SOIL, WATER AND CLIMATIC RESOURCES OF THE PHILIPPINES: CONSTRAINTS, PROBLEMS AND RESEARCH OPPORTUNITIES

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Geographic Location and Area

The Philippines is an archipelago comprising of more than 7,000 islands spanning 1,840 kilometers from north to south. It lies between 4°N and 21°N and between 116°N and 127°N, at the western rim of the Pacific Ocean, and fronts the southernmost extension of the Eurasian Continent. It is part of the East Indies, a vast island group lying southeast of mainland Asia, with Taiwan at its northwest coast and Borneo on the south. Being an archipelago, it has about 36,289 km of coastline, twice that of the United States.

The land area of the Philippines is approximately 30 million hectares or 300,000 km^2. Eleven (11) islands account for about 95 percent of the total land area, with small islands and islets comprising the remaining five percent. Mainland Luzon is the biggest, with an area of 106,850 km^2, followed by mainland Mindanao with 97,200 km^2. The Visayas group of islands and other islands take up the remaining 95,950 km^2. The other major islands are Mindoro, Samar, Leyte, Negros, Panay, Cebu, Bohol, Masbate and Palawan. Each of these islands has an area of at least 5,135 km^2.

Climate and water resources

The Philippines has an average annual rainfall of 2,400 mm, which is considered substantial. However, there is a wide seasonal variation in the occurrence of rainfall. In most areas of the country, about 80 percent of the annual precipitation falls from May to October, leaving the rest of the months dry. Thus, there is the problem of "too much water" during the rainy season and "too little" during the dry season. Based on the length of the rainy season, the Philippines has four types of climate as presented in Figure 1.

The Philippines lies within the typhoon belt. An average of 20 typhoons pass within the Philippine Area of Responsibility (PAR) annually. The period of typhoon occurrence coincides with the growing season of important crops like rice and corn; thus, farmers often suffer severe crop losses. The country is also vulnerable to other climatic aberrations like El Niño and La Niña. Great efforts are being exerted by the Philippine Government in the formulation and implementation of coping mechanisms to mitigate the effects of these climatic anomalies.

The Philippines has a tropical climate that is dominated by rainy and dry seasons. The mean annual temperature is about 27°C. The hottest months and their average temperature are May at 28.4 °C, June at 27.9 °C and April at 27.8 °C. The coldest months and their average temperature are January at 25.5 °C, February at 25.8 °C and December at 26.1 °C. The average annual humidity is about 82 percent.

Because of the high rainfall, there is generally an abundance of surface water. The major river basins generate about 455 million cubic meters of runoff annually. However, as with rainfall, the presence of surface water in small rivers is temporary or ephemeral.

Figure 1. Climate map of the Philippines

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These small rivers are mostly dry during the dry season. Nineteen (19) of the 57 country's major watershed areas have been declared to be in a crucial state of land degradation (ADB Report, cited by Phil. Star, Dec. 5, 2004). Because of the absence of adequate vegetative cover, soil erosion is a major concern in these areas. Some of the major river systems have been developed for hydro-power generation, irrigation and domestic water supply. In some areas, there is strong competition for water among different sectors (e.g., irrigation vs. domestic water supply).

Groundwater is also an important water resource. There are about 5.1 Mha of shallow aquifers waiting to be tapped (Lucas, 1992). Groundwater is used for irrigation, fisheries and domestic water supply. However, tapping groundwater, particularly in the small islands, is fraught with danger. Overextraction can result in the intrusion of saline water, irreversibly destroying the aquifer.

Land classification and land use

Out of the 30 million hectare land area of the Philippines, 52.9 percent or 15.9 million hectares are classified as forested land or public land. The remaining 47.1 percent, or 14.1 million hectares, is classified as alienable and disposable (A & D) land (Andin, 2004), which is open to use by private individuals for agriculture and other purposes. Out of the 15.9 million hectares classified as public or forested land, only 7.2 million hectares, or 45 percent, are actually forested (Andin, 2004). This is an indicator of the serious ecological and environmental problems facing the country. Serious efforts are being made to conserve the remaining forest through selective logging and by increasing the present forested area through reforestation. Recently, the clamor for a total logging ban has been gaining support because of serious disasters (landslides and flooding) resulting in severe infrastructure damage and death.

Despite numerous plans and efforts to industrialize, agriculture is still the main source of livelihood in the Philippines. More than 36 percent of the population depends on it, since agriculture contributes about 20 percent of the Gross Domestic Product (GDP). In 2003, the Gross Value Added (GVA) was PhP 213,345 million (US$ 3,810 million). Rice, the staple food of Filipino households, is the main crop, planted over large tracts of land. It is grown from the level coastal plain to terraced mountain slopes. Of the country's suitable agricultural land of 14.1 million hectares, 4.0 million or 28.4 percent are planted with rice (BAS, 2004). During the wet season, rice is the only crop suited to the lowland areas. Corn is another important cereal, and is grown on about 2.4 million hectares. The area planted to corn, however, has been declining because of a shift to other crops and other land uses. Coconuts are the most widespread perennial crop, at about 3 million hectares. In regions where coconuts are grown as a monocrop, poverty is prevalent because of low productivity and the fluctuating prices of coconut products and byproducts on world markets. Intercropping of other suitable crops will increase farm income and thus alleviate poverty. Other important plantation crops are sugar cane, bananas, tobacco, pineapples and mangoes. These are mainly export crops and are also subject to world market demand and prices. From 1980-1997, the Philippines had one of the lowest growth rates in agriculture among selected Asian countries, at less than two percent per annum. From 1998 onwards, the growth rate picked up to about 3.4 percent.

Most of the idle lands that have potential for agriculture are under grass and shrubs. The most common grass species is locally known as "cogon" (*Imperata cylindrica*) and is very difficult to eradicate. It is associated with soil degradation.

Landform and soils

The Philippines is hilly to mountainous. About 55 percent of the country's land area is steeper than 18 percent. Being an archipelago with numerous small islands and islets, the geomorphology is very varied. Some islands are made up entirely of raised coral reefs, while there are a number of island volcanoes. In a single island, it is common to see a wide range of geomorphology, from tidal mud flats to rugged mountains with alluvial plains, plateaus and other land forms in between.

For land use purposes, the soils in the Philippines can be classified into two broad classes: (1) upland, and (2) lowland (Kyuma, cited by Mitsuchi, 1994). Clays, nutrient elements and water accumulate in lowland or alluvial soils, while water does not accumulate in upland soils and nutrients are lost by leaching and erosion. For this reason, lowland soils are much more fertile than upland soils. Lowland soils in the Philippines are mainly used for paddy rice during the rainy season. However, during the dry season, some are used for upland crops like corn, tobacco and vegetables.

A major portion of the upland areas are occupied by Ultisols, regarded as problem soils because of their strong acidity, low base saturation, high P retention and highly leached condition. Moreover, due to being situated in upland areas, Ultisols are prone to erosion. Based on USDA Soil Taxonomy, Philippine soils can be classified into six (6) Soil Orders (Table 1), with Ultisols being the most extensive, covering 41.5 percent of the country, followed by Inceptisols and Alfisols at 13.7 and 9.9 percent, respectively. Ultisols, Alfisols, Oxisols and some families of Inceptisols and Entisols belong to the upland category. The Vertisols and most of the families of Inceptisols and Entisols belong to the lowland category.

Table. 1. Classes and extent of Philippine soils (USDA Soil Taxonomy)

Soil Order	Percent	Area (km^2)	*Broad class*
Ultisol	41.5	124,500	*Upland*
Inceptisol	13.7	41,500	*Upland/lowland*
Alfisol	9.9	29,700	*Upland*
Vertisol	3.6	10,800	*Mostly lowland*
Entisol	2.5	7,500	*Upland/lowland*
Oxisol	0.3	900	*Upland*
Mountain soils (Unclassified)	28.6	85,800	*Upland*

Adapted from Badayos: 1994

Population

As of 2004, the Philippines had an estimated population of 83 million, with an annual growth rate of 2.3 percent—one of the highest in Southeast Asia. In terms of population, it is the 14^{th} largest country in the world. In 2000, the average incidence of poverty was about 28.4 percent. About 4.3 M families or 26.5 M Filipinos were living below the poverty line. The incidence of poverty is closely related to soil and land condition, notably soil erosion. There are about 24 million people living and deriving their livelihood in the uplands (Villancio, 2004). These upland dwellers, the majority of whom live below the poverty line, are exerting tremendous pressure on upland resources, since most of them are using non-sustainable farming practices. As a result, upland biodiversity is decreasing and soil erosion is a serious concern. One of the causes of degradation in the upland is lack of security of land tenure. If farmers have no permanent hold on the land, they are not inclined to adopt conservation-type farming practices.

As the available lowland areas continue to decrease due to population pressure and the conversion of agricultural lands into other uses, more people will be forced to move into the uplands, causing further environmental stress. Other livelihood opportunities and the adoption of environment-friendly farming practices would reverse the trend in environmental degradation.

SOIL, WATER AND CLIMATE-RELATED CONSTRAINTS ON AGRICULTURAL PRODUCTIVITY AND BIODIVERSITY

Soil erosion

Soil erosion is recognized as the most serious threat to agricultural sustainability in the uplands. Annually, the equivalent of one meter's depth of soil over an area of 100,000 hectares of land is lost through erosion (ADB Report, cited by Phil. Star, Dec. 5, 2004). A regional study (SOTER/ASSOD) conducted by the International Soil Reference and Information Centre (ISRIC) in the Netherlands, found that the main land degradation problem in the Philippines is topsoil erosion, which affects 60 percent of the total land area (Table 2). It is interesting to note that the level of poverty in the country has a positive relationship with the magnitude of soil erosion, as can be seen in Table 2. For instance, Central Luzon (Region 3) has the lowest area affected by topsoil erosion and the lowest incidence of poverty. On the other hand, in the Bicol Region (Region 5), Central Mindanao (Region 12) and the Autonomous Region for Muslim Mindanao (ARMM) where poverty levels are over 48 percent, the area affected by erosion is over 70 percent. Moreover, most of the regions with high incidence of poverty are known to experience seasonal aridity (UNCCD NAP, 2004) and are located in the uplands. It is also interesting to note that the dominant land use in regions with high incidence of poverty is for coconuts. Monocrops of coconut have resulted in depletion of soil nutrients, increased soil erosion, decline in crop productivity and consequent decreases in farmers' incomes, hence the prevailing poverty.

Table. 2. Area affected by soil erosion and incidence of poverty by region

Region	Area (km^2)	Without soil degradation		Affected by topsoil erosion		Incidence of poverty
		km^2	%	km^2	%	(%)
CAR	18,000	1,800	10.0	15,660	87.0	31.1
1	12 ,000	4,212	35.1	5,520	46.0	29.6
2	27,000	6,588	24.4	17,064	63.2	24.8
3	18,000	8,442	46.9	6,192	34.4	17.0
4	48,000	28,994	60.3	16,800	35.0	20.8
5	18,000	3,618	20.1	13,212	73.4	49.0
6	20,000	10,300	51.5	7,160	35.8	37.8
7	15,000	3,075	20.5	10,545	70.3	32.3
8	21,000	9,681	46.1	10,500	50.0	37.8
9	16,000	3,088	19.3	12,272	76.7	38.3
10/Caraga	28,020	3,388	12.1	23,324	83.3	32.9*
11/Caraga	32,000	3,424	10.7	23,520	73.5	31.5**
12	15,000	2,595	17.3	11,490	76.6	48.4
ARMM	11,000	2,607	23.7	8,030	73.0	57.0
NCR	---	---	---	---	---	5.7
Total	299 000	91,762	---	181,289	---	---
PERCENT	100.00	30.69	---	60.63	---	28.4

Adapted from: Philippine National Action Plan (NAP), UNCCD.

* Excluding the provinces of Agusan del Sur and Agusan del Norte (Caraga)

** Excluding the provinces of Surigao del Sur and Surigao del Norte (Caraga)

Note: For the Caraga Region (Agusan and Surigao Provinces) which has separate NSCB data, the incidence of poverty is 42.9 percent.

The volume of soil loss in sloping farms "with" and "without" conservation measures applied is presented in Table 3. In Benguet, one of the provinces in the Cordillera Administrative Region (CAR), about

62 tons of soil loss per year is expected if no conservation measures are applied. About 87 percent of the total area of CAR is affected by topsoil erosion (Table 2). However, when soil conservation measures are applied, soil loss is about 2 t/ha/yr.

Table 3. Soil loss for farms "with" and "without" soil conservation measures.

Without soil conservation measures

Researcher	Location	Soil loss (t/ha/yr)	% slope
Bocato, 1981	Bicol	22.9	27
Colting, 1983	Benguet	62.3	29
Sajise, 1982	Negros	218.5	21

With soil conservation measures

Researcher	Location	Soil loss (t/ha/yr)	% slope
Limbaga, 1993	-	2.0	30–60
BSWM, 2001	Rizal	<2	30
BSWM, 2001	Bukidnon	<2	30
Palmer, 1996	SALT	3.4	-

In experiments conducted in 1977 and 1988 (Palis, 1994) estimated that only 5.1t/ha/yr soil is lost from areas covered with various grass species. However, on bare degraded Ultisols, about 200 t/ha/yr soil was lost through erosion. High rainfall intensity, steep slopes, highly erodible soils and the non-application of soil conservation measures are the main causes of soil erosion. Upland soils have very low organic matter content, making them highly erodible. With an upland population of 24 million that is still increasing, the need to adopt conservation-type farming practices is becoming ever more urgent and crucial.

High soil acidity

Based on the FAO-UNESCO Soil Map of the Philippines, acidic upland areas cover about 9.6 million hectares or 32 percent of the total land area of the country (IRRI, cited by Duque, 1996). This comprises 4.9 million hectares with topsoil of pH 5.0-5.5 and 4.7 million hectares with a topsoil pH of less than 5.0. These soils are classified by the FAO as either Orthic acrisols or Dystric nitosols, equivalent to Ultisols under the USDA Soil Taxonomy.

Soil acidity influences the availability of all essential elements. The solubility of metal ions like aluminum and manganese makes them toxic at low pH. Experiments in an Ultisol in Bukidnon have revealed that grain yield is low when the soil pH is 5.3 and where exchangeable aluminum is quite high (Duque, 1996). The use of lime eliminates toxic levels of aluminum on strongly acid soils planted with corn.

Nitrogen and phosphorus deficiency

The most critical nutrient constraints on upland soils in the Philippines are nitrogen and phosphorus. All upland soils in Bukidnon, a major corn producing area in Mindanao, are deficient in nitrogen and phosphorus (Duque, 1996). According to the Bray No. 2 method, the soils contain less than 16 ppm. Sixteen ppm has been designated the critical level of available phosphorus in acid soils. Other major upland areas where corn is grown (Isabela Province) are likewise acidic. In such areas, the simple application of lime can increase yields.

Another problem related to phosphorus availability in acid soils is phosphorus fixation or retention. The phosphorus adsorption capacity of Ultisols in Bukidnon ranges from 104 to 170 mgP/100 g soil. In such soils, the uptake by soybeans grown up to flowering time ranges from 4 to 16 percent only (Duque, 1996).

Liming is an effective way of correcting soil acidity making soil nutrients, especially phosphorus, available to crops. The BSWM-JICA Technical Cooperation Project (EPMMA, 2004) showed that an increase in phosphorus applications resulted in significant increases in sweet corn yields. The controls showed a yield of 1.2 t/ha compared to fertilized plots with 60, 120 and 180 kg P/ha, which gave a yield of 2.5, 3.9 and 4.5 t/ha respectively. Because of the high P retention capacity of acid soils, doubling the rate of P application based on soil analysis gives better crop yields.

In as much as the high temperature in the Philippines promotes the rapid breakdown of organic matter, soil organic matter is generally low. To maintain productivity, N fertilization from organic and inorganic sources is necessary. Crop residue management can enhance soil organic matter.

Calcium, magnesium and micronutrient deficiencies

Calcium and magnesium deficiency often occurs on acidic soils, notably ultisols, due to low base saturation. In Bukidnon, an important nutritional problem which affects the fruit development of tomatoes is calcium deficiency, leading to the formation of "Blossom-end rot" in tomato fruit (Duque, 1996). These soils likewise exhibit Mg deficiency, visible as interveinal chlorosis; and without the application of kieserite ($MgSO_4$), yield is reduced.

Deficiencies of micronutrients, particularly zinc, are known to exist due to continuous crop removal, and in the case of upland areas, due to soil erosion and leaching. Following nitrogen, zinc is known to be the next limiting factor for lowland rice. Deficiencies of boron have likewise been reported, particularly for some fruit crops like papaya.

Shrinking and swelling clays

Clays with high shrink-swell potential have a narrow range of suitable crops and very often, rice is the only practical alternative crop. Difficult workability, root impedance and poor drainage conditions are the main constraints of clayey soils. Extreme hardness when dry and extreme stickiness when wet are the main characteristics of clayey soils which are classified as Vertisols in the USDA Soil Taxonomy.

Soils of the broad alluvial valleys far from the river terraces and those derived from limestone often have high clay content.

Seasonal aridity

Most parts of the Philippines, particularly those with distinct wet and dry periods (6 months wet, 6 months dry) are seasonally dry. These are mostly in the western and central parts of the country. In such areas, seasonal cropping during the dry season is not possible without supplemental irrigation. Water-harvesting structures are needed in seasonally dry areas to increase cropping intensity and boost farm incomes.

Vulnerability to climatic aberration

The Philippines is particularly vulnerable to El Niño, which is observed to be increasing in its frequency of occurrence, magnitude and duration. The El Niño episode in 1997 resulted in major damage, estimated at approximately 100 billion dollars, to the Asian and the Pacific regions (CGRPT Centre Monograph No. 43, 2002). During the occurrence of El Niño, even the productivity of perennial crops like coconuts, mangoes and other fruit trees are affected.

La Niña, the opposite of El Niño, is likewise a regular occurrence in the country. High-intensity rainfall over long durations causes severe flooding of lowland areas.

Waterlogging and flooding

The low-lying alluvial plains and valleys suffer from waterlogging during the wet season. On account of their level topography, these areas are also vulnerable to flooding. During the wet season, the choice of crop is limited, and very often rice is the only alternative. Flooding is attributed to both natural and anthropogenic causes. Degraded watersheds and silted waterways exacerbate the flooding problem.

Saline water intrusion into groundwater

Of the more than 7,000 islands in the Philippine Archipelago, only 11 islands are regarded as major or big islands. These 11 islands account for about 95 percent of the total land area. Thus, it can be concluded that most of the islands in the country are rather small. Small islands are very vulnerable to saline water intrusion because of the small aquifer cells underneath them; thus, tapping groundwater is fraught with danger. Overextraction can result in the intrusion of saline water, irreversibly destroying the aquifer. Because of overextraction, highly populated areas like Metro Cebu have reported problems of saline water intrusion in their aquifers (Water Remind, 2004). Intrusion of salt water into aquifers has also been reported in the narrow coastal plain of the Ilocos Region. Because of its very long coastline, saline water intrusion is a risk in the Philippines.

Groundwater pollution

Pollutants are usually introduced into the groundwater through widespread sources which can be hard to detect. Groundwater pollution is likely to occur in sandy soils, shallow soils and in limestone areas or karst topography.

Areas with Karst topography are good water infiltration sites. Runoff accumulates in such areas and eventually infiltrates into the soil. Any man-made or natural pollutants can be readily carried down with the percolating water. Limestone formations are often highly fractured, have large crevices and are generally porous, and therefore cannot effectively prevent, by filtration, pollutants moving into the groundwater. Small islands like Bantayan in Cebu have a groundwater pollution problem deriving from various poultry farms, which is being aggravated by a shallow soil and the porous nature of the underlying limestone. In Metro Cebu, groundwater quality analysis indicates a significant upward trend in nitrate contamination. Most of the wells are found in populated limestone areas where 74% of septic tanks are bottomless (Water Reminder, 2004).

Heavy fertilization under upland conditions is likely to cause nitrate contamination of shallow groundwater. Because of the aerated condition of the soil, nitrogen will mostly be in nitrate form, which is mobile. Heavily fertilized vegetable farms in the uplands and plantation crops such as banana and pineapple are the most likely sites for groundwater pollution to occur.

RESEARCH OPPORTUNITIES

With the need to put more lands to productive purposes to sustain the growing population, there is a need to direct research priorities in the uplands. At present, the productivity of upland areas is low, and there is a need to direct research efforts towards higher productivity. After more than four decades of work by the International Rice Research Institute (IRRI) completed, I believe that lowland research has been adequately addressed and it is high time that upland research be given the emphasis it deserves.

The most eloquent statement on the need to focus attention on the development of the Philippine uplands was highlighted by the Philippine Agroforestry Development News:

" Even if the Philippine Government poured all of its resources, money and talents into expanding the carrying capacity of the lowlands, it would still become all too clear that the next focus for rural development efforts would have to be in the uplands. For it is in the uplands that supplementary and additional food sources will be grown. It is in the uplands that will give Filipinos elbow room for the land shortage. It is in the uplands where landless rural people will find new options for fighting rural poverty".

Soil Conservation Research

As already mentioned, soil erosion is the most serious threat to the sustained productivity of upland soils. Loss of topsoil and nutrients is often the cause of declining crop yields, and since upland areas are gradually to steeply sloping, even the application of fertilizer is not always effective, since can be washed out via runoff. Likewise, because of rapid runoff, there is not much time for water to infiltrate into the soil, thereby depriving the crops of much-needed moisture.

Use of suitable hedgerows

Live barriers can reduce runoff and soil loss to a significant degree. These barriers break the velocity of the runoff and allow sediment to accumulate behind the hedgerows, forming natural terraces over time. With the runoff slowed down, more water can infiltrate into the soil to be used by the crops.

There is a need to determine the types of hedgerows that are suitable for specific conditions and which are acceptable to the farmers. In some cases, farmers have expressed a preference for natural grasses (natural vegetative strips) because they are easy to establish and maintain. However, the opportunity to use economic crops as hedgerows is considerable, especially in areas where land is limited and farm sizes are small. Aside from determining types of hedgerows or barriers, it is necessary to select the appropriate hedgerow spacing based on slope.

Use of cover and companion crops

One effective way of reducing runoff and soil loss is through the use of cover crops. These cover crops protect the soil from direct rain impact and thus prevent soil dispersion and transport. When these cover crops die, they can be incorporated into the soil. There is a big opportunity to use cover crops for soil erosion control and fertility improvement in the Philippines. Unfortunately, this has not been emphasized by the government to the farmers, probably because its beneficial effects have not been demonstrated. In sloping areas, a combination of creeping crops, like sweet potato, and corn would be desirable. Ideally, legume and cereal combinations should be used. There is an urgent need for the utilization of cover crops as a soil conservation measure to be promoted in the uplands. An animal component in the system could be included.

Agroforestry research

Agroforestry is about the multiple use of land through a combination of annual and perennial crops and forest trees. It is a multi-purpose system, and for small farmers, it is a means of "risk-spreading," in which the failure of one commodity can be compensated by another commodity in the system.

Agroforestry can effectively reduce soil erosion and increase land productivity in the uplands. It can follow different models. The multi-storey cropping practiced by upland farmers in the Province of Cavite is a very successful model for increasing land productivity. In this model, four to five different crops of different height and growth habits are cultivated in the same area (coconuts, bananas, coffee, pineapples and root crops). Where land area is limited, multi-storey cropping is a very promising option.

The vast coconut area in the country also has major potential for agroforestry. Income from coconut farms is low and poverty is prevalent. Income can be raised by planting other suitable crops like forage grasses and legumes. The appropriate coconut intercrop will depend on the planting density, soil, and climatic conditions. The vast open grassland and degraded areas have perhaps the greatest potential for agroforestry. Here, perennial crops and forest trees could be used as nurse crops for sensitive crops like coffee or cacao. To prevent soil erosion (the most important concern in upland areas), hedgerows of forage grasses or perennial crops could be used.

Appropriate agroforestry models for specific soils and environmental conditions are ideal subjects for research. Consideration must also be given to the socio-economic conditions of the area. The problem of land tenure, which is prevalent in many upland areas, must be settled. Agroforestry is regarded as permanent land use, and could only be implemented by farmers if their hold on the land is secured.

Conservation tillage

The problem of soil water losses through erosion, runoff and evaporation is a major limiting factor in upland rainfed agriculture in the Philippines. In rainfed areas where there are distinct wet and dry periods, only one crop is possible because of the lack of soil moisture to sustain a second crop.

Tillage is defined as the mechanical manipulation of soil for any purpose. Manipulation involves soil disturbance, which can lead to deterioration of soil structure if not carefully or adequately done. Tillage modifies the soil surface, where the complex and crucial partitioning of rainfall into runoff, infiltration and subsequent evaporation occurs. It also modifies soil surface structure, total porosity, pore continuity and pore size distribution; hence the great influence of tillage on the hydrology of an agricultural catchment (Mwendera, cited by Kaumbutho, 2000). Tillage also affects the microbial biomass in soils by exposing new microbial sites and increasing microbial activity and growth.

It should be possible to grow a second crop at the beginning of the dry season after harvesting the main crop by practicing conservation tillage or minimum tillage. This will lessen the turnaround period, which is crucial if the farmer has to take advantage of the residual soil moisture. Tillage influences the upward movement of moisture to the soil surface, vapor from the surface to the atmosphere and heat transfer to the soil (Kaumbutho, 2000). By practicing conservation tillage, the upward movement of moisture from the soil profile and subsequent evaporation to the atmosphere is minimized. Conservation tillage will also lessen labor costs for the farmer, thus enhancing farm profitability.

In the Philippines, conservation or minimum tillage is still not yet widespread, despite its great potential for enhancing the productivity of upland areas. One hindrance is the perceived weed problem, but this could be solved by chemical or biological means. Also, the residue of the previous crop can be used to suppress the growth of weeds.

Conservation tillage is a promising area of research in the Philippines. Its impact on farm income, soil biodiversity, soil fertility and soil moisture must be determined before it can be introduced to farmers for adoption.

Hydrology and soil erosion modeling

Because of the varied topography, geology, soil, land use and climatic conditions in the country, hydrology and soil erosion modeling should be done at watershed scale. The output will be a very good tool in land use planning and environmental management. At present there are existing Geographic Information System (GIS)-assisted models that can simulate the runoff and soil erosion of a catchment area during a particular rainfall event, which could be validated by field investigation.

Models could be applied, since actual measurement of runoff and soil loss in the field is expensive, time-consuming, and demands considerable manpower.

Integrated Nutrient Research

Aside from soil erosion, low soil fertility is one of the major limiting factors on the productivity of upland areas. High soil acidity and low nutrient content, particularly nitrogen and phosphorus, limits crop growth.

Balanced fertilization

With the high cost of inorganic fertilizer, there is a need to shift to organic fertilizer sources. Using a higher proportion of organic fertilizer can improve long-term productivity, aside from increasing soil biodiversity. Determining the appropriate combination of organic and inorganic fertilizer under different soil conditions and farming systems should be a research priority. Aside from determining the appropriate rate of fertilizer to be applied, the method and frequency of application is also important. Usually, nitrogen fertilizer application is split to minimize N losses due to leaching and volatilization. However, some studies have established that staggered application of phosphorus in acid soils is also an option in solving the P fixation problem.

Efficiency of fertilizer use

Fertilizer use efficiency varies according to crop, soil type and climatic factors. In acid soils, the efficiency of phosphorus is generally low, since it is fixed in insoluble forms which cannot be used by crops. In sandy soils, fertilizer nutrients can easily move beyond the root zone through leaching. This downward movement of nutrients can result in groundwater contamination. Heavy fertilization in commercial and plantation farms is likely to lead to nitrate contamination of groundwater.

One way to monitor fertilizer use efficiency and potential groundwater contamination by applied fertilizer is by means of lysimeter studies. The use of an improvised lysimeter (Urriza, 2004) has been effective in monitoring nutrient movement and loss in the soil. There is a need to further study the movement of fertilizers under field conditions to allow effective fertilization strategies to be formulated according to the crop, soil type and weather conditions.

Crop residue management

To cut input costs and increase farm income, soil nutrients should be recycled through the use of crop residues. Most farmers still consider crop residues as a nuisance, since they interfere with tillage. The most convenient means of disposal is by burning, but this practice deprives the soil of essential nutrients and at the same time contributes to environmental problems through the release of carbon dioxide.

Crop residues can be incorporated into the soil or used as mulch. Mulch protects the soil against raindrop impact and conserves soil moisture by minimizing evaporation. Field research on the use of crop residues can convince farmers to make better use of this farm waste.

Liming

In acid soils, liming is essential to supply the soil with calcium and to make other elements, especially phosphorus, available to plants. Soil acidity is an excellent single indicator of soil fertility; and the availability of 13 or more essential elements in the soil is highly dependent on soil pH. Considering that there are about 9.6 million hectares of acid upland soils in the Philippines, the importance of liming is undeniable.

Liming experiments in the Philippines have been conducted on major crops. However, the method of determination of lime requirement has not received much attention. Soil pH indicates the need for lime, but gives no hint of the amount needed. Liming and fertilization studies should be done at the same time. The effect of liming should not only be directed at simply raising the pH but also on other factors such as soil biodiversity.

Micronutrient studies

Deficiencies of micronutrients, especially zinc, have been identified. Deficiencies can be attributed to crop removal, leaching and soil erosion. The production of papaya, an important export fruit crop, has reportedly been suffering from boron deficiency in many areas. As of now, the threshold limit of micronutrients, even for the most important crops in the Philippines, has not yet been established. This is an important and challenging research opportunity.

Water Management Research

Water management is a very critical aspect in the use of upland areas, where crops are totally dependent on rainfall. Because of the short wet season, it is necessary to take into account the timing of field operations and water conservation strategies.

Water harvesting

Rainfall is generally abundant in the Philippines. However, its occurrence is very seasonal; during the rainy season there is "too much" water while there is "too little" during the dry season. Thus, there is a need to establish water harvesting structures to capture and store runoff to be used for irrigation during the dry season. These structures range from small farm ponds to large-scale reservoirs.

Rainwater harvesting is regarded as a conservation strategy which controls runoff and stores water for supplementary irrigation during the dry season. With rainwater harvesting, it is possible to plant a second seasonal crop after the end of the rainy season. Because of the sloping to hilly topography of the upland areas, small water impoundments are more appropriate. For perennial crops, a challenging approach is to construct a catchment basin for individual trees. Location-specific studies should be conducted to determine the most appropriate methods or measures to be implemented in a certain area. Rainwater harvesting should be flexible; local conditions of rainfall, evaporation, topography, soil type and depth, vegetation, cost of labor and local technical know-how will determine which method of water harvesting and storage fits best in a given condition.

As a basis for design in the case of small water-impounding projects and dams, a study of runoff coefficients according to land cover is essential. Without adequate hydrological studies, there can be no firm basis for system design, which may result in the over- or under-design of structures.

Water conservation

Soil water should be encouraged to stay in the soil for as long as possible. To accomplish this, mulching materials, ranging from indigenous grasses to plastic sheets, can be utilized. Increasing the water to be stored in the soil through infiltration can be done by increasing the soil surface roughness, by trenching, use of grass mulch, or live vegetative barriers.

Groundwater quality monitoring

There is a need to monitor groundwater quality in highly intensive agricultural farms, limestone areas with karst topography, coastal zones and small islands where extraction of groundwater is very intensive. In karst topography, chemical pollutants could easily be drawn down into the groundwater with the percolating water without being filtered out due to the porous nature of the limestone materials. There are several islands and islets which are made up entirely of raised coral reefs. Most of these have shallow soils where the underlying limestone materials are highly fractured, with several crevices where the percolating water can move down easily.

In coastal zones where intensive groundwater extraction is being carried out, salinity intrusion is very likely. In the narrow coastal zone in the Ilocos Region, salinity intrusion has been reported to be a problem because of the limited recharge area combined with overextraction of groundwater. This problem has affected tobacco farming, the main industry in the region. Tobacco leaves affected by saline water have poor burning quality and fetch lower prices than high quality leaves.

Climate research

Weather records in the Philippines are not sufficiently detailed to allow the design of appropriate cropping patterns. At present, most weather stations are located in research centers or airports. When designing cropping patterns, data from these stations are used, but they may not represent actual conditions in far-flung upland and mountainous areas. Farmers in upland areas rely more on instinct and personal experience than on long-term climatic records which could tell them the levels of risk involved when making decisions when or when not to plant.

With the advancement of digital technology, it should now be possible to install weather stations in remote areas at minimal manpower cost. A network of weather stations in upland areas could give reliable estimates of rainfall patterns and other necessary parameters. It has been recognized that there is an apparent change in climate behavior, particularly in rainfall patterns. This is exemplified by the statement of a former Philippine Secretary of Agriculture: "Anybody who says that Mindanao has an evenly distributed rainfall does not know what he is saying and has not been to Mindanao lately". Existing climate classification states that most parts of Mindanao have an evenly distributed rainfall. However, it is a common observation that the dry season seems to be getting longer. This indicates the need to conduct an in-depth study of climate through a network of weather stations, especially in areas where there are no reliable long-term records.

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