Sustainable agriculture and fertilizer use

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Sustainable agriculture must produce enough food and fibre to satisfy changing human needs while conserving natural resources, maintaining the quality of environment and ultimately leading to community and gender equity. In the developed countries in Europe and to some extent in USA, chemical fertilizer has been held as a major culprit for environmental pollution, especially the nitrate enrichment of groundwater. However, evidence available also indicates that, animal slurry and septic cess pools largely contribute to nitrate enrichment of groundwater and also to environmental pollution with ammonia and nitrogen oxides (NO_x). There are other sources of environmental pollution such as exhaust fumes from motor vehicles, flyash from thermal power plants and other industrial effluents. Developing countries such as India, reeling under population pressure with no additional cultivable land are forced to increase their fertilizer consumption, which as of today is much less than the actual crop needs. Nevertheless, we must learn lessons from the ill-effects of overuse of chemical fertilizer by developed countries and use it judiciously with a well-planned integrated plant nutrient supply system.

SUSTAINABILITY of our agricultural systems is of global concern today and many definitions of sustainable agriculture have become available. The five main components of these definitions are:

- production of enough food and fibre to meet the increasing and changing needs of the people;
- conservation of natural resources;
- maintaining the quality of environment;
- achieving community and gender equity; and
- avoidance of regional imbalances

Why do we need fertilizers

In agriculture we convert solar energy into chemical energy, i.e. food, feed or fibre. It is common knowledge that this is achieved with the help of chlorophyll in plants. Keeping at optimum other conditions such as solar radiation, temperature, etc. the more the chlorophyll the higher the biomass and it is likely that more food is produced. However, for doing this plants need adequate supply of 13 elements (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, Mo, Cl) from soil, which are known as essential plant nutrients. Fertilizers are the chemicals that supply these essential plant nutrients, mostly N, P and K, which are removed by crop plants in the largest quantities.

In one study at New Delhi[1] 28 kg N, 4.4 kg P, 41 kg K, 4.9 kg S, 5.9 kg Ca, 4.2 kg Mg, 400 g Fe, 100 g each of Mn and Zn and 30 g Cu were removed from the soil for each tonne of wheat grain produced. Similarly from the International Rice Research Institute, Philippines[2] it is reported that 10–31 kg N, 1–5 kg P and 8–35 kg K were removed from the soil per tonne of rice grain produced. When crop yields of 5–8 t grain ha^{-1} are taken as with the high yielding varieties of crops, it is not possible for most soils to supply the needed amounts of plant nutrients and that is why fertilizers are needed. Such heavy removal of plant nutrients from soil leads to depletion of soil fertility, which shows up in crop yield decline and lowered factor productivity[3]. For example, in a long-term study[4] at four research centres rice yields declined by 32% in plots receiving nitrogen and phosphate fertilization; the decline in unfertilized plots was 57%. From the dryland rainfed areas where yields are low and very little fertilizer applied, a negative balance between crop removal and plant nutrient application of 6.37 million tonnes yr^{-1} ($N + P_2O_5 + K_2O$) in India has been reported[5]. Thus contrary to lowering the rates of fertilizer application, Indian farmers may have to think of fertilizing for crop production as well as for soil fertility resilience. Thus fertilizer has been and will continue to be the king input in India's achieving self sufficiency in foodgrain production.

Fertilizers and sustainability of agriculture

For the last three decades all over the developed world fingers have been raised on fertilizer, particularly nitrogen, as the number one enemy of sustainable agriculture[6–10]. One should not be surprised to see this happen if the rates of application are too high such as in Netherlands[11]. Nitrogen is a mobile nutrient both in plants

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and soils and considering the fact that its efficiency (nitrogen taken up by the above ground portion of crop expressed as percentage of that applied) varies from 30–40% in rice to 60–80% in other cereals[12], a sizeable amount could be added to the environment as ammonia by volatilization from soil surface[10,13–16], nitrous oxide or elemental nitrogen by denitrification which is not restricted to tropical rice regions[17,18], but also applies to temperate regions[19–23] and finally as nitrates by leaching in underground water[6–9]. The ammonia going in the atmosphere contributes to acid rains, while N_2O is involved in depletion of ozone layer. What one generally overlooks is that in the case of nitrogen fertilizers we recycle atmospheric nitrogen which is the raw material for ammonia and urea manufacture. Atleast 30–50% of it is converted into human edible food and about one-third is immobilized in the soil and only the rest goes back to atmosphere either as ammonia or as N_2O or N_2 after denitrification of nitrates. Phosphates, which are not so mobile in soil and get fixed in the soil as insoluble compounds could also leach from very light soils and may also move with eroded surface soil to surface waters such as lakes and ponds. Within the European Union, the average load of nitrogen in 1990 ranged from 35 kg N ha^{-1} in Spain to 195 kg N ha^{-1} in the Netherlands and average loads of phosphate ranged from 17 kg P_2O_5 ha^{-1} in Spain to 57 kg P_2O_5 ha^{-1} in the Belgium[24]. So great has been the concern of European researchers regarding pollution caused by fertilizers (and manures) that it has been referred to as a 'chemical time bomb' and to overcome the explosion of this the need for immediate change in the land management amounting to abandonment of part of the agricultural land has been suggested.

Pollution of waters

More than any other aspect of environmental degradation, pollution of surface and underground waters due to fertilizers has received greater attention. Water can be broadly classified into four categories: (i) non-flowing such as lakes and ponds; (ii) flowing such as rivers and canals; (iii) river estuaries and (iv) underground water.

Both nitrogen and phosphorus eutrophication of lakes and ponds leads to excessive growth of aquatic plants (macrophhytes) and algae (phytoplankton), which deplete the water of oxygen and this may lead to death of fishes and other aquatic animal life. Furthermore, algal and decaying algal and aquatic plant tissue can lead to discolouration and bad odour and this affects recreational and aesthetic water uses.

As regards flowing water, phosphorus is the limiting nutrient. When all phosphorus is used, plant growth ceases irrespective of the amount of nitrogen available[24]. Thus only if adequate phosphorus is available, increasing concentration of nitrates will lead to algal and macrophyte growth.

In estuaries, on the other hand, nitrogen controls the growth of algae and macrophytes. In USA nitrates and phosphates are suspected of causing *hypoxia* of the Dead Zone of Gulf of Mexico. Nutrient-enriched run-off from agriculture is also incriminated in the *pfiesteria* problem that killed a large number of fish in the Chakaspeake Bay, USA[25]. The recommended level of nitrogen is 0.1 to 1 mg l^{-1}, while the recommended level of phosphorus is nearly one-tenth of that of nitrogen[24].

Underground water is the major source of drinking water in India and even in developed countries like USA, 90% of the rural population depends on it for drinking water. The safe limit or MCL (maximum contamination level) established by the US Environmental Protection Agency is 45 mg NO_3–N or 10 mg N l^{-1}. The European Union has fixed MCL limit at 50 mg NO_3–N or 11 mg Nl^{-1}. Levels above this may lead to methaemoglobinaemia or blue baby syndrome. This is due to conversion of haemoglobin to methaemoglobin due to nitrites formed from nitrates ingested with drinking water. Haemoglobin is involved in transport of oxygen in the body, while methaemoglobin cannot and thus the patient suffers from anexia (lack of oxygen). There are some indications that excess nitrates in the human body may react with amines and form nitrosamines that may lead to gastric cancer, but substantive data are missing.

In India the highest rate of fertilizer N is in Punjab, where an increase in shallow well waters from 0.04–6.15 in 1975 to 0.31–13.3 mg NO_3–Nl^{-1} in 1988 has been reported[26]. A recent survey in Delhi reported[27] a range of 26–150 mg NO_3–Nl^{-1} in shallow well water, which is very high constituting a warning.

Other sources responsible for environmental pollution

There are a number of sources other than fertilizers which are responsible for environmental degradation. These include livestock and human excrement in rural areas and leaking septic systems, sewage, combustion of fossil fuels in motor cars and other vehicles in urban areas. Industries that use nitrates in their manufacturing processes such as meat curing, production of explosives including fire crackers, heat transfer fluid, etc. may also release substantial nitrates in their effluent water. Precise estimates on all these are not available. The available information is briefly discussed.

Livestock excrement

Ammonia emissions from dairy farms are one of the major sources of environmental pollution in Europe. Losses of ammonia occur during slurry application, housing, slurry storage and grazing. On an average 30% of nitrogen excreted by farm animals is released to the atmosphere as ammonia[10] and the bulk of it is contributed by urine. Estimates indicate that 50–90% of N contained in urine is urea and 4–41% of N from applied cattle urine may volatilize[28]. Estimated nitrogen excretion and ammonia emission in Western Europe are given in Table 1. The average ammonia emission per unit land area in Western Europe is 12 kg N ha^{-1} yr^{-1} and the highest is 45 kg ha^{-1} yr^{-1}; as a contrast ammonia emission from growing arable crops is estimated at 1–2 kg ha^{-1} yr^{-1}. What is to be noted is that ammonia emitted is not deposited in the same area but transported to other areas depending upon wind direction and velocity[16].

In India where cowdung is mostly used as cooking fuel, loss of nitrogen could be partly as ammonia during storage of wet dung but mostly as nitrogen oxides (NO_x) when the cowdung cakes are burnt. Nevertheless it does contribute to environmental pollution. We need to measure and generate data on this.

Ammonia emission is not the only way the animal excreta contributes to environment. After its application to soil, most of ammonia produced is retained by the soil exchange complex and is gradually nitrified. Nitrates are then leached to deeper layers and contribute to underground water pollution[29,30]. From a study in a rural community in California (USA)[31], based on ^{15}N ratio studies it was concluded that much of the nitrate in groundwater came from sewage or manure. As already discussed, under anoxic conditions nitrates are denitrified to nitrous oxides or elemental N (generally referred to as NO_x)[18,21,32].

In UK limits of organic manures have 250 kg N ha^{-1} on grassland and 210 kg N l land in nitrate vulnerable zones (NVZ); arable land will be reduced to 170 kg N December 2002 (ref. 33).

Septic systems and sewage

Septic systems and cesspools (a pit or a sewage collects) in heavily populated areas Island in USA have been major sources groundwater for decades and public suppl upper glacial aquifer of Nassau county were 1949 because of nitrate contamination[34]. estimated that 11.6 metric t N km^{-2} were cesspools and septic systems in the Nassau cou

In addition to nitrates, sewage sludge is tributor of toxic heavy metals such as Cd, P (Table 2)[36]. The damage may be caused by because the composition of crops may becc for human and animal consumption and at to the growth of crops[37].

Thermal power houses

While phosphate fertilizers have been bla aminating soil with heavy metals[38], thermal could also do it in their vicinity by gener

Table 1. Estimated nitrogen excretion and ammonia emission from Western Europe

Livestock	Number (millions)	N excretion (Kt N yr^{-1})	Ammonia emission (Kt N yr^{-1})		
			Stable + storage	Spreading	Grazing
Cattle < 1 yr	28	944	124	130	23
Cattle 1–2 yr	20	1572	163	161	59
Cattle > 2 yr	45	4656	634	586	123
Pigs for slaughter	76	1012	258	136	–
Boars & sows	12	402	100	56	–
Sheep	101	2147	27	58	86
Goats	9.4	296	3.7	7.2	12
Horses	3.2	161	5.3	15	7.6
Laying hens	413	309	33	103	–
Table fowl	562	198	38	12	–
Total		11697	1386	1264	310

Source: Ferm[16].

Table 2. Ranges for heavy metal concentrations in sewage sludges (mg kg^{-1} dry weight)

Country	Ni	Cd	Zn	Cu	Pb
UK	20–5300	2–1500	600–20000	200–8000	50–3600
USA	12–2800	2–1100	72–16400	84–10400	800–26000
Sweden	15–2120	2–171	700–14700	52–3300	52–2900
Canada	7–1500	2–147	400–19000	160–3000	85–4000
Australia	20–320	2–185	240–5500	250–2500	55–2000

Source: Webber[36].

posal of flyash. Of the total power production in India, 65.3% (during 1989–90) came from thermal power production[39]. About 35 million tonnes (MT) of flyash was produced from this and its value may rise to 125 MT by the turn of the century[40]. Considerable amount of flyash can be emitted into surrounding environments and the main method of disposal is by mixing the ash with water, the resultant slurry is then pumped to disposal ponds[41]. Heavy metal composition of fly ash from the Indraprastha and Rajghat Power Houses at New Delhi and the range of these in the soil in their vicinity is given in Table 3. In addition to heavy metals, coal also contains some nitrogen[42] and most of it will be lost to atmosphere as NO_x, which is yet another addition to environmental pollution.

Fossil fuels

Burning of fossil fuels in vehicles also contributes to NO_x to the atmosphere (Table 4)[43,44]. In a recent study in US[45], 24–29 tonnes of NH_3 day^{-1} were emitted from a vehicle fleet in the South Coast Air Basin that surrounds Los Angeles. These emissions were from vehicles fitted with three-way catalytic converters designed to reduce NO_x to N_2 and O_2. More studies are needed to find out the accurate global emissions of NO_x and ammonia from vehicles.

Biological nitrogen fixation

Biological nitrogen fixation (BNF) is considered as one of the major ways[46] by which the crop needs of fertilizer nitrogen can be partly (30–60 kg N ha^{-1})[47,48] met; the rates for green manuring[49] could be 80–185 kg N ha^{-1}. There can be no two opinions about it, and infact legumes as restorer of soil fertility have been known since ages[50–52].

Estimates of total annual terrestrial BNF range from 139 to 170 MT[53–55] with symbiotic N fixation in arable farming accounting for 35–44 MT N, and another 45 MT from permanent pastures and the rest from non-symbiotic N fixation. In comparison, only 91 MT of fertilizer N was globally manufactured in 1996–97; which is only 53–65% of biologically fixed N. The point to consider is that nitrogen fixed by BNF also enters the soil nitrogen pool and while some of it is available to associated crop[56–58], most of it is made available to the succeeding crop. Biologically-fixed N is much more readily available to plants than the native soil organic N, nevertheless, a part of it is also subject to loss. For example, a loss of 28–29% of nitrogen fixed by *Crotolaria* sp and *Sesbania* sp has been reported when these legumes were green-manured to rice[59], as compared to 36% from urea nitrogen. Similarly in maize[60] loss of *Leucaena* nitrogen was 25–30%, while that from ammonium sulphate was 14–35%. Thus part of biologically-fixed nitrogen may also contribute to environmental pollution including nitrate enrichment of groundwater. BNF is reported to contribute as much as 13.5% of total N_2O emission to the atmosphere[44], which was equal to the amount contributed by fertilizers (Table 4).

Thus there are many sources other than chemical fertilizer which are responsible for polluting atmosphere with NO_x and ammonia.

India's foodgrain needs

In 1951, we were only 361 million people and by 2000 AD, another year from now, we will be 1004.5 million, nearly trebling our population in the second half of twentieth century. A well-planned and concerted effort by agricultural scientists, extension workers, farmers and the government price support policies have made 'green revolution' realizable by increasing grain production at a rate faster than the increase in population. This has kept us away from hunger despite some very bad drought years. Hungry people can hardly think of a quality environment. Three major inputs that have made it possible are: seeds of high yielding varieties of crops, fertilizer and increased irrigation facilities. But then it is not all over and although there are good signs of decline in the rate of population increase from 2.14 to 1.70%, we are still likely to add another 420.5 million people in the next 20 years by 2020 AD, that is about 21 million people each year. This will certainly increase our food demand.

The total foodgrain demand by 2020 is estimated at 294 MT (122 MT rice, 103 MT wheat, 41 MT coarse grains and 28 MT pulses)[61]. Thus by 2020 we need to produce about 100 MT of additional food grain yr^{-1} from the same or even less area (some more area will go to meet the increasing needs for roads, rails, buildings, etc.). We have no choice but to increase the fertilizer application. During 1980–90 there has been 3–4% decrease in fertilizer nitrogen consumption in Europe and USA[62], while in Asia it has increased by 74.4%. In India

Table 3. Concentration (mg kg^{-1}) of some heavy metals in flyash and soil in the vicinity of thermal power houses at Delhi

Thermal plant/soil	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn
Indraprastha	0.6	5.2	39.4	28.6	204	21.6	17.4	33.9
Rajghat	0.4	3.3	35.4	19.3	204	13.4	12.0	18.2
Soil (range for 2–8 km distance)	0.78–1.91	14.4–47.0	48.1–72.7	15.1–56.3	308–688	16.4–36.4	16.8–92.9	53.0–164

Source: Mehra *et al.*[41].

Table 4. Global sources of N_2O

Source	Per cent of total global N_2O emission
Natural (oceans, lakes, soils)	54.7
N-fertilizers	13.5
Biological N-fixation	13.5
Fossil energy	8.8
Burning biomass	6.8
Recultivation	2.7

Source: Isermann[44]

the current fertilizer consumption is much below the mark. Only 19 out of 437 districts in India consumed more than 200 kg $N + P_2O_5 + K_2O$ ha^{-1} in 1996–97, while 176 districts consumed 50 kg ha^{-1} or less[63].

The way out

Social scientists are quite right in pointing out regional imbalances and lack of equity among communities due to modernization of agriculture, but fertilizers do not come in the way of achieving either of these social goals. There are other factors responsible such as lack of infrastructure, lack of small scale agro-industry and the need for appropriate government policies, etc. Only a carefully planned sustainable agriculture can provide a sustainable livelihood security for the poor, which should be the foundation for all development programmes. Gandhiji called such an approach to the development as 'Antyodaya' model, which even foreigners[64] are talking about and in its operational sense implies that the priorities in development should be measured by their potential benefit to the poorest sections of the community. In this exercise food of course will come as the first priority and in countries like India it can be produced only by the judicious use of fertilizers.

As regards environmental problems we have to find out ways to overcome these and reduce pollution hazards. A number of techniques are used by agricultural scientists for reducing nitrate leaching losses. These include growing high-yielding crop varieties, deep placement and split application of nitrogen fertilizers, use of ammonium or amide fertilizers and adopting an integrated plant nutrient system (IPNS).

Dudal and Roy[65] defined IPNS as an approach which adapts plant nutrition to a specific farming system and particular yield targets, the physical resource base, the available plant nutrient sources and the socio-economic background. The sources of plant nutrients may be mineral fertilizers and/or biological nitrogen fixation and/or organic materials depending upon a particular location. The FAO–IFFCO International Seminar on IPNS[66] recommended that IPNS should be science-based, associating agronomy, ecology and social sciences. It should use a farming system approach and not limit itself to cropping systems only. It should address both increased productivity and profitability and integrate maintenance and rehabilitation of natural resources.

Some new and promising methods include the use of nitrification inhibitors[67] and slow-release nitrogen fertilizers[68] including indigenous[69,70] materials such as neem cake or oil-coated materials. Some of these newly developed ecofriendly fertilizers are expensive[71] and their use in field crop production may not be economic. The question is 'should the farmers pay for environmental protection'. After all they are producing food for others, without which this country will have to import and incur heavy expenses. To conclude I would like to quote two sentences from Nobel Laureate Borlaug's[72] keynote address at the 15th World Congress of Soil Science: 'Indeed for those concerned with trying to preserve pristine environments or protect endangered species, we would submit that human demographic changes are the greatest threat to the planet Earth in the years ahead. Indeed, if this relentless growth in human numbers goes on unabated, *Homo sapiens* will no doubt end up as an endangered species themselves'. Fertilizers cannot check this growth in population but can help the world and its nations meet their increasing food, feed and fibre demands and in sustaining the humanity. Thus in developing countries reeling under population pressure the sustainable agriculture and efficient fertilizer use must go hand-in-hand for a better tomorrow.

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