The Nexus of Soil, Water and Waste

By Prof. Rattan Lal

Director, Carbon Management and Sequestration Center, Ohio State University.

Presentation given at the Opening Ceremony of United Nations University - Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES) held in the city of Dresden, Germany, on December 10, 2012.

This lecture is also available on video under: http://www.flores.unu.edu/lecture-1/

Mr. Rector, Colleagues, Friends, Ladies and Gentlemen,

First of all it is a great honor to be here; thank you for inviting me. It is a privilege to be a participant and a speaker at the opening ceremony of this institution. I really appreciate this. The topic that I am going to talk about is: The nexus of soil, water and waste. The importance of this topic, which I would like to emphasize, can perhaps be better stated by view of the planet Earth and the comments made about the planet by Carl Sagan. He said:

"Look again at that blue pearl in the space. That's here. That's home. That's us. On it is everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. The aggregates of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant. Every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every aspiring politician, every "super leader", every saint and sinner in the history of our species lived there- on a mote of dust suspended in a sunbeam".

This unique and serene planet was disturbed drastically. The climate changed dramatically about 15,000 years ago. The temperature that was fluctuating and was never stable increased by 5°C and with that not only the temperature increased, but it also stabilized. We call that period from ~15000 years ago till now The long summer (Fagan, 2004). It was during the early stages of the long summer, about 12,000 to 10,000 years ago, that the settled agriculture began in different parts of the World. With the beginning of Agriculture the human population grew in number and living in communities because agriculture improved both the diet quantity and quality. Subsequently in 1750 the discovery of fossil fuel, the coal, started the so called Anthropocene (Paul Crutzen, 2000), or the era since the industrial revolution.

However, as early as the neolithic revolution, agriculture emerged in different parts of the World.

- In the Near East, the Middle East, nine to fourteen thousands years before present, several crops: emmer, barley, pea, lentil etc. were cultivated;

- In northern China, the rice was cultivated circa nine thousand years ago;

- In Papua New Guinea, about six to nine thousand years ago, sugarcane and root crops were cultivated;

- In Central Mexico, Aztecs and Mayans, about seven to eight thousands years before present, domesticated maize, squash, gourds, beans and cocoa;

- In Indus Valley, wheat, barely, jujuba were cultivated 7.5 to 11 thousand years ago;

- In West Africa, four to five thousand years before present, yam and cassava were cultivated;

- In the Horn of Africa, Ethiopia, the Yeheb nut and teff and coffee and cucumber tree were domesticated 5 to 7 thousand years before present;

- In eastern North America, the Cherokees, were cultivating four to five thousand years ago, [long before 1492], several crops including cranberries, chenopod, marsh, elder, sugar maple, tobacco and squash;

- And of course, in the western North America, the Pueblo Dwellers were cultivating amaranth and pine nuts about 6 thousand years ago;

- And in South America, the Incas, were cultivating cocoa, potatoes and beans about 7 thousand years ago.

The origin of agriculture, in different parts of the World, was made possible by the truly defining moment in human history when the ice sheets melted and climate warmed. Things changed for the humans and the planet. There are two factors which are responsible for the origin of agriculture: (1) the increase in the global temperature, and (2) the increase in the atmospheric concentration of carbon dioxide from 180 ppm to 280 ppm. As a result of this combination, the biomass production of C-3 plants: wheat, barley, potato, sugarbeet increased drastically, and that of C-4 plants such as corn increased moderately. These increases were possible because also the legumes were able to fix atmospheric nitrogen through biological nitrogen fixation, which changed the fertility of the soil.

Consequently, there was a population boom. In 1800 we were only one billion people, compared with seven billion in 2011. The population is projected to be about ten billion people by 2100. The impact of this population may be expressed as per equation below (Ehrlich and Holdren, 1971):

$$\mathbf{I = PxAxT}$$

Where P=Population, A=Affluence of the population and T=Technology.

The impact of this drastic increase in population changed the planet Earth that Carl Sagan described, dramatically. Alterations of soil, water and the waste generated by humans impacted the natural resources. The soil, transferring run-off and percolation into the blue water and the latter by soil into the green water that plant use for their growth; The soil also contributing the transformation of waste from crop, animal and trees into humus and plant nutrients, and vice versa.

Similar to the link between soil and waste, that between water and waste is equally important. Human use of water creates grey and black waters which can through purification be used as source of water and plant nutrients, Application of sludge on soil is an important source of nutrients and organic matter.. The contaminated water, grey and black, must be converted into blue and green by denaturing and filtration through soil. The goal is reuse and recycling of the waste following appropriate purification treatment.

This nexus, the central theme of the UNU-FLORES, is very crucial to the existence of human, the wellbeing of all species and of course to that of the planet Earth.

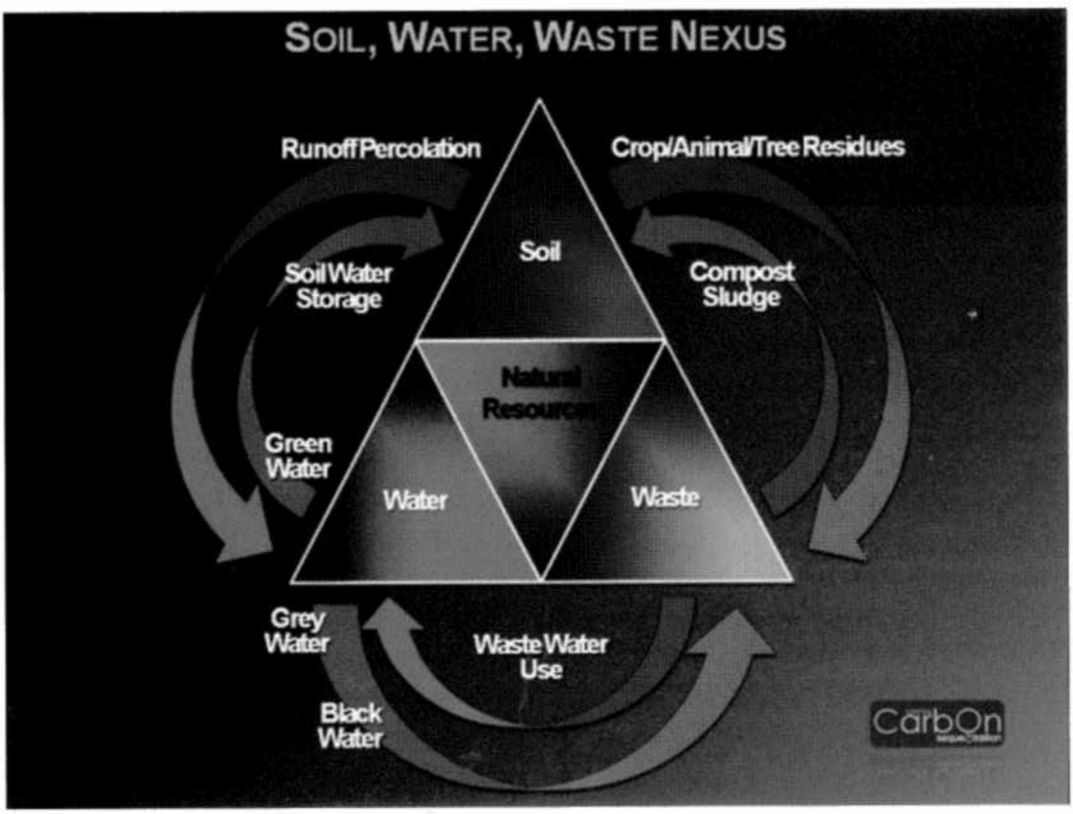

Figure 1 Soil, Water and Waste Nexus

Changing Climate

Now, after about fifteen thousand years, the climate is changing once again. Examples of the climate change include the unique drought that happened in the United States in 2012. This drought decreased production of corn by about 30 to 60%. The impact on food has not yet been felt, but I think it may be felt by the low income group in the near future. Every 1°C increase in temperature may lead to a decline of 10 to 17% in grain yields around the World, and the reduction of crop yield in Sub Saharan Africa may be as much as 8 to 20%.

Agriculture and food production systems are vulnerable to the changing climate. One of the things that may affect agriculture, agronomic productivity, and in the end well-being of human beings and of the other species is increase in frequency and intensity of drought, as one type of the extreme events which may happen more often in a changing climate. There are several types of droughts (Monzy et al., 2012):

- Meteorological drought: a long term deficiency of precipitation.

- Hydrological drought: decline of water in rivers, reservoirs, aquifers, etc.

- Pedological drought: reduction in soil water storage.

- Agronomical drought: low availability of water at critical stages of crop growth.

- Ecological drought: low water availability because of land use change and conversion

- Sociological drought: demand of a community exceeding the supply.

The anthropogenic demand and the increasing affluence of growing population can increase the pedological, agronomical, ecological and sociological drought, even if the meteorological and hydrological droughts do not happen. The change in climate on the other hand, will influence the top two categories, the meteorological and hydrological. The drought that we experienced in the Midwest of the United States in 2012 was of course the pedological and agronomic.

In terms of climate change, the question is when did the current climate change begin? Most people associate the current climate change to 1750 - remember the Anthropocene that I mentioned in the first slide - the on-set of the so called Industrial Revolution. That may be a debatable theory. Some researchers believe that the trend in increase of atmospheric carbon dioxide concentration began 8000 years ago and that of the methane, 5000 years ago, corresponding with the dawn of settled agriculture with attendant deforestation, soil cultivation, spread of rice paddies and raising of cattle. The increase of methane is associated with the spreading of rice paddies and cattle and the increase of CO^2 of course with deforestation and agriculture.

If that is correct, then the so called Carbon Civilization, beginning with the Industrial revolution and continuing perhaps for another century or so, may have started long time ago. The pre-historic land use has thus far contributed about 320 Pg

(Gigatons) of carbon into the atmosphere (Ruddiman, 2003; 2005). From 1750 to 2010, another 136 Pg were released into the atmosphere and from 2010 to 2030 it is projected that we may have additional 30 Pg coming from land use change and soil cultivation.

In comparison with emissions from land use, fossil fuel combustion from 1750 to 2010 contributed about 200 Pg, and another 200 Pg is projected between 2010 and 2030 (Holdren, 2008). Thus, from now on, obviously the fossil fuel combustion will be the major determinant of the atmospheric chemistry. But in the past, prior to circa 1750, that was not the case, because the principal source of atmospheric CO^2 was the land use conversion, biomass burning, soil cultivation and its implications. However, combined these emissions have and will affect the ecosystem, the soil, water and waste, the nexus that we are concerned about, and it is that nexus and its impact, that is going to drive the production of food, feed, fiber, fuel and shelter for the human well-being and that of the other species.

Let's start with the carbon civilization since the 1750 for the moment. By 1860 the coal production was 132 Mt per year. In 2010 it was 3731 Mt per year, an almost 30 fold increase. The oil consumption at present is 87.4 m bbl/day (IEA, 2012). That comes to about 0.6 gallons/ day/ person (for each among seven billion of us in 2011). In USA the per capita oil consumption is five times that of the world average, or3 gallons/ day/person. Thus, the present civilization is really addicted to oil. In addition, the global gas use is 8.1 billion m3/day.

And compare the use of oil with that of drinking water need, which is 0.6 gallon per day. (The average beer consumption in Ohio is merely 0.1 gallon/ day).

Soil degradation

Another characteristic of the anthropocene is the degraded land area. On a global scale, Bai et al. (2008) estimated that 3.5 Billion hectares, which is about 24% of the total territory, may be degraded to some degree. The global soil degradation (land and soil are different; and soil is a part of land) due to water erosion is 1.09 billion hectare (Oldeman, 1994), wind erosion accounts for 0.55 billion hectare (Oldeman, 1994) and salinization for 0.85 billion hectares (FAO, 2005). The risks of secondary salinization are increasing tremendously with changing climate.

What is the cause of the serious problem, what is driving the soil degradation? One of the reasons is survival and desperation, especially if these are resource-poor people. Other reasons include the purposely overuse of resources and subsidies, human greed and corruption, the desire to produce and consume in a "world without limit" and expectations: competition, territory and power. Ignorance and misunderstanding about functioning of soil ecosystems causes unsustainable soil use and management based on the lack of knowledge. There are many examples of such cause-effect relationship.

However, soil erosion may not be always or necessarily due to desperation. Extreme Erosion may not only happen in Africa or Asia, but also in the heart of the U.S. Corn

Belt. Land misuse and soil mismanagement can cause extreme erosion especially by extreme climate events. Accelerated erosion can also be a source of greenhouse gases .Based on my own data on a global scale, if 6 Pg of carbon is being displaced by water erosion, 1.1 Pg out of that can be emitted into the atmosphere as carbon dioxide and about 0.6 Pg is transported into the ocean and other aquatic ecosystems and depressional sites (Lal, 2003). Therefore, soil erosion not only impacts productivity of the land, and results in a loss of water resources, but also of the so-called anoxia of the ecosystems, along with emissions of greenhouse gases into the atmosphere. This issue needs multi-disciplinary research on watershed basis to study the fate of carbon transported by the erosional processes.

In developing countries, such as in West Africa, erosion can be caused by human desperateness because resource-poor farmers and people require everything they can harvest from the land. The risk for erosion in Africa is projected to increase by 36% between 1980 and by the end of the century. Globally though the risk of soil erosion may increase by 14%.

As the population increases, we not only encroach upon the prime agricultural land to construct buildings ,roads, malls, shopping centers ,airports and so forth; top soil is also used often for brick making. In India, the Indo-Gangetic Plains, China and other regions, one meter of top soil is used for brick making. As the population increases, it may require as much as 40,000 hectares to provide accommodation and infrastructure to one million people. The annual increase of population at the moment is about 75 million people, which means 75 million times 40,000 ha / million or three million hectares of prime land going out of production every year because of urbanization (Lal, 2011). Yet, this estimate does not include the land scalped of its topsoil for brick making that I just discussed. By 2015, there will be 236 cities in the world that will have a population of more than 10 million people. And these 10 million people require 6000 tons of food per day. Imagine the amount of nutrients, especially phosphorus, being transported from the rural areas into the cities (some of which may also have a population of 20 or 30 million). And those plant nutrients being brought into the cities as food are not getting back to the land where they came from and are needed to replace what has been removed.

The demand for food is going to increase: Feeding 7 billion in 2010 takes cropland the size of South America. Feeding 9.2 billion in 2050 would take the land area of South America plus that of Brazil, the additional area needed, unfortunately, we don't have. In addition, there is also the problem of land grabs that is just a symptom of the shortage of land in densely populated countries. Some estimates indicate that 57 million hectares (mostly in Africa, but also in other parts of the world, in South America and Central America) are already affected by the so called land grab. If estimates are correct, this is an issue that might eventually create lot of social and political problems which perhaps need to be addressed right now through improvement in productivity of the existing land. The land grab must also be distinguished from direct investments.

What kind of yields are required to meet the food production? We had a global average cereal yield in 2005 of 3.3 Mg (metric ton) per hectare. By 2025, the average cereal yield must be increased to 3.6 Mg/ha because of the increase in population. By 2050, the average yield must be 4.3 Mg/ha. Total cereal production has to go up from 2.2 billion Mg in 2005 to 2.8 billion Mg (2025) and about 3.3 billion Mg (2050). These numbers only hold, however, if the food habits do not change. But since the income of the population, e.g. in China, India and other developing countries are going to increase, unfortunately the food preferences towards animal-based diet are also going to change. Consequently, considering the animal-based diet preferences, the yield of cereal must increase from 3.3 Mg/ha in 2005 to 4.4 Mg/ha (instead of 3.6) in 2025 and to 6 Mg/ha in 2050 (Wild, 2003). That is a major major challenge.

Water use and management

Water is obviously a very important factor, remember that only 2.5% of the global entire water is fresh water. The remainder 97.5%, of course, is saline water.

We may distinguish several types of water (Falkenmark and Rockstrom, 2004):

- Blue water: the oceans, the rivers, lakes and so forth;
- Green water: the water that plants absorb and use in photosynthesis;
- Grey and black water: which is the sludge and the water used by human consumption;
- Virtual water: water that we do not have but we use by importing and exporting especially the food products.

We have to understand that blue and black water have to be converted to green, and hopefully we can manage the virtual water more properly.

Global water use is going up as summarized in below table. The total consumption increased from 430 Billion m^3 per year in 1990 to 6000 Billion m^3 per year in 2000. So total demand went up by a factor of 14, agricultural demand by a factor of 10, industrial by 63 times, and urban by 22 times.

And the increasing use by industrial and urban sectors is reducing the availability of water for agriculture, which is a serious issue.

Year	Total	Agricultural	Industrial	Urban
1990	430	350	30	20
2000	6000	3400	1900	440
Increase	**14**	**10**	**63.3**	**22**

Table 1 Global Water Use (Kondratyev et al., 2003) Units in 10^{9}m^3/year

Among the 10 top countries which import and export the virtual water (Thenkabail et al., 2010), the exporters are Australia, Canada, USA, Argentina, Brazil, Ivory Coast, Thailand, India, Ghana and Ukraine. The countries that import most of the virtual water are Japan, Italy, UK, Germany, South Korea, Mexico, Hong Kong, Iran, Spain and Saudi Arabia. In view of the growing scarcity of water globally, we have to consider whether trading of the virtual water is the best option or not.

Then we have the waste water. Many countries which have limited water resources also create a lot of wastewater, e.g. in North Africa and Middle East. Most water-deficit countries are also prone to creating more wastewater. Consequently, something has to give. Our thinking, societal values and philosophy has to change. And this is a policy issue, a political issue. Where politicians promote free access to pump water, as for example in Punjab and other states in India and elsewhere, such a wasteful use will result in overuse or non-sustainable use. No one protects or safeguards an undervalued resource. A rapid depletion of groundwater by as much as 1 meter per year is caused by undervaluing of the precious water resource. Policy implications are obviously very important in water use.

Nutrients

Looking at the global fertilizers use, the Haber-Bosch process of synthetizing fertilizers, has certainly increased the use of nitrogen fertilizers, from < 10 million Mg in 1950 to 11 - 12 million Mg in 1960, and increasing to 81 million Mg of nitrogen in 2000.The global N use is expected to be 135 million Mg in 2020 and 236 million Mg of N fertilizers by to 2050. Concerning phosphorus, its use has increased from 10 million Mg in 1960, to 33 in 2000, 48 in 2020 and 84 million Mg in 2050 (IFDC, 2004).

Haber-Bosch process obviously is very important for Nitrogen, but Phosphorus, where will that come from? There is a growing concern about peak phosphorus. By 2035, the phosphorus will peak out, like peak oil; we know that that problem exists. There are five countries in the world which contain most of the phosphorus reserves: Morocco, China, South Africa, USA and Jordan contain 90% of P reserves. This issue is also related to the concern that most of the nutrients are coming to megacities, where in reality we have more than 50% of the population living already and urban population is projected to be 70% of the total by 2050, which is a major liability as a cause of environmental pollution and eutrophication of water. Phosphorus is going to be one factor which we really need to consider. And high P losses in runoff and erosion from agro-ecosystems are causing considerable problems to water quality, such as anoxia in the coastal ecosystems.

In that context, is there also a peak soil, like peak phosphorus? Are there endangered soils? Of course there are. I can name quite a few of them. This question of overuse of soil and other resources is really an important issue.

Feeding the world

The question that I think the United Nations, and of course the United Nations University and the institutions like we are inaugurating today (UNU-FLORES) need to address is how can we feed the 10 billion people in view of the shortages of soil, water, energy, the carbon civilization ? That is a very important question. Some options to feeding the 10 billion people are:

- First and foremost, reduce post-harvest losses: 10 to 40% in developing countries.

- Minimize the food waste, from farm- to- fork- to landfill: 20 to 40% in developed countries. In United States, 40% of food already in the grocery store is wasted from homes.

- Reduce the diversion of food to biofuels. One third of corn even in 2012, with 30 to 60% reduction in yield in the US may go to ethanol production.

- Prefer plant-based diet. On unit area basis a lot more people can be fed on plant-based than animal-based diet (Global Soil Week, 2012).It takes 6 to 8 kg of grains per kg of grain-fed meat, especially lamb, pork or beef. Some other meat (chicken, fish) might be less grain-intensive.

- Per capita grain consumption in India, is only 170 kg per year and that of US is 4 times more and it is primarily because of the more meat –based diet in USA versus that in India, that is the main factor.

We must promote an efficient use of food that we produce.

More than one-fourth of all the water we use worldwide is taken to grow over one billion tons of food that no one eats, it is wasted (World Water Week 2012).

Therefore, the second option of course we have is to adopt a climate-resilient sustainable intensification of agriculture. Let's start with wasted food for a moment. For example in India, 16.6 million Mg of wheat produced in 2010 and stored in the open, is prone to wastage. One rain can waste the entire stock stored in the open. So, that is wasted morsels.

Management principles

In terms of sustainable soil management, there are three basic principles (Hammer, 2010):

- Replace what is removed;

- Respond wisely to what is changed,

- Predict what will happen from anthropogenic and natural perturbations. If you can predict, then obviously you can anticipate what to do about what may happen.

One other thing which is very important, two geographical regions that I discussed(sub Saharan Africa and Asia), are two among, major regions which are deficit in food production. These are also the regions with a serious "yield gap", or the difference in the national average yield and the research experiment or the attainable yield.

In India, for example, especially in the Indo-Gangetic plains, the present yield of wheat is about 3 Mg/ha. It can be 7.5 Mg/ha.

The proven technology exists to achieve the high yield. Similarly, the present yield of rice is 5 Mg/ha, and the technology exists to achieve 8.8 Mg/ha. In sub-Saharan Africa, maize yield averages~ 1Mg/ha (there are some regions with much higher national average yield such as Ghana, Malawi, Zambia) compared with the attainable yield of up to 4.5 Mg/ha or more. In some of my experiments in Nigeria conducted about 30 40 years ago (in 1970s and 1980s), yields of 4 and 5 Mg/ha/season were normal under recommended management. So, existing knowledge can be applied properly to bridge that yield gap.

We should not misuse the limited resources. There is no such thing as waste. Nature does not have a waste. The death leads to life and this cycle of life and death are the two sides of the same coin. These crop residues, which I had shown in a picture before, are being taken out from the agricultural land for multiple uses, and they contain a lot of nutrients. In addition, the residues left in the field are source of energy and habitat for the organisms.

The amount of nutrients harvested (kg of nutrients/Mg of crop residues) in grains and stover of corn are estimated at 36 and 15 for N, 8 and 2 for P, and 9 and 37 for K, and 58 and 72 total, respectively.. These nutrients removed have to be replaced, to minimize depletion and avoid the wide spread problem of negative nutrient budget on croplands of sub-Saharan Africa and South Asia.

Nutrient	Grains	Stover	TOTAL
N	36	15	52
P	8	2	10
K	9	37	46
TOTAL	58.4	71.8	130.2

Table 2 Nutrients removed per Mg of Corn Grains and Stover (Kg/ha) Calculated from Bundy (2012)

But it is not only the nutrients alone. In a set of experiments, conducted at IITA (in Nigeria) in 1970s, soil scientists studied the impacts of residue removal on soil properties and crop yields while all other management (e.g., variety ,fertilizer, tillage method, time of sowing etc.) were kept the same. The difference in soil properties was immense, especially in bulk density, crusting and soil structure. Therefore, the earthworm population, the microbial activity, the soil quality, soil bulk density, porosity, infiltration rate were superior in soil receiving the crop residue mulch.

Soil biota, the organisms that I just mentioned, are the bioengine of the Earth and that residue is the food for those organisms. If we deprive those organisms from the food, they cannot survive. My slogan has been "grains for people, and the residues for the soil". This equity must be maintained to achieve sustainable use of soil resources.

Those who also believe that the biofuels can be created from crop residues without any adverse impacts on soil quality must think again. There is no such thing as a free biofuel from crop residues. That residue is needed for survival of the organisms which are so essential to soil quality. In 1970s, the world faced the oil crisis as you know. At that time the famous soil scientist at UC Davis, Dr Hans Jenny stated in a note in Science: "I am arguing against indiscriminant conversion of biomass and organic wastes to fuels. The humus capital, which is substantial, deserves being maintained because good soils are a national asset". So, crop residues are not free. Their indiscriminant removal from agro-ecosystems certainly has a large price tag in terms of the adverse impacts on soil quality.

Another important product is the animal waste, which in southern Asia and many parts of Africa of course is used as a household cooking fuel. You can imagine the impact on health of the children sitting around the fire, or children not yet born, by the inhalation of the noxious gases which are released from incomplete combustion in a traditional stove under unventilated kitchen. It has been stated that during late 1990s and early 2000s, more plant nutrients were burnt in dung as households fuel than chemical fertilizers used in India. I had the opportunity to talk to a member of the Planning Commission in India, and I mentioned to him that one crucial strategy to restore degraded soils and improve the environment would be to provide clean cooking fuel to the housewives in the rural communities and elsewhere.

Throughout South Asia and sub-Saharan Africa, the so called atmospheric brown cloud (ABC), which I am not going to talk about at this occasion, is affecting the Monsoons through alterations of the energy budget. You can imagine the color of the first snow fall into the Himalayas because of the atmospheric brown cloud.

If the crop residues, the dung, the cover crop and other biomass such as city sludge can be put back on the land, it would have strong positive impacts on soil organic carbon pool and soil quality. In depleted soils, there occurs a notable increase in soil quality by improving the carbon concentration in soil. The available agronomic data show that increasing soil organic carbon stock in the root zone by 1 Mg/ha(even with the existing management of fertilizers, varieties and so on) can increase the productivity of maize, soybeans, wheat, rice, sorghum, millet and beans. The data in on increase in crop yields are from Africa and Asia, (Lal, 2006; 2010a;b):

Crop	Yield increase (Kg/Ha/Mg C)
Maize	100-300
Soybeans	20-50
Wheat	20-70
Rice	10-50
Sorghum	80-140
Millet	30-70
Beans	30-60

Table 3 Increase in crop yields

We can increase the production in the developing countries by 30 to 50 million Mg per year, which can substantially bridge the gap between the demand and supply at local level.

Adapting to climate change

Soil quality and adaptation to climate change are really crucial issues. What does adaptation mean? It involves any activity that reduces the negative impacts of climate change through anticipatory or reactive strategies and, – that is very important- take advantage of new and beneficial opportunities that may be presented by climate change.

I hear most of the time negative things about climate change. You remember that about 15,000 years ago, the settled agriculture was made possible by the climate change or the so called "Long Summer". I do not think that Mother Nature would create anything that has only negative impacts. While the magnitude of anthropogenic climate change must be minimized, any positive or opportunities in agriculture or forestry must also be explored. It is up to us to identify what positive things may happen, and then take advantage of those.

Thus, innovative technologies must be identified to take advantage of any new opportunities which may emerge? How will agriculture look like in 50 years from now? I am not in a position to recommend GMOs, I am neither a plant breeder nor geneticist, but I do believe that genetically modified plants/animals probably will be increasingly used, despite some of the disadvantages. This theme needs additional and an objective research. The plough-based agriculture, the so called conservation agriculture farming will also play an important role in the future. We may have nano-enhanced materials for use in fertilizers for example, so that the use efficiency can be increased. We may have plants which emit molecular-based signals, plants tell us "I am thirsty", "I am hungry", "Give me this nutrient", "I am being attacked by this grass hopers" or "I am being attacked by a certain virus". So they emit plant-based signals which can be detected by remote sensors and we can target treatment of those specific stresses, whether they are biotic or abiotic stresses. This is the kind of technology that has to come in the future, including of course the growing need for urban and peri-urban agriculture. And more important, the key resources (such as water and plant nutrients) must be delivered directly to the plant roots in a form and exactly at the time the plants need these resources at specific phenological and growth stages. Such innovations, also called "sustainable intensification" are important, so that the waste is avoided and key resources are used efficiently and sustainably.

In terms of climate change, a field of corn, managed with normal farming practices(such as crop residues and animal waste return under conservation agriculture) can produce 400 times the annual increase in atmospheric carbon pool contained in the air column above that field of corn. The total net biomass or biome productivity is three petagram (Pg) of C per year that is just about the same amount as the increase in atmospheric CO^2 during the 1990s. Herein lies the strategy of off-setting anthropogenic emissions through natural processes of greening the Earth. I am going to share with you here the data from Dr. Jim Hanson of NASA. He estimated that between now and 2100, 50 ppm of CO^2 can be withdrawn from the atmosphere by forestry and soil. Indeed, carbon sequestration in the terrestrial biosphere is the most cost-effective strategy of stabilizing the atmospheric chemistry. My estimates of the reduction in CO^2 sequestration are probably double that of Jim Hanson, and I think that this can be achieved through sustainable intensification of natural resources (soil, water, vegetation, waste etc.).

Laws of Natural Resources Management

We have a book coming out very soon, Dr. B.A. Stewart and myself are the editors. The book, as a series Advances in Soil Science published by Taylor and Francis is entitled "Laws of Sustainable Soil Management". It is based on ten tenets of soil management (Lal, 2007):

- The Law #1 describes "Causes of soil degradation". It is very important to realize that the "biophysical process of soil degradation is driven by economic, social and political forces". We know in Africa and Asia how to minimize soil degradation. It is the governance or the political will to implement the management that is often lacking. The vulnerability to degradation depends on how rather than what is grown.

- Law #2 states that "when people are poverty stricken, desperate and starving, they pass on their sufferings to the land". Poverty and degradation go together. The stewardship does not have any meaning when someone is starving.

- Law #3 states that "it is not possible to take more out of the soil than what it is put in it, without degrading its quality. Only by replacing what is taken can a soil be kept fertile, productive and responsive to inputs".

- Law #4 is called the "Marginality Principle". It states that "marginal soils, cultivated with marginal inputs, produce marginal yield and support marginal living". Take the case of Sub-Saharan Africa or South Asia: the soils are poor, they are cultivated poorly and they perpetuate poverty, misery and hunger. That vicious cycle can be broken. Recycling is good as long as there is something to recycle. I am not going through all the 10 laws on which this book is based, but I think these are the basic principles of soil management.

In the context of the new institute (UNU-FLORES), I would also like to share with you 10 basic laws of natural resources management, which I call the Laws of Nothingness (Lal, 2013). They are based on the Latin phrase: Ex nihilo nihil fit which means "Nothing comes from Nothing". In terms of soil, water and waste these laws can be stated as follows:

1. Nothing is appropriated. There are always trade offs (give and take).

2. Nothing is permanent. Everything is in a dynamic equilibrium (as was stated in the nexus concept stated earlier), and in a transient state.

3. Nothing is absolute: All processes, properties and values are relative to a baseline. We must know what the baseline is.

4. Nothing is a panacea: There is no silver bullet, there is a multitude/menu of options.

5. Nothing is universal: Soil/site/region specificity is an important consideration which must never be overlooked.

6. Nothing tangible is free: under valuing a commodity – I discussed with you the example of over use of irrigation water- leads to "Tragedy of the Commons".

7. Nothing is empty in nature: All space in rocks is occupied. Pores in solid rock contain water or air and injecting into these pores the fracking solutions can cause problems. Keep that in mind.

8. Nothing is given or for granted: It is the judicious use and management which produce goods and services.

9. Nothing is waste: There is no such thing as waste. Everything in nature has a use. Try to find out how to use that waste or better the by-product.

10. And finally, nothing is nothing: there is no such thing as nothing.

I think these are the basic things we have to understand, to implement the judicious management of limited resources.

In terms of the sustainable management, we need a combination of science and policy. We have natural resources and they must be Restored, Improved, Sustained and Enhanced (R.I.S.E.), through Science, Policy, Practices, but also Religion and Culture.

I want to share with you something about Religion and Culture (Lal, 2010), because you hear about science more often:

- Judaism: The word "homo" (man) is derived from the Latin word "humus" or the decomposed organic matter in soil, which is the essence of all terrestrial life. The Hebrew phrase "Tikkun Olam" means "repairing restoring the world".

- Hinduism: Human body is made of soil, water, energy, sky/space, and air" That is in the Prasna Upanishad.

- Sikhism: Air is the Guru, water is the Father, and soil is the Great Mother of all. That is in the Gurbani.

- Buddhism: "One should not break even the branch of a tree that has given one shelter"

- Christianity: The word "Adam" (man) is derived from the Hebrew word "adama" meaning "earth" or "soil", so the man is made of soil.

- Greek: The daughter of Earth goddess "Gaea" named Themis (goddess of Law), and her descendent Demeter was the goddess of agriculture and fertility

- Romans: The Earth goddess (Tellus) was related to the goddess of fertility and harvest, what they called Ceres.

- Islam: The Quran states that "He created the man of clay like the potters" (Suhrah Al-Rhman, verse 14) and "We made from water every living thing" (Quran 25:54). "Do not overuse water even if you are on a running river".

In continuation of these cultural believes, another concept I want to share with you is that from Khalil Gibran. Some of you may know him (a US citizen of Lebanese descent). He stated "Trees are poems that earth writes upon the sky. We fell them down and then turned them into paper, so that we may record our emptiness." That is a great message.

In the end, I want to share with you Gandhi's seven sins of Humanity which he listed in his autobiography "My Experiments with Truth". These are:

1. Wealth without work
2. Pleasure without conscience
3. Knowledge without character
4. Commerce without morality
5. Politics without principle
6. Religion without sacrifice
7. Science without humanity. Anything in Science we do must have a humanity angle, it must address societal problems.

I have been sharing with several colleagues what I call Trillema of Natural Resources Degradation (UNCCD, 2011). The data I am going to share are computed as rates per minute on global scale. What happens around the World every minute?

- Population increases by about 150 people.
- There are 250 births and 100 deaths.
- CO^2 increases by 6150 tons.
- Tropical deforestation: 25 hectares.
- Urban encroachment: 5.5 hectares.
- Soil degradation: 10 hectares.
- Deaths from hunger every minute: 16 people, including 12 children. These come down to several jumbo jets, like 70, crashing day after day, seven days a week, 365 days a year and yet it is not an issue for the news or a newsworthy item for TV primetime reports.
- We have municipal solid waste, every minute in the United States, 540 tons.

The political stability and civil strife are affected by the trilemma such as this and other issues. And I have often wondered if Gandhi were to see the statistics, what he would have added to the seven sins that he listed. I think he would have added the following (Lal, 2007):

- Technology without wisdom,
- Education without relevance
- Humanity without conscience.

Thank you so much.

ISBN: 978-3-944863-00-9
e-ISBN: 978-3-944863-01-6

This publication should be cited as:
"Rattan Lal (2013). The Nexus of Soil, Water and Waste. Lecture Series - No.1
Dresden: United Nations University Institute for Integrated
Management of Material Fluxes and of Resources".