Prediction, Impact and Control Variables for Field Research Evaluation

Prepared by Joe Tabor

For Food Aid Management

300 I Street, NE, Suite 212, Washington, D.C. 20002
202-544-6972 (phone) 202-544-7065 (fax) fam@foodaid.org

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FOREWORD

This document was commissioned by the FAM (Food Aid Management) M&E (Monitoring and Evaluation) Working Group. The purpose in contracting a consultant was to complement an earlier document written by P. Bonnard summarizing socio-economic baseline indicators used by Title II Cooperating Sponsors for monitoring and evaluation.

The M&E Working Group has made minimal changes to the original document prepared by Joe Tabor, with the exception of comments added for clarification or expansion. M&E Working Group comments appear in bold italics (blue in electronic copies, black in hard copies) for easy identification by readers. These editorial comments are based on current PVO knowledge and experience in agricultural development.

Status of M&E for Agriculture Projects

The wider community of international relief and development agencies (PVOs) has made more progress developing simple, straightforward monitoring and evaluation indicators in the sectors of health and micro-finance (village banking) than in Agriculture and Natural Resources (ANR). There are several reasons for this, but probably the most important is that, unlike health and micro-finance, ANR incorporates multiple diverse scientific disciplines (plant science, animal science, meteorology, economics, crop science, soil science, ecology, forestry, entomology, hydrology, agricultural engineering, microbiology, weed science, etc.) Each discipline has an array of indicators unique to that discipline, making selection of indicators and implementation of monitoring and evaluation systems potentially complex and costly.

There is a second reason there has been a delay in developing indicators that are appropriate for the needs of ANR development projects. Rural subsistence farmers cultivating small plots of land often grow their crops in marginal agro-ecological buffer zones. There can be high spatial and temporal variability with large differences in the values of basic indicators over short distances within short periods of time.

Although these ecological buffer zones are generally inappropriate for agriculture, it is the only land many resource-poor farmers have access to. Rainfall tends to be undependable in buffer zones, and timing and quantity varies from year to year. Soils are degraded or located on sloped land, where topsoil may be thin or completely eroded. Soil types can change dramatically in short distances, making them more difficult to manage. Changes in elevation further increase changes in micro-climates, making sampling and extrapolation of results to other sites difficult.

The third reason for the lack of proven, easy-to-measure biophysical indicators for agriculture is that those working in agricultural development don't necessarily have formal training in agronomy. Those who do have some agricultural training, often were trained to farm for high total yields, and may not have focused on how to monitor yield on a per-unit-of-land basis in irregularly shaped, disperse plots. Also, many times they were not trained in monitoring of key natural resource variables that affect yield, like climate and soils. Finally, those agronomists with college training who did learn monitoring methods, often learned methods more appropriate for research than fieldwork.

Goal of This Document

An important first step in moving the development community forward in Monitoring and Evaluation for ANR is to review the development-appropriate indicators that exist. FAM contracted the author of this document to survey simple, farmer-friendly indicators being used for on-farm monitoring in agricultural development projects.

Unfortunately, for several reasons, many of the indicators in this review are indicators developed for research, not development. In research, it is essential to determine cause and effect through careful, but generally costly, monitoring of multiple variables. The research approach entails a significant investment in scientific expertise and equipment, data collection and laboratory analysis.

However, this level of effort and precision is rarely appropriate for development projects. The one obvious exception is for a pilot project, where innovative methods are tested for later replication on a large scale. In this case, some of the variables in this review may very well be appropriate.

Balancing Implementation and Monitoring

Our main purpose as PVOs is not research and data collection, but high-impact, good quality development, that reaches many of the poor, and is based on stewardship of staff and financial resources. While it is important that we devote a reasonable amount of serious effort to M&E to ensure program quality, too many resources spent collecting data, means fewer farm families served by our development projects.

Monitoring & Evaluation (M&E) experts recommend the best approach to the use of indicators is to:

- ***use as few as possible,***
- ***keep them simple***
- ***select indicators that provide essential information and require minimum time and resources.***

Additionally, indicators should be tied closely to specific objectives and should either –

- ***monitor progress and provide "course correction" feedback during implementation***
- ***or provide essential information about results or impact.***

A Note of Caution

When given a long list of indicators like the ones included in this review, we tend to assume that because the indicators are included in the list, we ought to include them in our M&E systems. Yet the majority of the indicators are not necessary for most objectives in most ANR development projects. Use this list with caution. Carefully analyze first whether the indicator is important and useful, and then analyze costs and benefits, as well as staff and farmer capacity.

It is worth noting that many of the examples presented in this review and all of the recommended equipment, come from temperate, high technology agriculture. Their appropriateness for tropical, low technology farming is case-specific and debatable. The

review also includes frequent references to Internet websites, which are not easily accessible to PVO staff in many countries.

<u>Conclusion</u>

The indicators (or "variables") in this review provide a supermarket of choices. When you go shopping, rice and beans or bread and milk are all you probably need. And generally, that will be all you can afford to buy.

For those of you who are interested in a practical manual on this topic, a guide to user-friendly, on-farm biophysical indicators for M&E in ANR projects will be produced in 2001. FAM will distribute this guide to Title II Cooperating Sponsors when it becomes available.

Sincerely,
FAM M&E Working Group

Preface

Trade names and businesses mentioned or referred to in this report are used to provide specific information. Their mention does not constitute a guarantee nor imply endorsement over comparable goods and services not named by FAM or the author. The problems and success of impact monitoring that were reported by PVOs are incorporated in this report without attribution.

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Abbreviations

$US	US Dollar
B	boron
Cu	copper
CV	coefficient of variation
e.g.	for example
et al.	and others
FAM	Food Aid Management
Fe	iron
ft.	feet (measurement unit)
GDD	growing day-degrees
GIS	geographic information system
GPS	global positioning system
i.e.	that is
in.	inch
K	potassium
km	kilometer
m	meter
M&E	monitoring and evaluation
Mg	magnesium
mm	millimeters
Mn	manganese
Mo	molybdenum
N	nitrogen
NRM	(improved) natural resource management
P	phosphorus
p.	page
pH	negative log of hydrogen ion concentration*
pp.	pages
PVO	private voluntary organization
sq.	square
US	United States
USAID	US Agency for International Development
Zn	zinc

pH is a scale used to indicate acidity or alkalinity.

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1. INTRODUCTION

This report describes some of the techniques available for measuring biophysical variables. ***They are taken in large part from research and in many cases may not be appropriate for use in development projects.*** Title II projects are encouraged to use USAID's Generic Title II Indicators. The biophysical indicators are listed in Table 1 and described in more detail in Chapter 4. The methods discussed primarily, but not exclusively, address the needs of these Generic Title II Indicators.

The term "baseline surveying methods" refers to a baseline or reference for measuring changes in conditions and characteristics used to evaluate project effects and impacts. *Part 1: Socio-economic methods* defined baseline in terms of control groups, specifically internal, external, and historical controls (Bonnard, 1998, p. 21-22). Maintaining the same terminology, this report focuses on internal and historical plot-based control groups through the use of field measurements of biophysical characteristics and interviews. The primary methods of data collection are plot-based observations, household baseline surveys, and rapid rural appraisals.

Reinforcing the recommendations made in *Part 1*, baseline household surveys need more selective information of greater detail in order to adequately report project impacts. This is likely to increase the information burden on project managers. To more clearly identify indicators of impact, PVOs will need to allocate more effort and resources to project design. The likely result at the end of project design will be more indicator variables and the need to use a management information system to bring order to monitoring and evaluation (i2K, 1999).

Baseline surveys are a technique, taken from the human sciences. The term is used in development projects to refer to data collection completed prior to or at the beginning of a project. Most baseline surveys interview people about their lives, work and environment. When baselines are used to report on biophysical variables, the information is based on recollections or observations of survey respondents and is based on secondhand reporting, not direct measurement. These qualitative impressions need to be combined with direct measurement of a minimum dataset of key dependent and independent variables. The variables should be specific to project objectives, variables like rainfall amounts, soil quality, yield, plant diversity, factors related to weed or insect populations, etc.

The report begins with a review of techniques that can be used to monitor biophysical variables and is followed by a review of sampling methodologies. Generic Title II Indicators for agriculture productivity, natural resource management, and environmental impact are briefly discussed. The report concludes with an annotated bibliography. Discussions throughout the report refer to printed and Internet based sources of more detailed information about the use of monitoring tools and methods. One document in particular, the Organization for Economic Cooperation and Development's *Environmental Indicators for Agriculture* (OECD, 1997) provides an excellent overview of the issues discussed here. If you discover an Internet site that is no longer active, please report it to FAM (fam@foodaid.org) so they can direct you to the information and correct the reference for other readers.

Table 1. USAID's Generic Title II Biophysical Indicators Used by PVOs

Category	Level	Indicator
Agricultural productivity	Impact	Annual yield of targeted crops
		yield gaps (actual vs. potential)
		yield variability under varying conditions
		% of crops lost to pests or environment
	Annual monitoring	annual yield of targeted crops
		number of hectares in which improved practices adopted
Natural resource management	Impact	imputed soil erosion
		imputed soil fertility
		yields or yield variability (also annual monitoring)
	Annual monitoring	number of hectares in which NRM practices used
		seedling/sapling survival rate

2. REVIEW OF TECHNIQUES THAT CAN BE USED TO MONITOR BIOPHYSICAL VARIABLES

The focus of this chapter is to introduce PVO personnel to sources of information regarding techniques available for monitoring biophysical variables and for reporting project impacts according to USAID's Generic Title II Indicators (refer to Table 1). This chapter includes discussions of how techniques can be used in various settings. A range of costs for techniques is provided so that cost-effective budgets can be estimated. Although the discussion focuses on tools that can fulfill USAID's reporting requirements, the discussion also includes tools for measuring qualitative changes by farmers. ***(When used to measure biophysical variables on multiple farms at multiple project sites, some of the techniques below become costly or impossible to carry out, especially when laboratories, agronomy experts or equipment are not available in a particular country.)***

Instruments used to measure these variables have a wide range in price depending on measurement technique, measurement accuracy, data recording methods, and maintenance requirements. Equipment retailers, such as Ben Meadows (www.benmeadows.com) and Spectrum Technologies (http://www.specmeters.com/) can provide information for selecting equipment and material that meets both technical and budgetary requirements.

Technical information that may be useful for selecting indicators as well as for designing projects can be accessed at the US Natural Resource and Conservation Service's web site, http://www.nrcs.usda.gov/TechRes.html, and the US Forest Service site http://www.fs.fed.us/.

2.1 Climatic Variables

Relief organizations use climatic variables for early warning because they provide quantitative and objective measurements of the potential for crop failure. Climatic variables are also used to help distinguish non-project related effects from those of a project (*e.g.*, explaining effect of year to year and site variations of rainfall on crop yields). ***Control plots are used in agriculture to separate the effects of project-promoted practices from rainfall or other weather effects.*** Climatic variables (in terms of agricultural production) can be considered random events. Developing probabilities of occurrence for these events (*e.g.*, wind gusts in excess of 60 km/hr, annual rainfall less than 500 mm) can take many decades to develop and may not be available in your project area. If historical data from the closest weather monitoring station is insufficient for projects needs, PVOs may justify building or purchasing meteorological instruments.

2.1.1 Wind

Wind speed and direction are used for predicting water losses to the atmosphere and for designing more effective structures and windbreaks. Wind measuring instruments range from inexpensive hand held wind speed gages ($US 14) to wind velocity-monitoring systems ($US 550, data logger and other computer hardware not included).

2.1.2 Precipitation

Precipitation is used to predict ***or explain variation in*** crop yields. It is an indirect indicator for soil moisture ***(if soil texture is also known)*** that is available for crops which can then be used to estimate the amount of water stress a crop experiences. The usefulness of precipitation for predicting crop yields is complicated by its variability of occurrence in space and time, intensity (*e.g.*, amount falling per minute), water infiltration rates into the soil, water storage capacity of the soil, and losses of soil moisture. Taylor (1999, p. 36) describes how to make rain gauges from straight-sided cans. More sensitive instruments can be purchased for as little as $US 5 each. Gauge amounts should be recorded by event or at least daily and then the container emptied, especially for straight-sided gauges where evaporation losses could be significant.

It is important to account for rainfall variability in project activities, whether temporal (*e.g.* in terms of minutes or decades) or spatial (*e.g.*, distance apart, elevation, or aspect). Periods of drought are predictable in their length (*e.g.*, number of days, weeks, or years) and frequency of occurrence (*e.g.* once every ten years). Intensity of precipitation is equally important and predictable. For example, when rainfall intensity exceeds the soil's infiltration rate, even over a few minutes, the resulting runoff can wash away soil and water conservation structures that are not adequately constructed for extremely intense events. If production strategies and safety-net programs do not address these inevitable events, their occurrence (*e.g.*, droughts and floods) can wipe out household savings and productive assets. Extreme climatic events seem to be occurring more frequently in many areas. This apparent increase in variability is being attributed to global warming. Probabilities of extreme events are generally more useful in planning activities than long-term averages. Projects need to design activities that will address the need of extreme years, for both high precipitation (*e.g.*, soil conservation and depressed markets) and low precipitation years (*e.g.*, water conservation and crop failure).

Spatial variability of precipitation can affect land management and monitoring techniques. For example, spatial variability of rainfall in the Sahel is very high. Sites that are over 10 km apart are nearly independent of each other (Amani & Lebel, 1997). As a result, millet fields in the Sahel can receive perfect rainfall while 10 kilometers away millet fields can experience periods of severe drought. Sahelian farmers take advantage of this variability and cultivate fields that are widely spaced to reduce the risk of total crop failure. In areas with high spatial variability of precipitation rainfall gauges should be placed near each yield trial so that rainfall amounts can be used as a variable when evaluating the indicator — *yield variability under varying conditions*.

Averages and other descriptive statistics of climatic variables can drift over time (Todorov, 1985). These statistics are dependent on the time period from which they are based and can mask long-term trends (*e.g.*, the past 50 year average annual rainfall is 600 mm but during the past decade it averages 400 mm). Project designs need to be sensitive to possible drift in climatic statistics.

2.1.3 Evaporation

Pan evaporation is used as an indirect indicator of soil moisture losses to the atmosphere. This loss of moisture to the atmosphere is caused by surface evaporation and plant transpiration.

These losses of water, called evapotranspiration, are used to help predict weather as well as soil moisture stress to plants. There are mathematical models developed to estimate evapotranspiration losses that use pan evaporation measurements (*e.g.*, Penman and Thornthwaite equations) (Chow, 1964). PVOs can use evapotranspiration models for planning irrigation cycles or predicting when drought periods begin to reduce crop yields. ***Or farmers and PVO staff can simply feel the soil or check for plant wilting.*** Taylor (1999, p. 37) describes how to make an evaporation pan from an oil drum.

2.1.4 Temperature

"Temperature controls the developmental rate of many organisms. Plants and invertebrate animals, including insects and nematodes, require a certain amount of heat to develop from one point in their life cycles to another. This measure of accumulated heat is known as physiological time. Theoretically, physiological time provides a common reference for the development of organisms. The amount of heat required to complete a given organism's development does not vary — the combination of temperature (between thresholds) and time will always be the same. Physiological time is often expressed and approximated in units called degree-days." Degree-days is a useful tool for managing crops and predicting yields. It is also used in integrated pest management to predict the optimum time to control particular insect pests. For more information refer to the Internet web site http://www.ipm.ucdavis.edu/WEATHER/ddconcepts.html.

A method of describing physiological development, growth stages, and maturity is to define the accumulated degree-days, known as "growing degree-days" (GDD). The following formula can be used to compute GDD accumulations on a given day.

$$GDD \textbf{ for maize} = \frac{T_{max} + T_{min}}{2} - T_{base}\ (10^{o}\ C) = DD10s$$

where T_{max} = maximum daily temperature
T_{min} = minimum daily temperature
T_{base} = base temperature (temperature at which growth stops) T_{base} for maize is 10º C.

Different species have different base temperatures and different GDD thresholds for different growth stages. If GDD is negative, assume zero for that day. Each organism has a physiological optimal temperature range. For example, Maize has an assigned base temperature of 10º C and a maximum of 30º C. For more information refer to the Internet web sites http://www.maes.msu.edu/nwmihort/gdd_calc.html and http://www.cahe.nmsu.edu/pubs/_a/a-227.html.

A maximum-minimum thermometer is needed to make these calculations. The cost of these thermometers start at around $US 20 each — $US 350 each for thermometers and support system that meet US Weather Bureau Specifications.

Temperature and short growing seasons are commonly a limiting factor in temperate regions, less so in the tropics, unless elevations are high. GDD calculations are used by temperate-region farmers to determine planting dates and predict harvest dates. Except for use in IPM, GDD is generally not a useful calculation for small tropical farmers. Water, not temperature, is typically the most limiting factor for farmers in rainfed agriculture served by relief and development PVOs.

2.2 Water Quality Variables

Water quality variables are outside the scope of this report but deserve some mention. Agricultural and natural resource development interventions that affect water can have harmful public-health impacts as well as undesirable impacts on natural resources. Impacts can be biological (*e.g.*, causing disease), chemical (*e.g.*, poisoning the community), and physical (*e.g.*, increased risk of flooding).

Some of the biologically related problems include increased incidences of water-related diseases. These are infectious diseases that can be: (1) waterborne - infections that spread through water supplies; (2) water-washed - diseases caused by the lack of water for personal hygiene; (3) water-based - infections transmitted through aquatic invertebrates like schistosomiasis; or (4) water-related - infections transmitted by insects that depend on water for a portion of their life cycle like malaria, dengue fever, yellow fever, and encephalitis.

Some of the chemically related problems concern increased soil salinity and exposing communities to heavy metals such as arsenic, nitrates, and pesticides through contaminated water supplies.

Some of the physically related problems concern (1) increasing soil erosion and the turbidity of the water, and (2) changing the surface and subsurface hydrology and the possible harmful effect on the biological and chemical characteristics of water.

2.3 Soil Quality Variables

PVOs use soil quality variables to directly measure the sustainability of agricultural production. ***(In fact, PVOs generally do minimal monitoring of soil quality variables.)*** They also use these variables to stratify crop yield data so that better estimates can be made of household production. Both measures, sustainability of production and household levels of production, are used in determining impact on household food security.

The concepts of soil quality and health can help PVOs: (1) identify factors that limit production; (2) choose interventions to improve production; and (3) identify variables for project monitoring. Soil quality and health are subjective determinations based on the planned use of a soil and on objective measurements of soil related variables at the same site over a period of time. Sarrantonio *et al*. (1996), Pankhurst, *et al*. (1997), and Doran & Jones (1996) discuss soil quality and health.

In terms of agricultural production Pankhurst, *et al*. (1997) identified the properties in Table 2 as useful in determining soil quality and health. Also included in Table 2 are measures of variability that indicate the risk of using a single sampling, from a single site, to represent a field or region throughout the year. ***(Agronomists are trained <u>not</u> to take single soil samples to represent a field, but instead to take a "composite" sample from 20-30 or more spots selected randomly throughout a field.***) Other possible indicators to characterize and monitor soil quality include surface crusting, evidence of erosion, ponding of water, vegetative cover, soil structure, friability, and consistence.

Many of these characteristics are expensive and time consuming to measure (*e.g.*, microbial biomass, and micro-fauna quantity and quality) while others are not. Sarrantonio *et al*. (1996) and the *Soil Quality Test Kit Guide* (USDA, 1998) describe how to make a soil quality test kit and interpret the results. Many of the measurement tools described in these reference are simple to make and accurate. Pre-assembled kits are available through GEMPLER'S Inc. (http://www.gemplers.com/) and other retailers for around $US 380 each.

Farmer-based monitoring techniques allow farmers to detect small changes in the improvement or degradation of soils and the resulting impact on crop yields. Farmers usually test new management techniques before adopting them. If standardized methods of evaluating new techniques are used, projects can collect the information from farmer interviews and use this information to estimate household-level changes. Many of the farmer-based monitoring tools are qualitative and have limitations for reporting project impact in terms of the Title II indicators but they can aid extension efforts and serve as effect indicators for how the interventions are performing at the household level. The selection of these monitoring tools should be integrated with other participatory techniques.

Soil quality scorecards have been developed as extension tools in developed countries and are beginning to be used in developing countries. The following references can help guide the design of scorecards for your project: McQuaid (1996) describes score cards for grade school educators; Roming, Garlynd, & Harris (1996) and Sarrantonio *et al*. (1996) present tools for farmer-based monitoring in the US; Thompson & Pretty (1996) discuss how community-level, participatory impact study and self-evaluation of soil conservation activities worked in Kenya; and Burpee (1997) developed a score card for hillside farmers in Central American.

In addition to example costs for laboratory analysis given for variables described below, costs for analysis of other types of soil variables can be obtained from laboratories advertising on the Internet; for example, refer to the web site http://outreach.missouri.edu/mommag/labs.html. If commercial laboratories are not available in the host country, or if local laboratories are too expensive or unreliable, then projects may want to consider shipping soil samples to laboratories outside their host countries. If analysis by a foreign laboratory is an option, then project personnel need to make sure that the destination country's quarantine laws are obeyed and that the selected laboratory is licensed to analyze foreign soils. In situations where quality of analysis is in question, duplicate samples that are labeled differently can be used to verify that the laboratory analysis is at least consistent. ***(Certain common soil tests are temperature- and time-dependent and would result in inaccurate results if samples were shipped.)***

2.3.1 Erosion

The total amount of erosion occurring in PVOs' project areas cannot be directly measured but must be imputed through indirect or proxy indicators. ***This statement might imply that erosion cannot be measured directly. Erosion can be measured directly on small plots in simple, straightforward ways that are suitable for farmers in isolated, steeply sloped areas. Dr. R. Howeler of the CIAT research institute tested simple methods in Asia and Dr. J. Hellin did similar work in Central America. In some cases, results from small erosion plots can be extrapolated to larger areas when there is similarity in key independent variables (soil type, soil texture, slope, vegetative cover, rainfall amounts, etc.), using careful weighting, or stratification.*** Erosion rates can be highly variable, especially in an agricultural setting when the surface is bare during field preparation and before a crop canopy develops. Many predictive models have been developed that estimate soil loss. The Universal Soil Loss Equation (USLE), a revised form (RUSLE), and modified form (MUSLE), are the most commonly used. ***Agronomists and soil scientists have different opinions about the appropriateness of direct measurements or calculated erosion estimates for different purposes in different contexts. There are advantages and disadvantages to each method.***

Table 2. Soil indicators of soil quality and health and the variability of their measurement in space and time[a].

	Relevance to:		Variability	
Indicator	**Soil quality**	**Soil health**	**Spatial**	**Temporal**
Physical indicators				
Mineral composition	+	-	nd	None
Texture	+	-	30-40m, 3-55%CV	None
Depth	+	-	<2-100m, Low to high	None
Bulk density	+	+	3-26%CV, Medium	None
Water holding capacity	+	+	Low to medium	None
Porosity	+	+	7-11%CV	None
Chemical indicators				
pH	+	+	2m-32km, 2-15%CV	Low
Electrical conductivity	+	+	<80m->1.2km, Low to high	Low
Cation exchange capacity	+	+	nd	Low
Organic matter	+	+	<8m, High	Low
Major elements	+	+	61m	Low to High
Heavy metals	+	+	nd	Low
Biological indicators				
Microbial biomass	+	+	Low	Medium
Soil respiration	+	+	High	High
Mineralizable N	+	+	Medium	High
Enzyme activity	+	+	Medium	Medium
Abundance of microflora	+	+	High, 1->12	Low to high
Abundance of soil fauna	+	+	Medium to high	Medium to high
Root disease	+	+	High	High
Soil biodiversity	-	+	Medium to high	Medium to high
Food web structure	-	+	nd	nd
Plant growth	+	+	Low	High
Plant biodiversity	-	+	High	Low

[a] -, of little or no relevance; +, relevant; Variability information provided from several sources: nd, no data; Low, Medium, and High variability where not assigned quantitative parameters in Pankhurst, *et al*. (1997, p. 425 & 432) but were in Hillel (1998, p. 663) where CV (coefficient of variation) is used to indicate variability: Low with CV<15%, Medium with CV between 15 and 50%, and High with CV>50%. Jury *et. al* (1991, p. 269) also provides CV of variables. Values in m or km between sites represent the distance between samples needed before they can be considered independent (Klute, 1986), small distances indicate high variability.

Some readers may find this table difficult to interpret, as the distinction between soil quality and soil health is unclear, and quantitative reference values are not available in all cells. The USLE and later versions are empirical models that estimate average annual soil loss from sheet and rill erosion. It was developed from a large amount of data from the United States, primarily collected in the mid-western states, with a level of detail that is rarely available in developing countries. The modified and revised versions of the USLE include data from other parts of the world and are a work in progress to improve its predictive capabilities. The most recent version, the RUSLE, includes additional factors to the equation that is solved using a computer program. The computer program version of RUSLE and supporting documentation can be accessed on the web at http://www.sedlab.olemiss.edu/Rusle/index.html. To apply the models, site specific information must be collected such as land management techniques, slope of the land, length of slope, soil infiltration rates, and rainfall intensity. The equation is: A = RKLSCP, where A is the computed soil loss, R is a rainfall factor that is based on 30-minute rainfall intensity, K is a soil erodibility factor, L is a slope length factor, S is a slope degree factor, C is a crop practice factor, and P is a conservation practice factor (http://www.sedlab.olemiss.edu/Rusle/description.html). Pierce & Frye (1998, p. 5-8) describe the differences between USLE, MUSLE, and RUSLE.

Soil loss estimates are made by dividing the area of interest into sub-areas of similar conditions (*e.g.*, slope, soil type) and applying the equation to each homogenous area and summing the weighted average by each homogenous area. While the USLE can estimate long-term annual soil loss, it cannot be applied to a specific year or a specific storm.

The USLE's main use in the United States is to guide farmers in changing land management and in selecting combinations of crops and conservation practices that will keep estimated soil losses within acceptable limits. Acceptable limits are assigned to soils based on many factors, especially soil depth.

The USLE can also be used by PVOs to estimate the erosion rates from conventional land management practices and improved practices. For example, differences in erosion rates between conventional and improved practices can be multiplied by the area where the improved practices are used. This calculation provides impact estimates of the amount of soil saved by project interventions.

The USLE is a commonly accepted method for imputing soil erosion. There are, however, other models that may prove more appropriate — the selection of which will depend on site conditions and type of erosion threats. For example, the Water Erosion Prediction Project (WEPP) model is a process-based, distributed parameter, continuous simulation, erosion prediction model for use on personal computers. This model is receiving development funding by the US government and is likely to become the new standard for predicting water erosion. The WEPP program is available through the Internet at http://topsoil.nserl.purdue.edu/weppmain/wepp.html. It is applicable to hillslope erosion processes (sheet and rill erosion), as well as simulation of the hydrologic and erosion processes on small watersheds. A comparison of WEPP to other models you may consider (*e.g.*, USLE, CREAMS, EPIC, SWRRB, SPUR, and ANSWERS) is available at http://soils.ecn.purdue.edu/~wepphtml/wepp/wepptut/jhtml/advdisb.html .

Wind erosion may be the primary concern in sandy regions like the Sahel of Africa where water erosion models are not very helpful. The Wind Erosion eQuation (WEQ, http://www.itc.nrcs.usda.gov/focs/WEQ/index.html), Revised Wind Erosion Equation (RWEQ), and Wind Erosion Prediction System (WEPS, http://soils.ecn.purdue.edu/~wepphtml/wepp/wepptut/jhtml/weps.html), can be used to evaluate the effects of wind erosion.

The US Department of Agriculture's Modular Soil Erosion System project is working to combine existing Agriculture Research Service's wind and water erosion models (RUSLE-2, RWEQ, WEPS and WEPP) into a single erosion model with a common graphical user interface. Information on the current status of this model can be accessed on the Internet at http://www.csrl.ars.usda.gov/moses/. Boardman & Favis-Mortlock (1998) provide a technical discussion on US and European based models.

If you chose to use a model for imputing soil erosion impact, the web sites and references mentioned above will provide enough background information for you to discuss soil erosion models with the expert who will design the erosion monitoring system for your project. Once the erosion monitoring system is designed, project personnel need only to collect land management information from farmers through interviews. If skilled project personnel are available, random field checks should be considered to validate information collected from interviews.

The above models provide quantitative estimates to impute impact but they cannot serve as early warning tools or effect indicators. Direct field monitoring for evidence of erosion should be included with the monitoring and evaluation plans to validate the impact estimates. Field monitoring can be farmer based or project based. Hudson (1993, p. 13-17) discusses how to measure the change of the soil's surface with simple point measuring techniques like erosion pins, paint collars, bottle tops, and profile meters. These techniques are appropriate to measure localized erosion on rangelands and forested areas, however "it is usually not suitable for soil losses from arable land because the surface level is affected by cultivation and settlement." It may be possible to monitor seasonal erosion in the furrows of cultivated field as an effect indicator, but this technique cannot determine impact in terms of volume of soil loss over an area.

Hudson (1993) also describes volumetric measurement of erosion, but the complexity, expense, and site-specific nature of these measurements put these techniques in the realm of research. These measurement techniques are not appropriate for Title II activities. PVOs might consider using simple catch-pits that collect eroded soil from small areas. These have been used as an extension tool to show qualitative differences of erosion under different land management techniques.

Clark (1980) developed a relatively simple method of directly monitoring the effect of soil erosion. It is the Erosion Condition Classification System and is based on observation of seven indicators of soil movement and their reliability for indicating soil erosion. The seven indicators are soil movement, pedestalling, surface litter, surface rock fragments, flow patterns, rills, and gullies. A rating system, from stable to severe, for each indicator has been developed (Table 3). The assigned values of each indicator are summed to give an Erosion Condition Class (stable, slight, moderate, critical, or severe).

This method can be adapted for project conditions and monitored by project staff. Some modification to the criteria will need to be made by an expert to optimize the system to local conditions. Data sets collected from transects can be statistically evaluated. This monitoring method can be used as an extension tool if conducted in the presence of participating farmers. Potentially this method may be able to show qualitative impact between conventional and improved land management techniques. In order to show statistically significant differences between types of land management, this method may require intensive field sampling to account for spatial and temporal variability of the observations. The main limitations of this technique for impact monitoring are that it does not estimate volume of soil lost and is dependent on rainfall events occurring between the last cultivation and field observation.

2.3.2 Physical variables of soil quality

Physical variables of the soil generally do not change as fast as biological and chemical variables. Their relatively slow rate of change also makes them poor measures of Title II project impacts. ***(This statement is certainly true for soil texture, or the relative proportion of sand, silt and clay, but many other soil physical variables can change rapidly with a change in management practices. Deep tillage quickly changes a host of physical properties in soils that have compacted subsoil layers. Incorporation of large amounts of humus or organic matter can change water infiltration rates, water retention and porosity as quickly as it changes soil chemical factors.)*** However, many physical variables are important determinants for a soil's potential productivity and are important characteristics for stratifying crop yield sites. Some important physical variables that are not discussed in this section include soil infiltration rates and aggregate stability. Simple methods of measuring these characteristics are discussed in the *Soil Quality Test Kit Guide* (USDA, 1998, p. 7-8, 18-19, 55-56, 69-71).

Table 3. The Erosion Conditon Classification System's criteria for determining erosion condition class of site (Clark, 1980, p. 26)

Form 7310-12

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

DETERMINATION OF EROSION CONDITON CLASS
SOIL SURFACE FACTOR (SSF)

By Date

Location

Total SSF

Soil Movement	Depth of recent deposits around obstacles, or in microterraces; and/or depth of truncated areas, is between 0 and .1 in. (0 to 2.5 mm) 0 or 3	Depth of recent deposits around obstacles, or in microterraces; and/or depth of truncated areas, is between .1 and .2 in. (2 to 5 mm). 5	Depth of recent deposits around obstacles, or in microterraces; and/or depth of truncated areas, is between .2 and .4 in. (5 to 10 mm) 8	Depth of recent deposits around obstacles, or in microterraces, and/or depth of truncated area are between .4 and .8 in. (10 to 20 mm). 11	Depth of recent deposits around obstacles, or in microterraces, and/or depth of truncated areas are over .8 in. (20 mm). 14
Surface Litter	No movement, or if present, less than 2 percent of the litter has been translocated and redeposited against obstacles. 0 to 3	Between 2 and 10 percent of the litter has been translocated and redeposited against obstacles. 6	Between 10 and 25 percent of the litter has been translocated and redeposited against obstacles. 8	Between 25 and 50 percent of the litter has been translocated and redeposited against obstacles or removed from that area. 11	More than 50 percent of the litter has been translocated and redeposited against obstacles or removed fro the area. 14
Surface Rock Fragments	Depth of soil removal around the fragments, and/or depth of recent deposits around the fragments is less than .1 in. (2.5 mm) 0 or 2	Depth of soil removal around the fragments, and/or depth of recent deposits around the fragments are between .1 and .2 in. (2.5 to 5 mm). 5	Depth of soil removal around the fragments, and/or depth of recent deposits around the fragments are between .2 and .4 in. (5 to 10 mm). 8	Depth of soil removal around the fragments, and/or depth of recent deposits around the fragments are between .4 and .8 in. (10 to 20 mm). 11	Depth of soil removal around the fragments, and/or depth of recent deposits around the fragments are over.8 in. (20 mm). 14
Pedestalli ng	Pedestals are mostly less than .1 in. (2.5 mm) high and/or less frequent than 2 pedestals per 100 sq. ft. 0 or 3	Pedestals are mostly between .1 to .3 in. (2.5 to 8 mm) high and/or have a frequency of 2 to 5 pedestals per 100 sq. ft. 6	Pedestals are mostly between .3 to .6 in. (8 to 15 mm) high, and/or have a frequency of 5 to 7 pedestals per 100 sq. ft. 9	Pedestals are mostly between .6 and 1 in. (15 to 25 mm) high, and/or have a frequency of 7 to 10 pedestals per 100 sq. ft. 11	Pedestals are mostly over 1 in. (25 mm) high, and/or have a frequency of over 10 pedestals per 100 sq. ft. 14
Flow Patterns	None, if present, are mostly less than .5 in. (13 mm) deep, and generally at infrequent intervals over 10 ft. 0 to 3	Between 2 and 10 percent of the surface area shows evidence of recent translocation and deposition of soil and litter. 6	Between 10 and 25 percent of the surface area shows evidence of recent translocation and deposition of soil litter. 9	Between 25 and 50 percent of the surface area shows evidence of recent translocation and deposition of soil and litter. 12	Over 50 percent of the surface area shows evidence of recent translocation and deposition of soil and litter. 15
Rills	Rills, if present, are mostly less than .5 in. (13 mm) deep, and generally at infrequent intervals over 10 ft. 0 or 3	Rills are mostly .5 to 1 in. (13 to 25 mm) deep, and generally at infrequent intervals over 10 ft. 6	Rills are mostly 1 to 1.5 in. (25 to 38 mm) deep, and generally at 10 ft. intervals. 9	Rills are mostly 1.5 to 3 in. (38 to 76 mm) deep, and at intervals of 5 to 10 ft. 12	Rills are mostly 3 to 6 in. (76 to 152 mm) deep and at intervals of less than 5 ft. 14
Gullies	No gullies, or if present, less than 2 percent of the channel bed and walls show active erosion (are not vegetated), gullies make up less than 2 percent of the total area. 0 or 3	Between 2 and 5 percent of the channel-bed and walls show active erosion (are not vegetated), or gullies make up between 2 and 5 percent of the total area. 6	Between 5 and 10 percent of the channel bed and walls show active erosion (are not vegetated), or gullies make up between 5 and 10 percent of the total area. 9	Between 10 and 50 percent of the channel bed and walls show active erosion (are not vegetated), or gullies make up between 10 and 50 percent of the total area. 12	Over 50 percent of the channel bed and walls show active erosion (are not vegetated) along their length, or gullies make up over 50 percent of the total area. 15

2.3.2.1 Soil depth

An agricultural definition of soil is "a dynamic natural body on the surface of the earth in which plants grow, composed of mineral and organic materials and living forms" (Brady, 1974, p. 617). The lower boundary of a "soil" by this and other agricultural definitions cannot be determined, especially since microorganisms (some classified as plants) are found deep in the earth's crust. Even limiting definition to the depth occupied by plant roots does not allow easy identification of the lower boundary of a soil. Some plant roots can penetrate to depths greater than ten meters.

If soil depth is limited to just the top meter or two of the earth's surface then soil depth becomes a useful indicator of soil productivity because the top part of a soil is usually the most biologically active. (Also refer to *b. Effective rooting depth* below.) Even with this restrictive definition, soils can be quite variable in depth over short distances, especially when bedrock is close to the surface. For example, the presence of large boulders on the surface may indicate that soil depth may be highly variable. Soil depth is measured by digging a pit or hole in the ground and inspecting the material being exposed or removed. Generally the top layer of soil, usually darker in color, is the most productive. The thicker this layer is the more productive the soil will be.

Soil scientists commonly use soil augers to describe and map soils. This tool should be considered if many soil descriptions are needed. ***(In most cases, projects do not need detailed soil classification descriptions of an entire soil profile. Their main interest is soil conditions in the plant root zone and the tillage layer near the surface. If projects do need complete soil profile classification information at this level of detail and rigor, it is more appropriate to obtain already completed descriptions from relevant government departments, when available, or to contract out to local soil taxonomists for the work. Presumably, they will have advanced training, appropriate equipment and access to laboratories.)***

Soil auger prices start at around $US 100 each. Soil augers should not be confused with tools for sampling the soil surface (*e.g.*, to 20 cm deep). Their costs start at around $US 20 each. Art's Manufacturing & Supply, Inc. web site, http://ams-samplers.com/, is designed to help those with little or no experience select the appropriate tools for soil sampling. Soil pits, dug with pick and shovel, allow more accurate soil descriptions, especially by novices, but they are less convenient and more time consuming than soil augered holes. Soil pits are commonly dug to 1.5 meters deep if possible and wide enough that the person standing in the pit can comfortably view the pit face. The side of the pit that will be described should be flat, smooth, and orientated so that it faces the sun during the time that it is described. This orientation also provides proper lighting for photographic documentation. Before digging a pit or hole, it is important to first observe the area and pick a typical site were the soil pit or augered hole is to be dug (*e.g.*, typical surface conditions and micro-topography).

The *Soil Quality Test Kit Guide* (USDA, 1998, p. 23-26, 75) discusses how to describe and interpret topsoil depth.

2.3.2.2 Texture

Texture (grain size) of the mineral portion of soil is one of the most important properties because it is related to many other characteristics (soil is composed of minerals, organic matter, plants and animals, microbes, water, and air). There are several commonly used classification systems for texture that are used for agricultural purposes. The differences between them can be minor but a project should report soil texture information according to the system used by the host country. The *Soil Quality Test Kit Guide* (USDA, 1998, p. 27, 77-78) provides a decision-tree for determining soil texture and describes what soil texture classes represent. PVOs wanting to contract the texture analysis of soil samples should first consider sending them to a local soil scientist for a "feel method" of determination. This method usually provides adequate information

(Post *et al*., 1986) and is much less expensive than various laboratory methods that are described in Klute (1986). Cost of laboratory analyses start at around $US 12 per sample. ***(PVOs and local NGOs often train agricultural extensionists in several different "feel" methods of estimating soil texture. In many cases, these quick and easy estimates are sufficient for the purposes of farmer training and for informing most soil management decisions on small farms, ruling out the need for the services of an external agronomist, except perhaps in providing training in one of the "feel" methods.)*** Indigenous systems of soil texture classification may exist in targeted communities and may be useful in communicating site requirements for agricultural interventions to farmers or site characteristics from farmers for project monitoring.

2.3.2.3 Bulk density

Bulk density is a quantifiable measure that can be used to identify and report soil compaction. Soil compaction is useful in road construction by providing a firm foundation but is to be avoided in agricultural fields because it can restrict root growth and limit the nutritional and water sources that the crop can exploit. Compaction can be caused by cultivation practices. Some soil types are vulnerable to compaction. "Hardpan" is a general descriptive term for a layer of compacted soil. Hardpans can be man-made (plowpans) or natural layers of dense, root restricting soil (*e.g.*, fragipan, calcrete, and fericrete). Plowpans can be broken up by deep cultivation or by long fallow periods where the soil's macro-fauna breaks up the compacted layer over time.

Digging a pit or hole can expose suspected compacted layers. To identify the compacted layer look for any signs of a soil layer that restricts roots, has platy type structure, and/or feels denser and more brittle than the surrounding soil. The *Soil Quality Test Kit Guide* (USDA, 1998, p. 9-13, 57-58) gives a detailed description on how to determine bulk density, a quantitative measure of soil compaction. Alternatively, the cost of laboratory analysis start at around $US 6 for properly sampled soils. Another tool for measuring compaction are soil compaction testers (subsurface penetrometers). They measure the resisting force of the soil as you push a probe into the soil. These measurements are soil moisture dependent. Prices for them start at around $US 225 each.

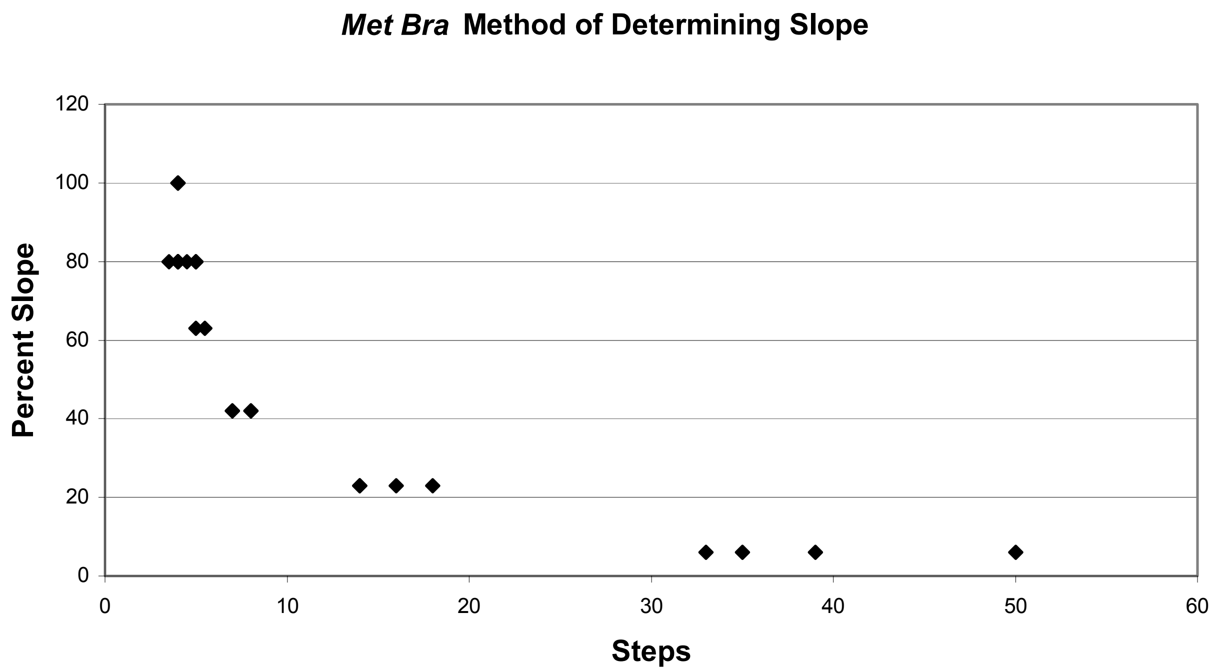
2.3.2.4 Slope and slope length

Slope (percent rise over run) is a conventional method of describing topographical steepness of the land. This measure is important in estimating erosion rates. Section *Soil erosion* refers to sources that describe slope-measuring requirements specific to soil erosion models. In general, the steeper the land the more susceptible it is to erosion. It is possible to make a rough estimate of slopes without using any instruments. Extend your arm forward, perpendicular from the body so that your line of sight to the distant horizon passes just over the fingertips. Once the angle of the arm is calibrated with the horizon, turn your body toward the slope, arm at the fixed angle with your body, and sight a point that is eye level on the slope and directly upstream from where you are standing. Once the point is established, walk up the slope, counting the number of steps to the point. By using this simple technique, farmers and project staff may be able to report slopes of agricultural fields, which will be useful in stratifying monitored information. Farmers and project staff can use this tool to determine which land management techniques are appropriate. Figure 1 shows the relationship between actual slope and the *met bra* distance that was established by Save the Children in Haiti (Tabor, 1988). You may need to establish your own relationship if the people in your area are exceptionally tall or short. This method can also be used to establish vertical spacing of soil conservation structures.

Clinometers and abney levels are hand-held slope measuring instruments and are much more accurate (±0.5°) than the *met bra* method. Prices start at around $US 80 each.

Slope length is a factor used in estimating soil erosion rates. Slope length is the distance down slope that runoff collects and flows. Drainage channels are natural breaks in slope length; contour terraces and bund are artificial ones. Project technicians can calibrate their steps to a known distance so that they can note the number of paces in the field and convert them to standard distance units later.

Figure 1. The relationship between percent slope and surface distance in steps when determining slope using the *Met Bra* method.



2.3.2.5 Erodibility

Different types of soil erode at different rates even when other factors affecting erosion are constant. Some important soil physical properties that influence erodibility are size and stability of soil structure, soil texture, percentage of coarse fragments — especially on the soil surface — organic matter, infiltration, permeability, type of clay mineral, and depth of soil material.

The soil erosion models described above use soil erodibility factors based on these soil characteristics and/or soil type. It is possible during project design to describe the major soil types and characteristic in the project area that are identifiable by farmers. By correlating local classification systems with the characteristics that are important for determining erosion rates, erodibility factors (for soil erosion models) can be established through structured interviews. Refer to section *Indigenous knowledge of soil quality* for more information on how to utilize local systems of resource classification.

2.3.2.6 Drainage

Drainage — surface and subsurface — is an important soil characteristic that affects agricultural production and land management. This characteristic can be a major indicator of a particular soil type and its related characteristics. Surface drainage can be adequately described by the depth and length of time water stands on the surface during and after rainfall events. Subsurface drainage can be identified by soil color (usually gray mottling) and at what level in the soil profile it occurs. Particular plant species can be used as indicators of soil drainage types. Much of this information can be collected during project design so that during project implementation only relevant, but complete, information is collected during interviews.

The USDA system of drainage classification is described in the *Soil Survey Manual* (USDA, 1993) or can be accessed through the Internet at http://www.irim.com/ssm/ssm00059.htm.

2.3.3 Biological variables of soil quality

Soil biological variables of soil quality such as microbial biomass, enzyme activity, and soil biodiversity are difficult to measure, expensive to conduct, and impossible to characterize at the household level for Title II projects. Other variables, such as soil respiration, are considered an important indicator of soil quality and can possibly be used to characterize a land-management system. For example, Yakoychenko *et al*. (1996) describe a 12-year-old Rodale Institute study that identifies microbial respiration plus net mineralized nitrogen as a useful indicator of soil quality. The *Soil Quality Test Kit Guide* (USDA, 1998, p. 4-6, 31-32, 52-54) describes relatively simple methods of measuring soil respiration that a Title II project might consider using. Other variables that have received mixed success are characteristics of macro-fauna populations. Measurements of macro-fauna can be made in the field with simple equipment and will be discussed below. Effective rooting depth is also discussed. Unlike other biological variables that are more ecosystem and productivity based, rooting depth is dependent on less dynamic soil physical and chemical properties and provides a measure of potential soil productivity.

2.3.3.1 Macro-fauna quantity, quality, diversity and change.

Earthworms are the most popular soil macro-faunal measure of soil quality discussed in research literature. There is significant correlation of earthworm abundance with grain yield. However, the distribution and abundance of earthworms are too dependent on land management, soil texture, climate, and other variable factors for it to serve as an indicator for farmer based monitoring. At an appropriate scale, macro-fauna may be a useful indicator of crop production and sustainability. The relevant scale will "depend on the spatial and temporal scales of activity of the organisms studied and the production and management processes involved" (Buckerfield *et al*., 1997). "It is clear that earthworm abundance cannot be used as a universal indicator of soil health because the key agronomic factors which determine plant yield and soil conservation are not necessarily those which influence earthworm abundance" (Pankhurst *et al*., 1997, p 289). The same reasoning extends to other types of soil fauna. In spite of these limitations *Soil Quality Test Kit Guide* (USDA, 1998, p. 22, 73-74) suggest using earthworms as a measure of soil quality and describes how to measure them. Buckerfield *et al*. and Pankhurst *et al*. discuss other aspects of macro-fauna quantity, quality, diversity, and change.

2.3.3.2 Effective rooting depth

Effective rooting depth is the total depth of surface soil, subsoil, and parent material that is at least reasonably favorable to the growth and development of plant roots. Effective rooting depth is also dependent on the rooting characteristics of the type of plants at the site. For example, some plants are deep rooted, some shallow rooted, and others are more tolerant to soil salinity. The rooting zone of a soil is biologically very active. Root exudates provide food for microorganisms. Some microorganisms fix nitrogen, some make phosphate more available to crops, and others feed on potential crop pathogens. The macro-fauna is particularly active in this region as well.

Decomposed roots give the soil a darker color that is used to distinguish horizons. The surface horizon, commonly called the "A" horizon, is usually the darkest and most biologically active. The lower "B" horizon is usually lighter in color and less biologically active. The next horizon in this idealized soil is the "C" horizon. It supports some roots, but its biological activity is generally much lower that of the horizons above. The "C" horizon is usually not considered within the effective rooting depth. More clear limits to the effective rooting depth are associated with characteristics that retard or prevent root penetration, such as rock, hardpan, or perched watertables.

Effective rooting depth is a subjective but useful measure to determine a soil's potential productivity and can be helpful in making management decisions (*e.g.*, determining irrigation rates and frequency, fertilizer management, and acceptable soil erosion rates). The *Soil Quality Test Kit Guide* (USDA, 1998, p. 23, 75-56) describes many of the variables that are useful in assigning an effective rooting depth.

2.3.4 Chemical variables of soil quality

Soil chemical variables generally do not change as much as biological variables and are potentially good direct indicators of Title II project effects if they can be isolated from non-project effects. ***(Project effects are commonly separated from non-project effects in agriculture by using standard experimental design methods -- by including control plots adjacent to treatment plots, by blocking and using replications appropriately. Although this may seem complex, basic methods for one or two types of experimental design can be presented simply and clearly to farmers. For example, Farmer Field Schools developed in Asia have had great success adapting research methods for use by farmers in insect control.)*** Previously conducted agricultural research in the project area may have identified variables that might serve as good indicators, or at least identify ones that will not. For example, old soil analysis of sites within the project area show high concentrations of phosphate in the soil throughout the project area. This information indicates that soil phosphate concentrations would not be a good measure of environmental impact for the project area. Project designers should seek out and consult with agronomists and soil scientists knowledgeable of the project area.

PVO Title II projects should avoid conducting soil analysis to provide fertilizer recommendations unless adequate field trials in the project area have been conducted. Nearly all fertilizer recommendations to increase crop production are based site characteristics, soil analysis, and/or plant tissue analysis. These recommendations are usually based on numerous field experiments because yield responses to fertilizer application is dependent on soil conditions and climate, as well as amount of fertilizer applied. Recommendations are also based on particular types of analysis procedure or ones that create conditions similar to those occurring naturally in the type of soil being analyzed. Different procedures can produce different results for the same soil sample. For example, pH affects the availability of nutrients in the soil. If one procedure extracts nutrients with a basic solution and another procedure uses an acidic solution, the results of the two procedures are likely to be different, sometimes significantly different. Soil chemical analysis is only an estimation of what the plant roots experience. Soil chemistry is complicated, as is the interaction of plant roots with the microbes surrounding roots, and the roots and microbe interaction with the soil matrix.

If there is insufficient information on yield response to fertilizer in the project area, then nutrient deficiency symptoms (see Table 4) and soil analysis could be used to identify potentially deficient nutrients and provide farmers the chemical or organic means of fertilization to address the problem. The farmers then conduct their own experiments and develop some general recommendations. The project could monitor yield and fertilization rates for impact. Monitoring soil chemical variables in this case might allow projects to develop fertilizer recommendations for other farmers with similar soils.

The least expensive forms of soil analysis are usually colorimetric based kits. If colorimetric analyses are used, it is important that the operators have good color vision or tools to measure the different wavelengths. If you plan to contract with a laboratory for soil analysis, the costs of individual types of analysis can, in some cases, be reduced if sample preparation costs are shared among several types of analysis on each sample.

2.3.4.1 pH

Soil pH indicates the relative availability of soil nutrients to plants; if a nutrient is present in low concentration then deficiencies can occur regardless of the pH. In some cases changing the soil pH (*e.g.*, with addition of lime) so that nutrients are more available is more cost effective than applying the nutrients directly to the soil in adequate amounts. The *Soil Quality Test Kit Guide* (USDA, 1998, p. 15, 33-34, 63-66) describes how to determine and evaluate soil pH. Ion specific meters with ±0.2 pH accuracy start at $US 150 each (refer to the Internet web site http://www.specmeters.com/ph_meter.htm). Colorimetric test kits have a more narrow range of detection (*e.g.*, 3.8 - 8.4) and are less accurate (*e.g.*, ±0.5) but cost less, starting at around $US 26 for 200 tests. The cost of laboratory analysis starts at around $US 6 per sample. CODEL (1985, p. 1-4) describes how to measure soil pH using standard pH paper, rainwater (distilled water), and small plastic containers.

2.3.4.2 Nitrogen

There are five basic types of soil nitrogen (N) analyses, nitrate (N form most available to plants), nitrite, ammonia, organic, and total. Rapid biological transformation of N in the soil or in the sample bag complicates evaluation of the analysis ***(unless samples are kept at appropriately cool temperatures until analyzed).*** Refer to Page (1982, p. 595-734) for a technical discussion of the numerous different methods of N analysis. Local agronomists and soil scientists should be consulted to help select the most appropriate type of analysis. Colorimetric and ion electrode methods of nitrate analysis are the methods most likely to be used by PVO projects. Colorimetric soil nitrate analysis is described in *Soil Quality Test Kit Guide* (USDA, 1998, p. 17, 67-68). Colorimetric test kits start at around $US 40 for 25 tests. Distilled or rain water is required for testing. Less accurate colorimetric tests start at around $US 20 each for 50 tests. Portable handheld ion meters for soil and plant tissue start at around $US 360 each (refer to the Internet web site http://www.specmeters.com/nutrients.htm). The cost of laboratory analysis of nitrate-nitrogen starts at around $US 4 each.

2.3.4.3 Phosphorous

The availability of soil phosphorous (P) to plants is relatively complicated compared to the other plant nutrients. In general, P is not very soluble nor is it very mobile in the soil. This characteristic makes it one of the safer chemical fertilizers to apply. Some soil types require higher concentrations of P to produce the same yields than do other types of soil. This is because these soils have minerals that strongly bind to any P in solution, making it unavailable to plants. Some limestone derived soils are very high in phosphate and do not require P fertilization. Local soil surveys, if they exist, should provide this information.

Many analytical procedures have been developed to determine P availability to plants under widely varying conditions. As a result, a novice may select the wrong procedure and misinterpret the results of a soil analysis. Local soil scientists, agronomists, or soil studies may provide information useful for selecting the correct analysis procedure.

Laboratory analysis of P starts at around $US 5 per sample. Page (1982, p. 403-430) describes standard procedures for soil P analysis. Colorimetric N-P-K kits that report concentration levels as high, medium or low are available for around $US 20 each for 50 tests. These test kits are unlikely to provide the accuracy need to make crop management decisions or determine project impact.

2.3.4.4 Potassium

Exchangeable forms of potassium (K) are the primary source for plant uptake. Only a relatively small portion (approximately 1%) of the total K in the soil is exchangeable. Old, highly weathered soils are unlikely to have much exchangeable K, but younger soils that have developed from rocks that are rich in potassium may not need any K fertilization. Local soil surveys, if they exist, are likely to provide this information.

Laboratory analysis of K starts at around $US 5 per sample. Page (1982, p. 225-246) describes standard procedures for soil K analysis. Colorimetric N-P-K kits that report concentration levels as high, medium or low are available for around $US 20 each for 50 tests. These test kit are unlikely to provide the accuracy need to make crop management decisions or determine project impact. Ion meters for soil and plant tissue analysis start at around $US 350 each (refer to the Internet web site http://www.specmeters.com/nutrients.htm).

2.3.4.5 Organic matter

Soil organic matter is a major factor in determining soil productivity. It affects many important characteristics such as nutrient holding capacity, soil structure, water infiltration, and biological activity. Land use practices are major influences on soil organic matter content. Erosion and cultivation practices are major causes of organic matter reduction in soils. Soil organic matter consists of plant and animal residues in various stages of decomposition. The nonhumic substances still have recognizable physical and chemical characteristics of their original form. They support much of the soil's biological activity and are generally in a state of rapid decomposition. Humic substances or humus are chemically complex and relatively stable. Humus is a form of organic matter contributing the most to long-term soil productivity. Humus takes a long time to form and a long time to degrade. For example, it takes 3 to 5 years before the decline in soil organic matter under continuous cultivation of maize (one of the more degrading practices in terms of soil organic matter maintenance) is detectable by conventional analytical procedures (Magdoff, Tabatabai, & Hanlon, 1996, p. 44). Total organic matter is the conventional, and least expensive, method of organic matter analysis. As a result, short term monitoring of organic matter will weigh heavily on nonhumic substances (lot of mass, quickly formed but short lived) and will likely overstate any positive impact by the project. Total organic matter analysis by combustion starts at around $US 7 each. Colorimetric determination starts at around $US 5 each.

Soil organic matter content may soon become a required indicator for reporting owing to the concerns about global warming and the effectiveness of mitigation measures such as carbon sequestration in the soil. For further information refer to *Global Climate Change Treaty: The Kyoto Protocol* at http://www.cnie.org/nle/clim-3.html and Soil *Carbon Sequestration: Frequently Asked Questions* at http://www.usda.gov/oce/gcpo/sequeste.htm.

2.3.5 Indigenous knowledge of soil quality

There is a lot of literature on the use of indigenous knowledge and soil management. The best initial source of information is Nuffic's Indigenous Knowledge homepage on the Internet at http://www.nuffic.nl/ciran/ik.html. Indigenous knowledge provides outsiders a practical means to quickly achieve a better understanding of the local environment and constraints to its use. The methodological issues concerning the best way to truly understand local perspectives are often conflicted by the need for timely information at reasonable costs. Group meetings usually provide an opportunity to get a more balanced and informed opinion from the community than numerous individual discussions. ***(This can work both ways. Group meetings are biased toward the opinions of dominant, vocal personalities or sub-groups, those individuals who tend to be landowners of the richest land in the household or community. Group meetings can be appropriate for an initial contact, but need to be balanced by a few individual meetings with key informants from different sub-groups in the community.)*** Group meetings also allow the PVO to identify soil characteristics that can be consistently described by individual members of the community. This relationship is required before useful questionnaires can be designed. It is very important that the PVO conducting the meetings include an agronomist or soil scientist in the discussions to help translate local perceptions to scientifically based ones. The main benefit of acquiring indigenous knowledge is being able to translate and correlate different perceptions of the world (Park, 1993, p. 31-50). Often major constraints or opportunities can be identified when the perceived value of a resource is very different between that of the local population and that of PVO personnel.

The following Internet web sites are a few of the many discussions concerning indigenous knowledge of soil quality: Soil Surveys And Indigenous Soil Classification http://www.nuffic.nl/ciran/ikdm/1-1/tabor.html; Using Indigenous Knowledge, Remote Sensing And GIS For Sustainable Development http://www.nuffic.nl/ciran/ikdm/2-1/articles/tabor.html; Recording And Using Indigenous Knowledge http://www.panasia.org.sg/iirr/ikmanual/index.htm; and The Adoption Of Soil Conservation Practices In Burkina Faso http://www.nuffic.nl/ciran/ikdm/2-1/articles/dialla.html.

Projects should also seek out local knowledge about biophysical indicators from research organization, projects, and government employees.

2.4 Vegetation Quality Variables

Vegetation quality variables are very sensitive to environmental changes and can serve as indicators of Title II project impacts if project related effects can be separated from non-project ones (*e.g.*, rainfall and variability of soil productivity levels). ***(See discussion in Section 2.3.4.)***

2.4.1 Leaf color

Deficiencies of nutrients in plants have various visual symptoms that are usually similar regardless of the species. The most common deficiency symptom is reduced growth, which is difficult to detect and diagnose at a glance. Other visual symptoms usually involve changes in leaf coloration that follows a specific pattern, such as from the leaf tip down the midrib towards the base of the leaf or from the leaf margin toward the midrib, or between the veins of the leaf. Such symptoms may appear in new leaves or old leaves, depending on the mobility of the deficient nutrient and the ability of the plant to transfer existing stocks of the deficient nutrient. Many nutrient deficiency symptoms are ambiguous unless well developed, and a visual diagnosis can be regarded as an educated guess until tissue samples are gathered and chemical analyses are used to compare elemental composition with healthy leaf tissue. Many types of environmental and management damage can be confused as visual nutrient deficiency symptoms (Barak, 1999).

Table 4 provides a guide for determining potential nutrient deficiencies. The Minnesota Association of Wheat Grower's Internet web site, http://www.smallgrains.org/Techfile/Franzen2.htm, is the beginning page of a decision tree for determining plant nutrient deficiencies.

2.4.2 Plant populations

Plant population characteristics are important factors in both cultivated and non-cultivated forms of land management. Their measurement is necessary for comparing different management techniques. In actively managed systems like cultivated agriculture they are generally controlled variables for producing a harvest. In more passively managed systems like range and forest management they are generally measures of the effects cause by management decisions like intensity of grazing pressure and wood harvesting. Many of the methods used to measure plant population in ecological sciences, like range management, are appropriate for describing agricultural systems, especially mixed cropping systems that are generally practiced by subsistence farmers in developing countries.

2.4.2.1 Density

Crop density is an important management tool that usually is the result of economic decisions affected by availability and cost of labor, land, and production inputs. ***Crop density is more than the result of an economic decision on small farms of developing countries, where farmers do not have the luxury of overriding native soil quality with agro-chemicals and other purchased inputs. In this case, crop density is also the result of soil quality, as well as the absence or presence of weed, disease or insect infestations.*** Crop density also affects the quality and quantity of biomass produced and affects the total value of the crop. It should be noted that grain is not the only product of value. Leaves can have forage value and stalks can have value as a construction material.

Plant density and techniques of measurement are described at the following Internet web site address http://ag.arizona.edu/OALS/agnic/knowledge/chapter5/density.html. A plant density calculator can be access on the Internet at the web site http://www.fssystem.com/CedarValley/Solutions/Calculators/Calc4.html.

2.4.2.2 Species diversity and composition

Species diversity (biodiversity) is a general term reflecting the number of species and the number of individuals, surface cover, volume, or mass that is represented by each species. There are mathematical measures of species diversity — for example, Shannon-Weaver (or Shannon-Wiener) Index, Simpson Index, and Equitability Indices. These indexes are defined at the following Internet web site: http://marisa.aquabio.swt.edu/ecology/notes/spdiversity/spdiversity.html.

Species composition is a necessary measure for diversity and is described at the following Internet web site address: http://ag.arizona.edu/OALS/agnic/knowledge/chapter5/composition.html.

In agricultural fields species composition is an important variable, as well as a very important measure for evaluating crop yields for mixed cropping systems. It is also a measure of management (*e.g.*, weed species) that affects yields.

Table 4. Symptoms of plant nutrient deficiencies and over fertilization (Kaye, 1997).

DEFICIENCIES OF NUTRIENT ELEMENTS											
Symptoms	**Suspected Element**										
	N	P	K	Mg	Fe	Cu	Zn	B	Mo	Mn	Over Fertilization
Yellowing of:											
Younger leaves					✓					✓	
Middle leaves									✓		
Older leaves	✓		✓	✓			✓				
Between veins				✓						✓	
Old leaves drop	✓										
Leaf Curl Over				✓							
Leaf Curl Under			✓			✓					✓
Leaf tips burn:											
Younger leaves								✓			
Older leaves	✓						✓				
Young leaves wrinkle and curl			✓				✓	✓	✓		
Necrosis			✓	✓	✓		✓			✓	
Leaf growth stunted	✓	✓									
Dark green/purplish leaves & stems		✓									
Pale green leaf color	✓								✓		
Mottling							✓				
Spindly	✓										
Soft stems	✓		✓								
Hard/brittle stems		✓	✓								
Growing tips die			✓					✓			
Stunted root growth		✓									
Wilting						✓					

2.4.2.3 Species and genetic diversity considerations

Genetic conservation and genetic erosion are important considerations for agriculture development projects. Negative impacts can occur from a wide range of activities that promote food security. For example, in Malawi the introduction of high yielding hybrid maize is contaminating the open pollinated cultivars of maize upon which most farmers depend. The hybrid introduction is reducing the yields of these local cultivars (FAO, 1998). For more information on genetic conservation refer to the Internet web site: http://www.fao.org/WAICENT/FAOINFO/SUSTDEV/EPdirect/EPre0041.htm or Green & Guarino (1999).

Soil seed banks are important for forest and range management. They provide the foundation for plant recruitment (regeneration) and future productivity of the land. For example, in cases where rangelands depend on annual plants for forage production, long periods of overgrazing can transform the soil seed bank into just a small reserve of seeds that produce unpalatable, low value plants. Under this condition, even good rainfall produces poor biomass production. Also, under this condition the promotion of sustainable management could assure the establishment of only low value plant species. Refer to Leck *et al*. (1989) for more information on soil seedbanks.

2.4.3 Plant survival

Long-term plant survival rates can be important measures of sustainability and farmer adoption of improved management. Plant survival (or plant mortality) rates are simple ratios of the number of plants living (or dead) divided by the total of number of plants seeded or directly planted over a specified period of time (*e.g.*, 83% survival over the first 5 years from planting). Plant survival rates are also important measures for planning and managing direct seeding and planting interventions. For example, expected plant survival rates can be used as a guide to determine cost effective ways of achieving uniform plant densities. The cost of over-planting, followed by a later thinning, is balanced against the value of having an even stand. Random sampling methods can be used to measure survival rates early in the project if good estimates are not available from previous experiences in the project area.

2.4.4 Germination rates

If a *PVO* collects or purchases seeds for planting, germination rates should be evaluated so that seeding rates can be adjusted in order to achieve proper plant density. To determine germination rates, cover random samples of seeds with moist towels or cloth for a period of several days (number of days that sufficient soil moisture is expected to be available to the seeds for germination and establishment of roots). The germination rates are the number of seeds that germinated divided by the total number of seeds in the samples ***multiplied by 100 to produce the percent germination rate*** (*e.g.*, 40% germination rate). If the germination rates are low (*e.g.*, leguminous tree seeds), then scarification or other treatment may be needed to improve rates.

2.4.5 Measures of biomass production

Biomass production is generally evaluated as a productivity measure where the quantity and quality of biomass produced is compared to another factor that is related to production. Yield is a common measure of productivity (*e.g.*, kilograms of oranges per tree, kilograms of milk per cow), and for crops, area is the most common basis of comparison (*e.g.*, kilograms of grain per hectare). Other economic factors such as labor and input costs are used for comparing yield measurements. For example, in the Sahel, yield measurements in kilograms of millet per planting pocket (indirect measure of labor and input costs) explained better than kilogram per hectare why farmers did not readily adopt water-harvesting methods (Tabor, 1995).

2.4.5.1 Yield

Yield is a measure of productivity and when multiplied by area or units cultivated it provides an estimate of production (*e.g.*, kilograms per tree times number of trees equals kilograms of production). Yield is an important variable in the list of Generic Title II indicators (Table 1). It is a component of 3 out of the 8 biophysical indicators. Yield is usually considered the dry weight amount of grain produced per unit area. Diskin (1997) discusses yield measurement techniques for Title II projects and provides references to additional sources of information. Casley & Lury (1982, p. 32-35, 40-41, 91-92) provides a sobering discussion on yield measurements as indictors in agricultural development projects. Mixed cropping methods, spatial and temporal variability of land productivity, and human resource constraints are some of the complicating factors of conducting statistically valid yield measurements. The chapter *Review Of Sampling Methodologies For Biophysical Variables* discusses how to design sampling programs to address some of these factors. FAO (1982), Murphy & Sprey (1982, p. 226-229), and Diskin (1997) describe methods of measuring the area of fields. Projects can also measure field areas using handheld GPS receivers and GIS software. It is only a matter of time when costs of using these computer based technologies become lower than the costs of not using them. Currently, large projects that will be making many field measurements should consider GIS, GPS, and other associated technologies for M&E. ***While GPS units can be useful tools, they have limitations. In politically sensitive areas, satellite data is scrambled or blocked for security purposes, resulting in inaccurate***

GPS coordinates. In mountainous areas or areas near tall trees or structures, it can be difficult to get accurate readings and consistency.

Site selection is fundamental to data validity when measuring yields. If sampling is random, sites need to be truly random (*e.g.*, just using a random selection of households does not assure a random selection for fields or yield plots). If yields are used to compare different land management techniques then comparison plots need to be placed close together in a uniform site. Farmers should be consulted when selecting sites for yield comparison plots. Site selection may require the use of selective sampling techniques for choosing plot sites within a field.

An "estimated maize yield calculator" can be access on the Internet at http://www.fssystem.com/CedarValley/Solutions/Calculators/Calc1.html. Similar methods of estimation could be used for pre-harvest estimations of other crops.

2.4.5.2 Plant height

Plant height can be a good indicator of soil productivity and can provide useful information for selecting sites for crop management comparisons. In order that plant height serves as a good indicator of soil productivity the following conditions within a field must be met:

- land management techniques must be applied uniformly over the area evaluated;
- the genetics of the crop being evaluated must be uniform; and
- the crop being evaluated should be easily measured and require the same environmental conditions as the crop or plant for which the evaluation is being conducted (*e.g.*, maize may not be the best crop to evaluate soil productivity for potatoes since optimum production for these crops require different soil pH levels).

Plant height can be used as a method to estimate biomass. Tree height and basal diameter are standard forestry measurements for determining biomass of timber trees, the best example of plant height providing a good estimate of biomass. Plant height is much less successful as a measurement of biomass for other species. It is very difficult to estimate the biomass of shrubs. Calculations require many types of variables, including height, to estimate biomass. Plant height is not a good estimate of crop yields, especially for grain crops because of their determinant flowering. Good environmental conditions may produce a healthy tall plant, but bad conditions during or after flowering can reduce or eliminate yields.

2.5 Land-Use and Land Management Variables

Land-use and land management variables can be used to impute project effects and impacts if a strong relationship between the use or management practices and their effect can be shown. For example, much research on soil erosion has shown with good levels of confidence that erosion can be predicted by land-use and land management variables. Land-use and land management are also used as stratification criteria for statistical analysis of the Generic Title II biophysical indicators, especially crop yields.

2.5.1 Slope length

Slope length, as describe above in the sub-section *Slope and slope length* of *Soil Physical Variables*, can be modified by land management techniques. Strip cropping, terraces, contour bunds, and check dams are some techniques used to decrease soil erosion. More information on these and other techniques can be accessed on the Internet at http://www.ftw.nrcs.usda.gov/nhcp_2.html. If slope length reduction is a project intervention then the experts who design the intervention should also describe how project personnel measure the variables for soil erosion modeling and impact reporting.

2.5.2 Natural resource management practices

Land management practices are major determinants of crop yields and natural resource conservation. Soil erosion prediction models use coefficients that are dependent on management practices (Morgan, 1995). Crop yield comparisons use management practices as independent and fixed variables (*e.g.*, a yield response experiment uses the same planting density — fixed variable — while comparing different fertilization rates — independent variable). During project design it is important to identify natural resource management practices that are important for evaluating project effects and impacts. It is equally important that farmers, through interviews and questionnaires, clearly and consistently communicate the use of these practices to the project. Location specific information of land management practices is needed so that random field checks can be conducted for project monitoring and evaluation (*e.g.*, farmer *X* has three fields that she names red, white, and black; the red field is located etc., etc.). Including GPS coordinates (cost of GPS receivers start at around $US 100 each) with descriptions of sites will reduce confusion and assure that they are geographically unique locations. ***The lower the price, generally the lower the resolution and the less reliable the data. See also the discussion on limitations of GPS as a locator tool in Section 2.4.5.1.***

2.5.3 Vegetative cover and type

Vegetative cover and type are important variables in determining project effect and impact on natural resource conservation. Vegetative cover is also used as a variable to estimate biomass. The Internet web site *Methods to Determine Cover*, http://ag.arizona.edu/OALS/agnic/knowledge/chapter5/covermethods.html, describes methods that are useful in characterizing mixed and intercropped systems as well as the amount of weeds in fields. Charactering vegetative cover is especially important if random site selection is used to measure crop yields in actual field conditions. Sampling methodologies appropriate for each project should be developed during project design unless project staff has the skill and knowledge to develop them.

3. REVIEW OF SAMPLING METHODOLOGIES FOR BIOPHYSICAL VARIABLES

The complexity and variability of biophysical characteristics, as well as the cost of measuring them, requires PVOs to use statistical sampling techniques to achieve cost effective estimates of project impacts. Sampling and analysis methodologies used to describe biophysical conditions are well developed but they usually require sophisticated methods of sampling and data analysis, and often require precise measurement of characteristics.

There are actually a number of publications produced by university extension services that simplify and explain experimental design and analysis for use in farmer-led, on-farm research. These documents explain the fundamentals of experimental design and basic statistical analysis for agriculture in clear language, providing guidance and straightforward methods to measure agricultural variables, increase statistical reliability, reduce experimental error and increase confidence levels. See, for example:

- ***Exner, R. and R. Thompson. 1992. The paired comparison: a good design for farmer-managed trials. Cooperative Extension Services, Iowa State University, Iowa, USA.***
- ***Janke, R. and D. Thompson, K. McNamara, C. Cramer. 1990. A farmer's guide to on-farm research. Rodale Institute, 222 Main Street, Emmaus, PA 18098 USA.***
- ***Nielsen, R.L. 1994. Fundamentals of on-farm research and demonstration. Agronomy Department Publication Number AGRY-91-03. Purdue University, West Lafayette, Indiana, USA.***

- ***Rzewnicki, P. On-farm trials for farmers using randomized complete block design. Nebraska Cooperative Extension Publication EC 92-125-D. University of Nebraska, Nebraska, USA.***

It is unlikely that project staff have the skills to be good at both project implementation and design of monitoring and evaluation systems. Expert help should be used to help design a monitoring and evaluation system that can be conducted by the human and financial resources available to the project.

Professionals in the field of M&E for development agriculture disagree with this point of view. They argue that project implementers need to be closely involved in designing M&E as an integral part of project planning and that with appropriate guidance, they can and should design systems that they not only understand, but also implement (Poate and Sharrock, ITAD, Agriculture M&E Workshop for Title II Cooperating Sponsors, Wye College, 1999). Past PVO experience with outside experts called in to design an M&E system after project planning tend to develop cumbersome, detailed, costly systems that detract from effective project implementation.

ITAD in the UK specializes in training and consulting on effective, appropriate agriculture M&E for development. They emphasize agriculture M&E that can be done at reasonable cost, and they define it as a perfectly feasible, necessary part of project design and management:

- ***ITAD (Information Training and Development Ltd.)***

  West Sussex, England

  Email: mail@itad.com

  Website: www.itad.com

  Tel: 44 (0) 1444-248088

The follow review of sampling methodologies and sources of more detailed information is provided to help project staff follow a monitoring and evaluation design.

Two web sites provide a excellent overview of soil and vegetative sampling, they are: *Soil Sampling as a Basis for Fertilizer Application* at http://www.sbreb.org/brochures/SoilSampling/soilsamp.htm and *Rangeland Inventory, Monitoring, and Evaluation* at http://ag.arizona.edu/OALS/agnic/knowledge/chapter5/index.html. *Soil Sampling as a Basis for Fertilizer Application* describes composite sampling, sampling depth, sample handling, and other soil sampling topics. *Rangeland Inventory, Monitoring, and Evaluation* discusses sampling methodologies that are appropriate for soil sampling, crop yield sampling, and vegetation sampling.

3.1 Socio-Economic Tools

Socio-economic tools such as baseline household surveys, discussed by Bonnard (1998), are required for Title II project reporting. These tools provide part of the context for which land use and management decision are made and are important for developing a lexicon between local and project languages so that biophysical classifications can be correlated. Perceived value of biophysical resources can be identified using these tools. Examples of how socio-economic and biophysical tools can be used to solve development problems are further discussed in *Indigenous knowledge of soil quality* sub-section of *Soil Quality Variables*.

3.2 Sample Units

A sampling frame sets the parameters for selecting samples (Casley & Lury, 1987, p. 52-57), in effect defining the population[1] from which samples are collected. The selection of a sample frame, whether it is a list or area sample frame, depends on what is to be described. Selection of sampling units must be precisely defined or ambiguities will arise. Definitions must be clear to the stakeholders and appropriate to local customs. Possible sampling units include an individual, a household, a cooperative or operational group, a village or social group, an economic or social class, a plot of ground or field, a holding (farm), a mapped area, a place where a specific activity occurs, and/or an area administered as a single entity (Casley & Lury, 1982, p. 70-71).

The choice of sampling units and sampling frame determines many of the statistical properties of the selected variables. For example, the soil fertility status of maize fields can be measured in several different ways. One way is to use numerous samplings of one square meter units randomly spread over the fields. In this case one or more soil samples are collected within the one square meter sampling area and mixed together as a composite sample representing the one square meter (refer to the Internet web site http://www.sbreb.org/brochures/SoilSampling/soilsamp.htm). The one square meter sample unit is selected because it best represents the area that the roots of a maize plant exploits (different species of plants have different rooting patterns). Another sampling unit could be the entire maize field where one or more soil samples from the field are mixed together as a composite sample. If the spatial variability soil fertility in a field is high, one soil sample from the field will be a poor estimator of the average fertility level for the field. If, however, 50 soil samples are collected from all over the field and thoroughly mixed together then this composite sample will be a much better estimator of the average fertility level of a field. If soil fertility levels in maze fields are fairly uniform and/or if the fields are managed as one homogenous unit, then fields are an appropriate sampling units. Otherwise, smaller sampling units may be more appropriate because they can be used to: (1) distinguish areas within fields that have high or low fertility levels, and (2) determine the confidence level of the estimated field average.

A benefit of composite sampling is that it transforms data into a more normal distribution (bell shaped curve). The distribution of sample data can be skewed, multimodal, or otherwise abnormal. If data does not conform to the primary statistical assumption that the data is normally distributed, then most statistical tools will not produce valid results unless the data is mathematically transformed to a normal distribution. Increasing the area of the sample unit and collecting composite samples of the sample unit will have the effect of normalizing the data and reducing the variance. Unfortunately, by increasing the sample unit area important information may be lost. Additional information on sample units can be found in statistical textbooks.

Where and how to sample sites are described in *Soil Quality Test Kit Guide* (USDA, 1998, p 2-3) and the Internet web sites http://www.sbreb.org/brochures/SoilSampling/soilsamp.htm and http://ag.arizona.edu/OALS/agnic/knowledge/chapter5/sampling.html.

3.3 Random Sampling and Stratification of Populations

There are many ways to sample a population. Sampling designs, including random and stratified sampling, are described at the Internet web site http://ag.arizona.edu/OALS/agnic/knowledge/chapter5/allocation.html. Casley & Lury (1982, p. 72) also describe random sampling, purposive (selective) sampling, and quota sampling as ways to describe populations. Each type of sampling has advantages, but random sampling is the more common method used by *PVO* projects.

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[1] This is the statistical usage of “population” and refers to a collection of objects, numbers, measurement, or observations collected within the parameters of the study. Refer to the Internet web site http://ag.arizona.edu/OALS/agnic/knowledge/chapter5/population.html.

The population of data collected from a sampling frame can be stratified by distinguishable characteristics in order to provide more detailed or accurate information. Effective stratification is the most powerful tool for improving precision. There is very little risk attached to its adoption. Even if the stratification is not as successful in achieving homogeneous strata, some benefit will almost certainly accrue (Casley & Lury, 1982, p. 82).

For example, a sample frame consists of households of a particular socio-economic level that occurs within a particular administrative boundary. Household crop production is determined by crop-yield plots (sample unit) in randomly selected fields of randomly selected households but the resulting yield variability is considered too high to show project impact. If household interview data includes the area and type of soil in each field, then stratification of the yield studies by soil type can produce better estimates of household production. Production estimates are improved because the contrasting soil productivity levels of cultivated land cause a large part of the variability from the original yield study. Stratification is powerful but its power is limited if total sample size[2] is fixed — as commonly happens with limited budgets. Additional stratification of other distinguishable characteristics can account for portions of the remaining variability of data, but eventually the resulting smaller sample sizes of each stratified group reduces confidence levels more than the decreased variability improves confidence levels.

Determining the degree of stratification of data is an economic decision based mainly on the improvement of information *vs*. the cost of increasing sample size and difficulty in collecting data for stratification. Stratified sampling is described by Casley & Lury (1982, p. 81) and on the Internet web site http://ag.arizona.edu/OALS/agnic/knowledge/chapter5/stratified.html.

Combining cluster sampling with stratification is a common feature of sample designs. Cluster sampling, or choosing geographical areas for sampling, is primarily used to reduce costs. Poate & Casley (1985) note that the logistical efficiency gained with clustering samples (*e.g.*, by communities) can be lost when the difference between clusters accounts for a large part of the sampling variance. The result is that cluster sampling requires much larger numbers of samples that need to be taken compared to simple random sampling in order to achieve the same levels of confidence for the average of the total population.

[2] Sample size refers to the number of samples. It is the conventional definition in statistical literature and is often given the symbol "n."

3.4 Controls in Title II Agricultural Programs

Bonnard (1998, p. 21) classifies control groups as internal, external, and historical. This section discusses controls that are used in experimental plots — a type of internal control — as a point of reference for measuring biophysical changes. Experimental control plots could also be used as external control groups but the difficulty in controlling for confounding biophysical factors makes this type of control group impractical. Historical control groups are discussed in the next section, *Baseline in space and time*.

Title II agricultural programs often include interventions to increase productivity, usually measured by crop yields. Crop productivity is affected by so many factors that are spatially and temporally variable (*e.g.*, soil productivity and rainfall) that control plots are necessary to evaluate the effect of interventions. It is important to evaluate an intervention under project conditions because even though a technological package may be well proven in other areas — both experimentally and in terms of experience — the response in new areas cannot always be predicted with precision in advance of project implementation (Casley & Lury, 1982, p. 2).

Randomized block and Latin square experimental designs were developed to deal with difficulties posed by natural variability in soil productivity. These designs are described in most introductory statistical textbooks written for the biological and agricultural sciences. They are also described at the Internet web site http://149.170.199.144/resdesgn/aovblock.htm. It is very important to select sites for these designs that are as uniform as possible. For suggestions about site selection refer to the *Plant height* subsection of *Measures of biomass production* and *Leaf color* subsection of *Vegetation Quality Variables*. The boundary of each block should include a buffer strip to avoid "boundary effects". The width of these strips should be determined by the rooting characteristic of the crop, both of which limit the minimum effective size of a treatment block.

Careful site selection is only one element of good on-farm analysis of biophysical variables. Accurate results also depend on making wise choices in experimental design (the physical arrangement of treatments in a field), in determining the objective of the M&E, selection of treatments, blocking criteria, number of replications, randomization of treatment locations, plot size, choice of collaborating farmers, design of monitoring plans, appropriate data collection and statistical analysis methods. Though it may seem complicated, the extension services cited in a comment above in Section 3, Review of Sampling Methodologies, have simplified and published user-friendly guidance. See also:

- ***Petersen, R.G. 1985. Design and analysis of experiments. Marcel Dekker, Inc., 270 Madison Ave., New York, NY 10016 USA***

3.4.1 Project-monitored yield plots

Project-monitored yield plots are likely to be conducted under more controlled conditions than farmer-monitored plots. The assumed better management of plots allow more complicated experimental designs that account for more variables than can be expected from farmer monitored yield plots. Better management also assures better documentation of problems that may occur during the experiments that might confound the results or increase data variance.

3.4.2 Farmer-monitored yield plots

Farmer-monitored yield plots have the advantage of requiring fewer resources from the project than project-monitored plots. There is the possibility that by using farmer-monitored plots an increase in sample size will increase the confidence-levels of the results. These experiments must be designed simply so that farmers can conduct consistent trials. Farmer-based monitoring also provides an opportunity for the project to demonstrate to the farmer the effects of intervention that otherwise would go unnoticed or take longer to appreciate. The same experimental rigor needs to be applied to both project and farmer monitored yield plot — the main difference is the level of simplicity.

3.5 Baseline in Space and Time: Referencing a Point, Velocity, or Acceleration.

Historical baselines of biophysical indicators can be used to evaluate location-specific changes, especially for interventions that have amorphous effects on land use and management (*e.g.*, socio-economic and public health interventions). PVOs should consider using historical baselines in situations where project impacts on sustainable agricultural production cannot be attributed to a single or small group of land management practices.

Since biophysical characteristics usually change in response to environmental conditions outside the control of project intervention, baselines need to document the magnitude of measured variables and their direction and rate of change occurring before project interventions. Baselines often require multiple observations over space and time in order to appreciate their inherent variability and how they change spatially and temporally.

For example, the conclusions founded on crop yield impact depend on the type of baseline information collected. This assumes that good estimates of crop yields have been made and that short and long-term variability have been taken into account. If baseline data is limited to one cropping season, a "point" value might be produced such as 1000 kg/ha for a particular season. If two cropping seasons of data are available (in this example 5 years apart), then the baseline represents a "velocity" such as 1000 kg/ha per season that is decreasing at a rate of 25 kg/ha per year over the past 5 years because of unsustainable land management practices. If three or more cropping seasons of baseline data are collected they can represent an "acceleration" such as 1000 kg/ha that is decreasing at 25 kg/ha per year over the past 5 years. Based on the population growth rate and crop yields over the past 30 years, the next 5 years will likely decrease at a rate of 35 kg/ha per year for various reasons.

This is not an overly hypothetical example. This dynamic is occurring in the Sahel and other regions of the world. As sons and daughters of farmers expand production onto available but less productive land, average yields of communities decrease at a decreasing rate regardless of sustainable land management techniques. If a project goal is to be realistic then it should take into account the dynamic nature of the variables it is monitoring, otherwise a real increase in yield (*e.g.*, goal of 5% in 5 years) may be under reported (*e.g.*, a change in yield of +5%, -7.5% or -12.5%, depending on how "velocity" and "acceleration" of variables are taken in consideration). If impact reporting is just for fixed holdings of households and does not represent community production, then a "velocity" may be all that is needed. If, however, project interventions produce very large increase in yields (*e.g.*, 30% increase in 5 years) to the degree that the non-project factors causing changes in yield are minor, then a "point" sample could be justified.

3.6 Significance

Significance of data is fundamental when reporting effect and impact results. Reporting just an average value without measures of significance is like saying "on average I feel ok" when one hand is in a fire and the other hand is in ice water. Many factors contribute to the variability of biophysical data which then affect the significance of results. Some of these include:

- long-term directional changes being complicated by 'normal' seasonal and annual cycles (*e.g.*, global warming);
- irregular and natural fluctuations which may mask the features of interest (*e.g.*, pest invasions);

- ecosystem and species adjusting to current and recent management, especially when discontinued or changed (*e.g.* changing grazing pressure or soil erosion rates, sometimes brought about by socio-economic changes);
- adjustment or 'relaxation' to historical changes, such as drainage, fire, clear cutting of forests, migrations, and changes in resource tenure; and
- successional changes, which can be either directional or cyclical (*e.g.*, annual increase of crop pests and disease forcing a period of fallow) (Goldsmith, 1991).

Commonly, the variance caused by these and other factors cannot be removed through sample frame selection or stratification. The remaining options for improving significance are to increase the sample size (a costly choice), increase the area of sample units (usually not an option if household data is the required reference), and/or increase the confidence intervals (*e.g.*, select interventions that create larger, more detectable effects or impacts).

During project design, the establishment of baseline data should provide the opportunity to determine the economic balance between sample size, sample unit area, and confidence interval required to show project effects and impacts. A relatively simple estimate of sample size that uses the Student's t statistic is describe in most introductory statistical textbooks and at the Internet web site http://ag.arizona.edu/OALS/agnic/knowledge/chapter5/samplesize.html.

3.7 Resource Mapping and Inventories

Resource mapping and inventories can provide useful information for developing sample frames and identifying variables for stratification. PVOs should consider using them, especially when biophysical impacts are difficult to demonstrate because of insufficient stratification of data. Maps and inventories that are useful for monitoring and evaluation of Title II projects also should provide information at a level of detail needed for making household decisions about individual agricultural fields. Unfortunately, not many of these studies are available in developing countries due to the costs required to conduct them at this scale over large areas. Maps with scales[3] smaller than 1:25,000 are usually worthless for household level impact assessment. Also, many of the maps and inventories that do provide sufficient detail provide information that is not very useful. The common fault is that the resource classification systems used do not correlate well with local classification systems. This places a great burden on the user of the information (*e.g.*, the PVO) to interpret the study correctly and apply it to the way farmers classify and use their resources.

If adequate maps and inventories are not available for the target area, PVOs can use indigenous knowledge to develop inventories of the biophysical resources of targeted communities and possibly identify cost effective ways of stratifying data from information. This information can be collected through interviews. Knowledgeable members of communities can also help map their resources using local classification systems. For more information on mapping and inventories refer the section *Indigenous knowledge of soil quality*.

3.8 Measured or Imputed Indicators.

When indicator variables are too costly to measure and/or when excessive variability of the data prevents showing significant impact, then imputed indicators may be needed. PVO personnel may have to justify their rationale to USAID personnel for choosing more subjective imputed indicators over measured ones. Analysis of baseline data collected during project design may provide justification for using imputed variables or provide justification for increasing the project's budget to cover additional costs needed to make measured indicators valid (*e.g.*, increase the sample size).

[3] Mapping scales are ratios, the smaller the denominator the larger the scale of map and likewise the larger the denominator the smaller scale of map. For example a 1:12,000 scale map is a much larger scale than 1:1,000,000.

4. GENERIC TITLE II INDICATORS FOR AGRICULTURE PRODUCTIVITY, NATURAL RESOURCE MANAGEMENT, AND ENVIRONMENTAL IMPACT

4.1 Annual Yield of Targeted Crop

This generic indicator should be renamed "yield of targeted crop". The term "annual" for this indicator may present confusion and accounting problems when crops require longer than a year to mature (*e.g.*, cassava) or when land can be double or triple cropped (*e.g.*, with irrigation). Yield can be annualize later when production comparison are needed.

Yield is a measure of productivity but can be used to determine production if it is multiplied by its base unit (*e.g.*, a yield of 1000 kg/ha on 1000 hectares of land equals 1,000,000 kg of production). Yield and production can be good indicators of project effects or impacts if separated from non-project effects and if the problems of measuring yield and area of production can be overcome.

"Yield of targeted crop" is generic and incomplete as an indicator. Projects must develop functional definitions of what yield indicates before they can select biophysical variables and methods of analysis. To complete the indicator's definition, project designers need to identify (1) for what purpose is yield measured, (2) for what interventions is it an indicator, (3) what are the units of analysis, and (4) what is the basis for comparison. For example:

- yield for productivity;
- yield plus area for production (*e.g.*, per season or per year);
- yield of all management techniques (*e.g.*, showing impact of socio-economic interventions);
- yield of specific land management technique (*e.g.*, showing the difference between conventional and improved management techniques);
- yield of plot of land (productivity of soil type);
- yield of farmer's field;
- yield of household;
- yield compared to community, regional, or national average;
- yield compared to different land management techniques (use of plot data for internal controls); and
- yield compared to historical yields (use of historical controls).

4.2 Gap Between Actual and Potential Yields

This indicator measures unfulfilled potential between actual yield and potential yield. "Potential yield" is an unfortunate choice of words for this indicator because "potential" is very context dependent and is not sufficiently explained in supporting documents. If "potential yield" is used to define a target yield ("maximum potential yield" by Kumar, 1989, p. 29) then it must be assumed that the target is comprised of realistic practices and inputs. Comparing "actual" with "potential" yields also assumes that actual yields are based on (1) soils with the same productivity potential and yield response as those used to develop the targeted potential yield (cultivated soils have a wide range of productivity potential), and (2) markets and profit margins support the management techniques used for obtaining potential yields. The latter assumption is difficult to control because farmers commonly change management techniques year to year in order to accommodate changes in markets, rainfall, labor availability, and household constraints. This interpretation of "gap between actual and potential yields" will measure the quality of application of prescribed techniques and indirectly the effectiveness of extension efforts. It might also measure the relevancy of prescribed practices to actual farming conditions, assuming farmers make wise economic choices.

Kumar (1989, p. 29) described this indicator as an "indicator for measuring impacts on soils" or for measuring the change in soil productivity (*i.e.*, natural resource improvement or degradation). The complexity and expense of measuring "maximum" yield response to "fertilizer" on household plots of land are described in the *Chemical variables of soil quality* section of *Soil Quality Variables*.

Another interpretation of this indicator is the "gap between yields by using conventional techniques and improved techniques." With this interpretation, "potential yield" is a value for measuring change in productivity and can also be used to measure change of production if the area cultivated is factored in the calculation. Methods used to measure this indicator are discussed in *Yield* subsection of *Measures of Biomass Production*.

4.3 Yield Variability Under Varying Conditions

Yield variability is an important factor in determining household food security and is an important impact indicator. Increased yield variability can increase financial risk that negates the benefits of increased average yields from "improved" cultivation practices.

Yield variance and range are the statistics used for this indicator, but ideally this indicator should show the difference in financial risk of using conventional practices compared to improved practices — financial risk being one way of placing a value on resource allocation and benefits. Farmers can provide financial break-even yields for conventional practices, but yield variability of introduced land management practices may initially be evaluated solely on yield variance and range until the farmers can fully evaluate the costs and benefits of the new techniques.

The yield data from widely dispersed sites can be used to evaluate yield variability under a wider range of conditions than would be possible if data is collected from a more limited area. For example, sites in areas with high average rainfall might be grouped with those in areas of low average rainfall so that it is possible to evaluate how yields respond to greater extremes of annual rainfall. Other site conditions, such as soil characteristics, should be noted along with yield data so that potential confounding factors can be removed before the data is analyzed.

4.4 Percent of Crops Lost to Pests or Environment

Climate, insects, birds, disease, wildlife, domesticated animals, and theft threaten crops in the field. Insects, rodents, heat damage from biological respiration, fungi or mold, bacteria, and theft threaten stored harvests. This report will discuss how to monitor crop losses during storage.

4.4.1 Crop Storage Losses

There are many factors that complicate impact monitoring of improved crop storage techniques. These factors are also difficult to control. The major pre-storage factors are type of crop cultivars (*e.g.*, grain density), sanitation during processing and preparation for storage (*e.g.*, insect contamination), and condition of the crop when stored (*e.g.*, moisture content). Hoveland (1980) discusses ways to reduce crop losses. Diskin (1997, p. 15-17) discusses the constraints to measuring crop storage losses for a monitoring system.

Basically, there are no cost effective ways of directly monitoring household level impact of improved storage techniques unless the high costs of monitoring are justified by project focus. If statistical sampling occurs in an environment of minimal confounding factors then simple, inexpensive monitoring systems might be possible. For example, crop losses could be measured from a random selection of storage structures by evaluating the entire stored crop or evaluating random sub-samples if the amounts are too large. Major factors affecting the cost of this approach are sample-size requirement for showing an impact, time and personnel required to evaluate crop losses of selected sites, and compensation paid to farmers for inventorying the condition of their stored crops.

A less costly approach is to use demonstrations to compare conventional *vs*. improved storage techniques. This could be considered a selective sampling approach. These comparisons can provide an estimate of storage losses from both techniques and can be used to impute impact. The demonstration would also serve as an extension tool. Household surveys and random site visits of storage facilities can be used for effect indicators to validate impact estimates. Surveys and site visits can also provide early warning of storage problems.

4.5 Imputed Soil Erosion

This indicator can be quantitative by using soil erosion models or qualitative by making observations and comparisons between sites affected by project interventions and those that are not. Both quantitative and qualitative tools of measurements are discussed in the *Erosion* sub-section of *Soil Quality Variables.*

4.6 Imputed Soil Fertility

Direct measurement of soil fertility is possible but requires intensive stratification of numerous sampling sites in order to detect change over time or between management techniques. This is probably not an option for projects unless the project area has very uniform site characteristics. Imputing soil fertility level by the appearance of vegetation has the same sampling problems posed by direct soil fertility measurement, plus the additional problem posed by subjective observations. Project impacts on soil fertility can be imputed by monitoring land management practices and using limited numbers of direct soil fertility measurements along with crop yield trials, assuming they are part of the project's monitoring program. Soil fertility changes measured during the yield trial are assigned to the respective changes of land management practices. Changes in land-management practices of targeted farmers can be collected from household interviews and verified by randomly selected site visits.

4.7 Number of Hectares in which NRM Practices Used

Effect and impact indicators of NRM practices can be measured by randomly selecting sites where projects have reported NRM activities and outputs. The quality of NRM practices at selected sites is assessed with regard to project effects and impacts. The quality assessment of practices can be subjective or objective. Techniques used to assess quality will depend on the NRM practices that are evaluated. Exact location of practices must be identified so that evaluators can visit randomly selected sites. The indicator "number of hectares in which NRM practices use" should include both the number of hectares and the quality of effect for each sampled area. For example, an impact indicator of NRM practices could be the weighted sum of the effects as determined by site evaluations divided by the total area of reported practices. Weighting would be by the number of hectares assigned to each effect category (*e.g.*, low to high, or 0 to 10).

4.8 Seedling and Sapling Survival Rates

This indicator can be used as a measure of quality to assess NRM practices. It can be used to impute the effect or impact of extension activities or to measure farmer adoption of practices. It is also an output indicator for project management. Tools for measuring seedling and sapling survival rates are described in *Plant survival* sub-section of *Vegetative Quality Variables*.

5. ANNOTATED BIBLIOGRAPHY

The following bibliography includes comments on references that PVO personnel and project designers might find useful. Not all of the references that appear in this bibliography are cited in the text of the report. Also, refer to annotated bibliographies by Dumanski *et al*. (1998), Newton & Erickson (1998), and Bingham *et al*. (1999).

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> Technical descriptions of indicators for research and high management forest production. Intensive sample collection and laboratory analysis are required for most indicators. This publication may be useful to M&E design specialists for developing soil indicators for forestry and agriculture.

Amani, A.,& T. Lebel (1997). Lagrangian kriging for the estimation of Sahelian rainfall at small time steps. *Journal of Hydrology*, Elsevier Science B.V. 192:125-157.

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Becerra, E.H. (1995). *Monitoring and evaluation of watershed management project achievements*. FAO Conservation Guide 24. Food and Agriculture Organization of the United Nations, Rome. 118 pp.

> General overview of monitoring and evaluation. The breath of topics covered limits the discussions to generalizations. The reader should realize the limits of this guide and not limit the M&E design base on the structure and methods proposed in this publication.

Bingham, C., W. Knausenberger, & W. Fisher, Editors (1999). *Environmental Documentation Manual for P.L. 480 Title II Cooperating Sponsors Implementing Food-Aided Development Programs*. US Agency for International Development, Washington DC.

> This document includes an annotated bibliography by Jessica Graef of FAM of over 500 entries that concern environmental issues.

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> Boardman & Favis-Mortlock present a collection of scientific papers from the NATO Advanced Research Workshop “Global Change: Modeling Soil Erosion by Water” that occurred at the University of Oxford, September 1995. Numerous erosion prediction models are discussed in detail. Unlike general discussions in other publication, these technical papers may provide useful information for developing an impact monitoring system that is appropriate for specific project conditions.

Bonnard, P. (1998). Review of Agriculture Project Baseline Surveying Methods of Title II Funded PVOs, Part 1: Socio-economic methods. Food Aid Management, Washington DC. Funded by USAID. Accessable on the Internet at http://www.foodaid.org/moneval.htm. 39 pp.

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The standard introductory textbook on soils.

Buckerfield, J.C., K.E. Lee, C.W. Davoren, & J.N. Hannay (1997). Earthworms as indicators of sustainable production in dryland cropping in southern Australia. *Soil Biology and Biochemistry*, Elsevier Science Ltd. 29(3/4):547-554.

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Casley, D.J., & K. Kumar (1987). *Project Monitoring and Evaluation in Agriculture*. The World Bank, and John Hopkins University Press, Baltimore, Maryland. 159 pp.

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Chow and 44 other contributors present a comprehensive handbook from basic information to mathematical modeling on every aspect of hydrology from an engineering perspective.

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Darrow and Saxenian's most recent edition of a very large annotated bibliography. The agriculture and natural resource entries are comprised mostly of documents that focus on extension activities. Appropriate Technology Project, Volunteers in Asia, P.O. Box 4543, Stanford, CA 94309, (800) 648-8043, (415) 326-8581 / 326-3475 Fax, http://www.volasia.org/info2.html

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Diskin, P. (1997). *Agricultural Productivity Indicators Measurement Guide*. Arlington, Va.: Food Security and Nutrition Monitoring (IMPACT) Project, ISTI, for the US Agency for International Development. 49 pp. + references. http://www.fantaproject.org/docs/agriprod.htm

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Hart, M. (1999) *Guide to Sustainable Community Indicators.* Hart Environmental Data, North Andover Massachusetts. 202 pp. (US$19.95)

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"The standard text for school-based water quality monitoring programs in schools around the world. The Manual details nine water quality tests: dissolved oxygen, fecal coliform, pH, total solids, total phosphorous, nitrates, turbidity, biochemical oxygen demand, and temperature. Also includes chapters on heavy metals testing, land use practices, and computer networking." Information on this and other related material can be accessed on the Internet at http://www.igc.org/green/catalog.html .

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Robertson *et al*. present general descriptions of numerous models that have been used in the US and elsewhere for imputing the impact of a range of agricultural management systems on the environment as well as risk and benefit of different land management options. This book may be useful for organizations that are developing a computerized monitoring and evaluation system that considers environmental impact as well as household food security impacts.

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University of Guelph (1999). *The Agroecosystem Health Project*. Accessed on the Internet at: http://www.uoguelph.ca/~aeshinfo/index.html

Number of discussion papers can be accessed at this site.

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