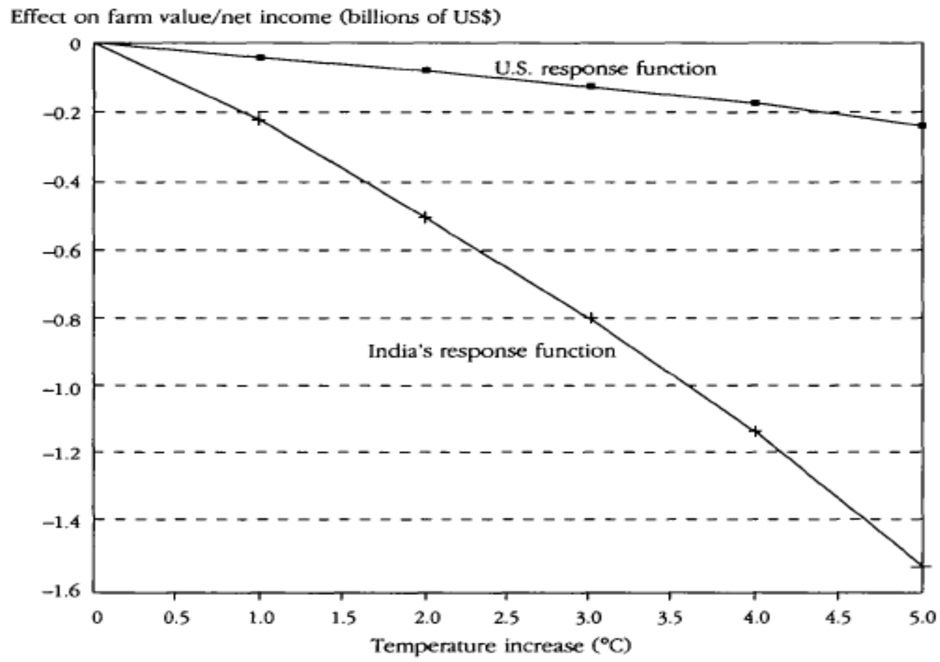

Figure 4: The lower function represents India's estimated decline in net income of US$ 82m per every degree Celsius increase in temperature (Mendelsohn and Dinar, 1999).

For this demographic of Indians, the agro-ecological impacts of climate change will be, undoubtedly, catastrophic. Arguably, it is rural groups that are the most marginalized in India. Indian smallholders suffer from a rural-urban divide that runs deep throughout the country, relatively little financial support from their governments, scarce amounts of disposable household capital, and limited access to new capital.

These are some of the factors that have contributed to smallholders' low adaptive capacity to climate change (Sathaye *et al*, 2006). A study by Kumar and Parikh (1998) forecasts that a small increase of 2 degrees Celsius in mean annual temperatures would be enough to lower net farmer income by approximately 8 percent [Figure 4] (Mendelsohn and Dinar, 1999).

Higher temperatures have direct detrimental impacts on small farm productivity. However, it is the indirect impacts, expressed through hydrological volatility, that are the biggest cost to small farmers. The combination of smallholders' low adaptive capacity and their reliance on rain-fed agriculture will result in lower productivity if rainfall decreases.

Many smallholder groups have already been deprived of their entitlements and confined to a cycle of rural poverty. The destructive hydrological volatility of climate change will only increase the magnitude of this groups' suffering. Although moisture regime deficits will negatively impact the plant species producing the final harvest, it is the smallholders who will suffer the in the end.

1.5 5 Hydrological Changes: Impact on Indian Grasslands and Livestock

It is likely that moisture deficits will create destructive costs to grassland productivity. Moisture deficits add ecological pressure on common resource pastures used for grazing. Moisture stress lowers grassland carrying capacity and grazing at normal rates of consumption further exacerbates this strain (Subramaniam, 1992). The drought prone state of Rajasthan is a historical example of the positive correlation between moisture regimes and the capacity of grasslands to sustain livestock [Figure 5]. In the event of statewide drought, forage production can fall short of minimum requirements in ten out of the eleven districts (Subramaniam, 1992).

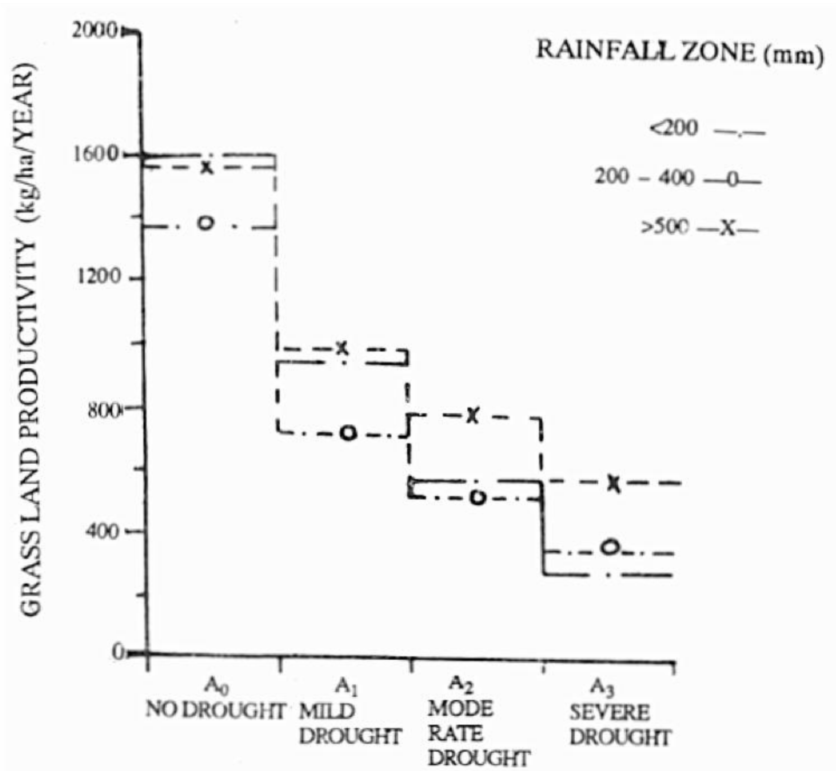

Figure 5: Grassland productivity decreases drastically as drought intensifies (Subramaniam, 1992).

Subsequently, as grassland resources diminish, farmers are left with the option of using grain feed to maintain their number of livestock. However, in reality, the regular expense of buying grain inputs is not financially feasible for many smallholder households. Instead, they will be forced to have fewer heads of cattle. Cows are the integral unit on many small farms, the absence of which can cause a serious collapse in the sustainability and viability of smallholder agriculture.

Despite the many cultural and household purposes that cows have in rural India, ruminants are the most sacred mechanism in the smallholder farming system.

Specifically, the Zebu cow (*Bos primigenius indicus L.*) plays a pivotal role in the farm system. Because it is difficult for smallholders to access or afford mechanized farm implements, draught animals are a versatile source of labor (i.e. plowing fields, transporting goods). Additionally, cow dung is an essential farm input because it acts as a synthesizing bridge in nutrient cycles and as a means for organic matter to be efficiently re-introduced into the soil. Therefore, it would be fair to speculate that fewer cows will lead to a reduction in soil fertility on small farms (Subramaniam, 1992).

Climate change threatens relationships between livestock pastures and soil fertility. These relationships are examples of the ecological interconnectedness in farming systems. As such, comparably holistic and sustainable agricultural solutions must be incorporated into adaptation strategies.

2.0 Smallholder Solutions for Global Climate Change

2.1 Adaptation vs. Mitigation

It could be argued that mitigation should be included in agricultural strategies that address global climate change. This is not a valid argument in the context of Indian smallholders' response to climate change. Impoverished farmers cannot afford to mitigate a global phenomenon to which they have contributed very little.

The benefits of mitigation are not immediately realized and are also dispersed globally. The benefits of adaptation are realized much sooner and directly benefit those affected by climate change (Sathaye *et al*, 2006). Indian smallholders have no reason to be interested in mitigation unless it comes as the bi-product of their preferred adaptation strategy.

2.2 Agricultural Approach for Smallholder Adaptation: Transgenic, Conventional, Organic, and Ecological

The IPCC defines adaptation as "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, 2001). This is an adequate framework, but we must employ a precautionary principle to identify the most contextually viable means of agricultural adaptation.

We should consider the various agricultural technologies for adaptation in relation to the capacity of smallholders to exploit beneficial opportunities, which will efficiently and sustainably moderate the harms of climate change.

Developing transgenic plant cultivars that exhibit climate resilience is a scientifically constructive pursuit. The exploration of these technologies is worthwhile for the advancement of genetic research. A strictly theoretical role is the extent of the involvement transgenic technologies should have in smallholder adaptation.

Precautionary principle dictates that the historical cases of transgenic use in India, the commercial demands of private agribusiness, and the fundamental ethics obliged of scientific theory should nullify any notion of broadly introducing transgenic plants at this point. The volatile threats of climate change, placed upon an immense population of highly disenfranchised farmers, offer enough risk as it is.

The scientific argument on climate resilient transgenic varieties is far beyond the scope of this report. However, one example of scientific error is the pleiotropic effect. This can materialize when one genetic alteration results in unforeseen physiological ripple effects throughout the entire plant (Grains Research and Development Corporation, 2008). When a plant is under stress from dynamic biophysical factors, there are many genes that can express themselves in unforeseeable ways (Bhatnagar-Mathur *et al*, 2007).

There is no certainty in predicting what negative feedback may arise in 20 to 50 years if we introduce climate resilient varieties. There is too much at risk to afford error (Bhatnagar-Mathur *et al*, 2007).

For India, inarguably, the achievement of modern agricultural technologies was the miraculous increase in national food production. This was accomplished without transgenic innovations, rather relying entirely upon conventional methods of plant breeding. Now, in the face of climate change, smallholders must rely less on conventional plant technologies and high-yielding varieties (HYVs), many of which only function under ideal conditions (Pandey, 1994).

Even renowned geneticist and plant scientist Dr. M.S. Swaminathan, celebrated as the 'Father of India's Green Revolution,' understands that global climate change is a game changer for conventional agriculture. Indian farmers and scientists must reconsider the agro-ecological adaptability of these technologies being widely used.

Dr. Swaminathan has initiated a research foundation and network of knowledge centers for smallholders. The organization focuses on 'pro-nature and pro-sustainable eco-technologies.' In the face of global climate change, perhaps Dr. Swaminathan has realized the adaptive shortcomings of many beneficial technologies he previously advocated for.

For farmlands that must withstand adverse climate conditions, there should be a more conservative application of conventional technologies, such as HYVs, synthetic fertilizers, and pesticides. In some instances, the high-yielding variety of a particular cereal (i.e. rice, wheat) will demand up to eight times more water than the landrace of an indigenous coarse-grain cereal (i.e. millet, sorghum) (Barker *et al,* 2008).

Conventional soils, cultivated with maize and soybean under dry conditions, respectively, have shown to yield up to 34% and 56% less than sustainably cultivated soils. This is due to lower levels of SOM, leading to a lower rate of water absorption and lower water-holding capacity (Niggli *et al*, 2008).

The preferential application of synthetic fertilizers as opposed to natural fertilizers (i.e. compost, mulch) is likely to increase soil pH over time (Singh *et al*, 2004). Balancing soil pH is important to prevent micronutrient problems (i.e. zinc deficiency, iron deficiency, molybdenum toxicity). Stable pH is also important for the population of essential soil microbes, earthworms, and other beneficial arthropods that help regulate SOM and soil porosity. Adequate porosity will prevent runoff, lower soil temperatures, improve water absorption rate, and increase water-holding capacity. There is also a tendency for herbicides to reduce the presence of beneficial soil organisms (Shiva and Tarafdar, 2009).

To address the limitation of conventional farming practices, the science of organic farming will have to sustain an agro-ecological system that is resilient to the stress of moisture and thermal volatility.

Percent Increase in Organic Soils

Agro-ecozones	*Range*	*Mean*
Arid	2 – 9	5.3
Semi-arid	3 – 16	7.2
Sub-humid	4 – 15	6.9
Humid	3 – 17	6.8

Table 1: Water holding capacity of organically managed soils. (Shiva and Tarafdar, 2009)

Maeder *et al* (2002) found a positive correlation between microbial biomass and the aggregate stability of soil. These findings also indicated that, in an organic system, the presence of beneficial mycorrhizae microbes near the plant-root system were 40 percent higher, which benefited soil aggregate stability up to 60% (Maeder *et al,* 2002).

Shiva and Tarafdar (2009) analyzed water-holding capacity between 40 organic farms and 40 conventional farms, across four agro-ecozones in three different states (Arid: W. Rajasthan, Semi-arid: SE. Rajasthan, Sub-humid: Mahrashtra, and Humid: Uttarakhand). Ten organic farms and 10 conventional farms were studied from each agro-ecozone, focusing on organic soils that were adjacent to conventional ones and had been using organic practices for at least four years. The study found that water-holding capacity increased in every instance where soil was being organically managed [Table 1] (Shiva and Tarafdar, 2009).

The resilience of organic agriculture has been recognized by a number of key international bodies, including the IPCC and the United Nations Food and Agriculture Organization. However, there are discursive political reasons why 'organic agriculture' should not be the explicit term or school of thought to which we adhere in order to identify the sustainable adaptation strategy that is most practical. Not only is the label of 'organic agriculture' highly stigmatized and admonished by many strong proponents of conventional agriculture, but there is also a north-south divide in the perception and understanding of what organic farming entails (Scialabba, 2000). Historically, India's traditional farming practices were *de facto* organic, long before the international organic movement began.

In this situation, small farms should not be restricted from the use of beneficial conventional technologies (i.e. synthetic fertilizers), as long as they are employed at a sustainable level. Unlike many other organic producing regions in the global south, the relevant objective is not necessarily the sale and export of certified organic goods. The objective is to promote and implement a sustainable adaptation strategy centered on agricultural ecology. The term 'ecological agriculture' embodies what is most important for an adaptation strategy in India, and directly focuses on the ecological sustainability of farming systems. Both systems, organic and ecological, have proven to be highly cost-effective and productive on small-farms in developing countries (Badgley and Perfecto, 2007; Badgley *et al*, 2007; Pande and Akermann, 2008; Pimentel and Berardi, 1983; Pimentel *et al*, 2005; Pretty and Hine, 2001; Singh *et al*, 2004). However, regardless of the mutual viability these two systems have on a small farm, it is the explicit resilience of holistic, practical, and efficient farming practice – not the pious prohibition of certain technologies – that is most relevant for Indian smallholder adaptation.

2.3 Adaptive Benefits of Ecological Agriculture: Key Traits of Resilience

Ecological agriculture exhibits traits of climate resilience in the three key areas of 1) Soil, 2) Biodiversity, and 3) Water. Ecological agriculture exhibits sustainable resilience because it is a holistic approach that addresses interconnected and interdependent relationships existing among all three of the key areas; the functions of soil, water, and biodiversity all impact one another. Additionally, ecological agriculture is a holistic approach because it places broad emphasis on 1) context-specificity, 2) diversification, and 3) incorporation of traditional knowledge (Niggli *et al*, 2008). It can be demonstrated, discursively**,** how such a holistic approach functions to incorporate the most climate resilient agro-ecological traits, into an overarching strategy that will sustainably benefit Indian smallholder adaptation.

2.3.1 Smallholder Adaptation and Soil Resilience

First and foremost, ecological agriculture prioritizes soil health. Soil health is a fundamental determinant of farm resilience and productivity, and is strongly maintained by the presence of SOM. Soil organic matter acts as the most vital mechanism for smallholder adaptation. Primarily, SOM consists of dead carbon-based organisms, at various stages of decomposition.

A healthy supply of organic matter creates a natural reservoir of important macro-nutrients (Ammonium Nitrate, Phosphate, Potassium). Even when synthetic fertilizers are being used, SOM is still needed to prevent leaching by storing the added nutrients within the upper soil horizons, close to the plant root zone.

Humus is a key form of SOM that will act as a storehouse of nutrients and, additionally, as a natural reservoir of moisture. Humus functions like a sponge and a protective buffer during periods of drought. Humus can hold 30 times its weight in water (Jordan *et al*, 2009). Under extreme hydrologic conditions, SOM is crucial for resilience because of its improved water-holding capacity and because it strengthens soil structure and prevents against erosion. Protection against erosion will be extremely useful during the monsoon seasons when torrential downpours have the potential to devastate agricultural landscapes (FAO, 2007)

SOM can be maintained using practical and cost-effective ecological methods, including conservation tillage, mulching, green-manures, intercropping, mixed cropping, crop rotation, agro-forestry, permaculture, vermiculture, aquaculture, and composting (FAO, 2007; FAO, 2009; Singh *et al*, 2004; Venkateswarlu and Shanker, 2009). Composting livestock manure is an excellent source of SOM and, when done properly to eliminate the presence of any pathogens, human waste is also a safe and nutrient-rich source of SOM (Kramer, 2011; Kulkarni, 2009).

There have been initiatives in agro-forestry with nitrogen fixing trees to improve soil fertility and reduce wind and water soil erosion (Pande and Akermann, 2008). On an Indian rice paddy, a practical and cost-effective way to maintain SOM is with green-manure, using a non-invasive water fern called Azolla (*Azolla filiculoides Lam.*) (Arumugasamy *et al*, 2007). This unique intercropping method reintroduces organic matter to the soil when, after the rice is harvested, the azolla is ploughed into the soil, where it will naturally decompose. To further improve the resilience of wetland agricultural soils, fish and duck species can be domesticated within the cultivated area.

Certainly, one adaptive benefit of introducing plant and animal species together will be the provision of SOM from diversified sources. However, in most examples of ecological farming, the agricultural benefit of biological diversity is not based on the autonomous provision of one thing or another. Within ecological agriculture, the functioning resilience of all organisms is interconnected through natural synergies with one another and with the surrounding physical environment.

2.3.2 Smallholder Adaptation and Biodiversity Resilience

In the context of the surrounding physical environment, ecological agriculture studies synergistic relationships between domesticated and non-domesticated plant and animal species. By understanding some of the internal mechanisms within these relationships, positive synergies can be safeguarded and their adaptive benefits can be sustainably exploited.

According to the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), it is crucial to "collect, conserve, and characterize the inter- and intra-specific diversity of wild relatives in order to mitigate against the biotic and a biotic stresses caused by climate change" (Lane and Jarvis, 2007). In this regard, ecological agriculture fosters agro-ecosystem biodiversity that stabilizes small farm production systems against future events of biophysical chaos (Niggli *et al*, 2008). There are positive synergies between the few cultivated species in a farm system and the genetic variety of the many uncultivated wild species (Niggli *et al*, 2008).

Biodiversity conservation is reflective of an *in situ* breeding method because it allows domesticated species to co-evolve with changing adverse conditions. For example, a plant's resilience can co-evolve in relation to the marginal presence of pests and diseases in their surrounding environment (Ramprasad, 1994). A strong presence of biodiversity will buffer against catastrophic disease and pest outbreaks by limiting the variety of niche habitats in which harmful organisms thrive (Niggli *et al*, 2008).

Ecological agriculture also recognizes the intrinsic value in traditional methods of biodiversity conservation. Communities of Indian smallholders have preserved traditional practices of biodiversity conservation. Sacred groves are areas of untouched forest that are communally protected. These areas are hot zones of biodiversity and provide habitat for life forms that may not exist on farms. This wild environment interacts with the local agro-ecosystems, and they mutually benefit one another's resilience to abiotic and biotic stresses (Boron, 2006).

Biodiversity does not exclusively enable current domesticated species to evolve against the indirect ecological adversities caused by climate change. It also facilitates the evolution of new species. Undiscovered plant species can exhibit novel traits of resilience against indirect ecological adversity, in addition to resilience against direct thermal and moisture adversities.

This has immense value for smallholder adaptation. Benefits can be exploited in cases where undomesticated landraces – perhaps a rice landrace exhibiting extreme drought tolerance discovered in a community's sacred grove – could be successfully cultivated for adaptive agricultural purposes. It is equally valuable that this ecological mechanism of innovation, naturally assisting in the breeding of potentially climate resilient species, continues to be safeguarded through ecology-centered agricultural practices. More so, it is important that this mechanism continues to exist as a public agro-ecological resource (Navdanya, 2009).

Biodiversity would be rendered useless to those most marginalized in society if it became proprietary. Indian smallholders have scarce fiscal capital at their disposal but have comparably abundant natural capital that can be harnessed for their own empowerment (Shiva and Trafdar, 2009). Basu (2000) suggested that a public network of seed banks across India's many agro-ecozones would enable the equitable exchange of genetic common property resources among communities and regions. Indeed, without needing to emphasize the preservation of wild species any further, Indian smallholders should prioritize the agro-ecological vigor of biodiversity cultivated within their farm system.

Reasons for promoting biodiversity within the farm system are extensive. In regards to climate change adaptation, there are more specific explanations, which address indirect environmental adversities and direct thermal and moisture adversities.

Broadly speaking, ecological agriculture promotes a biologically diverse agro-ecological system as a built-in system of insurance for smallholders. In the event that direct or indirect climatic adversities result in failure of a particular crop, the assumption is that other strategic crops will not be as adversely affected and guarantee a safety net on which small farmers can rely. This will enable smallholder gains under worst-case climate scenarios through a balance of precautionary measures and desired risks.

In a basic example, this type of bio-diverse system might cultivate a diversity of marketable cash crop species (i.e. cotton, spices, horticultural vegetables), complimented by a diversity of crop species that could be used for emergency household subsistence (i.e. millet, cowpea, lentils, sesame, dry land rice). More specifically, if temperatures are abnormally high in a given season, wheat and cotton (*Gossypium arboretum*) harvests may diminish or fail entirely from stress during juvenile and reproductive (grain producing) periods of the plant life cycle. However, in this event, sorghum (*Sorghum bicolor)* and lentil (*Lens culinaris*) yields would be less affected by heat stress, and provide an emergency source of household calories.

Of all the beneficial species that can be cultivated to increase biodiversity on a small Indian farm, the most resilient physiological traits are found among indigenous coarse-grain landraces, such as sorghum and millet. Traditionally, Pearl Millet (*Pennisetum glaucum (L.) R.Br.*) and Finger Millet (*Eleusine coracana Gaertn.*) have been cultivated in many regions of India. It is easy for them to thrive under rain fed conditions, and they are able to grow in some of the most forsaken soils imaginable (Ghosal and Krishnan, 1995). Millet is a photosensitive plant with short growing periods. This means that farmers can have the opportunity of growing two crops in a single season. So, if a season's cash crop fails, the consecutive harvest of more than one emergency crop will be an added safeguard for household food security (Ghosal and Krishnan, 1995).

Strictly speaking, however, a diverse selection of resilient food-producing species will not afford the full suite of adaptive benefits that ecological agriculture can offer through biodiversity. The strategic companionship of different crop species (intercropping), along with the spatial and temporal sequencing of species (crop rotation), will ensure that soil nutrients are being consumed efficiently and, therefore, more sustainably.

Pertaining to the species and breed of any given plant, there is a unique set of nutrient requirements. Therefore, strategic crop companionship is favorable if plant species have disparate nutrient requirements that complement one another (Niggli *et al*, 2008). Using a random example, there would be more efficient use of soil nutrients in an intercrop of wheat and pigeon pea that respectively consume 120-70-70 NPK (kg/ha) and 90-20-60 NPK. Pigeon pea and wheat might be in competition for the consumption of K (potassium) nutrients, but pigeon pea's smaller demand for P (phosphorous) would compliment the higher P demand of wheat.

More so, the general compliment between these two species is that wheat production will not be hindered since the minimum nutrient requirements of pigeon pea are downwardly elastic. For smallholders that cannot afford to buy fertilizer inputs, the most rewarding function of this synergy is that pigeon pea's root system is a host for populations of nitrogen fixing microorganisms. Once the pigeon pea has been harvested, fixed nitrogen can be reintroduced to the soil by composting or mulching plant fodder.

This demonstrates the importance of temporally and spatially sequencing species through crop rotation. Unless soil resources are simultaneously replaced by intercropping appropriate plant species, appropriate crops should be scheduled in the subsequent season to restore the nutrients expended. The implication is that the rotation of crops in the following season will have nutrient priorities different to that of the previous one (Arumugasamy *et al*, 2007). It is still possible to cultivate the same plant species from season to season; however, the physical location of where they are cultivated should be strategically rotated as well. Soil nutrients and other resources (i.e. SOM, microorganisms) will be exploited more efficiently and more sustainably by diversifying seasonal plant species with intercropping and by using crop rotation to diversify inter-seasonal plant species (temporal) over different areas of cultivated farmland (spatial).

Smallholders in Uttarkhand have diversified their cropping systems through a traditional poly-culture called *Baranaaja* (Pande and Akermann, 2008). This method of mixed cropping involves at least twelve food crops, grown in a matrix where agro-ecological interactions are both spatial and temporal, and the end result is the efficient, synergistic, and sequential use of specific nutrients within the soil (Pande and Akermann, 2008). This sustainable method is useful for small farmers because it does not deplete the soil of nutrients, and land rarely needs to be left fallow (Pande and Akermann, 2008). Financial benefits were compared between a paddy (rice) monocrop and a mixed crop of finger millet, foxtail millet (*Setaria italica (L.) P. Beauvois*), beans (*Phaseolus vulgaris L.*), and amaranth (*Amaranthus L.*) (Pande and Akermann, 2008). The net profit of the mono-crop was Rs. 6,720, and net profit for the mixed crop was Rs. 15,800 (Pande and Akermann, 2008).

Figure 6: Healthy rice harvest produced during season that experienced sufficient watering. (Bargout, 2010a)

Ecological agriculture also prescribes that biodiversity will improve farmland adaptation through the cultivation of non-food plant species. Even though the apparent investment in biodiversity produces true adaptive revenue within the agro-ecological interconnectedness of all farm species, and the positive synergies they form with one another.

For Indian smallholders, once again, the cultivation of azolla is a prime example of non-food species providing adaptive benefits through positive synergies. Azolla is a nitrogen-fixing plant that directly supplies nitrates (labile forms of nitrogen available for plant uptake) to the intermingled rice crop. This reduces the need for ammonium sulfate fertilizers. When the azolla crop is ploughed back into the soil, it will restore many of the lost macro-nutrients, along with adding organic matter. Intercropping azolla in rice paddies means that competitive weeds will find fewer niche environments to thrive in, and the rice crop will not be threatened because azolla is a non-invasive species (Arumugasamy *et al*, 2007).

As previously mentioned, adding ducks and fish will contribute towards a more resilient agro-ecological system. In rice paddies, populations of aquatic and dry-land pests are a potential food source for these domesticated animal species. So far, we have emphasized the importance of natural and domesticated plant biodiversity, however, it should be self-evident that biodiversity in animal species is no less pivotal for agro-ecological resilience to climate adversity. Particularly, it is the interconnected role of buffer-fauna, forminrsity and evolution of species. Similarly, arboreal biodiversity (trees) is interconnected with the biodiversity of bird species. Agricultural initiatives in the past have sought to create habitat for more bird species through agro-forestry (Pande and Akermann, 2008). Tree biodiversity is also interconnected with insect biodiversity.

Agro-forestry depends heavily on insect pollination for the production of a healthy harvest, particularly for orchards and the respective production of fruit (FAO, 2009). Wild apiformes (bees) and apiculture (domestication of bee species) are absolutely vital for fruit production. What is more, apiculture is absolutely essential for the survival of our global agricultural system. A smallholder, along with other surrounding farms, would benefit exponentially from the pollination services of a single beehive; whether involved in tree crop farming or field crop production. A regional network of beehives would undoubtedly increase resilience.

Figure 7: Inferior rice harvest produced during season that experienced insufficient watering. (Bargout, 2010a)

2.3.3 Smallholder Adaptation and Water

Biodiversity will also enhance moisture conservation by increasing water use efficiency, and reducing moisture loss from evapotranspiration (water evaporation off of soil and leaf surfaces). Particularly, because there is more ground cover in crop poly-cultures, protection from sun radiation will lower soil temperature, and less water will evaporate (Singh *et al*, 2004). Water scarcity and hydrological volatility, caused by increasing temperatures, is the number one climate change adversity to which Indian smallholders will have to adapt.

Moisture regime is easily the number one limiting factor in a small rain-fed agro-ecosystem. It cannot be emphasized enough that smallholders will need practical and affordable tools in order to sustainably increase their resilience to hydrological volatility and moisture scarcity. For Indian smallholders, the utmost importance of water is symbolized by the acute impact that moisture scarcity has had on the rice harvests of one household.

For this particular farming family, growing cereal crops in the state of Uttarkhand, their rice harvest has been healthy during seasons when water supply was adequate [Figure 6] (Bargout, 2010a). However, when the supply of water has been scarce, their rice crop has suffered significantly. During a growing season in 2009, the insufficient supply of water desecrated the quality and the quantity of grain they were able to harvest [Figure 7] (Bargout, 2010b). Smallholder households, such as this one, desperately require an alternative set of tools that can simultaneously empower their adaptive knowledge and their adaptive faculties. Within ecological agriculture, there exist a variety of appropriate tools that will enhance adaptive capacity through the conservation of moisture.

When considering smallholder rice production, there are practical and cost-effective strategies for strengthening paddy resilience to moisture stress. System of Rice Intensification (SRI) is one of the most promising and practical water saving technologies being practiced in India (Sinah and Jayesh, 2006; Venkateswarlu and Shanker, 2009). As opposed to completely flooding the rice paddy, the soil can be kept moist or have an inch or two of water at most. The aim of this is to improve root growth through a higher level of soil aerobic activity and lower anaerobic activity. However, through this process, water conservation is one of the main achievements (Venkateswarlu and Shanker, 2009). Smallholders in Uttarkhand have successfully experimented with a traditional method of SRI known as *Thakuli* (Pande and Akermann, 2008).

The use of SRI in a mono-cropped system is still not a strategy that offers a holistic solution to the overarching problem. In order to fully benefit from the resilience of an ecological system, smallholders will still need to increase biodiversity, cultivate more poly-cultures, and consider cultivating more drought tolerant crop species.

A participatory study by Kelkar *et al* (2008) interviewed 62 households from two villages in a water stressed district in the state of Uttarakhand (Kelkar *et al*, 2008). When coping against climate change, the majority respondents attributed a quarter of their effort toward growing crops with lower water requirements (Kelkar *et al*, 2008).

Millet is well suited for poly-culture farming systems because of its extremely low moisture demand. Millet will deprive neighboring plant species of only a marginal quantity of water (Ghosal and Krishnan, 1995). Millet has been known to withstand up to a seventy five percent absence of moisture in the soil (Shiva and Tarafdar, 2009). Finger millets are the type most widely grown in India and have evolved into many unique drought resistant varieties that are indigenous to different bioregions (Ghosal and Krishnan, 1995). Millets produce a large amount of fodder, which can be fed to livestock or used as mulch.

Similar to millet, sorghum is a crop that can be grown successfully under the most extreme drought scenarios. Sorghum has a fascinating trait of resilience where it lies dormant during moisture deficient periods and then continues growth when minimal moisture requirements are met once again (Ghosal and Krishnan, 1995).

Recalling the agro-ecological interconnectedness in a farm system, most of the practices in ecological agriculture also buffer against hydrological volatility. The practice of agro-forestry creates windbreaks that reduce wind erosion of topsoil. Tree cover will also reduce moisture evaporation from the soil surface (Singh *et al*, 2004). Vermiculture increases earthworm populations, resulting in large pores being carved into the soil, which increases the rate of water infiltration. A higher rate of water infiltration will protect soil from erosion and water-logging during periods of torrential downpour in the monsoon seasons (Singh *et al*, 2004).

Internalized within the agro-ecology of a smallholder's farm system, the ecological agriculture traits of resilience will provide vital adaptation services. Because ecological agriculture is holistic and values the use of traditional knowledge, there are further steps smallholders can take to conserve moisture by altering the biophysical environment of their farm. Smallholders should resurrect the traditional Indian 'water tank' system of moisture conservation. The water tank method of water conservation is practical, readily accessible, and cost-effective.

Water tanks are essentially earthen dams, 1 to 10 hectares in size. This tool has been used in India for approximately 1,200 years (Biksham *et al*, 2008). The majority of precipitation occurs during India's monsoon seasons. It has been common for the majority of a year's precipitation to occur within only 100 hours of rainfall (Biksham *et al*, 2008). Therefore, storing water from catchment areas becomes an essential activity and will guarantee agricultural access to water during the rest of the year.

Unfortunately, during the latter half of the twentieth century water tanks in India have sat dormant due to changes in government policy that focused on extracting ground water resources and using irrigated sources of water, theoretically afforded by the damming of rivers (Biksham *et al*, 2008). More recently, due to a widely recognized need for **pro-poor** methods of water conservation in India, there have been highly successful initiatives to resurrect water tanks.

A grassroots project in the Godavari River basin, funded by the World Wildlife Foundation (WWF), was able to successfully restore traditional tank systems of water conservation (Biksham *et al*, 2008). Following which, the intended beneficiaries reported how, "crop yields increased significantly, by +1.1 t/ha [ton per hectare] for maize and +0.4 t/ha for turmeric, increasing total production by Rs 5.8 million (US$ 69,600) per annum" (Biksham *et al*, 2008).

Due to the abundant supply of water, farmers described how their plants became noticeably healthier. By collectively improving plant health, the entire region exhibited agro-ecological resilience to pests. This facilitated fewer outbreaks, and smallholders were able to spend less money on pesticides. There became a more frequently available supply of both water and crop residues for smallholders with which to feed their livestock. Per-hectare, this increases farm carrying capacity to support cattle and allows farmers to be less dependent on common resource grasslands (Biksham *et al*, 2008). Smallholders also used the water tanks to support aquaculture, and net annual fish production was valued at US$ 3,700 (Biksham *et al*, 2008). Water tanks are also attractive habitats for different bird species, both wild and domesticated.

The benefit of using water tank systems should not countermand the benefit of large-scale dam projects or detract Indian authorities from investing in such projects. With specific regard to the agricultural needs of Indian smallholders, large-scale dam projects do not appear to directly address their concerns holistically. Although dam projects can generate expansive sets of revenue, in both social capital and financial capital nationwide, small-scale farmers do not directly enjoy many of the benefits from these projects. Smallholders will exponentially benefit from practical cost-effective strategies that are, first and foremost, aimed at developing their resilience to climate change by empowering them to actually regulate their farm moisture regime.

Smallholders directly benefit from the implementation of a water tank system. Water tanks have a lower cost-benefit ratio, lower storage costs per cubic meter of water, and are relatively inexpensive to construct or restore. Furthermore, they are locally manageable and will not result in unforeseen environmental or social disruptions (Biksham *et al*, 2008). The success of the Godavari River project demonstrated how, "applying technologies that are locally available, and undertaking small-scale measures could add up to effective and inexpensive large-scale and pro-poor adaptation" (Biksham *et al*, 2008). There is potentially immense value in expanding projects like this one, since there are an estimated 208,000 water tanks across India. (Biksham *et al*, 2008)

Locally managed, context specific water conservation is best for smallholder adaptation to climate change. This strategy will give farmers an empowering tool with which they can simulate the most ideal temporal distribution of potentially exploitable water resources provided by monsoon rains.

3.0 Limitations: Dynamic Barriers for Ecological Agriculture

Despite the suitability of ecological agriculture to sustainably enhance agro-ecological resilience on small Indian farms, there remain dynamic political, economic, and social structures that inhibit widespread adoption of this adaptation strategy.

Presently, the Indian government has little economic incentive to institute strong policies encouraging ecological agriculture (Scialabba, 2000). Agricultural policies are typically formed around the large-scale commercial imperatives of agricultural development, focusing on the revenue generated from export-oriented food production. It is not that Indian public authority is unaware of the imperative need for climate change adaptation on its small farms (Planning Commission Government of India, 2007; Sharma *et al*, 2004). In this regard, neither is the government misinformed about the resilient traits of ecological agriculture. Technocratic knowledge on the agricultural impacts of climate change and knowledge of the adaptation solutions, which are available, is demonstrated quite comprehensively in *India's Initial National Communication to the United Nations Framework Convention on Climate Change* (Sharma *et al*, 2004).

Unfortunately, the historical reality is that the administrative bodies of public representatives have always marginalized Indian smallholders, who are collectively disempowered and have few equitable civic mechanisms at their disposal through which to assert their interests. The government is an aggregate of highly compartmentalized bodies administered by the decisions of rationally performing bureaucratic agents, who are subject to the prescription of top-down agendas (Burnell and Randall, 2008).

There are structures within India's public authority that enjoy the luxury of embedded autonomy. It is only the interests of highly empowered groups that can be successfully articulated throughout the silos of government structure, and this is only to the point where there is a clear and impending consequence for the government itself, the implications of which are the only impetus for rational consideration and adoption of these articulations within the government narrative (Burnell and Randall, 2008). Through many of its faculties, the Indian government has maintained a strictly patron-client relationship with rural society (Scialabba, 2000; Burnell and Randall, 2008).

Certainly, for all nations, dynamic malfunction within state establishments becomes an apparent obstruction to social innovation. Within India, it is very possible that any political vehicle for promoting agricultural innovation will be halted or de-railed by the public authority, safely characterized by their weak bureaucracy, low transparency, divided political factions, and burdened by the pressure of extra-national forces (i.e. foreign national agendas, multi-lateral lending bodies, trans-national firms). Having said this, there has been some government action in support of ecological agriculture for sustainable climate change adaptation.

India's government has been not been unsuccessful in occasionally enacting meaningful pieces of legislature. Neither have they failed in making attempts to allocate federal budgetary resources towards sustainable agriculture and climate change adaptation. For India's national 2012 Union Budget, the Ministry of Agriculture made formal grant requests of approximately USD 180 million and USD 180,000, respectively, for their planned 'Climate Resilient Agriculture Initiative' and 'National Mission on Sustainable Agriculture' (Department of Agricultural Cooperation, 2012; Department of Agricultural Research and Education, 2012). It is uncertain if the Ministry of Finance will allocate their budget to fund the full amounts requested. Due to weakness in government transparency and the overhead costs of operating large agricultural programs, it is difficult to determine how much of this allocated capital will actually find its way on to the farmland of intended beneficiaries.

These government efforts still reflect a patron-client relationship and will likely fail to facilitate expedient transition towards sustainable adaptation, particularly for India's vulnerable multitude of disempowered smallholders. If adoption of a sustainable adaptation strategy is to be widely realized – one that resembles the resiliency and practicality of ecological agriculture – it will have to come from the ground up. Veritably, a national mandate for adopting sustainable adaptation should not be contingent on the evident passiveness of federal government. The structural labyrinth of India's public authority will need to be largely circumvented. The most legitimate ratification of a public demand for sustainable adaptation and a public demand for transition towards ecological agriculture will come from the autonomous social authority of Indian smallholders and the popular grassroots organizations that strictly advocate on the behalf of marginalized rural communities.

In accordance with this perspective – emphasizing smallholder agency and autonomy – preponderant social variables within India will also limit the open adoption of certain adaptive practices that ecological agriculture emphasizes. The social perspectives within smallholder communities will influence their decisions. The perspectives of smallholder households are contextually influenced by dynamic rural social realities. The rural social realities that will influence smallholder adaptation decisions include 1) access to power and knowledge (access to capital) and 2) cultural values.

Due to the fact that rural households already have a scarce supply of fiscal capital, many smallholders will face challenges affording the costs of adaptation. Some of India's small farmers are so marginalized in this regard that they have virtually zero capacity to implement a sustainable adaptation strategy. Despite governmental and non-governmental efforts, smallholders continue to have limited access to financial credit. For a large proportion of India's small-scale farmers, adaptive transitioning to ecological agriculture will not be feasible without external support. For acutely disempowered smallholders, transitional stimuli may need to come from non-governmental and grassroots organizations, since government bodies have continually failed to deliver significant adaptation assistance. Perhaps what is more formidable than the linear distribution of any financial aid, is that adaptive assistance will need to include the provision of social capital distributed to an immense rural population and requiring a dynamic network of knowledge dissemination.

Greatly contributing to the disempowerment and deprivation of Indian smallholders is the lack of access to formal education. India's rural poor are financially and socially excluded from many institutions of higher training, particularly institutions that offer agricultural training. Additionally, the Ministry of Agriculture has a weak and underfunded network of farm extension agents tasked with providing useful knowledge and advice to farmers. For smallholders to even attempt the implementation of a sustainable adaptation strategy, they will need to, first and foremost, acquire relevant information about ecological practices. To begin with, smallholders will require awareness to the existing uses of ecological agriculture for climate change adaptation. Second, smallholder perception of ecological agriculture and its relevancy to their realities must be addressed. In some scenarios, smallholders may not value adaptation using ecological agriculture perhaps until they are offered relevant evidence that demonstrates resilient traits.

Rural socio-economic dynamics have also led to the stigmatization of traditional Indian farming systems as an anachronism. In the perception of many smallholders, their use of conventional technologies and practices – such as synthetic fertilizers, pesticides, transgenic and hybrid plant varieties, or mono-cropping – may serve as a social symbol of modernization, creating a higher perceived vocational status for them within society if farmers can openly demonstrate their capacity to afford the most advanced agricultural technologies available. The nature of this social dynamic, where embedded cultural perceptions are negatively influenced by the reality of deprivation in rural India, manifestly reduces the cultural relevancy of other practical adaptation tools recommended within ecological agriculture.

Modern dietary preference in India, both urban and rural, contravenes with some of the resilient traits in biodiversity, limiting the adaptive benefits that can be exploited through crop diversification. India has progressed from a developing to an emerging nation in the last fifty years, and Indian diets have evolved to consume far less quantities of coarse-grain cereal. There has been increased demand for rice and wheat as staple grains throughout Indian society and an increasingly stigmatized perception of millet and sorghum. Coarse-grain foodstuffs are perceived as one of the only cereals that can be easily afforded by the extreme poor and, indeed, in many ways they are. Even though millet and sorghum cereals are exceedingly nutritious, rice and wheat have become the most popular cereal for reasons of color, taste, and general palatability. Understandably so, experiencing the vast textural difference of eating a flatbread cooked with wheat and a flatbread cooked with millet, it is clear that there is a literal significance to the term 'coarse' grain.

Rice and wheat are resource intensive crops with high nutrient demands, making them more expensive to produce. As a result, rice and wheat are more expensive household commodities. The high market price of luxury cereal is reflective of a social dynamic in India, which necessitates the superior demand for rice and grain. It is not solely the afforded luxury of staple foods that, despite their inferior nutritional value, are simply more enjoyable for people to eat. In fact, maintaining a food supply of high quality rice and wheat is one of the most basic household status symbols in Indian society. Cultural and religious dynamics embedded within the country's social hierarchy have also contributed to this perception of status.

Even if it is more costly for farmers to produce, the high market bid for rice and wheat offers a desirable risk for any farmer who, so long as their yield is successful, can receive a far greater return on their investment in any given growing season (Ghosal and Krishnan, 1995; Huang and David, 1993; Popkin *et al*, 2001). Since rice and wheat are preferred food sources to that of less appealing coarse-grains, and because they are lucrative crops to grow, it is foreseeable that smallholders will be hesitant to corroborate millet and sorghum as welcomed constituents of an ecological agriculture adaptation strategy.

4.0 Recommendations

For the many attributes that identify ecological agriculture as a sustainable adaptation strategy, there should be a triage of priorities to emphasize areas where adaptation is needed most urgently and where it can be achieved most effectively. Adaptation will be achieved most effectively through ecological practices that address the interconnected dependency of all three key areas: soil, biodiversity, and water.

The restoration of India's traditional water tank system should be prioritized to address the urgent issue of water shortage. This also addresses the issue of soil and the preservation of soil organic matter. Improved water supply will increase the availability of valuable crop residues, which will sustain crucial livestock populations and can be used for mulch.

Smallholder training and education services should also remain a priority. This will address all areas of urgency but will most effectively address the urgent need for improved biodiversity. Principle skills in plant breeding and seed saving are the most effective long-term adaptation tools for smallholders. This will require equitable collaboration between farmers and scientists.

Navdanya is a grassroots organization that focuses on the genetic conservation of India's resilient landraces by training farmers and promoting locally managed seed banks (Navdanya, 1995). The M.S. Swaminathan Foundation has initiated 26 professional research and training centers throughout the country. The highest mandate of each knowledge center is to address regional agro-ecological needs through knowledge-based empowerment among smallholder communities, offering practical information on sustainable adaptation methods such as System of Rice Intensification and Azolla intercropping. These are encouraging examples of collaboration.

Crop diversification and poly-cultures should be prioritized in order to address the urgent area of soil. The biodiversity of domesticated plant species will address all areas of urgency and will most effectively address the urgency to maintain and improve levels of soil organic matter, which in turn serves to strengthen soil health and conserve precious nutrients. Mono-crops of rice and wheat should be avoided. Cultivation of grain-producing plants should, first, be intercropped with nitrogen fixing legumes and, second, subject to a crop rotation schedule.

Despite social barriers to the following recommendation, there is immense adaptation value to the intercropping of climate resilient coarse-grains. Under the most destructive climatic conditions, there is no other grain-producing plant that has sustainably proven to exhibit resilience comparable to that of millet and sorghum.

Particular to India, the most interesting paradox is that of millet. Arguably, the exploitable opportunity within millet cultivation makes it the most valuable crop for agricultural adaptation while, simultaneously, it remains one of the most devalorized crops in Indian society. Considering this apparent dilemma, agricultural and social research on millet should be prioritized. In the holistic interest of ecological agriculture – that smallholders might incorporate millet as part of their adaptation strategy – it would be beneficial to further understand India's social structures that work to exclude the cultivation of millet. For acutely marginalized farmers who have minimal insurance to protect their livelihood from unforeseen adversity, cultivating an emergency crop of millet will guarantee a backup harvest, even under the worst-case scenarios of climate change. Without exaggeration, this agro-ecological safety net will not only protect rural livelihoods from ruin, but also protect poor households from an impending food shortage.

In 2011, Canada's International Development Research Centre disbursed US$ 3.5 million in funding for a 42-month, multi-donor initiative on *Revalorizing Minor Millets in Rainfed Regions of South Asia*. India is one of three countries where the valorization of millet is being studied, particularly in the states of Tamil Nadu, Orissa, and Jharkhand. The study is being conducted through a North-South partnership, between researchers from Canadian Mennonite University (Manitoba), University of Guelph (Ontario), and researchers from the Rainfed Farming Development Program of the Development of Humane Action Foundation (Tamil Nadu) (IDRC, 2011).

Participatory multi-stakeholder research on the use of millets in India should be prioritized. We know that ecological agriculture is a relevant adaptation strategy for Indian smallholders because it is a practical and holistic system of farming. However, even though ecological agriculture already exhibits a surplus of resilient traits that will support sustainable adaptation to climate change, smallholders' limited cultivation of millet represents a forfeit of a crucial opportunity.

Bibliography

Arumugasamy, S., Subramanian, K., & Sridhar, S. (2007). *Enhancing Soil Fertility in Organic Farming.* Chennai: Centre for Indian Knowledge Systems.

Badgley, C., & Perfecto, I. (2007). Can organic agriculture feed the world? *Renewable Agriculture and Food Systems, 22[2], 80-86*.

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M., Jahi, A., Katia, S., A., & Perfecto, I. (2007). Organic agriculture and the global food supply. *Renewable Agriculture and Food Systems, 22[2], 86-108*.

Bargout, R.N. (2010a). *Smallholder Rice Harvest in Uttarakhand: Adequate Water Supply*. Digital Image: JPEG.

Bargout, R.N. (2010b). *Smallholder Rice Harvest in Uttarakhand: Insufficient Water Supply*. Digital Image: JPEG.

Barker, D., Buiatti, M., Brunori, G., Fliessbach, A., Geier, B., Haerlin, B., Ho, M., Maracchi, G., Retallack, S., Shiva, V., & Vazzana, C. (2008). *Manifesto on Climate Change and the Future of Food Security.* Sesto Fiorentino, Italy: International Commission on the Future of Food and Agriculture.

Basu, P. (2000). *Trainer's Training Manual for Sustainable Agriculture and Biodiversity Conservation*. Delhi: Navdanya.

Bhatnagar-Mathur, P., Vadez, V., & Sharma, K.K. (2007). Transgenic approaches for abiotic stress tolerance in plants: retrospect and prospects. *International Crops Research Institute, 27, 411-424*.

Biksham, G., Sraban, D., Hajara, S., & Vinod, G. (2008). *Water for Life: Lessons for Climate Change Adaptation from Better Management of Rivers for People and Nature.* Goldalming, UK: World Wildlife Fund.

Boron, S. (2006). *Building Resilience for an unpredictable future: How organic agriculture can help farmers adapt to climate change.* Rome: United Nations Food and Agriculture Organization, Sustainable Development Department.

Brown, L.R. (2009, May 1). Could Food Shortages Bring Down Civilization? *Scientific American,* 23-45.

Burnell, P., & Randall, V. (2008). *Politics in the Developing World: Second Edition.* Oxford: Oxford University Press.

Department of Agricultural Cooperation. (2012). Union Budget 2012-2013: Notes on Demands for Grants, Demand No. 1. *Ministry of Agriculture, Government of*

India. Retrieved November 16, 2012, from http://indiabudget.nic.in/ub2012-13/eb/sbe1.pdf

Department of Agricultural Research and Education. (2012). Union Budget 2012-2013: Notes on Demands for Grants, Demand No. 2. *Ministry of Agriculture, Government of India*. Retrieved November 16, 2012, from http://indiabudget.nic.in/ub2012-13/eb/sbe2.pdf

FAO. (2007). *Adaptation to climate change in agriculture, forestry and fisheries: Perspective, framework and priorities.* Rome: United Nations Food and Agriculture Organization.

FAO. (2009). *Harvesting agriculture's multiple benefits: Mitigation, Adaptation, Development and Food Security.* Rome: United Nations Food and Agriculture Organization. Retrieved February 21, 2010, from ftp://ftp.fao.org/docrep/fao/012/ak914e/ak914e00.pdf

Gadgil, S. (1995). Climate Change and Agriculture – An Indian Perspective. *Current Science, 69[8], 649-659.*

Ghosal, A., & Krishnan, O. (1995). *Millets of India.* Delhi: Navdanya.

Grains Research and Development Corporation. (2008). *Scientists share keys to drought tolerance.* Kingston, Australia: Ground Cover.

Huang, J., & David, C.C. (1993). Demand for Cereal Grains in Asia: the effect of urbanization. *Agricultural Economics, 8[2], 107-124.*

IDRC. (2011). *Increasing Millet Production in South Asia.* Ottawa: Canadian International Food Security Research Fund. Retrieved November 19, 2012, from www.idrc.ca/EN/Programs/...and.../106506-South-Asia.PDF

IPCC. (2001). *Synthesis Report: A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.

Indian Institute of Tropical Meteorology. (2010). *2009: The Warmest Year Since 1901.* Delhi: Ministry of Earth Sciences, Government of India. Retrieved May 5, 2010, from www.imd.gov.in/doc/warm2009.pdf

India Meteorological Department. (2010a). *Rainfall (mm.) for the Month, Update June to Sept. 2009.* Delhi: Ministry of Earth Sciences, Government of India. Retrieved May 5, 2010, from http://www.imd.gov.in/section/hydro/dynamic/rfmaps/mapsmain.html

India Meteorological Department. (2010b). *Rainfall (mm.) for the Month, Update for Year 2009*. Delhi: Ministry of Earth Sciences, Government of India. Retrieved May 5, 2010, from http://www.imd.gov.in/section/hydro/dynamic/rfmaps/mapsmain.html

Jordan, R., Muller, A., & Oudes, A. (2009). *Organic Agriculture: a Guide to Climate Change and Food Security*. Bonn, Germany: International Federation of Organic Movements, European Union Group.

Kelkar, U., Narula, K.K., Sharma, V.P., & Chandna, U. (2008). Vulnerability and adaptation to climate variability and water stress in Uttarakhand State, India. *Global Environmental Change, 18, 564-574.*

Kothyari, U.C., & Singh, V.P. (1996). *Rainfall and Temperature Trends in India. Hydrological Processes, 10, 357-372.*

Kramer, S., Preneta, N., Kilbride, A., Page, L.N., Coe, C.M., & Dahlberg, A. (2011). *The SOIL Guide to Ecological Sanitation: First Edition*. Sherburne, NY: Sustainable Organic Integrated Livelihoods.

Kulkarni, C. (2009). *The Implications of Composting Toilets for Nitrogen Flows in Haiti.* Providence, RI: Center for Environmental Studies, Brown University.

Kumar, A. (2009). *Ladakh: Climate Change Affects Villagers*. Delhi: Bija, Navdanya.

Lane, A., & Jarvis, A. (2007). Changes in Climate will modify the Gography of Crop Suitability: Agricultural Biodiversity Can Help with Adaptation. *International Crops Research Institute for the Semi-Arid Tropics, 4[1], 1-12.*

Maeder, P., Fliebach, A., Dubois, D., Gunst, L., Fried, P., & Niggli, U. (2002). Soil Fertility and Biodiversity in Organic Farming. *Science, 296[1694], 411-424.*

Mendelsohn, R., & Dinar, A. (1999). Climate Change, Agriculture, and Developing Countries: Does Adaptation Matter? *The World Bank Research Observer, 14[2], 277-293.*

Navdanya. (1995). *The Navdanya Community Seed Register*. Delhi: Research Foundation for Science, Technology and Natural Resource Policy.

Navdanya. (2009). *Biopiracy of Climate Resilient Crops*. Delhi: Research Foundation for Science, Technology, and Ecology.

Niggli, U., Hepperly, P., Fliessbach, A., & Maeder, P. (2008). Does Organic Farming have a Greater Potential to Adapt to Climate Change? 16th IFOAM Organic World Conference, Proceedings of the Second Scientific Conference of the International Society of Organic Agriculture Research (ISOFAR), Cultivating the Future Based on Science. *Livestock, Socio-economy and Cross Disciplinary Research in Organic Agriculture, 2[19], 586-589.*

Pande, P., & Akermann, K. (2008). *Adaptation of small scale farmers to climate risks in India.* Eschborn, Germany: Sustainet India.

Pandey, B. (1994), Hybrid Seed Controversy in India. *Biotechnology and Development Monitor, 19, 9-11.*

Pankaj, M. K., & Rakshit, A. (2008). Consequences of Climate Change for Indian Agricultural Productivity and Land Use. *International Journal of Agriculture Environment and Biotechnology, 1[3], 160-162.*

Pimentel, D., & Berardi, G. (1983). Energy Efficiency of Farming Systems: Organic and Conventional Agriculture. *Agriculture, Ecosystems and Environment, 9[4], 359-372.*

Pimentel, D., Hepperly, P., Hanson, J., Douds, D., & Seidel, R. (2005). Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems. *American Institute of Biological Science, BioScience, 55[7], 573-582.*

Planning Commission Government of India. (2007). *Eleventh Five Year Plan 2007-2012, Vol. III: Agriculture, Rural Development, Industry, Services, and Physical Infrastructure.* Delhi: Oxford University Press.

Popkin, B.M., Horton, S., Kim, S., Mahal, A., & Shuigao, J. (2001). Trends in Diet, Nutritional Status, and Diet-related Noncommunicable Diseases in China in India: The Economic Costs of the Nutrition Transition. *Nutrition Reviews, 59[12], 379-390.*

Pretty, J., & Hine, R. (2001). *Reducing Food Poverty with Sustainable Agriculture: A Summary of New Evidence.* Essex, UK: University of Essex, UK Department for International Development, Bread for the World, Greenpeace.

Ramprasad, V. (1994). Conserving Biodiversity. *Economic and Political Weekly, 29[43], 2795-2797.*

Sathaye, J., Shukla, P.R., & Ravindranath, N. H. Climate change, sustainable development and India: Global and national concerns. *Current Science, 90[10], 314-324.*

Scialabba, N. (2000). *Factors Influencing Organic Agriculture Policies With a Focus on Developing Countries.* Rome: International Federation of Organic Movements Conference, United Nations Food and Agriculture Organization.

Sharma, S.K., Garg, A., & Lal, S. (2004). *India's Initial National Communication to the United Nations Framework Convention on Climate Change.* Delhi: Ministry of Environment and Forests, Government of India.

Shiva, V., & Tarafdar, J.C. (2009). *Climate Change at the Third Pole: Role of Organic Agriculture in Climate Change Mitigation.* Delhi: Navdanya Research Foundation for Science Technology and Ecology.

Sinah, S.K., & Talati, J. (2006). Productivity impacts of the system of rice intensification (SRI): a case study in West Bengal, India. *Agricultural Water Management, 87[1], 55-60.*

Singh, J., Pande, P., & Shiva, V. (2004). *Principles of Organic Farming: Renewing the Earth's Harvest.* Delhi: Navdanya.

Sontakke, N.A., Singh, H.N., & Singh, N. (2008). *Chief Features of Physiographic Rainfall Variations Across India During Instrumental Periods (1813-2006).* Pashan, India: Indian Institute of Tropical Meteorology.

Subramaniam, A.R. (1992). Climatic Variability in India. *Department of Meteorology and Oceanography, Andhra University Annals, 12[1], 1-13.*

Venkateswarlu, B., & Shanker, A.K. (2009). Climate change and agriculture: Adaptation and Mitigation Strategies. *Indian Journal of Agronomy, 54[2], 226-230.*