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Review

Soil management in mitigating the adverse effects of climate change

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Abstract

Emission of Green House Gases (GHGs) from various sources into the atmosphere causes rise in air temperature. This addition of GHGs has a great impact on the environment. Among the GHGs, carbon dioxide (CO_2) is the major contributor. A variety of options exists for mitigation of GHGs emissions in agriculture. The most prominent options are improved soil management practices viz. integrated plant nutrient management, precision agriculture (variable rate fertilizer technology), use of nitrification inhibitors, crop residue management, moisture restoration and restoration of crop productivity of degraded lands, which increase crop production per unit area, enhancing crop production and withdraw atmospheric CO_2 through enhanced photosynthesis. This paper shows that such improved soil management practices can restore the crop productivity of marginal lands and purify the air by withdrawing atmospheric CO_2.

Keywords: Mitigating, climate change, GHGs, atmosphere, temperature

The soil is a place for plants to grow-the factory that produces the plants which maintain human life. Soils and plants growing on them maintain the natural balance in the system and purify the air. Plants are the sources of the oxygen essential for life, converting one of man's major waste products, carbon dioxide, back to life-giving oxygen. In so doing, they produce the food and the fibers which are essential to our existence.

All of energy on earth as we find it, in the form of food, fiber, coal, oil, comes from plants that have grown in the soil while obtaining their energy from the sun. The only energy not obtained from the soil directly is electric power obtained from nuclear fusion, and even the uranium used in this process is obtained from the earth. With growing concern over our environment, and with the ever-increasing problems of waste disposal, it is comforting to know that the soil, when properly utilized, offers us almost unlimited potential for disposal and recycling of our waste materials.

Climate

Climate refers to the average weather over a certain period of time, usually a season, at a certain place. The atmosphere is the most dynamic part of the system and is therefore, responsible for most of the perceptible changes in the climate. Dry air is composed mainly of nitrogen, 78 % by volume, oxygen 21 %, and argon 0.9 %. These gases have very little interaction with the incoming solar energy, nor do they interfere with the infrared (heat) radiation emitted by the Earth. In addition, there are a number of trace gases, with a total volume of less than 0.1 %, such as carbon dioxide, methane, nitrous oxide and ozone which do adsorb and emit infrared radiation. These gases are responsible for the Greenhouse effect and play a crucial role in our planet's energy budget. Water vapor, present in the atmosphere, is also a natural greenhouse gas. Water vapor, carbon dioxide and ozone also adsorb short-wave radiation coming from the sun.

Climate Changes

Temperature

The average surface temperature of the earth is increased by 0.6 C° (with an uncertainty range of + 30 %) since the late nineteenth century. The 1990s was probably the warmest decade and 1998 the warmest year since 1860 IPCC, 2001). According to the Fourth Assessment Report of IPCC (2007), world temperatures could rise by between 1.1 to 6.4 °C during the 21st century.

Rainfall and humidity

Over the sub-tropics (10°N to 30°N), land-surface rainfall has decreased on average by 0.3 % per decade. At many places, this has been manifested in extreme events such as severe droughts experienced recently in Iran, Turkey, Jordan and Pakistan. Jordan's agricultural production has been greatly damaged by two years of drought. In fact, most countries in the middle east are suffering prolonged water shortages since about 2001 (Jameel, 2004).

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Snow cover and ice extent

In the Himalayas, glaciers are melting at record pace. The Dokriani Barnak glacier retreated more than 20 meters in 1998 alone; the Gangotri glacier in Nepal receded by 600 meters in the last 50 years. In the Tien Shien mountains, China, glacial ice has reduced by 25 % in the past 40 years. Ice over Mount Kilimanjaro has decreased drastically from as much as 12 sq. km. in 1910 to about 3 sq. km. in the year 2000 (Jameel, 2004).

Key changes at glance

Key climate changes during 20th century are summarized in table below:

Indicator	**Change**
Atmospheric concentration of carbon dioxide	280 ppm for the period of 1000-1750 to 368 ppm in year 2000 (~30 % rise)
Atmospheric concentration of methane	700 ppb for the period 1000-1750 to 1750 ppb in year 2000 (~ 150 % rise)
Tropospheric concentration of Ozone	Increased by 35 $\pm$ 15 % from 1750 to 2000; varies with region.
Global mean surface temperature	Increased by 0.6^{o}C over 20th century (30 % uncertainty).
Frequency and severity of droughts	In parts of Asia and Africa, frequency and severity of droughts rose in recent decades
Snow cover	Decreased by ~10 % since 1960s
EI Nino Events	More frequent and intense during last 20-30 years as compared to previous 100 years.

Source: Adapted from Jameel (2004)

Emission of green house gases (GHGs)

When we burn fuel, such as wood, coal, oil, and natural gas, in our furnaces, we also liberate vast amounts of carbon dioxide. By burning gasoline and diesel oil in our automobiles and trucks, we also liberate large amounts of carbon monoxide and carbon dioxide gases, as well as nitrogen oxide. As the population is increasing, production of carbon dioxide is also increasing. Scientists have predicted that increased production of carbon dioxide would create an "insulating blanket" in the atmosphere, causing the temperatures to warm up. Some have predicted that this would cause the polar icecaps to melt, resulting in a rising ocean level and the flooding of many coastal areas, including large cities of the world. Agricultural N_2O emissions are projected to increase by 35-60 % up to 2030 due to increased nitrogen fertilizer use and increased animal manure (FAO, 2003). But improved management practices and emerging technologies may permit a reduction in emissions per unit of food produced.

Adverse Effects of Climate Change

It seems obvious that any significant change in climate on a global scale would impact agriculture, and therefore affect the world's food supply. One relates to the degree of temperature increase and its geographic distribution. Another pertains to the concomitant changes likely to occur in the precipitation patterns that determine the water supply to crops, and to the evaporative demand imposed on crops by the warmer climate. It is very much dependent upon environmental variables and is in turn an important agent of environmental change.

Effects of higher temperature

In warmer, lower latitude regions, increased temperatures may accelerate the rate at which plants release CO_2 in the process of respiration, resulting in less than optimal conditions for net growth. When temperatures exceed the optimal for biological processes, crops often respond negatively with a steep drop in net growth and yield. If nighttime temperature minima rise more than daytime maxima-as is expected from greenhouse warming projections-heat stress during the day may be less severe than otherwise, but increased nighttime respiration may also reduce potential yields. Another important effect of high temperature is accelerated physiological development, resulting in hastened maturation and reduced yield (Vu *et al.*, 1997; Ofir *et al.*, 1993; Abrol and Ingram, 1996).

Moisture and water availability will be affected by a temperature increase, regardless of any change in precipitation. Higher temperatures increase the evaporation rate, thus reducing the level of moisture available for plant growth, although other climatic variables are involved. A warming of 1°C, with no change in precipitation, may decrease yields of wheat and maize in the core cropping regions by about 5% (Jameel, 2004). A very large decrease in moisture availability in the dryer regions of the world would be of great concern to the subsistence farmers that farm these lands. Reduced moisture availability would only exacerbate the existing problems of infertile soils, soil erosion and poor crop yields. In the extreme case, a reduction in moisture could lead to desertification.

Available water

Agriculture of any kind is strongly influenced by the availability of water. Climate change will modify rainfall, evaporation, runoff, and soil moisture storage. Changes in total seasonal precipitation or in its pattern of variability are both important. The occurrence of moisture stress during flowering, pollination, and grain-filling is harmful to most crops and particularly so to corn, soybeans, and wheat (Singh and Malik, 1987; Kazi *et al.*, 2002). Increased evaporation from the soil and accelerated transpiration in the plants themselves will cause moisture stress; as a result there will be a need to develop crop varieties with greater drought tolerance.

The demand of water for irrigation is projected to rise in a warmer climate, bringing increased competition between agriculture-already the largest consumer of water resources in semiarid regions-and urban as well as industrial users. Falling water tables and the resulting increase in the energy needed to pump water will make the practice of irrigation more expensive, particularly when with drier conditions more water will be required per acre. Additional investment for dams, reservoirs, canals, wells, pumps, and piping may be needed to develop irrigation networks in new locations. Finally, intensified evaporation will increase the hazard of salt accumulation in the soil.

Impact on water resources

Global climate and water resources are closely interlinked. Confirmation from climate change studies suggests that warmer temperature lead to intensification of the hydrological cycle (Lanen van *et al*., 2004; Demuth *et al*., 2006). The increased magnitude and frequency of extreme events entail the highest socioeconomic costs to human settlements. Droughts in Pakistan, Middle East and the Swahel region in Africa and intense flooding of low lying plains in Bangladesh, East Asia, Far East and present flooding in Pakistan provide the recent examples.

There are, however, regional variations in trends due to the high natural variability in climate as well as catchment properties for hydrological drought conditions in Europe (Hisdal, *et al.*, 2001).

Climate variability

Extreme meteorological events, such as spells of high temperature, heavy storms, or droughts, disrupt crop production. Recent studies have considered possible changes in the variability as well as in the mean values of climatic variables (Tallaksen and Van Lanen, 2004; Ramamasy and Bass, 2007). Where certain varieties of crops are grown near their limits of maximum temperature tolerance, such as rice in Southern Asia, heat spells can be particularly detrimental. Similarly, frequent droughts not only reduce water supplies but also increase the amount of water needed for plant transpiration.

Provinces of Balochistan, Sindh and southern Punjab were severely affected due to prolonged dry spell for three years (1999-2001), causing severe water shortages for human, livestock and agricultural uses. It has been estimated that 2.2 million people and 7.2 million heads of livestock were affected (PARC, 2002). The 2010 floods in Pakistan resulting from heavy monsoon rains (200 mm in 4 days) in the Khyber Pakhtunkhwa, Sind, Punjab and Balochistan regions of Pakistan caused heavy life and crop losses. Approximately, one-fifth of Pakistan's total area was under water. The floods directly affected about 20 million people mostly by destruction of property, livelihood and infrastructure, with a death toll of close to 2000. According to an estimate, 28340 ha of cotton, 81000 ha each of rice and sugarcane, 121000 ha of fodder crops, and 500'000 tonnes of stocked wheat were destroyed. In addition, about 200,000 livestock were killed and about 2.88 million ha of fertile land were eroded (Wikipedia, 2010).

During 2011 floods in the Province of Sind caused by heavy rains, 8,920,631 people were affected, 1,524,841 homes devastated, 2,749,420 ha of land damaged, 877,176 ha of crops wiped out,while 450 people lost their lives and 756 were injured (Wikipedia, 2011).

Soil fertility and erosion

Higher air temperatures will also be felt in the soil, where warmer conditions are likely to speed the natural decomposition of organic matter and to increase the rates of other soil processes that affect fertility. Additional application of fertilizer may be needed to counteract these processes and to take advantage of the potential for enhanced crop growth that can result from increased atmospheric CO_2. The continual cycling of plant nutrients-carbon, nitrogen, phosphorus, potassium, and sulfur-in the soil-plant-atmosphere system is also likely to accelerate in warmer conditions, enhancing CO_2 and N_2O greenhouse gas emissions.

Nitrogen is made available to plants in a biologically usable form through the action of bacteria in the soil. This process of nitrogen fixation, associated with greater root development, is also predicted to increase in warmer conditions and with higher CO_2, if soil moisture is not limiting. Where they occur, drier soil conditions will suppress both root growth and decomposition of organic matter, and will increase vulnerability to wind erosion, especially if winds intensify. Such "extreme precipitation events" can cause increased soil erosion.

A change in extreme weather events

A shift in global climate could bring about a change in the frequency and intensity of drought in already droughtprone regions. Years of successive extremes quickly lead to hunger and eventually widespread famine. An example of this is the devastating drought that affected the Sahel in northern Africa during the 1970s and 1980s (Jameel, 2004).

In recent years, however, there has been an unprecedented increase in the frequency of extreme events causing widespread death, disruption and destruction. Furthermore, unlike historical examples, these events reflect climate change arising largely from anthropogenic forcing.

1991: A catastrophic cyclonic storm in Bangladesh left 100,000 people dead.
1992: Worst flood of the 20th century in River Jhelum, Pakistan.
1998: Two thirds of land area of Bangladesh was inundated by flood water; more than 20 million people had to be evacuated.
1999: A severe tropical cyclonic storm hit the coastal areas of Southern Sindh, Pakistan; In Iran rainfall has decreased by as much as 25% since 1999.
1999-2001: Pakistan experienced one of history's worst droughts.
2000: Climate change was responsible for 150,000 deaths, 2.4% of diarrhea cases and 2% of malaria cases in the world.
2001: Islamabad, Pakistan flooded due to 621 mm rainfall during a 10-hour period in July.
2002: Extensive flooding in August in Eastern Europe.
2003: Violent forest fires devastated the environs of Canberra, Australia, in January (South hemisphere summer); An unprecedented heat wave in August led to 35,000 deaths in Europe.
2004: In July, heavy rains and rising river levels caused the worst flood of South Asia in sixteen years; two-third of Bangladesh came under water, over 30 million people were rendered homeless, and hundreds of thousands faced hunger and disease. In September, Bangladesh was flooded again due to five days continuous, 50-years record rainfall. Flooding twice in the same Monsoon season is a rare event in Bangladesh (Jameel, 2004).

Effect of elevated carbon dioxide concentration on plant growth

Life's basic reaction

All of our food, and basic energy, with the exception of nuclear energy, stems from one basic reaction-photosynthesis. The reaction in which energy is captured in green, living plants responding to sunlight, causing carbon dioxide to unite with water in the presence of chlorophyll-the green coloring matter in plants-to form simple sugars.

$$CO_2 + H_2O \xrightarrow{\text{light}} CH_2O + O_2$$

Plants grow through the well-known process of photosynthesis, utilizing the energy of sunlight to convert water from the soil and carbon dioxide from the air into sugar, starches, and cellulose-the carbohydrates that are the foundations of the entire food chain. CO_2 enters a plant through its leaves. Greater atmospheric concentrations tend to increase the difference in partial pressure between the air outside and inside the plant leaves, and as a result more CO_2 is absorbed and converted to carbohydrates (Campbell, 1986).

$$P_n = \frac{\rho_{ca} - \rho_{cc}}{r_{ca} + r_{cs} + r_{cm}}$$

Where P_n = net photosynthesis

ρ_{ca} = CO_2 conc. in the air
ρ_{cc} = CO_2 conc. in the chloroplast
r_{ca} = Boundary layer resistance
r_{cs} = Stomatal resistance
r_{cm} = Mesophyl resistance

Crop species vary in their response to CO_2. Wheat, rice, and soybeans belong to physiological class (called C-3 plants) respond readily to increased CO_2 levels. Under a doubling of carbon dioxide (with no other limiting factors) some studies have shown that growth rate in these crops increases by 10 to 50%. Crops of more importance as a source of food in the tropical regions are more efficient at photosynthesis under present day carbon dioxide concentrations but show little positive response to an increased concentration of the gas. Corn, sorghum, sugarcane, and millet are C-4 plants that follow a different pathway. The latter, though more efficient photosynthetically than C-3 crops, at present, levels of CO_2, tend to be less responsive to enriched concentrations. Thus far, these effects have been demonstrated mainly in controlled environments such as growth chambers, greenhouses, and plastic enclosures (Leakey, 2009). Experimental studies of the long-term effects of CO_2 in more realistic field settings have not yet been done on a comprehensive scale. Higher levels of atmospheric CO_2 also induce plants to close the small leaf openings known as *stomates* through which CO_2 is absorbed and water vapor is released. Thus, under CO_2 enrichment crops may use less water even while they produce more carbohydrates. This dual effect will likely improve water-use efficiency, which is the ratio between net photosynthesis and water loss by transpiration (Campbell, 1986; Geijn and De, 1996).

$$WUE = P_n / E = 0.67\ \rho_{ca} (1 - f) / \rho'_{va} - \rho_{va}$$

Where

WUE = water use efficiency

ρ'_{va} = standard water vapor density

ρ_{va} = ambient water vapor density

$$f = \begin{cases} 0.7 \text{ for C -3 plants} \\ 0.4 \text{ for C -4 plants} \end{cases}$$

At the same time, associated climatic effects, such as higher temperatures, changes in rainfall and soil moisture, and increased frequencies of extreme meteorological events, could either enhance or negate potentially beneficial effects of enhanced atmospheric CO_2 on crop physiology.

Climate change is associated with increasing atmospheric concentrations of atmospheric carbon dioxide; with higher levels stimulating the rate of photosynthesis, the growth rate and productivity of a plant could be expected to increase (Vu and Allen, 2009; Leakey, 2009).. Examples of these food staples include sorghum, maize, sugarcane and millet (C-4). C-4 crops are responsible for 40 per cent of world's grain harvest in 2006 (United State Department of Agriculture, Foreign Agricultural Service, USDA-FAS). The largest fraction of the world's C-4 grains is produced in the fertile regions of the USA (approx. 34 % in 2006; USDA-FAS). More than 25 countries in Africa and central America devote 50-88 per cent of their agricultural land to the production of C-4 crops.

The response of C-4 species to many factors of climatic and atmospheric changes, including temperature, precipitation, elevated CO2 concentration and land use, have been comprehensively reviewed by Sage and Kubien (2003).

Adaptations strategies for mitigating adverse effects of climate changes

The adaptation of agriculture to moderate climate change can be facilitated by improving irrigation, developing less water-demanding and more heat-resistant crop varieties, using minimum tillage and other practices to improve nutrient and moisture retention in soil, and changing timing of planting/ harvesting and other management activities. Any strategy adopted to increase crop production will mitigate the adverse effects of climate changes. The most adverse effects of climate changes related to soil problems are high temperatures and extreme events of drought and floods. High temperatures are the result of emission of Green House Gases (GHGs). This effect can be mitigated partly by following soil management strategies.

Integrated plant nutrient management (IPNM)

Integrated plant nutrient management for irrigated wheat

Data from an experiment on Integrated Plant Nutrition in wheat (Bakhsh *et al.*, 2001) showed that there was **a** significant response of wheat to the application of fertilizers whether applied alone or in combination with different organics. However, there was a greater response to fertilizers when combined with farm yard manure (FYM) i.e., 0.0062 t ha^{-1} per kg of fertilizers (NPK) followed by dhincha green manure with an increase of 0.0053 t ha^{-1} per kg of fertilizers (NPK). Response to fertilizers in combination with mung bean was low. It is obvious that efficiency of applied fertilizers is increased when combined with organics (Figure 1)

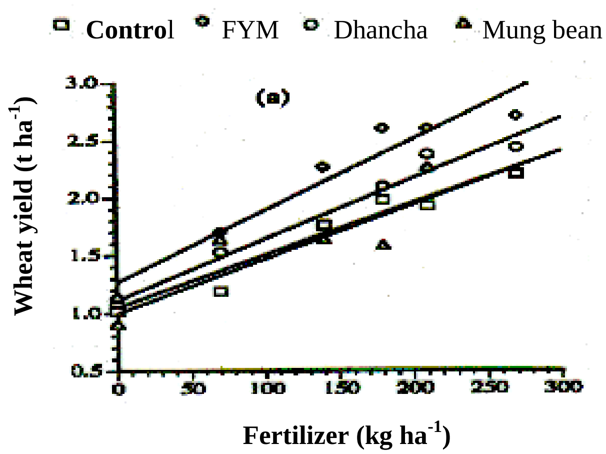

Figure 1: Effect of chemical fertilizers and organic manures on the yield of wheat

Integrated plant nutrient management for rice

Yield equations developed for response of paddy to fertilizers with different organics (Bakhsh *et al.*, 2001) showed that there was a significant response to the application of fertilizers (NPK) whether applied alone or in combination with different organics. The response to fertilizers with FYM was 0.012 t ha^{-1} per kg NPK; with dhancha green manure, it was 0.014 t ha^{-1}; and with mung bean green manure 0.0144 t ha^{-1}. The r^2-value for dhincha green manure was 0.99 showing the best fit. Moreover, the intercept for dhancha green manure equation was 4.4073 t ha^{-1} which was the highest yield without fertilizers, and only with green manure. It is clear from these results that the efficiency of fertilizers can be increased with organics combined with chemical fertilizers (Figure 2).

Integrated plant nutrient management for wheat on eroded land

Yield data collected from various fertilizer treatments at Thana, Malakand Agency, (Bhatti *et al.*, 1998) showed that the differences among various treatments were significant (p<0.05) (Table 1). The significantly highest yield of 3997 kg ha^{-1} was obtained from treatment receiving FYM in combination with NPK Zn which gave an increase of 58% over T-1 (farmer's practice) and 23% over T_2 (NPK Zn). This was followed by the treatment receiving NPK Zn (T_2) which gave an increase of 28% over the farmer's practice (T-1). The significantly lowest yield of 2536 kg ha^{-1} was obtained from the farmer's practice. Reduction of N (60 kg ha^{-1}) by the addition of FYM produced the highest grain yield. The results showed that the IPNM can restore the crop productivity of degraded lands which can be seen from figure 3.

yield significantly over control (Table 2 and Figure 3). As regards increase in yield, T_2 registered an increase of 38% over T3 and 53% over T1.

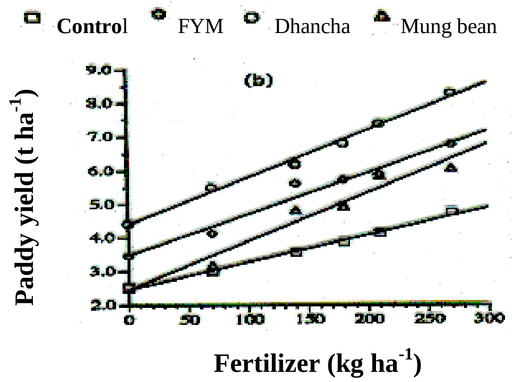

Figure 2: Effect of chemical fertilizers and organic manures on the yield of paddy

Table 1: Effect of various fertilizer treatments on the grain yield of wheat at Thana Malakand Agency

Treatment				FYM	Yield	Increase over	
N	P_2O_5	K_2O	Zn			T_1	T_2
kg ha^{-1}				t ha^{-1}	kg ha^{-1}	kg ha^{-1}	
60	45	0	0	0	2536 c	-	-
120	90	60	5	0	3241 b	705 (28*)	-
60	90	60	5	20	3997 a	1461(58*)	756(23*)

Means followed by similar letter(s) do not differ significantly from one another. *Values in parentheses refer to % increase
T1: Farmer's practice; T2: NPK Zn

Table 2: Straw yield of wheat as influenced by various fertilizer treatments at Thana

Treatment				FYM	Yield	Increase over	
N	P_2O_5	K_2O	Zn			T_1	T_2
kg ha$^-$				t ha^{-1}	kg ha^{-1}	kg ha^{-1}	
60	45	0	0	0	5864 b	-	-
120	90	60	5	0	8121 a	2257 (38*)	-
60	90	60	5	20	9000 a	3136(53*)	879(11*)

Means followed by similar letter(s) do not differ significantly from one another. *Values in parentheses refer to % increase
T1: Farmer's practice; T2: NPK Zn

Table 3: Comparison of variable with uniform fertilizer rate on the yield of wheat

N rate	Yield (kg ha^{-1})	
	Variable	Uniform
0	3701	3650
28	3896	3499
56	4162	3852

Data collected regarding straw yield as influenced by various fertilizer treatments showed that the treatment receiving NPK Zn alone and the one with FYM plus NPK Zn, were comparable with each other (Table 2). However, both of these treatments (T2 and T_3) increased the straw

Variable rate fertilizer management

Bhatti and Mulla (1995) studied the spatial variability of soil properties and wheat yields on complex hills in a large field (22 ha) near Colfax, Washington State, USA. They devised a variable rate fertilizer management strategy based on the differences in soil fertility status of the field and compared the variable rate strategy with the uniform rate application (Table 3). They found that grain yields in each management zone under variable rates of N were considerably higher than those in uniform rate strategy. As regards the economics of fertilizer use, lower rate of N (21 kg ha^{-1}) on the average was used in variable rate strategy as compared to uniform rate (101 kg N ha^{-1}). Net profit in variable strategy was \$ 601.91 ha^{-1} as compared to \$554.31 ha^{-1} in uniform strategy (Table 4). Using the variable rates of fertilizer increased the net profit by \$57.60 ha^{-1} over uniform rate of N (Table 4).

Bhatti *et al.* (1998 a) studied the spatial variability of soil properties and wheat yield on an eroded field at Thana, Malakand Agency, for determination of fertilizer rates. Soil properties as well as wheat yields exhibited spatial patterns. These spatial patterns were used to divide the field into three different management zones. Variable rates of N were compared with the recommended uniform rate of N (Bhatti *et al.*, 1998b). The results (Table 5) showed that variable rate of N application gave higher cost: benefit ratio than the uniform rate. In zones I and II, respectively, 40 and 10 kg N ha^{-1} (variably fertilized strip) was applied less than the adjacent uniformly fertilized strip (Table 6).

Use of nitrification inhibitors

Nitrification inhibitors are used to inhibit nitrification of NH_4 by soil bacteria. The most extensively tested inhibitor is nitrapyrin. Nitrapyrine is known to inhibit the first step in nitrification, the oxidation of NH_4 to NO_2 by inhibiting the cytochrome oxidation by nitrosomonas. Abbassi *et al.* (2003) reported that addition of nitrapyrin resulted in a decrease and delay of NH_4-N disappearance, accumulation of much lower soil NO_3-N contents and a substantial reduction in N_2O emissions (Shah *et al.*, 1997; Shah, 1998).

Figure3: Response of wheat to various fertilizer treatments

Incorporation of crop residues

Crop residues are important renewable but scattered organic sources which are readily available to farmers. These can be directly applied to the field. Their effects on improving soil physical properties, conserving soil moisture and controlling weeds are well recognized. Crop residues on decomposition, supply plant nutrients to the succeeding crop. However, C:N ratio of crop residues is an important consideration while incorporating crop residues. While using wide C:N ratio materials, care should be taken to supplement with nitrogen and phosphorus, otherwise crop growth will suffer due to their deficiency caused by microbial immobilization during the initial period of decomposition. Incorporation of crop residues especially of legumes (Table 7) increases the yield of succeeding crop considerably (Shah *et al*, 1999).

Table 4: Economics of fertilizer use under the two management strategies

Strategy	Fertilizer applied (N)	Yield	Value of produce	Cost of fertilizer	Profit
Variable	21 kg ha^{-1}	3867 kg ha^{-1}	609.05 \$ ha^{-1}	7.14 \$ ha^{-1}	601.91 \$ ha^{-1}
Uniform	101	3674	578.65	34.34	544.31
Net profit over uniform strategy					57.60

Table 5: Economics of fertilizer application for the two strategies

Management strategy	Fertilizer	Yield	Cost: benefit-ratio
	kg ha^{-1}		
Variable	111-90-60	3631	4.35
Uniform	120-90-60	3729	4.29

Table 6: Grain yield resulting from different management units

Management Zone (N kg ha^{-1})	Grain Yield (kg ha^{-1})	
	Uniform	Variable
I (80 vs 120)	3434	3302
II (110 vs 120	3928	3454
III (125 vs 120)	3650	3923

Table 7: Effect of crop residues incorporation on the yield of wheat at Kabal, Swat

Crop rotation	Grain yield (kg ha^{-1})	
	Without residues	With residues
Wheat – maize – wheat	599	1115
Wheat – mung – wheat	993	1170
Wheat + N – mung – wheat	1982	2380

Management of marginal lands (salt affected soils)

A field experiment conducted to study the effect of different treatments on the yield of rice and wheat on a salt affected soil at Dera Ismail Khan in a farmer's field (Bhatti *et al*., 2005) showed that the differences among the paddy yields from various treatments during 2001 were not significant (Table 8). The effects of various cropping systems on the yield of wheat during 2001-2002 were highly significant ($p < 0.01$). Comparing treatments, yield of the gypsum treatment (T_2) was significantly higher ($p < 0.01$) than the other treatments. This was followed by the farmyard manure treatment (T3), which was significantly higher ($p < 0.01$) than the remaining treatments. The yields obtained from dhancha as green manure (T5) were comparable with the control (T1).

For paddy yield in 2002 all management practices increased the yields significantly over the control ($p < 0.01$). The highest yield was obtained n treatment T4. This might be due to the green manure effect of berseem on organic matter content and physical properties of the soil.

As with the results during the kharif of 2002, all treatments were also significantly greater ($p < 0.01$) over the control in the yield of wheat during 2002-2003 (Table 1). However, significantly higher yields ($p < 0.01$) were found in T5 (dhancha as green manure) and T3 (FYM). The reason for higher yield in dhancha as green manure and FYM plots might be due to their effects on organic matter and physical properties of the soil. Thus, even though during the first cropping season there were no significant effects on paddy yield, the various management practices had a significant effect on the yield of the following wheat and paddy rice crops. Especially for the last rice and wheat crops, green manure with berseem and dhancha were more effective than the other treatments followed by FYM. These results were most likely due to improvement in organic matter and physical conditions of the soil.

Moisture Conservation

Soil and Water Conservation Research Institute (SAWCRI), Chakwal has developed cost effective farm water control structures for the storage and safe disposal of rain water (Rashid *et al*., 2008b). They have installed more than 65 such structures with a very low cost in the districts of Attock, Chakwal, Jehlum and Rawalpindi. The efficiency of these structures was evaluated during monsoon 2002-2003. All the structures showed excellent performance. These structures are affordable by the farmers from their own resources. Crop productivity of various sites was increased by 20 to 25 % due to these structures. Scientists at SAWCRI also have successfully conserved soil moisture through application of gypsum. Gypsum application at the rate of 2.5 t ha^{-1} increased the yield of wheat by 46 % during the years of low rainfall (Rashid *et al*., 2008a); such practices will mitigate the adverse effects of drought.

It has been reported by Moss (1984) that each kg of dry matter of maize contains approximately 17.6 x 10^6 J of energy. Ten photons are required to reduce 1 molecule of CO_2 to the average reduction state of plant material. One photon having a wavelength of 0.55 µrn would have an energy equal to 3.6 x 10^{-19} J. Thus 3.6 x 10^{-18} J would be required for reduction of 1 molecule of CO_2. This shows that 4.89 x 10^{24} molecules of CO_2 will be reduced to produce 1 kg dry matter of maize. So increasing the dry matter yield of agricultural crops will consume huge amounts of CO_2 which will help in minimizing the adverse effects of CO_2.

It has been shown by these examples of improved soil management practices given in this paper that various soil management practices increase crop production per unit area. Carbon lost to the atmosphere can be recovered through these management practices, thereby withdrawing atmospheric CO_2. Such practices increase the photosynthetic input of carbon, sequestering carbon or building carbon sinks. West and Post (2002) reported that use of crop rotation with legume crops reduce reliance on

Table 8: Effect of various management practices on the yield of rice and wheat on a salt affected soil

Treatment	Yield			
	Rice 2001	Wheat 2001-02	Rice 2002	Wheat 2002-03
	kg ha^{-1}			
T_1: Rice-Wheat-Rice-Wheat	3707 a	3972 c	6400 d	3466 c
T_2: Gypsum+Rice-Wheat-Rice-Wheat	3858 a	5271 a	6900 c	3900 b
T_3: FYM+Rice-Wheat-Rice-Wheat-Berseem	3825 a	4281 b	6600 c	4066 ab
T_4: Rice-Berseem-Rice-Berseem	3550 a	-	7133 a	-
T_5: Dhincha(Green Manure)-Wheat-Rice-Wheat	-	3976 c	6800 b	4233 a

Means followed by the same letter (s) in each column are not significantly different at $p < 0.01$ using an LSD test external inputs. These fluxes of GHGs can be reduced by more efficient management of carbon and nitrogen flows in agricultural ecosystems. Practices that improve efficiency of added N often reduce N_2O emission. Schelsinger (1999) reported that improving N use efficiency can reduce N_2O emissions and indirectly reduce GHGs emissions from N fertilizer manufacture. Cerrie *et al*. (2004) reported that avoiding the burning of crop residues also avoids emissions of aerosols and GHGs generated from fire. These crop residues can be incorporated into the soil, which increase the soil carbon. Conservation measures can also enhance carbon storage in soils through enhanced yields and residue returns (Lai, 2004).

In the above examples, integrated plant nutrient management, variable rate fertilizer technology (precision agriculture), use of inhibitors, crop residue management and moisture conservation practices increase fertilizer use efficiency. The ultimate result is enhancement of photosynthetic activity and carbon sequestration, and mitigation of release of GHGs from agricultural ecosystems.

Conclusion

It can be concluded from this review paper that various soil management practices viz., integrated plant nutrient management, variable rate fertilizer technology (precision agriculture), use of N inhibitors, restoration of crop productivity of marginal lands, crop residue management, and moisture conservation measures increase crop production per unit area through increasing fertilizer and water use efficiency This will ultimately mitigate the emission of GHGs into the air and improve the sequestration of CO_2.

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