UPM Inaugural Lecture Series

FROM THE SOIL TO THE TABLE

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FROM THE SOIL TO THE TABLE

ABSTRACT

Soil is the most important resource for food production. The increase in the world population puts pressure on the soil resource to continuously provide food security for the population. The per capita arable land is 0.29 ha per capita and it is expected to reduce due to population increase, land degradation processes and competition for non-agriculture land use. The agricultural sector has been successful to continuously supply food for the growing population. This is brought about by the green revolution resulting from technological improvement through advancement in scientific knowledge. With more constraints and greater challenges the agriculture sector requires more efficient and productive technology. Since horizontal increase through expansion of arable land is restricted the increase in food production has to be achieved vertically by increasing soil productivity. The use of fertilizer for improvement of soil productivity is widely practiced and N fertilizer is the most important fertilizer use world wide. The use of N fertilizer has no doubt increase the soil productivity; however it has also created serious environmental problems. The efficiency of N fertilizer is often low due to losses through denitrification, volatilization, and leaching and clay fixation. The N that leaks to the environment causes serious environmental problems such as ground water pollution, emission of greenhouse gases, eutrophication and nitrate pollution. For sustainable N management, the N loss has to be minimized to subsequently increase N fertilizer efficiency. Co-applying urea with selected cations, micronutrients and urease inhibitors can effectively improve urea efficiency. It was also shown that rice yield was not affected when irrigation was applied only at soil saturation level instead of continuous flooding at 5-10 cm as currently practiced. Thus, potentially, tremendous amount of irrigation water can be saved and more area of land can be used for rice production .The public awareness on the importance of soil resource for food production and human survival should be provided through the education system. Research for public good on sustainable soil management must be given top priority alongside the market driven research, to ensure the agriculture sector continue to supply us with food **from the soil to the table**.

INTRODUCTION

Soil is the single most important resource required for food production. The early human civilization started in areas with deltas and valleys endowed with rich and fertile soil that enable agriculture for food production. The Mesopotamia civilization in the Tigris Euphrates, the Nile valley, Hwang Ho and Yang Tze Kiang in China and the Indus Valley are examples of these civilizations which owed their origin to fertile soil. The word agriculture originated from a Latin words *agre* and *cultura*, in which *agre* means land and *cultura* means cultivation, thus agriculture means cultivation of land The significance of soil in agriculture and its role in food production cannot be disputed. Thus sound soil conservation and management are vital to support human lives on this planet. Its effect is not only relevant to the current inhabitants but also to the unborn in the future.

The performance of the agriculture sector has been very assuring, at every meal a variety of food in sufficient quantity can be found on our tables. Can this situation be taken for granted? Will the soil resource continue to be sufficient to support agriculture so that our dinning tables will continue to be replenished with food indefinitely? It was however reported, famine did occur in certain part of the world due to food shortage.

Soil is nature's gift; it cannot be produced within human life span. Thus the available arable land area globally is fixed and cannot be extended. The arable land up till now can support the global population, which stands at 6.4 billion with 800 million of the world population undernourished (Eswaran et al 1999). The global population, however, increases at the rate of about 2% annually. At every one second 4.1 new babies are born. Thus with the increase in world population the per capita arable land decreases. The decrease in the per capita arable land is further aggravated by the process of land degradation and irreversible land use for non agriculture purposes brought about by population pressure. Both these factors i.e. land degradation and population increase threaten the ability of the soil resource to support agriculture for food supply. If population increase is unavoidable, serious effort should be focused to reduce land degradation and agricultural productivity has to increase to cope with the food demand of the growing population.

Soils are not created equal, some soils are fertile require little input while some are poor that require high input and special management. It is an irony that Asia and Africa being the most populous region of the world are provided with low quality soil, while the temperate regions of Europe, America and Australia are blessed with very productive soils that require minimal input. In addition to the presence of poor soils, the soils in the Asian and African regions are situated in the vulnerable climatic condition which expose the soils to excessive land degradation processes. The Asian and African regions often referred to as the third world, will have to strive harder to provide food to the ever increasing population with low fertility soil and under adverse climatic condition favoring land degradation. Is it a coincidence; poor countries have poor soils?

This paper attempts to elucidate the significance of soil as a natural resource for food production that supports human life. It also examines the soil carrying capacity to support human life at the global and national level. It discussed some of the R & D efforts carried out by the author to improve soil carrying capacity in Malaysia. The paper also offers some suggestions to improve soil productivity in Malaysia for sustainable food production. The future lies how best we can manage soil resources to ensure continue supply of food from the soil to the table.

FOOD SECURITY

The most important development in the twentieth century has been our ability to produce larger harvest, thereby ensuring food stability and security for the constantly growing population. This great achievement however was unnoticed, largely because most people do not realize how insecure and unstable agriculture was in the past. In Malaysia the1997-98 economic crisis served us as a wake-up call. It was suddenly realized that Malaysia imported a hovering RM13 billion of food to sustain the lives of the population: This is the result of the country bias towards the other more lucrative economic sectors and neglecting the agriculture, especially the food production sector. All countries in the world have no choice; they have to depend on agriculture for food supplies. The choice is whether domestic agriculture or the agriculture beyond the national border. This leads to the issue of food security, which has strong political, economic and sovereignty implications.

Food security is defined as. ' providing physical and economic access to balanced diets and safe drinking water to all people at all times'(Swaminathan,1986). Food produced domestically ensure stable long term supply and political sovereignty. It is less vulnerable to political, economic and military instability. It is the best option if the soil resource is available.

Learning from the Asian economic crisis Malaysia had declared agriculture as the third engine of growth, with creation of new wealth, improvement of the rural economy and ensuring food security as the main thrusts. This simply means that while the country embarks on the industrial and service sectors to fuel the economy the agriculture- food sector would not be neglected. In fact the agriculture sector specifically the oil palm industry has proved to be resilient. In the Asian economic crisis it was the oil palm industry that provided the export earning to sustain the economy. Malaysia is at present the world biggest palm oil producer contributing about RM 30 billion to the county's export earning. It is the food production sector that requires the needed push to support the nation food security agenda.

Based on the available arable land, it is reported that China and India with a combined population of 2.3 billion and occupying more than 14 million km^2 of land will find difficulty in feeding their population unless these countries employ high level agricultural technology (Eswaran et al, 2001). Afghanistan, Bangladesh and Pakistan are other Asian countries that are facing food security problem due to limited arable land to support the ever increasing population. Based on the report Malaysia has a medium risk to food security at low level of technology and is classified as low risk with medium technology level. This means that Malaysia has sufficient soil resource to support its population up to 2020 with the expected population of 30 million, provided medium agricultural technology level is being employed. In the Asian countries with the exception of Laos, Kampuchea and Papua New Guinea the region will have declined markedly in its capacity to sustain food security.

ARABLE LAND AND GLOBAL POPULATION

The distribution and area of land under different land use world wide are given in Table 1.The total area of land not covered by sea is 14.8 billion ha (Nat. Geog. Atlas of the world, 1981). Of this total area of land only 1.46 billion ha is arable land suitable for food production, a major portion of the land area are not suitable for agriculture either due to their unsuitable topography or adverse climatic condition. The arable land is distributed in various continents, where most of the arable land are in America, Canada, Europe and Australia. The arable land in Asia, however, is relatively less especially when the magnitude of the population is being taken into consideration.

Table 1. Major land and water areas

Earth	Tons or ha
Mass	5.974×10^{21} tons
Total Area	51,006,600,000 ha
Land	14,642,900,000 ha
Water	36,163,700,000 ha
Arable Land	1,480,000,000 ha

(Source: National Geography Atlas of the World, 1981)

The number of the world population and its demography in relation to soil resource is important to asses the distribution of arable land per capita of the population. The per capita arable land in different regions are given in Table 2.

The current world population is 6. 4 billion. In 2020 the world population is expected to increase to about 8 billion. The world population increase at the rate of 2.0 % per year. Most of the population increase occurs in the third world countries especially the Asian country. With current population the mean of arable land is 0.29 ha per capita. Each hectare of the arable land is expected to produce sufficient food for four persons. Based on the FAO land carrying capacity data the 0.29 ha per capita arable is above the critical value 0.07 ha per capita considered sufficient for food production (Smil, 1987).

Table 2. The arable land available per person in different geographical areas

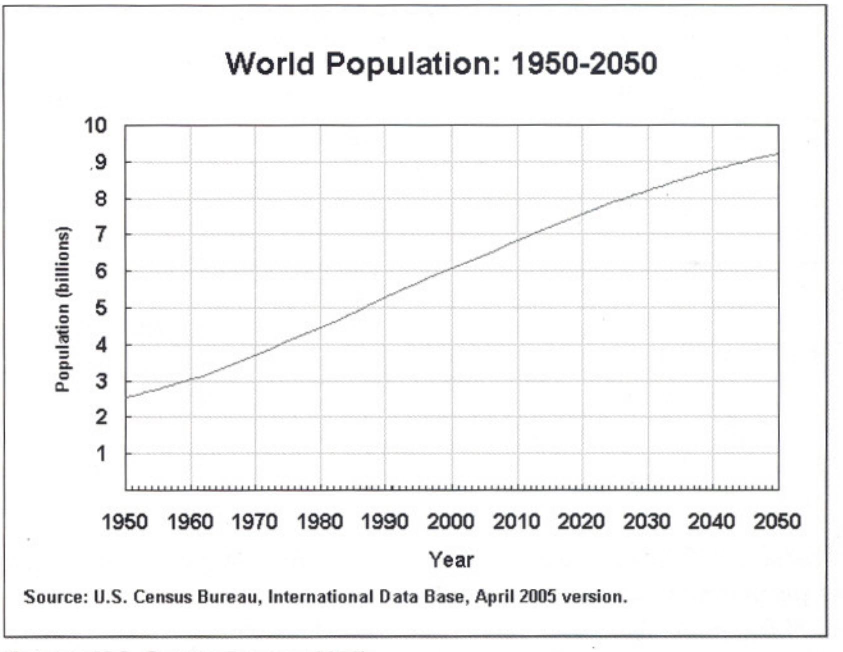
Geographical areas	Available land(ha/person)
World	0.29
Africa	0.30
Asia	0.15
China	0.09
India	0.21
Russia	0.81
Europe	0.28
Canada	1.77
United States of America	0.77
Australia	2.88

(Source: FAO Production Yearbook, 1988)

Although the world per capita arable land is above the critical level, a closer examination reveals that some of the countries such as China, Indonesia, India, and Bangladesh have very low per capita arable land. The high per capita arable land is located in Australia, Canada and America. Thus the populous country of the world will have to depend on the west for their food supply in the future. Given the increasing population, land degradation processing and urbanization the per capita available land for food production will continue to decrease. For the world to support the growing population on the decreasing soil resource tremendous advance in science technology is required to the soil increase productivity vertically as opposed to horizontal increase when soil resource is in abundance. The use of fertilizer, agro-chemical, machineries, precision farming and biotechnology will be the tools to bring about this needed change. The agriculture sector in the future should be knowledge and science driven not as in the past where it was land driven.

POPULATION CARRYING CAPACITY

The current world population is 6.4 billion. In 2025 the population is expected to reach 8 billion and about 97% of this increase will occur in the developing countries (Swaminathan 1994, World Bank 1992). The population of Malaysia now is 24 million and expected to increase to about 30 million in 2020. The urban population worldwide will increase from 1 billion to 4 billion in 2020.



(Source: U.S. Census Bureau, 2005)

Figure 1: World population from 1950 to 2050

With steady increase the world population, there is a greater challenge for the agriculture sector to supply food to the increasing population. The increase in food production in the future has to come from increase in land productivity. The increase in food production through increasing land area is minimal because of limited land area is available. With population increase there is a tendency for more rapid land degradation process and the per capita arable is expected to diminish.

Advances in science and technology in agriculture is required to sustain the increasing world population. Application of high level technology is required for increasing the production capacity and to minimized land degradation.

Malthus in 1798 created awareness regarding the state of the global food security in relation to the population increase. He stated that 'the power of the population is indefinitely greater than the power in the earth to produce food for man'. The Malthus concept is a pessimist view and it is a controversial concept till this day. The world continues to increase its food production (Table 3) and provides sufficient food to the increasing population.

Table 3. The world total cereal production, average yield and area harvested from 1960 – 2004

Year	Total production (metric ton x billion)	Average yield (ton/ha)	Area harvested (ha x 100 million)
1960	0.877	1.35	6.48
1970	1.19	1.77	6.76
1980	1.55	2.16	7.17
1990	1.95	2.75	7.08
2000	2.06	3.06	6.74
2004	2.25	3.30	6.81

(Source: FAOSTAT 2005 http://faostat.fao.org)

The failure of Malthus prediction up this point is because of the advances in knowledge and science which manage to increase the agricultural productivity over less unit area of land. Emergence of new varieties, fertilizers, pesticides, machineries, irrigation systems etc. as the results of R& D are responsible for the productivity increase. The advances in biotechnology will push the agricultural productivity higher to a magnitude beyond our imagination in the near future. Thus the Malthus prediction will never be fulfilled for along time to come. In the words of Marquis de Condorcet 'when hunger threaten new instruments, machines and looms will continue to appear, and a very small amount of ground will be able to produce a great quantities of supply (Mann, 1993). The optimist view of continuous food supply took into consideration of human ability to pursue new knowledge and its application to the agriculture system.

The ability for the world to support the growing population actually depends on the population carrying capacity. The population carrying capacity of an area of land depends on the land quality and the level of technology employed (Beinroth et al., 2001, Eswaran et al., 1999). The soil quality is based on its inherent characteristics and the climatic regime. The soil quality is classified into nine classes (from I to IX) in a descending order. The best agricultural soils with minimum constraint for food production are classified in the I, II and III categories. While class IV, V and VI are soils with moderate constrain that require high input for food production. The VII, IIX and IX soil classes are not capable for agriculture production because of adverse soil properties and climatic condition. Looking at the distribution of the soil based on the soil quality classification, most of the class I and II soils are found in the temperate country, while the soil in most of the Asian countries are of class III, IV and V. In Malaysia no class I and II soils are found, thus Malaysia requires more inputs for food production as compared to the developed countries.

The level of technology used is important in determining the level of soil productivity. The level of technology used is classified as low, medium and high. The soil productivity increase with higher level of technology. A combination of class I soil with high technology will give the highest productivity. While the poor class soil with low technology level will give the lowest productivity. A matrix of soil class and technology level used gives different population capacity. The value of population carrying each combination range between 0 to 10 people (Table 4).

Table 4. Idealized population supporting capacity (persons/ha)

Level of Input	Land Quality Class								
	I	II	III	IV	V	VI	VII	VIII	IX
Low	4.0	3.5	3.0	2.0	1.5	1.0	0	0	0
Medium	6.0	5.0	4.0	3.0	2.0	1.5	0	0	0
High	10	9.0	8.0	7.0	6.0	5.0	0	0	0

(Source: Beinroth et al., 2001)

The value of the carrying capacity reported by others did not take into consideration the soil quality and technology level factors. The values range from 1 to 14 people per ha. The reciprocal of the population carrying capacity gives the land area requires to provide food for one person. The carrying capacity value of 14 is being used by the FAO as the critical value for various calculation of estimate. Discrepancy occurs on the value of the population carrying capacity reported in the literature. Further study is required to accurately determine the value of the population carrying capacity to ensure more realistic estimate. Based on the analysis by Eswaran et al 2001 the population carrying capacity of the world is 6.159 billion at low level of input. 8.725 billion with medium level of input and 19.816 with high level of input (Table 5)

Table 5. Population supporting capacity (in billion persons) of each land quality class under low, medium and high technology input.

Land Class	Low level input		Medium level input		High level input	
	Optimal population supporting capacity	Cumulative population capacity	Optimal population supporting capacity	Cumulative population supporting capacity	Optimal population supporting capacity	Cumulative population supporting capacity
I	0.982	0.982	1.472	1.472	2.45	2.45
II	1.371	2.353	1.959	3.431	2.351	4.801
III	0.884	3.237	1.178	4.609	2.695	7.496
IV	0.460	3.697	0.689	5.298	1.610	9.106
V	1.601	5.298	2.135	7.433	6.405	15.511
VI	0.861	6.159	1.292	8.725	4.305	19.816

(Source: Beinroth et al., 2001)

LAND DEGRADATION

Land degradation which is characterized by the loss of soil quality, productivity and utility. The extents of land degradation worldwide are given in Table 6. The degraded land lost its ability to support agricultural production. Land degradation is either irreversible in severe case or it may require costly mitigation effort. Among the significant physical mechanism resulting in land degradation are erosion, desertification and destruction of soil structure. Important chemical processes include acidification, soil contamination, salinization, nutrient mining and loss of cation retention. While biological processes involved are loss of organic matter and loss of soil biodiversity. Erosion and desertification are the most serious land degradation phenomena responsible for reducing the global capacity for food production.

Table 6. Estimate of the global extent (in million km^2) of land degradation

Type	Light	Moderate	Strong + extreme	Total
Water erosion	3.43	5.27	2.24	10.94
Wind erosion	2.66	2.54	0.26	5.49
Chemical degradation	0.93	1.03	0.43	2.39
Physical degradation	0.44	0.27	0.12	0.83
Total	7.49	9.11	3.05	19.65

(Source: Oldeman, 1994)

Several reports had shown that land degradation reduced farm yield and resulted in loss of income (Lal, 1998, NEP 1994, Pimental et al., 1995). In south Asia, annual loss in productivity is estimated at 36 million tons of cereal valued at US$ 5.4 billion (UNEP 1994). On a global scale the annual loss of 75 billion ton of top soil cost the world about US$400 billion per year (Lal, 1998) the economic impact of land degradation is extremely severe in the densely populated South Asia and sub Saharan Africa. In Malaysia perhaps soil erosion is the main cause for land degradation, especially in the areas with sloping land. Severe soil erosion occurs in Malaysia due to high rainfall.

With population pressure and limited land area excessive land degradation processes will reduce the capacity for food production. Thus globally land degradation issue is being given top priority in international forum and it is recognized as the important global agenda.

IMPROVEMENT OF SOIL PRODUCTIVITY

The current issues on food security, population, land degradation and scarcity of arable land indicate that the land carrying capacity has to be maximized to ensure the world population to have sufficient food supply. Improvement of soil productivity through fertilizer use is viable and reliable option. In modern agriculture the use fertilizer to provide plant nutrients had increase crop yield and had increase soil productivity. The increase in crop yield due fertilizer application has provided more harvest per unit area with increasing land area. The use of fertilizer in crop production has put more food from the soil to the table. Nitrogen is the most required nutrient by plants and the demand cannot be sufficiently supplied by soil. Thus N fertilizer is the most common fertilizer use in crop production and it is used in large amount.

The use of Nitrogen fertilizer has also being reported to cause environmental problems such as, groundwater contamination, N_2O emission and nitrate pollution. These problems can be minimized with proper management practices based on scientific knowledge and understanding.

NITROGEN BALANCE

Almost all crops planted require N fertilizer to obtain high yield. The N balance of lowland rice is given in Table 7.

Table 7. N fertilizer balance of rice at different seasons

	Main season	**Off-season**
N fertilizer added (kg/ha)	80	80
N fertilizer in plants (kg/ha)	29	24
Grain	(25)	(15)
Straw	(4)	(9)
Plant recovery of N fertilizer (%)	36	30
N fertilizer in soil or loss (%)	64	70

(Source: Khanif, 1988)

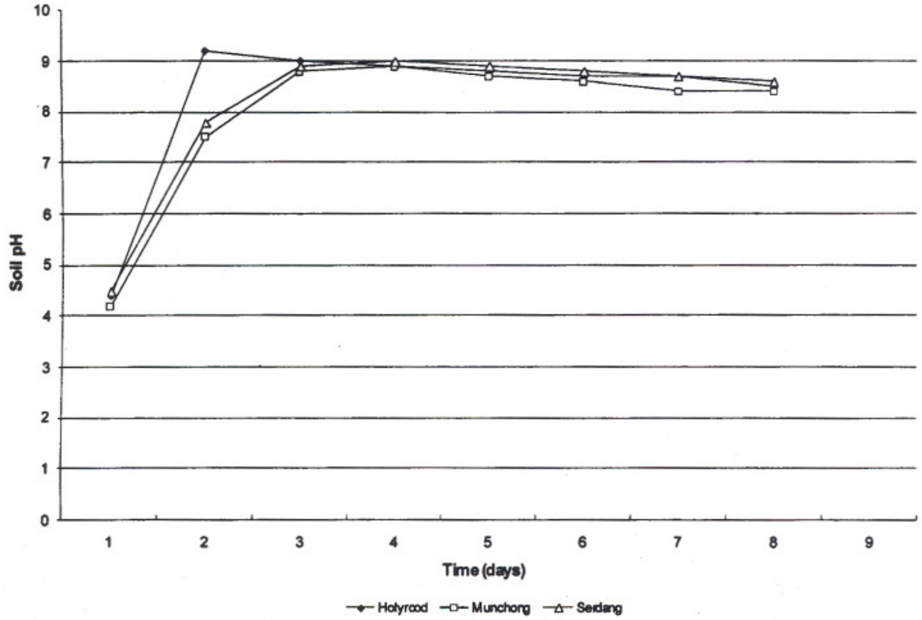
A larger portion is lost or remains in the soil. The N fertilizer is lost through leaching or gaseous loss (Khanif et al., 1984, Khanif et al., 1983). When N fertilizer is applied to soil less than 50% of the N applied is actually removed by plants (Choudhury and Khanif, 2001, Khanif, 1988).

DENITRIFICATION

Under anaerobic condition N fertilizer in NO_3 form is reduced to gaseous form, N_2O and N_2. This loss mechanism is brought by about microbial activity called denitrification and it is a common loss mechanism in flooded rice soil or in soil with low redox potential (Patrick and Tsuneem, 1972). The redox potential at which denitrification occurs is at +200 mV and below (Patrick and Tsuneem, 1972). The magnitude of loss through this process depends on the redox potential, the amount of nitrate and the presence of energy source for microbial activities. The gaseous loss trough denitrification is a not only an economic loss but it is also a source of atmospheric pollution. The N_2O gas emission to the atmosphere contributes to the increase in the atmospheric temperature which contributes to global warming (Houghton et al., 1996).

AMMONIA VOLATILIZATION

Another mechanism by which N fertilizer is lost from the soil is through volatilization. Volatilization is another mechanism for gaseous loss usually occurs among the Urea fertilizers. When urea is applied to soil it is rapidly hydrolyzed to $(NH_4)_2CO_3$ and subsequently to NH_4OH and CO_2 (Bremner and Mulvaney, 1978). The hydrolysis results in high pH increase at the urea micro-sites, which favors the liberation of NH_3 (Furgeson et.al., 1984). The magnitude of pH increase depends on the soil buffering capacity while the rate of urea hydrolysis depends on the urease activity. Thus in tropical soils, the soil pH is generally low, NH_3 volatilization loss can occur in soils with high pH increase at urea micro-sites during urea hydrolysis. The soil pH at urea micro-sites increased to a maximum of pH 9 during urea hydrolysis (Khanif and Pancras,1988). At this pH excessive NH_3 volatilization will take place. Thus, although the pH of most tropical soils are low (pH<5), urea hydrolysis could increase soil pH at urea micro-sites sufficiently for ammonia volatilization to take place. The pH at urea micro-sites during urea hydrolysis are given in Figure 2.



(Source : Khanif and Pancras, 1988)

Figure 2. The soil pH at urea micro-sites during urea hydrolysis

The NH_3 volatilization loss and urease activity of 22 Malaysian soils are given in Table 8. The NH_3 loss ranged between 0.5 to 52% and the urease activity ranged between 12.18 to 150.50 ug N/g/h. The total NH_3 loss is highly correlated with urease activity (Khanif, 1992). Other soil characteristics that influence NH_3 loss are soil texture, soil pH, CEC. and organic matter content. Severe loss occurs when urea is surface applied while loss is reduced when urea is incorporated with the soil. In Malaysia urea volatilization loss can be significant in upland soil with low buffering capacity. The volatilization loss in the alluvial soils is usually very minimal.

The understanding of the fate of applied fertilizer urea is very important when using urea. This is to avoid unnecessary loss due to volatilization. Although urea is very popular N source, proper management is required to minimize loss and improve its efficiency.

Table 8. Total ammonia volatilization loss and urease activity in selected Malaysian soils

Soils	Ammonia loss (%)	Urease activity(ugN/g/hr)
Bungor	14.4	12.18
Munchong	13.2	44.37
Serdang	33.0	49.61
Holyrood	49.2	126.90
Prang	33.2	132,60
Sedu	0.5	93.61
Carey	16.4	93.61
Segamat	40.0	105.20
Baging	42.4	144.21
Lanchang	52.8	150.50
Kuantan	33.7	88.13
Beserah	19.3	84.95
Kuala Berang	28.6	66.76
Rengam	44.5	10.07
Durian	41.6	53.19
Batu Anam	40.4	82.61
Jerangau	13.9	59.13
Chat	42.3	92.44
Kuah	30.5	46.07
Jitra	30.7	56.13
Gajah Mati	37.4	87.83
Tai Tak	45.8	76.11

(Source: Khanif, 1992)

LEACHING

When N fertilizer is applied to soil the N is transformed to NH_4 and NO_3 through microbial activities. The $N0_3$-N is an anion is negatively charged and is very mobile in soil. This is because the soil colloid is negatively charged thus the NO_3 ion is repelled from the soil surface. The NO_3 is soluble and move freely with water movement. When water percolates into the deeper layer the NO_3 move along with the soil water, this mechanism is called leaching. This mechanism is an important mechanism by which nitrogen fertilizer is lost from the soil. If the leaching occurs up to below the rooting zone the N fertilizer is not available for pant use. The NH_4 form is less subjected to leaching because it is positively charged thus it is adsorbed to the negatively charged clay colloids.

Leaching of N fertilizer not only reduces its availability for plant uptake it also can lead to serious environmental problem. The NO_3 leached can reach the ground water and can cause serious ground water pollution. In some countries ground water is us for drinking, excessive concentration of NO_3 in drinking water can pose a serious health hazard. The WHO (World Health Organization) has set the 10 mg/l of NO_3-N is the maximum limit of NO_3–N in the drinking water (WHO, 1971, Kross et al., 1993). Intake of NO_3 by human can cause heamaglobinemia or blue babies and the occurrence of stomach cancer (Bruning-Fann and Kaneene 1993).

In good fertilizer practice the use of NO_3 as nitrogen source is minimized to reduce leaching. The rate of N fertilizer leaching is affected by the soil texture, soil organic matter, soil structure and rainfall. Sandy textured soil with high rainfall will be exposed to high leaching loss. In Malaysia due to high rainfall leaching is a very significant mechanism for N loss. To avoid excessive leaching N fertilizer is applied in split application and in a more recent approached the controlled release or slow released N fertilizer is being used. Both these approaches will allow a minimum amount of N fertilizer to present in the root zone that will coincide with the plant uptake.

ORGANIC MATTER AND CLAY FIXATION OF N

N fertilizer not absorbed by plants or lost through leaching or gaseous loss remains in the soil. The N remains in the soil however can be transformed into unavailable form through organic matter and clay fixation. The mineral N if presents in organic matter with high C/N ratio can be converted to biomass N through microbial process. This form of N is not immediately available for plant uptake. In the presence of 2:1 illite clay NH_4-N present in soil can be fixed in the clay lattice and become unavailable for plant uptake. The NH_4 ions replace the K ions normally present in the lattices; this is possible because NH_4 ion is isomorphous to K.

The fixed NH_4 in both cases are not permanently lost from the soil; in most cases they are made available to plants at a very slow rate. In fertilizer programme this phenomenon has to be taken into consideration.

NITRATE POLLUTION

When N fertilizer is applied to soil the N is mineralized to NH_4-N and finally to NO_3-N. Nitrate although can be absorbed by plants and not phyto-toxic but its consumption by human being can cause serious health problem. When NO_3-N is ingested it is being reduced to nitrite in the intestine and is absorbed by the blood. The nitrite in the blood competes for oxygen with the hemoglobin to be oxidized to nitrate. Thus the blood is deprived of oxygen and respiration is interrupted. This condition is known as heamaglobinemia or 'blue babies', under severe condition can be lethal (Bruning-Fann and Kaneene 1993). It is also reported that due to the formation of nitrosamine in the digestive tract nitrate consumption can cause gastro-intestinal cancer (Kolenbrander, 1982). The WHO (World Health Organization) recommended that the safe level of NO_3-N in drinking water should not be more than 10 mg/l (Kross et al., 1993). Due to the health hazard, the use of N fertilizer is being given wide attention by the public. Human is exposed to NO_3 pollution either through drinking water or plant tissue containing high nitrate content. The amount of NO_3 found in some vegetables in Malaysia is presented in Table 9.

Table 9. Nitrate content (ug/g) of some vegetables found in Malaysia grown under different system

Vegetable	Organic Farming	Hydrophonic	Pasar Malam
		----------- ug/g -----------	
Sawi *(Brassica rapa)*	540	8615	12283
Sawi Putih *(Brassica chinensis)*	1646	1872	10509
Spinach *(Amarnthus viridis)*	181	6020	2116
Kailan *(Brassica oleraceae)*	541	15869	5283
Pak Choy *(Brassica chinensis)*	Na	7385	7500

(Khanif et al. 1999)

Previous work had shown the use of excessive N either through fertilizer or organic manure application had resulted in high level of NO_3-N in the ground water (Khanif et al,1984). Earlier reports also showed that excessive accumulation of nitrate occurred in plants receiving either inorganic N fertilizer or organic manure as N source. Thus the general belief that the use of organic manure guarantees production of safe food and environment is not necessarily true, if it is not scientifically managed.

When NO_3 is present in excessive amount in the soil the plant will absorb and accumulate in the tissue to a level more than required for normal growth. This absorption of excessive nutrient is often referred to as 'luxury consumption'. The NO_3 in the tissue is then reduced to amino acids, while excess nitrate remains in the tissue and can cause health hazard when consumed by human or animals. Nitrate accumulation usually occurs in condition where nitrate absorption is maximized and NO_3 transformation in the plant tissue is reduced. High nitrate accumulation usually occurred in plants grown in soil with high NO_3 - N, low light intensity, insufficient water and at low temperature (Benton et al., 1991, Breimner, 1986). It is also affected by the stage of maturity, plant parts, and plant species (Andrews, 1986)). Normally the younger plants have higher NO_3 accumulation than the older plants. Many leafy vegetables are known to be high nitrate accumulators notably the spinach (Pate, 1980). Vegetables grown in hydroponics system were shown to accumulate high nitrate because the N source in the nutrient solution was mainly from nitrate salt (Khanif et al., 1999).

The NO_3 accumulation in plant tissue and groundwater can be avoided by applying optimum rate of N fertilizer and by avoiding NO_3 source of N. The plants should be provided with optimum condition for N assimilation and minimizing stress to reduce NO_3 accumulation. The fertilizer should be applied in amount that coincides with the rate of plant uptake to avoid leaching. This can be through achieved through split application or by applying controlled release N fertilizer. It should also be understood that both organic manure and inorganic fertilizer supplying N are capable of causing NO_3 pollution. The built up of NO_3 in the soil can occur from both sources, NO_3 can originate from both organic and inorganic source.

NITROGEN EFFICIENCY

The efficiency of fertilizer in crop production is often low. The efficiency in grain crops often is not satisfactory due to fertilizer N loss. In rice production several reports showed that the efficiency is less than 30% (Khanif, 1988, Chaudhury et al., 2001). The low N efficiency is not only an economic loss but it will also cause serious environmental problem. The N fertilizer not removed by crop is either leach to the ground water or undergoes denitrification. Excess fertilizer when discharged in surface water can cause eutrophication. It is a condition where the surface water being rich in nutrients, tend to support excessive aquatic plants. Eutrophication reduces the available oxygen that can threaten the lives of other aquatic organism. For sustainable N fertilizer management the N fertilizer efficiency must be increase by reducing N fertilizer loss. This is to ensure sufficient and safe food is supplied to our dining table without any detrimental effect to the environment.

REDUCING N LOSS

The strategy to improve N efficiency for sustainable crop production is to reduce N fertilizer loss. Reducing N loss will reduce production cost; ensure production of safe agricultural produce and minimized environmental pollution. Some of the approaches have been reduction in ammonia volatilization loss, denitrification loss and leaching loss.

AMMONIA VOLATILIZATION LOSS

Ammonia volatilization loss can be substantial when urea is used as the N source (Khanif, 1992). The loss in most soil is around 30%. Minimizing this loss can reduce fertilizer cost. High NH_3 volatilization loss usually occurs in soil with sandy texture, high urease activity and low pH buffering capacity(Khanif, 1992)). The NH_3 volatilization loss usually is very minimal when urea is used in heavy textured alluvial soils. In rice soils the NH_3 volatilization loss under Malaysian conditions is about 12% (Aziz et al.1988). Although urea is a cheaper source of N, however, it is not the automatic choice as the N fertilizer, due to the perception that it will be subjected to volatilization loss.

When urea is applied to soils it is rapidly hydrolysed by an enzyme urease to NH_4; with subsequent increase in pH. At high pH gaseous NH_3 is released to the atmosphere; this gaseous loss mechanism is called ammonia volatilization. Base on the understanding of the mechanism by which the loss occur several methods were employed to reduce the extent of the loss.

One agronomic approach to reduce NH_3 volatilization loss is to incorporate the urea fertilizer into the soil. Ammonia volatilization from urea incorporation is lower than the loss from surface applied urea. Increase of urea granular size is also effective in reducing NH_3 volatilization loss. Another approach is to avoid the use of urea in sandy soil because in this soil NH_3 volatilization can occur at very high rate.

Several earlier works had shown that reducing the rate of urea hydrolysis can reduce the volatilization loss (Khanif and Wong, 1988). Many chemicals are known to have urease inhibitory property which when applied with urea will reduce the rate of urea hydrolysis and subsequently reduce the volatilization loss. Some widely used urease inhibitors are PPD, NBPT and hydroquinone (Khanif and Wong, et al. 1988). The effect of some selected urease inhibitors on urea volatilization loss are given in (Table 10). The effect of the urease inhibitors even at very low concentration is effective in reducing NH_3 volatilization loss.

Table 10. Cumulative ammonia volatilization loss from urea after one week with treatment of different rate of PPD and hydroquinone

Rate of Inhibitor (%)	Ammonia loss (%)	
	PPD	Hydroquinone
0	31.9	35.3
0.5	16.4	18.3
1.0	9.3	22.5
2.0	6.3	22.5
5.0	7.6	11.9

(Source: Khanif and Wong, 1988)

The effectiveness of the urease inhibitor is due to the reduction in the rate of urea hydrolysis, thus less NH_4 is available for volatilization and pH increase at the urea micro site is not substantial. With reduction in urea loss more is available for plant uptake and fertilizer efficiency is improved.

Similar approached was also employed by using Cu (Khanif, 1986). It was shown that Cu in relatively small amount is effective in reducing urea volatilization loss through urease inhibition. It is also very interesting to note that adding Cu to urea will give an added advantage because Cu is an essential micronutrient that has the potential to increase crop yield especially in Cu deficient soil. A copper coated was developed to reduce urea volatilization loss and to provide Cu as a micronutrient. This approached has been shown to be effective (Leong, 2002). In the study rice yield, N and Cu uptake were significantly increased with application of copper-coated urea. The technique used can be extended to other micronutrients such as Zn, B or a combination of relevant micronutrients.

Urea volatilization was successfully reduced with addition of cations such as Ca, Mg and K together with urea (Table 11). The present of Ca or Mg during urea hydrolysis prevent the formation of $(NH_4)_2CO_3$, insoluble $CaCO_3$ or $MgCO_3$ instead were formed. Thus urea volatilization is inhibited because $(NH_4)_2CO_3$ which is the intermediate for NH_3 volatilization can not be formed in the present of Ca and Mg ions. Co-application of urea with K reduce[b] NH_3 volatilization because the present high K in solution causes Ca or Al that may present on the clay complex to be release into the soil solution. Calcium ion will prevent urea volatilization as describe earlier.

Table 11. Cumulative ammonia volatilization loss of urea, after one week, with treatment of different rates of Ca, Mg and K

Cation/N	Cumulative Ammonia Loss (%)		
	Ca	Mg	K
0	41.7	31.0	38.0
0.25	35.8	28.9	31.4
0.50	26.1	20.2	22.3
1.00	18.5	18.6	18.7
2.00	7.4	13.1	8.4

(Source; Khanif and Wong, 1988)

In the case of Al, its release to the soil solution tends to reduce soil pH thus preventing excessive increase in soil pH during urea hydrolysis and consequently reduce NH_3 volatilization. The later case is a more acceptable explanation for tropical which is usually high in exchangeable Al.

The use of cations Ca, Mg and K to reduce NH_3 volatilization is a very practical and attractive approach. This is because all the cations that can be used to control urea loss are also plant nutrients often required in large amount. Thus addition of these cations serves dual purposes i.e. as a plant nutrient and also as an agent to reduce NH_3 volatilization. Thus the technique will not require additional cost. The K, Mg or Ca can be applied together with urea as bulk blend or as compound fertilizer. In this approach the cations applied must be at the right cation/N ratio and the cation must be at the urea micro sites when applied.

SLOW RELEASE N FERTILIZER

The low N fertilizer efficiency can be increased by reducing the rate of urea dissolution in soil. When urea dissolution occurs at a lower rate and if it can be adjusted to match plant uptake, minimum N fertilizer is exposed to loss mechanisms such as volatilization, denitrification and leaching. Thus the applied fertilizer will be more effective in increasing crop yield and N fertilizer efficiency. Without N fertilizer loss less fertilizer is required to achieve yield target thus reducing fertilizer and production cost.

A slow release fertilizer (SRF) N is a fertilizer that has been amended in such way that the N is released over long period of time that coincides with plant requirement. The term slow release fertilizer is interchangeably used with controlled release fertilizer (CRF). This is achieved by coating the urea with material such as polymer that regulates the N release to the soil solution. There are several slow release fertilizer available in the market with various trade name such as *Meister, Duration, IBDU, Humate coated urea* and *SCU*. Most of these fertilizers have slow release properties and the rate of release is affected by temperature, soil moisture, soil pH and other soil properties. The SRF has been shown to reduce urea loss, increase yield and N fertilizer efficiency. The production of SRF world wide however is still very low and is only being use niche market such in turf grass and high value crop. Although SRF is an ideal fertilizer having desirable agronomic properties and environment-friendly it is not widely use due to high cost in production. It is envisaged that the cost will come down with more advance in the coating technology. Slightly higher SRF than normal fertilizer cost can be tolerated since it requires lower application rate with reduced frequency and it is environment friendly. The use SRF in large plantation usually faced with labor shortage is very attractive because it can save labor cost by reducing the fertilizer application frequency.

REDUCING WATER REQUIREMENT

Water is a very important input in agriculture and about 70% of the water available globally is used for irrigation (Kindall and Pimentel, 1994). Large quantity of water is required for crop production, for example the production one kilogram of the following crop requires: 1400 liters of water for corn; 4700 liters for rice, and 17000 litters for cotton (Ritschard, and Tsao 1978). Pressure from the population increase has strained water resources worldwide. The use of water for irrigation has to compete with domestic and industrial use. To be sustainable the water usage efficiency in agriculture has to improve. The concept of 'more crop per drop' is being widely advocated. In the production of lowland rice, the current practice is to flood the field to about 5-10 cm during the growing period. This practice requires tremendous amount of water and reduces the acreage of land that can be cultivated with rice. If water use in rice production can be minimized the saving in the irrigation water can be used for other purposes and more land can be used for rice production. Our recent work had shown that rice production can be carried out with reduction in water input (Table 12). In this study water applied at soil saturation is sufficient to maintained similar yield as obtained by the current practice of flooding at 5 cm of water (Sarwar and Khanif, 2005). The lower water input also did not have any significant effect on nutrient content and soil pH (Sarwar and Khanif, 2005, Khanif and Sarwar, 2003). At soil saturation treatment the redox potential was higher that can potentially reduce CH_4 production, which is one of the greenhouse gases responsible for global warming . Production of CH4 requires a much reduced condition with very low redox potential.

Table 12. Yield of rice grown under different flood regime

Treatment	Tiller Number	Panicle Number	Yield (ton/ha)
W1	440	418	12,39
W2	443	423	11.87
W3	434	412	12.23
W4	432	408	12.27
W5.	429	405	12.24

W1 : Control, W2 : Continuous flooding at 1 cm, W3 : Continuous flooding at 5 cm in first 3 weeks followed by flooding at 1 cm, W4: Continuous flooding at 5cm for the first 6 weeks followed by flooding at 1 cm, W4 : Continuous flooding at 5cm for the first 9 weeks followed by flooding at 1 cm

(Sarwar and Khanif , 2004)

CONCLUSION

The agriculture sector supplies food for the population thus it is very vital for human survival. Soil is an important resource for food production. The current scenario suggests that the population carrying capacity of the soil resource has to increase to cater for the growing population which will reach about 10 billion in 2050. The increase in food production from expansion of the arable land is minimal due to scarcity of suitable land brought about by the competition for non agriculture land use and land degradation processes.

To ensure sustainable food supply from the agricultural sector the soil productivity has to increased and land degradation processes has to be minimized. Both this measures require a concerted global effort. Improvement of soil productivity and conservation of the soil resource require advances in knowledge through education and R&D for improving the existing technology. It requires public awareness through the education system and investment in R&D fund. To ensure the soil resource will continue to be healthy to supply food for the population, research efforts that address the sustainable management of soil resource should be given top priority. Although market driven research is important, the research for public good that has wider implication and long term effect should be given equal if not more emphasis to ensure human survival.

One approach for soil productivity improvement is through the use of fertilizer. Nitrogen fertilizer is the most widely use fertilizer in agriculture and important implication on soil productivity and the environment. While N fertilizer has been shown to increase crop yield it also creates environmental problem through production of green house gases, ground water pollution and eutrophication. Several approaches such as co-applying Urea with selected cation, micronutrient and the use slow release fertilizer can improve fertilizer efficiency while reducing environmental pollution.

In the words of President Franklin Roosevelt, 'nation that destroys its soil destroys itself', sustainable soil management ensures that we will be provided with continuous food supply **from the soil to the table**.

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